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Arizona

Organ Pipe Cactus National Monument
Ecological Monitoring Report, 1997 - 2005

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The Ecological Monitoring Program report series are designed for dissemination of data and results of ecological monitoring protocols and resource management projects. The series allows the flexibility of retaining considerable information on study design, methods, results, and applications not afforded in formal scientific publications. Reports are given peer review and editing. Mention of trade names or commercial products does not constitute endorsement or use by NPS.

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Executive Summary

The Ecological Monitoring Program at Organ Pipe Cactus National Monument was the outcome of several natural resources studies initiated in the late 1980s. The primary objective was to determine the condition of monument ecosystems and, if change was detected, management alternatives and effectiveness of implemented programs. Guidance for program development was provided by the Ecological Monitoring Program Assistance Committee throughout much of the 1990s. This program has focused on collecting as much data as possible with available staff. Two recent and significant developments include creation of the National Park Service Sonoran Desert Network inventory and monitoring program and an external review of the Ecological Monitoring Program. These efforts have been valuable opportunities to revise objectives and protocols and achieve new efficiencies.

This report summarizes monitoring activities and results for the period 1997 to 2005 with individual chapters on monitoring elements organized into sections on vegetation, vertebrates, and physical resources. Each chapter presents one or more data reductions (tabular, graphic, or statistical) that provide some insight into change or fluctuation over time. Where appropriate, recommendations are also provided. Some trends appear to be warning us of possible future problems such as declining groundwater levels, increasing temperatures, and declines in the abundance of some species of concern. Various indicators of abundance, species richness, and diversity indicate fluctuation over time.

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Introduction

Peter Holm, Ami Pate, Sue Rutman

Organ Pipe Cactus National Monument (OPCNM) was established in 1937 and is located in southwestern Arizona, near the geographic center of the Sonoran Desert (Figure 1-1). The monument was established by presidential proclamation under the Antiquities Act in order to preserve a representative area of the Sonoran Desert for the public trust. Its namesake, the organ pipe cactus (*Stenocereus thurberi*), is a species of columnar cactus with multiple stems. Currently, OPCNM is one of the most biologically diverse protected areas within the Sonoran desert biome in either the United States or Mexico.

The monument encompasses 330,689 acres (133,882 ha), of which approximately 95% is designated wilderness. On October 26, 1976, the United Nations Education, Scientific, and Cultural Organization (UNESCO) recognized and selected OPCNM as a Biosphere Reserve. OPCNM preserves many biotic communities that are typical of southwestern Arizona, including Arizona Upland desertscrub, Lower Colorado Valley desertscrub, temperate woodlands and scrub, xeroriparian woodlands and scrub, and a small wetland. Geomorphological features include mountain ranges, bajadas (coalesced alluvial fans), valley floors, as well as diverse drainage systems, including canyons, washes, and areas dominated by sheet flows.

Resource Concerns

As Arizona's population continues to grow, the pressure of human-related impacts on wildlands and natural resources will likely increase. The monument is vulnerable to a number of threats that have evolved over time. When the monitoring program was in its early stages of formation, concerns about monument resources included the impacts of historic grazing, adjacent land uses, and vehicle traffic on State Route 85. Livestock were removed from most of the monument by 1979. Grazing continues today only in the southeast corner. There had been approximately 1500 head of cattle and 200 wild burros; the recommended stocking rate had been 300 (Warren and Anderson 1992). The entire monument was affected by grazing, except for the steepest slopes. Large areas remain nearly barren around some of the historic structures where large numbers of cattle were concentrated. Some areas exhibit severe erosion with head-cutting and gullying that continues today.

Adjacent land uses has not only included continued grazing but also extensive agricultural and residential development along the international boundary. Associated threats include groundwater overdraft, spread of exotic species, wildfires, pesticide drift, and feral or escaped domestic animals. Impacts to wilderness values include not only land development but also impacts to soundscapes and night skies. Short incursions into the monument include woodcutting, poaching, and dismantling of historic structures. The population of Sonoyta, Sonora was 16,500 in 2000 and is estimated to be 29,500 by 2020 (EPA 2001).

State Route 85 connects Phoenix, Tucson and other southwestern urban areas to the beaches and resorts of Puerto Peñasco (Rocky Point), Sonora. This highway bisects the monument and motor vehicles are known to kill large numbers of wildlife. In 2003, the posted speed limit was raised to 65 MPH. Highway maintenance activities (grading, oiling, vegetation removal, etc.) can also adversely affect natural resources along the right-of-way. The volume of traffic on Highway 85 has grown throughout the history of the monitoring program.

Impacts of undocumented aliens (UDAs) migrating north from Mexico through OPCNM are deleteriously affecting both the natural and cultural landscapes and resources of OPCNM

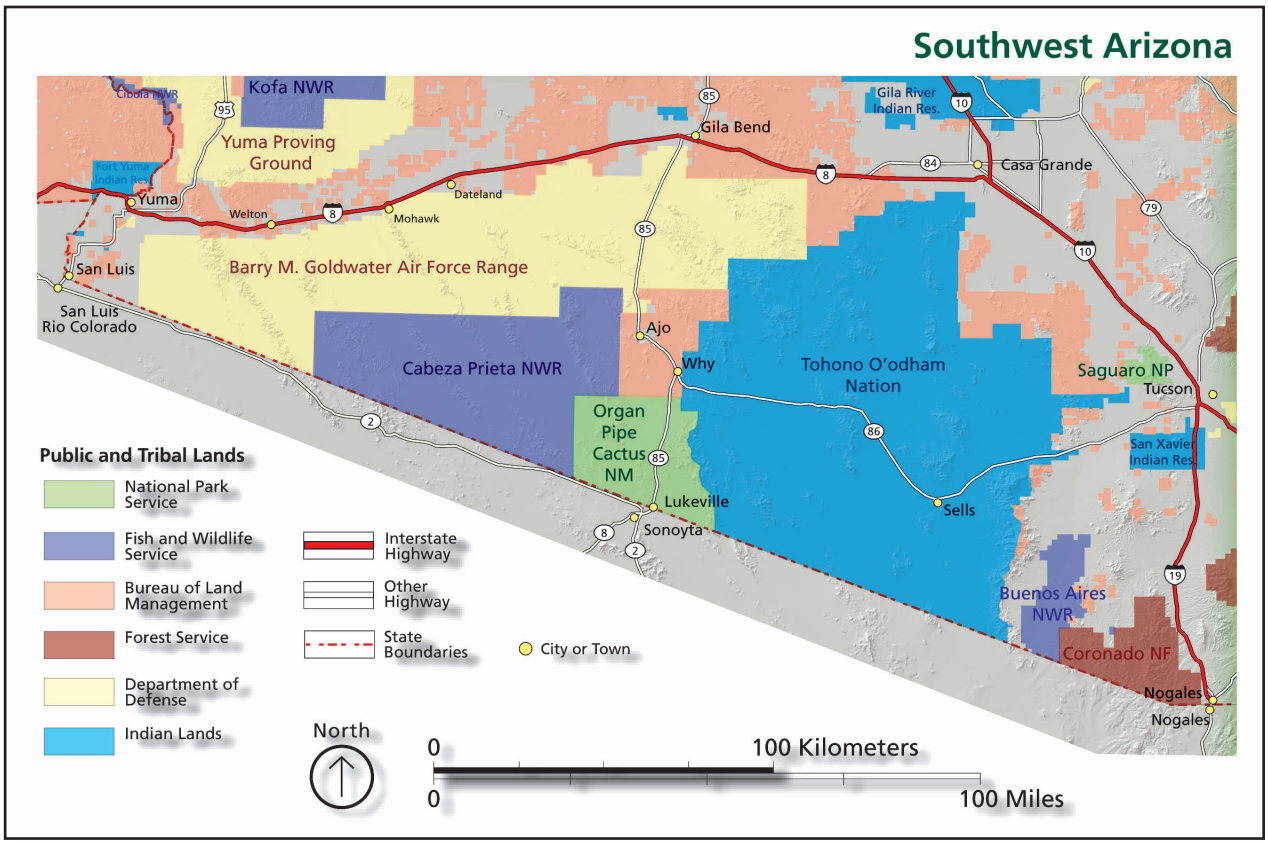


Figure 1-1. Organ Pipe Cactus N.M. and adjacent lands in southwest Arizona.

(A history of border traffic is presented in Appendix F). Undocumented aliens are people who enter OPCNM temporarily in order to collect monument resources of various types, or people who are migrating north to obtain jobs, contact family members, or smuggle contraband. Impacts include compaction of soils, trampling of vegetation, campfires, and accumulations of trash and human waste. Related impacts from law enforcement include increased traffic on roads and off road vehicle use. The number of apprehensions of UDAs in the Tucson sector rose from less than 100,000 in FY1992 to over 600,000 in FY2000 and has fluctuated between 300,000 and 500,000 since (CRS 2005).

Historical Perspective

Sensitive Habitats Project

The present Ecological Monitoring Program (EMP) at OPCNM was formulated in 1994. Research, monitoring, and monitoring-like studies at OPCNM, however, can be traced back to the early 1970s (Table 1-1). In the 1980s, park managers recognized the need for an integrated approach to assessing the condition and trend of OPCNM's biotic communities. The first program to meet this goal was known as the Sensitive Habitats Project. Proposed in 1985, this project stemmed from 4 high priority research projects identified in the 1984 Resources Management Plan: 1) Effects of Mexican Agriculture on OPCNM Ecosystems, 2) Inventory of OPCNM Herpetofauna, 3) Survey of OPCNM Insect Fauna, and 4) Climatological Monitoring. These projects were later combined under the proposal: Changes in Sonoran Desert Ecosystems at Organ Pipe Cactus National Monument with Reference to Sensitive Habitats. The monument's habitats were considered sensitive because many plant and animal species occur near the edge of their geographical distribution limits, and thus are subject to greater stresses and more rapid changes

than elsewhere.

Sensitive Ecosystems Program

In 1986, an international panel of scientists, resource managers and administrators was convened to design a more extensive and integrated program. It was named the Sensitive Ecosystems Program (SEP) and encompassed numerous projects, including the former Sensitive Habitats Project. Like the successful Channel Islands Inventory & Monitoring Initiative, the step-down planning technique was used to organize the management goals and objectives of the program (Bennett and Kunzman 1987).

The primary objective for the SEP was to develop a management program, based on synthesis reports, to determine: 1) the condition of monument ecosystems, 2) alternatives available for ecosystem management, and 3) the effectiveness of implemented action programs. Steps that were identified to support this objective included policy review, surveys and investigations of biotic and physical environmental components, long-term monitoring protocols and the development of an information management system.

In 1988, baseline research associated with 12 studies was undertaken (Table 1-2). By 1991, base-funding increases had allowed the monument to bring on a minimal staff to implement recommended long-term monitoring protocols associated with the original research projects. A critical element during the research phase was that resource management staff worked extensively with the principal investigators in the field. The monitoring protocols have been, and continue to be, tested and refined because of the feedback loop connecting researchers, monument managers and field staff.

Ecological Monitoring Program

In the spring of 1994, the title of the SEP was changed to the Ecological Monitoring Program (EMP) to reflect a change from the historic focus on "sensitive" monument areas to a broader look at the ecosystem's many components. As a result of the EMP, OPCNM has the framework for one of the most extensive ecological research and inventorying and monitoring programs in the National Park Service (NPS). The methodologies and tools for long-term monitoring will assist park managers with tracking the "vital signs" of the monument ecosystem.

The EMP has played many roles in monument management. Development of the Organ Pipe Cactus National Monument General Management Plan and Resources Management Plan (1994) was influenced by the EMP expansion workshop held in 1993. Cooperative resources management efforts have been developed with neighboring land management agencies. Contacts have been established with resource counterparts in Sonoyta, Sonora, Mexico, and data are shared on land use trends, water usage and development, pesticide and herbicide use, and other concerns.

Information Management

After more than a decade of baseline data acquired as part of the EMP, the integration and synthesis of results has been initiated. Key components in the synthesis of ecological data are Database Management Systems and new cooperative agreements and proposals will shape the future links between monitoring data and predictions on the status of monument resources. The GIS database is currently being expanded to include detailed information on each monitoring site. A more detailed summary on information and database management and OPCNM-specific information retrieval and archiving will be presented in the next annual report.

Synthesis and Management Decisions

Synthesis was supposed to be the basis for making the monitoring program work for management. The procedure was described in Bennett and Kunzman (1987) and the first paragraph is reproduced here: "*Synthesis reports incorporate in summary form, the status of the monument ecosystem, problems (actual or potential) identified as well as alternatives available for action,*

Figure 1-1. Chronology of the Ecological Monitoring Program at Organ Pipe Cactus N.M.

Date	Action(s)
1970	The first known "monitoring" project begins in Organ Pipe Cactus National Monument when Ranger Fred Goodsell begins annual measurement of stem growth increments for Organ pipe cactus (*Stenocereus thurberi*) and Senita cactus (*Pachycereus schottii*). This project is still extant.
1975	Domestic livestock grazing (cattle) expires in Organ Pipe Cactus National Monument.
1976	Organ Pipe Cactus National Monument is named as an International Biosphere Reserve.
1977	Vegetation plots and photo points were established by Dr. Peter Warren to gather baseline data on ecosystem recovery response to the removal of cattle and termination of associated impacts.
1978	Most of Organ Pipe Cactus National Monument (≈312,000 ac) is Congressionally designated Wilderness under the Wilderness Act of 1964.
1984	Four high-priority research projects identified by Organ Pipe Cactus National Monument in the 1984 Resources Management Plan: 1. Effects of Mexican agriculture on ORPI resources 2. Inventory of ORPI herpetofauna 3. Survey of terrestrial invertebrates 4. Weather monitoring
1985	The NPS Western Regional Office combined the four projects into one *Sensitive Habitats Project* and awarded $82,000 annually for three consecutive years.
Late 1985	Funding for the *Sensitive Habitats Project* is withdrawn.
1986	Sensitive Ecosystems Program (SEP) initiated with a $247,000 annual park operations base increase in the form of a Congressional appropriation sponsored by Sen. Dennis De Concini.
1986	The Quitobacquito pupfish is listed as an endangered species under the Endangered Species Act of 1973.
1987	SEP Program Design and Status Report Published with a Step-down implementation plan.
1987	Fourteen study sites are chosen for the SEP research and monitoring focus.

Table 1-1, continued. Chronology of the Ecological Monitoring Program at Organ Pipe Cactus N.M.

1988	Baseline research and monitoring begins on twelve studies: 1. Land use trends 2. Special status birds 3. Terrestrial invertebrates 4. Amphibians and reptiles 5. Non-native vegetation 6. Special status mammals 7. Special status plants 8. Recovery of monument ecosystems since termination of cattle grazing 9. Climatological monitoring 10. Vegetation community patterns on the boundaries of Organ Pipe Cactus National Monument 11. Vegetation structure and diversity in natural communities 12. Treaties, agreements and accords affecting natural resources management at ORPI
1991	The addition of botanist and wildlife biologist positions "rounds out" ORPI's monitoring and natural resources management program.
1993	Formation of Ecological Monitoring Program Assistance Committee (EMPAC).
1994	Sensitive Ecosystems Program renamed Ecological Monitoring Program or EMP.
1995	Organ Pipe Cactus National Monument and EMPAC add two new long-term study sites in inadequately represented biotic communities.
1995-1999	Ecological Monitoring Program Annual Reports issued for the years 1993-1996.
1997-1999	Bird monitoring protocol revised 3 times, 4-night monitoring and expanded grids tested at selected rodent monitoring grids, new winter ephemeral plant monitoring tested at 4 sites.
2001	Sonoran Desert Inventory and Monitoring Network established. OPCNM is the largest of the 11 units.
2005	Ecological Monitoring Program begins internal review and integration with Sonoran Desert Network.

Table 1-2. Summary of initial ecological monitoring program components and their current status, Organ Pipe Cactus N.M.

1988 Baseline Research Study	End Product(s)	Status of Protocol, 2005
Land Use Trends Surrounding Organ Pipe Cactus National Monument Principal investigator: Bruce Brown	• Technical report describing groundwater pumpage rates and agricultural production in Rio Sonoyta Valley, Mexico. (Brown 1991) • Monitoring protocol (Brown 1995): biannual photo-point photography of Sonoyta Valley agricultural areas, continued collection of data from Mexican agricultural officials on crops, acreage, chemical use, and well depths and electrical use.	• Land use photos are taken by EMP staff biannually at 8 locations along international boundary.
Inventory and Assessment: Special Status Birds Principal investigator: R. Roy Johnson	• Draft technical report (Johnson and Hiett 1992) describes ecology of special status birds. Belt transect monitoring protocol (Johnson 1995).	• Belt transect avian monitoring discontinued in 1995; new protocol developed in 1997, adjusted in 1998 and 1999, and implemented through 2004.
Inventory and Assessment: Terrestrial Invertebrates Principal investigator: Kenneth Kingsley	• 1,024 invertebrate taxa identified in 3-year survey. • 2 possible tiers of monitoring recommended; both beyond scope of budget constraints and staff expertise. • Technical report (Kingsley 1998).	• No revised invertebrate monitoring protocol established.
Inventory and Assessment: Amphibians and Reptiles Principal investigators: Charles Lowe and Phil Rosen	• Technical report describing reptile and amphibian species occurrence, distribution, and relative abundance in OPCNM (Rosen and Lowe 1996). • Lizard transects established for long-term monitoring of indicator species (Rosen and Lowe 1995).	• EMP staff continues annual spring and summer lizard monitoring at all sites.
Inventory and Assessment: Nonnative Vegetation Principal investigator: Richard Felger	• Technical report identifying species of nonnative plants in OPCNM (Felger 1990).	• No protocol associated with this project.

Table 1-2, continued. Summary of initial ecological monitoring program components and their current status, Organ Pipe Cactus N.M.

1988 Baseline Research Study	End Product(s)	Status of Protocol, 2005
Inventory and Assessment: Special Status Plants Principal investigator: George Ruffner	• Final report presenting distribution and abundance of 17 unique or vulnerable plant species in OPCNM (Johnson et al. 1991). • Long-term monitoring protocols for 5 of the 17 species: acuña cactus, dahlia-rooted cactus, desert caper, ashy jatropha, and senita and organ pipe cactus (Ruffner Associates 1995).	• Protocols followed for acuña cactus, discontinued for other species.
Recovery of Monument Ecosystems since Termination of Cattle Grazing Principal investigator: Peter Warren.	• Final report (Warren and Anderson 1992). • Protocol for monitoring grazing recovery (Warren and Anderson 1995).	• Protocol not followed.
Climate Monitoring (Resource Management staff)	• Nine automated weather stations installed near EMP study sites. • Protocol developed by OPCNM Resource Management personnel.	• Weather stations upgraded, 2 stations removed and 4 stations added. All or some of the following parameters measured: wind speed & direction, solar radiation, precipitation, air temperature, humidity, soil moisture, and soil temperature.
Vegetation Community Patterns on the Boundaries of Organ Pipe Cactus National Monument. Principal investigator: Peter Warren	• Final report describing patterns of plant community composition and distribution within 2 km of all OPCNM boundaries.	• Protocol not followed.
Vegetation Structure and Diversity in Natural Communities Principal investigators: Charles Lowe, Elizabeth Wirt, Phil Rosen	• Final report containing perennial vegetation density, cover, and diversity data from plots located at EMP study sites (Lowe et al. 1994). • Protocol (Lowe et al. 1995).	• EMP staff completed initial 5 year re-reading of vegetation plots.
Treaties, Agreements, and Accords Affecting Natural Resource Management at Organ Pipe Cactus National Monument Principal investigator: Carlos Nagel.	• Technical report compiling treaties, legal agreements, and memoranda of understanding between U.S. and Mexico affecting land management (Nagel 1988).	• No protocol associated with this project.

efficacy of action programs, and the availability of applicable information in the scientific literature. These reports address objective #1 of management's Primary Objectives. Synthesis is achieved through gathering of multi-disciplinary team(s) as needed to update old syntheses and incorporate new information. The synthesis report is the primary document used to make resource management decisions."

The monitoring program will only succeed if it implements the synthesis procedure or develops an alternative procedure for accomplishing the primary program objective (see primary objective under Sensitive Ecosystems Program, above). The synthesis procedure appears to have been superseded by the Ecological Monitoring Program Assistance Committee when the SEP became the EMP.

Ecological Monitoring Program Assistance Committee

The first meeting of the Ecological Monitoring Program Assistance Committee (EMPAC) was held in October 1993. This committee consisted of a balanced mix of scientists and managers. The EMPAC role and function statements are reproduced here:

Role

The Ecological Monitoring Program Assistance Committee is responsible for the evaluation, integration and assessment of the ecological inventorying and monitoring program at Organ Pipe Cactus National Monument.

Function

The function of the Ecological Monitoring Program Assistance Committee is to provide an On-going evaluation and assessment of activities associated with the ecological inventorying and monitoring program at Organ Pipe Cactus National Monument and to direct progress towards synthesis of the program. Committee activities include, but are not limited to, assessing the history of the program and providing guidance for future direction, updating elements of the step-down plan, examining and critiquing completed research and monitoring protocols, providing recommendations for future baseline studies and advanced specialized research, evaluating results of current monitoring and suggesting modifications if needed, developing strategies for integration and synthesis (i.e., community ecology), examining alternative methods for data management and linkages with geographic information systems, providing evaluation of natural resource scientific proposals and establishing methods for expansion of monitoring efforts within the region.

In 1995, the EMPAC assisted with the selection of two new Core-I EMP sites and placement of nocturnal rodent and vegetation quadrats and lizard transects at these sites. Also in 1995, the committee met with resources management staff to discuss issues related to vegetation monitoring protocols, weather station placement, and the logistics of installing soil moisture and soil temperature probes at weather stations. Into the late 1990s, the EMPAC continued to advise OPCNM with developing the EMP until October 1998. Projects included testing alternative sampling techniques for vegetation, birds, and rodents, review of statistical power, and recommendations for peer review of the monitoring protocols.

An EMPAC meeting was held in December 2004 to discuss program status, an outline for this report, and integration of EMP with resource management, public education, and the Sonoran Desert Network Inventory and Monitoring Program. A suggestion was made for an external review of the EMP. This review is in progress (see below). We hope to reconvene the EMPAC, or similar interdisciplinary body, in the near future and include new members who possess specialized skills in biostatistics and physical resources (soil, air, and water). An additional member representing sociological disciplines might also be a distinct advantage.

Sonoran Desert Network

Planning for the Vital Signs program began in 2001 and OPCNM played an important role in

the early planning stages. In 2005, OPCNM, SODN, and Southern Arizona Office staff met to discuss integration of the EMP and network Vital Signs programs. Participants identified monitoring components that were essentially similar, others that were somewhat similar but needed to be brought into alignment, and others that were unique to one program or the other. Priorities for integration were identified and personnel assigned to work on various protocols. Initial integration is focusing on data sharing and management. Later actions will include revisions of protocols and standardization of data collection, management, analysis, and reporting procedures.

Objectives of the NPS vital signs program are:
1. Determine the status and trends in selected indicators of the condition of park ecosystems to allow managers to make better-informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources.
2. Provide early warning of abnormal conditions of selected resources to help develop effective mitigation measures and reduce costs of management.
3. Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments.
4. Provide data to meet certain legal and Congressional mandates related to natural resource protection and visitor enjoyment.
5. Provide a means of measuring progress towards performance goals.

Review of the Ecological Monitoring Program
A partial internal review of the EMP was accomplished in the late 1990s. Resources management staff reviewed protocols and recommended modifications to the objectives and methods to better meet more rigorous NPS standards (Petterson, 1998). However, the recommendations were not formalized. Peter Rowlands (1999) reviewed the definitions and distinctions between inventory, monitoring, and research and discussed the role and significance of the monitoring program at OPCNM.
In 2005, OPCNM began a thorough review of the EMP. A workshop was held in March 2006 with an external review panel consisting of scientists and managers from the USGS and NPS. Objectives of this review were to:

- Determine if the Ecological Monitoring Program at Organ Pipe Cactus National Monument is adequate for long-term monitoring of status and trends.
- Determine if individual monitoring protocols are scientifically sound.
- Determine how well the current program addresses evolving park issues/threats and if monitoring protocols should be dropped, changed or added in order to address current issues/threats.
- Design the long-term Ecological Monitoring Program to meet Organ Pipe Cactus National Monument management objectives and National Park Service inventory and monitoring guidelines.

Some important recommendations included, a thorough analysis of the data sets to determine what information can be provided by the monitoring, development of new monitoring/ management questions, revision of monitoring protocols to meet newer standards, and development of partnerships to insure that sufficient expertise is available for all phases of program implementation. The results of this external review will be presented in a later report.

Ecological Monitoring Program Report

The standard format for annual EMP reports was described as follows (OPCNM 1995). "Annual reports of Organ Pipe National Monument's Ecological Monitoring Program will summarize monitoring activities completed and data collected. They will follow a similar format from year to year in order to easily provide comparisons. For each monitoring protocol the following will be provided: introduction, project history, summary of monitoring activities, methods and results. Simple data summaries in

tabular and graphic format will also be provided." The types and formats of data reductions have tended to vary from year to year. In some years, there may be some additional literature review and analysis, but this has not been consistent. Normally the EMP report would be an annual report, summarizing monitoring activities and results for one year.

This report summarizes monitoring activities and results for the period 1997 to 2005. However, it is not practical to present all data reductions for each year. An important objective of monitoring is to be able to detect changes in selected indicators. With this in mind, each chapter will present one or more data reductions (tabular, graphic, or statistical) that provide some insight into change or fluctuation over time. Where appropriate, recommendations are also provided. While there is some opportunity to make recommendations within each chapter, the interdisciplinary nature of most issues makes it awkward to place them in any one chapter. Furthermore, there was a separate process for synthesis and management decisions, see above, that needs to be implemented or revised.

Study Site Descriptions

The majority of SEP and EMP research was conducted at 16 select study sites. Sites ranged in size from 2.5 ha to 126 ha. Sites were selected to meet the goal of representing the various ecological communities of the monument. In addition, some sites were selected to monitor community change after disturbance (e.g. fires, livestock grazing) or change due to impacts from agricultural development and urbanization on adjacent Mexican lands. Over time, sites have been added to bridge gaps in the program, bringing the total number of sites to 20 (Figure 1-2).

Monitoring sites have been prioritized into 2 groups, based on the relative level of importance for monitoring. At Core I sites, the full monitoring program is carried out. These sites contain bird and lizard transects, vegetation quadrats, nocturnal rodent grids, and have an automated climate station either on site or nearby (Figure 1-3). Non-Core I sites also contain wildlife and vegetation plots, but have second priority in the monitoring program and only monthly rainfall totals are collected at most of these sites. The following study site descriptions are grouped according to their core designations. Historic land use information is provided. Putative vegetation associations described here were determined by considering information presented in Warren (1981), who classified the monument vegetation according to the Brown, Lowe, and Pase system (Brown 1982), and field examination of vegetation structure.

Core I Sites

Aguajita Wash (Figure 1-4)

Elevation ca. 335 m. This site incorporates a portion of Aguajita Wash and adjacent flats, all of Holocene age. Aguajita Wash is a large wash that drains much of the south half of the monument. Velvet mesquite *(Prosopis velutina)* riparian woodland and Velvet mesquite—blue palo verde *(Parkinsonia florida)* subassociation are the 2 main vegetation types of the xeroriparian corridor. Desert caper *(Atamisquea emarginata)* reaches its northern geographic limits here. The saline flats are dominated by a saltbush *(Atriplex polycarpa* and *A. linearis)*—velvet mesquite subassociation. Two vegetation plots are on flat sites outside the xeroriparian zone, and one plot spans Aguajita Wash. Historically, this site was a livestock concentration area due to its proximity to a water source (Aguajita Spring), feeding station, holding pasture, and other ranch facilities.

The Aguajita Wash site lies within a desert saltbush scrub plant community. Desert saltbush is a dominant species in three types of plant associations on approximately 10,000 acres of the monument (Warren at al. 1981). Extensive stands of saltbush were once common on the floodplains of major river systems in Arizona (Nichol 1937). Most of these have been lost due to conversion to agriculture and urbanization; other remaining areas have been altered by livestock grazing and

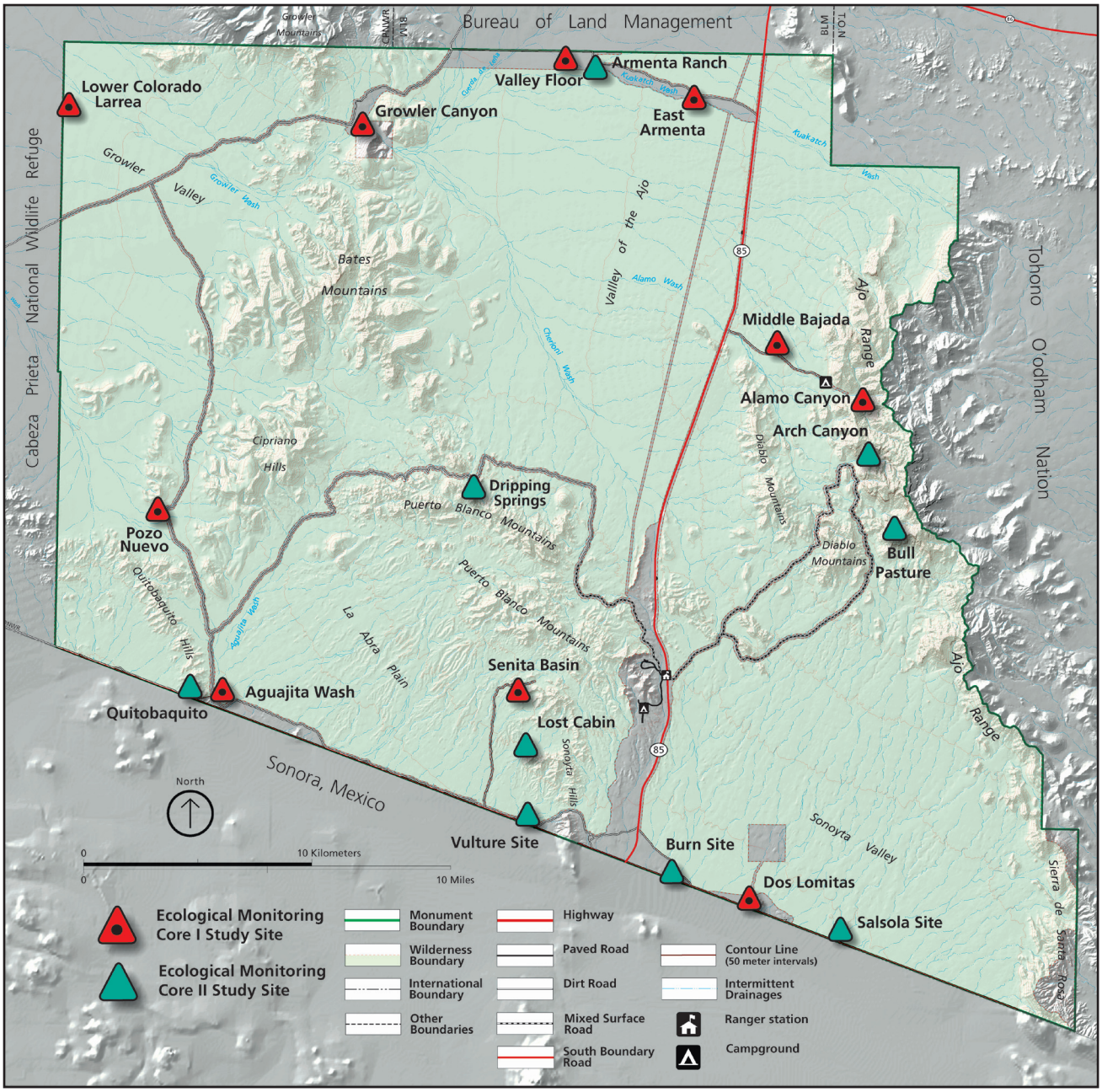
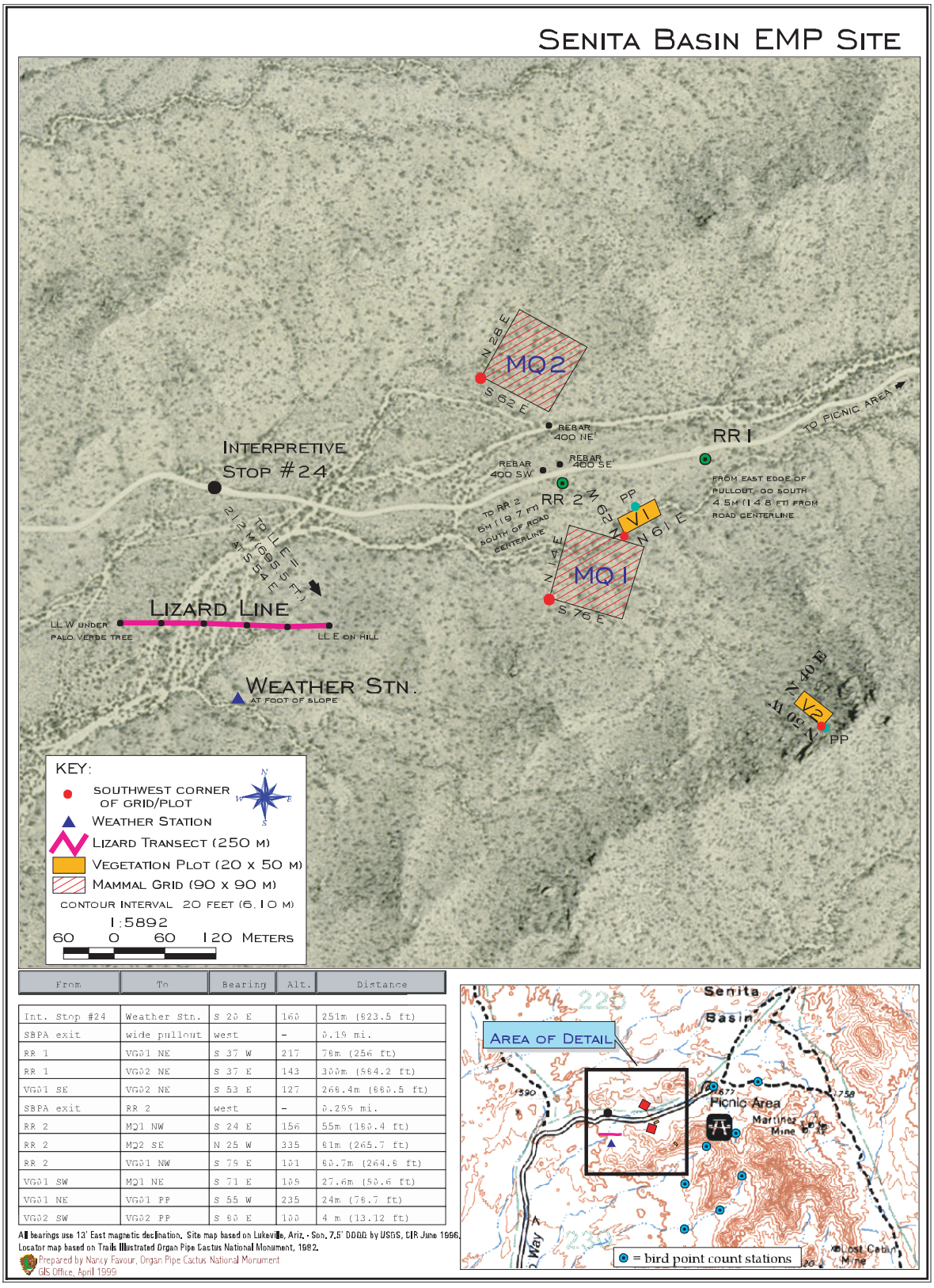


Figure 1-2. Ecological Monitoring Program study sites, Organ Pipe Cactus N.M.



From	To	Bearing	Alt.	Distance
Int. Stop #24	Weather Stn.	S 20 E	160	251m (823.5 ft)
SBPA exit	wide pullout	west	-	0.19 mi.
RR 1	VG01 NE	S 37 W	217	78m (256 ft)
RR 1	VG02 NE	S 37 E	143	300m (984.2 ft)
VG01 SE	VG02 NE	S 53 E	127	268.4m (880.5 ft)
SBPA exit	RR 2	west	-	0.299 mi.
RR 2	MQ1 NW	S 24 E	156	55m (180.4 ft)
RR 2	MQ2 SE	N 25 W	335	81m (265.7 ft)
RR 2	VG01 NW	S 79 E	101	80.7m (264.8 ft)
VG01 SW	MQ1 NE	S 71 E	109	27.6m (90.6 ft)
VG01 NE	VG01 PP	S 55 W	235	24m (78.7 ft)
VG02 SW	VG02 PP	S 80 E	100	4 m (13.12 ft)

All bearings use 13° East magnetic declination. Site map based on Lukeville, Ariz. - Son. 7.5' DOQQ by USGS, CIR June 1996.
Locator map based on Trails Illustrated Organ Pipe Cactus National Monument, 1982.
Prepared by Nancy Favour, Organ Pipe Cactus National Monument GIS Office, April 1999

Figure 1-3. Sample Ecological Monitoring Program study site configuration, Organ Pipe Cactus N.M.

other uses (Turner and Brown 1982). Desert saltbush scrub was evaluated in an ecoregional analysis by a binational team of experts. This community was identified as a conservation target whose distribution is limited and whose minimum number of conservation sites has not been met (Marshall et al. 2000).

Alamo Canyon (Figure 1-5)

Elevation ca. 900 m. This site is located in a steep, narrow canyon dissecting the Ajo Mountains. Surficial age is a complex mosaic. Below-freezing temperatures are common at this site. The vegetation plot is mostly contained within the tree-dominated xeroriparian zone of Alamo Wash. The xeroriparian community is classified as a scrub oak *(Quercus turbinella)* mixed shrub subassociation; velvet mesquite, netleaf hackberry *(Celtis reticulata),* desert hackberry *(Celtis pallida)*, and desert olive *(Forestiera shrevei)* are common canopy species. Understory shrubs and herbs were diverse, community structure was relatively diverse and plant cover in the xeroriparian corridor was high. The Alamo Canyon rodent grids are located on steep, rocky canyon slopes upstream from the vegetation plot. Jojoba *(Simmondsia chinensis)*, velvet mesquite, foothill palo verde *(Parkinsonia microphylla)* and mixed shrubs are the dominant species. The vegetation plot, rodent grids, and lizard transect are located within 400 m of a well and former holding pasture for livestock, where grazing impacts were severe. The vegetation plot was used formerly as a campsite and experienced a fire in the 1940s. The presence of shade intolerant species such as brittlebush *(Encelia farinosa)* in the shady understory indicates the site had a more open canopy in the recent past.

Dos Lomitas (Figure 1-6)

Elevation ca. 487 m. This site is adjacent to the International Boundary, east of Lukeville, on a Holocene-aged deep sandy loam. Extreme livestock overgrazing and other environmental disturbances have occurred at this site in the past (BLM 1971, ORPI unpublished data), causing plant community collapse, site desertification, and severe accelerated soil erosion. The vegetation association prior to this degradation is unknown, but probably included desert saltbush (*Atriplex polycarpa*), *A. linearis,* and creosote bush (*L. divaricata* var. *tridentata*), and velvet mesquite. These species are currently colonizing the area. All plots in the general area are threatened by continuing accelerated erosion. In 1998, a headcut on a gully that was about 1 m deep had nearly entered the livestock grazing exclosure and monitoring plot that was constructed in 1964. The hydrology of the area is changing rapidly as deep gullies capture shallow gullies.

East Armenta (Figure 1-7)

Elevation 480 m. This nearly level site within the East Armenta sandy plain area supports a *L. tridentata—P. rigida—P. velutina* floodplain subassociation on a sandy loam. Compared with other sites in the Ecological Monitoring Program, this site was the least affected by livestock overgrazing. Erosion, triggered by livestock grazing and other land-use practices, has cut a few gullies in the vicinity of the site but may not have significantly lowered the water table yet. An old east-west road, now long abandoned, paralleled Kuakatch Wash and passed through this site. An unusual assemblage of species occurs on the East Armenta sandy plain in the north-central part of the monument. An unusual combination of physical features—overland surface flows, distributory channels, coarse sandy loam of Holocene age, and a low probability of freezing temperatures—supports trees, shrubs, grasses, cacti, vines, and annuals in a mixture not found elsewhere in the monument. The species richness and relatively high alpha-diversity of this small area (NPS, unpublished data) is remarkable in the Sonoran Desert. At least 16 species of grasses produce significant cover in the area, including bush muhly (*Muhlenbergia porteri*), big galleta (*Hilaria rigida*), three-awn (*Aristida species*), Cottea pappophoroides, and cottontop (*Digitaria californica*). Two annual grasses—six-week grama (*Bouteloua barbata*) and needle grama (*B. aristidoides*)—are abundant during the summer monsoon. Notable species of cacti in the area are

desert night-blooming cereus (*Peniocereus greggii var. transmontanus*), cane cholla (*Cylindropuntia spinosior*), and large specimens of pencil cholla (*Cylindropuntia arbuscula*). Parish club cholla (*Grusonia parishii*) reaches its western range limit here.

Growler Canyon (Figure 1-8)

Elevation ca. 420 m. This site is located in a wide canyon that trends east to west in the northern end of the Bates Mountains. Growler Wash through the canyon is a fourth-order stream; the watershed above the canyon is very large (thousands of hectares). Soil type and surficial age is variable. The riparian area along the wash is a velvet mesquite riparian woodland subassociation. One vegetation plot is located on an 'island' in the wash that is periodically scoured by floods. The second vegetation plot is located on a loamy bench several feet above the wash bed.

The Bates Well/Growler Wash area has one of the longest documented histories (more than one century) of continuous livestock overuse anywhere in the monument. The negative effects of this sustained overuse were particularly severe on loamy soils of the floodplain benches in the canyon as well as the plains upstream and downstream from the canyon. The BLM (1971) reported that range condition was poor and livestock utilization was severe.

The base level of the drainage through the canyon and into the Growler Valley has dropped about 2 m during the mid-1900s. Evidence of this entrenchment episode lies in the 1940s-era earthen dam that once spanned the wash but is now elevated above the base level.

Historic deforestation for mining, ranch improvements and subsistence was widespread. The riparian area through the canyon and adjacent Cuerda de Lena provided the wood needed to fire the 3 smelters located at the Growler Mine, a short distance from Bates Well.

Lower Colorado Larrea (Figure 1-9)

Elevation ca. 335 m. This site is located in the northwest corner of the monument, near the boundary of the Cabeza Prieta National Wildlife Refuge. The single vegetation plot, lizard transect and two rodent grids are within a creosote bush—white bursage (*Ambrosia dumosa*) and/or triangle-leaf bursage (*Ambrosia deltoidea*) subassociation on Holocene-aged loamy soil. Two additional rodent grids are located in the Growler Wash floodplain, which supports a velvet mesquite—blue palo verde association. The site is fairly close to a large prehistoric settlement that employed floodplain farming techniques. Livestock herds ranged between Jose Juan charco and the water haul (tank) at Palo Verde Camp, and between Bates Well and Palo Verde Camp. Accelerated erosion, manifested in sheet and rill erosion and deep gullies, was triggered by the devegetation and surface disturbances.

Middle Bajada (Figure 1-10)

Elevation ca. 630 m. This Core I site is located on the middle bajada of the west-facing slope of the Ajo Mountains, to the north of the Alamo Canyon Road. The vegetation on the slopes is a triangle-leaf bursage—foothills palo verde—mixed cactus association. The bajada is deeply dissected by drainages, which have with xeroriparian zones dominated by cat-claw acacia *(Acacia constricta),* foothills palo verde, jojoba, wolfberry *(Lycium berlandieri)*, and *Brickellia coulteri.* The upland soil is in the Cipriano Series, a very gravelly loam underlain by a duripan. One of the vegetation plots The drainage, where one of the vegetation plots is located, is rocky and steep-sided. Livestock concentrated around the mouth of Alamo Canyon because a water tank was situated there. Photographs of the area from the 1940s and 1950s showed severe habitat degradation.

Pozo Nuevo (Figure 1-11)

Elevation ca. 380 m. This site is located near the western boundary of the monument, and is situated on fine sandy loam and cobbley sandy loam soils. The vegetation classification is creosote bush—white bursage association. It is very likely that big galleta was a codominant

plant at this site before decades of overgrazing occurred. Concentrated livestock use formerly occurred in the monitoring site due to the proximity of Pozo Nuevo (well) and other ranching facilities.

Senita Basin (Figure 1-12)
Elevation ca. 510 m. This site includes a north-facing slope, a south-facing slope, and level ground. Soils are variable. On the rocky slopes, the substrate is granite bedrock or a very stony loam in the Lomitas Series. On level ground is a very gravelly variant of the Antho Series. The site is frost-free most years. The vegetation types are the three most frost sensitive ones: foothills palo verde—brittlebush—organ pipe cactus *(Stenocereus thurberi)*—limberbush *(Jatropha cuneata)* hillside subassociation, foothills palo verde—brittlebush—organ pipe cactus—elephant tree *(Bursera microphylla)* subassociation and foothills palo verde—triangle-leaf bursage—organ pipe cactus with *Jatropha* spp. subassociation. Photographs from the 1930s and 1940s show the plants in this area were hedged by livestock. The very old Ajo-Sonoyta wagon road followed, in part, the Senita Basin road.

Valley Floor (Figure 1-13)
Elevation ca. 450 m. This new Core I site is located in the Valley of the Ajo and encloses one channel of Kuakatch Wash, a fourth-order stream. This and other drainages in the area are shallow and floodwaters often breach channels during the summer. The soil at the site is a deep and well-drained very fine sandy loam in the Gilman Series. The xeroriparian vegetation is dominated by velvet mesquite, ironwood *(Olneya tesota)*, and blue palo verde with a prominent vine component: Texas virgin bower *(Clematis drummondii),* climbing milkweed *(Sarcostemma cynanchoides),* and Indian-root *(Aristolochia watsonii)*. Areas between drainages are dominated by creosote bush, bush muhly *(Muhlenbergia porteri)* and annuals. One vegetation plot, a rodent grid and a lizard transect are located mostly within the xeroriparian zone, and the second vegetation plot and rodent grid are located on a creosote bush flat. The wash channels were former movement corridors for livestock because the riparian area offered shade. The natural tangle of understory plants, vines, and low-hanging tree branches was degraded by livestock. In addition, records indicate that woodcutting was particularly severe in the area. The former Ajo-Sonoyta Road passed very close to this site. Kuakatch Wash has been destabilized by the North Boundary Road (downstream from the monitoring site) and various other historic land uses.

Non-Core I Sites
Arch Canyon
Arch Canyon is a west-facing canyon located in the Ajo Mountains. The site spans the canyon at about 915 m elevation. One vegetation plot is located on a steep north-facing drainage in a rocky side canyon below the arch. The vegetation on this slope is characterized by dense thickets of large sclerophyllous shrubs 1-2 m tall. The dominant shrub is jojoba. The other vegetation plot is located across the canyon on a steep slope with a southern exposure. The dominants on this plot are various grass species, jojoba, triangle-leaf bursage, *Ambrosia cordifolia,* and brittlebush. Lizards and rodents are not monitored at this site. Photographs from the mouth of Arch Canyon from the 1940s through the 1970s show severe overgrazing.

Armenta Ranch
Elevation ca. 480 m. This site is located on a severely degraded site that was acquired by the NPS in the 1970s. The monitoring site is on relatively flat Gilman Series sandy loam and incorporates the former ranch house, fields, pastures, and road. It includes the floodplain and xeroriparian area of Kuakatch Wash as well as upland habitats. This area was overgrazed for decades, vegetation was cleared for housing and farming in the 1930s, and fuelwood was harvested. These uses caused devegetation, which led to desertification and the severe accelerated erosion that is continuing. The water table is presumed to have dropped dramatically, resulting in the widespread death of deep-rooted plants.

Figure 1-4. Aguajita Wash Ecological Monitoring Program study site, Organ Pipe Cactus N.M.

Figure 1-5. Alamo Canyon Ecological Monitoring Program study site, Organ Pipe Cactus N.M.

Figure 1-6. Dos Lomitas Ecological Monitoring Program study site, Organ Pipe Cactus N.M.

Figure 1-7. East Armenta Ecological Monitoring Program study site, Organ Pipe Cactus N.M.

Figure 1-8. Growler Canyon Ecological Monitoring Program study site, Organ Pipe Cactus N.M.

Figure 1-9. Lower Colorado Larrea Ecological Monitoring Program study site, Organ Pipe Cactus N.M.

Figure 1-10. Middle Bajada Ecological Monitoring Program study site, Organ Pipe Cactus N.M.

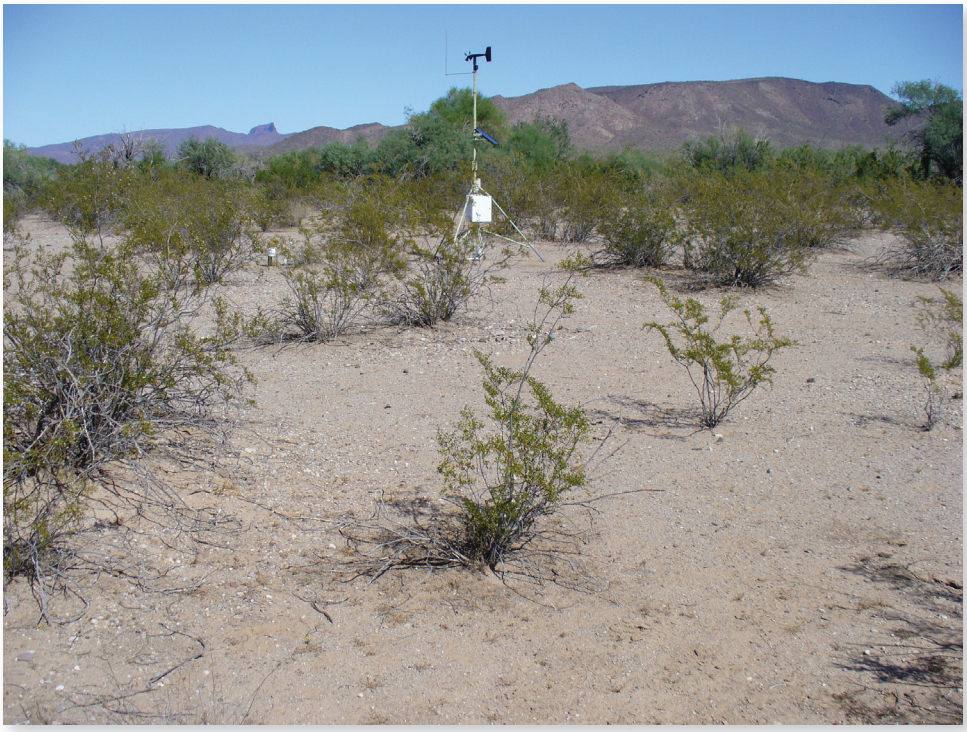


Figure 1-11. Pozo Nuevo Ecological Monitoring Program study site, Organ Pipe Cactus N.M.

Figure 1-12. Senita Basin Ecological Monitoring Program study site, Organ Pipe Cactus N.M.

Figure 1-13. Valley Floor Ecological Monitoring Program study site, Organ Pipe Cactus N.M.

Creosote bush is the dominant species outside the xeroriparian zone. The xeroriparian area is classified as creosote bush—velvet mesquite floodplain. One vegetation plot is located in the floodplain. The second vegetation plot is located to the northwest of the ranch house in an area nearly devegetated by historic land use and its long-lasting effects. The lizard transect crosses both habitat types. One rodent grid overlies the former farm field, the other rodent grid overlays an historic charco, now approximately 2 meters above the base level of the nearby drainage.

Bull Pasture

Elevation ca. 920 m. This site is located on a wide, fairly flat bench below the crest of the Ajo Mountains. The site incorporates two drainages, one shallow without permanent water and the other deeper and fed by an intermittent spring. Soils are very shallow and rocky. The vegetation subassociation varies according to slope and exposure. One vegetation plot is located on the flat bench and supports a desert grassland dominated by big galleta, broom snakeweed *(Gutierrezia sarothrae),* shin-dagger *(Agave schottii),* desert prickly pear *(Cylindropuntia engelmannii),* fairy duster *(Calliandra eriophylla)* and ocotillo *(Fouquieria splendens)*. A second vegetation plot and the only rodent grid span a drainage and include some bedrock upland. Grasses and large shrubs such as samota *(Coursetia glandulosa)* and *A. greggii* occur along the drainage. On the upland part of this plot are a mixture of grasses, ferns, small shrubs, and medium-sized shrubs such as *G. sarothrae,* Parish goldeneye *(Viguiera parishii),* Wright buckwheat *(Eriogonum wrightii),* Mormon tea *(Ephedra aspera),* and wormwood *(Artemisia ludoviciana).* Lizards are not monitored at this site. Bull Pasture was aptly named. Ranchers formerly used the area as a pasture for their bulls. The area was used prehistorically and historically; the *Villistas* camped there during the Mexican Revolution. We presume past human use was intensive because of the presence of water.

Burn Site

Elevation ca. 425 m. This severely disturbed, relatively flat site is located near the International Boundary east of Lukeville. The area was severely overgrazed until 1979; water was available to livestock less than 800 m away. The stocking rate of livestock was uncontrolled and extremely high in the area until the 1940s when the fence along the International Boundary was constructed. Surface disturbance was caused when various soil erosion control structures were built in the 1950s to 1960s. The recovering vegetation burned in 1983. Since 1999, various border activities including off-road driving and trash disposal have degraded the site. The potential plant association throughout most of the site is probably dominated by creosote bush, triangle-leaf bursage, desert saltbush and *Atriplex linearis*.

Dripping Springs

Elevation ca. 650 m. This site is located in a steep north-facing mountain slope with thin, rocky soil derived from lava and tuff. Subsurface moisture is abundant locally, especially on tuff deposits. Free water, of low salinity, is found in several caves. Characteristic species of the xeroriparian zone include jojoba, samota, Parish goldeneye, and ocotillo. The single vegetation plot includes subplots in the riparian zone and subplots on the east-facing rocky slope. The single rodent grid is located downslope from the springs and vegetation plot in a foothills palo verde—brittlebush—triangle-leaf bursage association. In approximately 1919–1920, Bill and Birdie Miller centered their livestock operation on this spring system. Water from the spring was piped out of the drainage to a tank where cattle could drink. The pipe remained in place until February 1951. Since 1999, undocumented aliens have been using the drainage and spring, leaving quantities of trash behind.

Lost Cabin

Elevation ca. 500 m. This site incorporates the floodplain and upper rocky slope habitats. Like the nearby Senita Basin EMP site, most years the Lost Cabin site is frost-free. The single vegetation plot and one lizard transect are located on a rocky granite slope with some bedrock exposed. The

vegetation subassociation on the rocky slope is foothills palo verde— triangle-leaf bursage—organ pipe cactus—*Jatropha* spp. The two rodent grids are located in the floodplain of a braided drainage. The types of human uses in this area and the severity of their impact are unknown.

Neolloydia Habitat

Elevation ca. 500 m. This site includes habitat for acuna cactus *(Echinomastus* (formerly *Neolloydia) erectocentrus* var. *acuñensis)*, an edaphic specialist. The plants occur on level, north- or south-facing slopes of dissected hills near the north pediment of the Puerto Blanco Mountains. The cactus is confined to a habitat nearly devoid of soil and the plants prefer to grow in cracks in the fractured granite bedrock. The vegetation association is triangle-leaf bursage—foothill palo verde pediment subassociation.

Quitobaquito

Elevation ca. 330 m. This site incorporated a spring-fed channel and pond surrounded by a velvet mesquite bosque with a dense shrub layer consisting mostly of Fremont wolfberry *(Lycium fremontii).* The littoral zone around the perimeter of the pond is occupied by bulrush (*Scirpus americanus).* Surrounding the mesquite bosque is a plant association dominated by desert saltbush, *A. linearis*, alkali goldenbush *(Isocoma acradenia)*, and desert sheepweed *(Suaeda nigra = S. moquinii = S. torreyana*). Arrow-weed *(Pluchea sericea)* and bulrush dominates the spring heads and salt grass *(Distichlis spicata)* carpets the open slopes. This diverse system continues to change since the last human occupants left in the 1950s and livestock grazing ended in the 1970s. Large barren areas remain where adobe houses formerly occurred on the northwest side of the pond. The lizard transects and rodent grids are located in habitat types: a formerly cultivated field, now a developing bosque west of the pond, and on a west-facing granite slope to the northeast of the pond. Vegetation is not monitored at this site.

Salsola Site

Elevation ca. 500 m. This site is located adjacent to the International Boundary east of the Dos Lomitas ranch house. The deep soil is a very fine sandy loam in the Gilman Series. Along the broad floodplain of this fourth-order drainage, the vegetation association is classified as a creosote bush—*Ambrosia* spp. subassociation and creosote bush—velvet mesquite. Outside the riparian zone, the subassociation is potentially dominated by desert saltbush, four-wing saltbush (*Atriplex canescens),* creosote bush, and scattered trees. The area is dominated by weedy species, including annual globe mallow *(Sphaeralcea coulteri),* tumbleweed *(Salsola australis)* and careless weed *(Amaranthus palmeri).* The vegetation plot, two rodent grids and lizard transect are in a previously burned area; numerous fire-scarred living plants and charcoal skeletons of dead plants were visible in 1995. The time and extent of the fire is unknown. The composition of this community has been profoundly altered by erosion, non-native plants, past overgrazing and wood cutting.

Vulture Site

Elevation ca. 450 m. This relatively flat site is located adjacent to the International Boundary on sandy cobbley soil. It is situated on the lower bajada of the Sonoyta Mountains and is transversely dissected by a fourth-order wash. The site was named after a colony of roosting black vultures *(Coragyps atratus)*, a species which reaches its western range limit in southwestern Arizona. Along the shallow and braided drainage, the xeroriparian plant community is dominated by foothills palo verde, ironwood and a diversity of shrubs and sub-shrubs. Outside of the narrow riparian corridor, the vegetation was dominated by creosote bush and triangle-leaf bursage. One of the vegetation monitoring plots incorporates the riparian area; the other is located in the nearby upland. The lizard transect includes both vegetation types. The two rodent grids are located on uplands dominated by triangle-leaf bursage and foothill palo verde.

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Acuña Cactus

Peter Holm

Objectives

Acuña cactus sampling was designed to detect population trends and dynamics by monitoring growth, mortality, recruitment, and reproductive status.

Introduction

Acuña cactus (*Echinomastus erectocentrus* var. *acunensis*) is known from only 5 populations in southern Arizona and one in northern Sonora, Mexico. These populations are in hills and flats of the desert at 400m to 1200m elevation in south-central and southwestern Arizona (Pima, Pinal and Maricopa Counties) and in Sonora, Mexico. The five documented populations are in Organ Pipe Cactus National Monument (OPCNM), Coffee Pot Mountain (BLM), Ajo (private land), Florence (state and private land) and Sonoyta, Mexico. Potential habitats exist in the Sand Tank Mountains of the Barry M. Goldwater Air Force Range and Tohono O'odham tribal lands.

Acuña cactus is listed as a Candidate species by the U.S. Fish and Wildlife Service due to its small, isolated populations, and impacts from past mining operations, illegal collecting and drought. The population at OPCNM is one of 2 that may be considered relatively free from habitat degradation due to land management practices (the other is located in the recently established Sonoran Desert National Monument), however, climate change, predation pressures and border related impacts have the potential to impact the species.

Occurrence of the species is associated with granite or granodiorite materials, with coarse to fine texture; with a patchy distribution on open, rounded small hills, benches and flats at elevations 400 to 1200m elevation, restricted to well drained knolls (Phillips et. al 1982). Dominant associated species include *Larrea divaricata, Fouquieria splendens, Ambrosia deltoidea, Encelia farinosa, Olneya tesota, Opuntia acanthocarpa, Cercidium microphyllum* and *Ephedra spp.*

Dr. William Buskirk and students from the Southwest Studies Field Program at Earlham College, Indiana, surveyed and mapped acuña cactus distribution at OPCNM from 1977 – 1986 (Buskirk 1981, Phillips III and Buskirk 1982). Buskirk also set up 4 study plots to monitor growth patterns and population dynamics. Two additional plots were added by Ruffner Associates in 1988 as part of the Special Status Plants inventory and monitoring program. The six plots have been monitored by OPCNM staff annually since 1989 for growth and mortality. Two major declines in population on acuña plots have been documented: 1980 – 81 and in the mid-1990s. Although the current sample size and methods may be insufficient to determine the long-term viability of the OPCNM population, monitoring to date has provided managers with important data on acuña longevity, growth, reproduction and natural history.

Methods

In 1977, Buskirk established two 0.1 ha (20 x 50m) plots (Plot 0 and Plot 1) in the heart of the acuña population, one adjacent to the North Puerto Blanco drive and one 170 meters away from the drive. Both plots were selected for their high densities of acuña cactus. The plots were searched systematically by a team of students, and most plants over 2 cm high were located and measured. In 1980, a mapping system was instituted to track individual plants without permanent marking.

In 1983, two more (20 x 50 m) plots (Plot 2 and Plot 3) were added. Cacti were measured to the nearest 0.5 cm from the ground (the base of

the spined body of the cactus) to the tip of the highest spine. Measurements were taken along the longitudinal axis of the plant – not the perpendicular distance from spine tip to ground, which is less than the length of the long axis for leaning cacti. Measuring methods changed in 1988, so size class information may not be comparable with the earlier data.

The current monitoring methods were developed in 1988 by Ruffner Associates (Ruffner Associates 1995). Two additional plots (Plot 4 and Plot 5) were added at the extreme eastern and western limits of the acuña distribution near the North Puerto Blanco Drive. At all 6 plots, acuña plants were mapped and permanent identification tags were wired to small rocks next to the plants. Plants were assigned X and Y coordinate values relative to the 0 x 0-m corner point ("origin") of the plot (southwest corner).

From 1988 to 2005, primary sampling was conducted in March. All mapped plants were located and measured to the nearest mm. Height was measured as a perpendicular distance from the base of the plant (from a standardized measuring point) to the top of the fleshy part of the plant (not the top of the spines). Two perpendicular width measurements were taken at the widest point of the plant using calipers. The average of these two width measurements was used. If plants were not found, evidence of mortality (carcass or spine clusters) was recorded. Flowers and buds were counted during the primary visit, and during two subsequent visits to determine peak flowers per plant. In 2004 and 2005, the six plots were revisited to count fruits.

From 1988 to 1994 during the primary March visit, an intensive and systematic search was made of each plot to locate new, small plants-including: seedlings (plants that probably had germinated since the last monitoring activity) and young pre-reproductive plants that may have been present during the previous census but had not been detected. For the seedling search effort, plots were divided into 2 x 20-m subplots using non-stretchable measuring tapes, and staff intensively searched for seedlings in the 2 m lanes, often on hands and knees. All new plants were measured, tagged (tag attached to rock near plant), and given an X and Y coordinate. Associated nurse plants or rock or bare substrate were recorded.

Concerns were raised in 1995 that the intensive seedling search may be impacting very small seedlings and plants due to trampling. In order to reduce these possible impacts, the seedling search was conducted on only half of each plot (10 x 50 m, including origin), with staff searching while standing up, at a rate calculated to detect very small plants, but not necessarily seedlings. In 2003 and 2005, the intensive seedling search was not conducted due to staff constraints.

Results

Numbers of individuals

Acuña cacti numbers in the three size classes ranging from 31-120 mm in height declined from 1988 to 2005 (Table 2-1, Figure 2-1). Numbers of individuals in the three size classes from 121-180+mm height classes have shown fluctuations, but no significant changes in numbers. Due to changes in how seedlings were sampled, we are not able to draw conclusions about the 1-30 mm size class. When data are compared from 1977-1981 from Buskirk's original two plots, to data collected from 1988-2005, it appears there has been a decline in the number of individuals on these two plots over time (Figure 2-3). The long-term trends (1977-1981, 1988-2005) for these original plots (0 and 1), indicate a major decline in the late 1970s and early 1980s, followed by partial recovery in the late 1980s and early 1990s, followed by another decline in the mid 1990s.

Annual mortality

Annual mortality is generally greatest for the smallest (1-10 mm height) individuals. Annual mortality was highly variable between years for all size classes. Annual mortality rates (since previous census) appear to spike over 20% in 1993, 1996-2000, and 2003-2004, for

individuals 11-40 or 41+ mm height (Table 2-4, Figure 2-4). Only in 2005 was the rate zero. The annual mortality rate for individuals 1-10 mm height tops out at 49.5% in 1996 For the period 1996-2000, mortality among 41+ mm height individuals appears to be delayed by one year compared to the smaller, 11-40 mm height individuals.

Reproduction

Acuña cacti are estimated to reach reproductive status at 25 mm in height. Data indicates there has been a decline from 143 to 75 individuals (47.6%) of the population that is 25 mm in height or taller (Table 2-2, Figure 2-2). Total flower production on all plots combined, ranged from 63 in 2002 to 902 in 1992 (Table 2-5, Figure 2-5). Peaks in flower production occur in 1989, 1992-1993, 1995, 1998, and 2001. Total flower production has increased steadily on all 6 plots since 2002. Total fruit production was 265 and 361 in 2004 and 2005, respectively (Table 2-5). Combined with flower data, this translates to fruit set rates of 75.1 and 84.0%, for 2004 and 2005, respectively.

Growth

Analyzing growth as a mean annual % change in height was misleading as some of the change represents change in level of hydration and not true growth (Table 2-6, Figure 2-6). A look at long-term individual growth trajectories (Figure 2-6b) is more informative. Data on individual plants indicates that seedlings reach maturity at widely different rates. For example, plant number 54 on plot 1 grew from 4 to 28 mm height in 4 years, whereas number 73 only grew from 3 to 10 mm in 8 years and seemed to stagnate for the next 5 years.

Precipitation data from the Acuña Site climate station are presented in Table 2-7 and Figure 2-7. The wettest and driest 12 months preceding a census were for 1993 and 1990, respectively. There was zero precipitation for October-March (cool season), preceding the 2002 census and only 0.3 inches for the April-September (warm season) preceding the 2003 census.

Discussion

The pronounced decline in acuña cactus numbers from 1980 - 1981 and 1988 - 2005 is a serious concern for park managers. Although some patterns are evident in the data such as low precipitation seasons followed by seedling mortality, there is no single factor that can explain all declines. Several factors relating to mortality and reproduction are discussed below.

Johnson (1992) found that fruit-set per flower was not limited by either pollinators or resources, yet flower production was limited by water availability, and ovule numbers varied seasonally with resource availability.

Johnson et al. (ca 1991) determined that seedling survival was dependent on summer precipitation. However, this result was based on analysis of only 4 years of data. A similar comparison of 1988-2000 data, regressing % annual mortality of 1-10 mm height individuals on previous April-September precipitation totals, yields an insignificant result (R^2=0.05, N=12, P=0.48). Two major outliers are for high mortality and wet summers preceding the 1993 and 1995 censuses.

In 2004, the old skeletons were removed from pots that had acuña cactus growing in the OPCNM nursery. These had produced many offspring, now ranging from seedling to golf ball size. After the protective lattice was removed, all of the acuña were soon decimated by a white-throated woodrat (*Neotoma albigula*). Petryszyn and Russ (1996) indicated that the Acuña Site had an unusually high cricetid rodent abundance. Buskirk's discussion on the 1981 acuña decline reported that the majority of mortality in the larger size classes were evidenced by scattered spines, and speculated the decline may be due to small mammal predation. Small mammal population growth during wet years may be a concern for the rare cactus.

Johnson (1991) stated that the opuntia

borer, *Moneilema gigas*, may be responsible for considerable mortality of larger acuña specimens. These cerambycid beetle larvae typically consume the cactus flesh and sever the root and stem, causing the plant to fall over. Johnson also noted that large plants, not producing flowers, invariably contained a large beetle larva. Many large acuña specimens on ORPI plots have been noted with bore holes on the sides or uprooted. Table 2-8 provides notes on the condition and fate of 7 abnormal acuña specimens on plot 4 in 1997.

Flower production between 1988 and 1991 was positively correlated with adult size (Johnson 1991) and with winter precipitation (AGFD 2004). Johnson (1991) reported 97.5% (39/40) fruit set at ORPI in 1988, somewhat higher than the 75.1 and 84.0%, we obtained for 2004 and 2005, respectively. Like many other cacti, the acuña cactus is pollinated by anthophorid, halictid, and megachilid bees (Johnson 1991). Late in the flowering season, seed production may be limited by a lack of pollinators due to competition with the hedgehog cactus (*Echinocereus engelmannii*). It is not clear if lower fruit set in 2004 and 2005 is due to pollinator availability or some other factor. Another factor affecting reproduction is seed and fruit predation by the pyralid moth larva, *Yosemitia graciella* (Johnson 1991).

Finally, germination, establishment, and ultimately, the distribution of acuña appear to be related to local soil properties (Johnson 1991). Soil pH of 6.0-7.5 was found at acuña substrates, and available soil B, available Cu and exchangeable Mg were all significantly higher than in areas not inhabited by the cactus (Johnson 1990). Despite the occurrence of acuña populations on gravelly ridges, local distribution is limited to finer soils where adequate moisture is available during germination and establishment.

Although serious declines have been documented by 1977 – 2005 acuña monitoring, fluctuations in population size may be a natural history adaptation to insect outbreaks and elevated predator levels-- low density metapopulations may help avoid detection (Rutman, pers. communication).

Recommendations

- Relate existing acuña data to climate data to determine relationships. Analyze archived Buskirk data from 1982 – 1986. Determine if the fluctuations in the acuña data are similar to the normal fluctuations one would see in other cacti populations. Conduct a literature review for recent data that indicate declines in other cacti populations due to the prolonged drought.

- Revise the acuña cactus monitoring protocol to better address factors relating to reproduction and mortality.

- Systematically survey and map occupied habitat; compare with Buskirk and Ruffner Associates survey maps to detect any significant expansion or contraction of distribution and range.

- Conduct studies of predators such as cricetine rodents, *Moneilema gigas,* and *Yosemitia graciella* to better understand their relationships to acuña cactus. Determine if other species are impacting the cactus. Consider resurrecting the Acuña Site rodent monitoring grid or establishing a new one.

- Experiment with methods to protect acuña cactus from predators such as exclosures around cacti.

- Determine the genetic and environmental sources of variation in fruit set and low seed set.

- Continue to discourage visitor access to the population by maintaining the road as a narrow and rough trail, without obvious pullouts near the population.

- Employ law enforcement strategies that discourage undocumented alien traffic and off-road vehicle activity in acuña cactus habitat.

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Charles Conner, Ami Pate, Sue Rutman, Bryan Milstead, Jim Petterson, Tim Tibbitts, Nancy Favour, Tom Potter, Peter Rowlands, and many seasonal employees and volunteers.

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Table 2-1. Comparison of acuña cactus size distribution from 1988 to 2005 on all monitoring plots combined at Organ Pipe Cactus N.M. Full intensive seedling search in 1988-1994; half intensive seedling search in 1995-2002, 2004; No intensive seedling search in 2003, 2005.

Height Class (mm)	1988	1989	1990	1991	1992	1993	1994	1995	1996
1-30	114	168	181	281	249	198	180	195	123
31-60	58	49	65	54	47	53	55	60	59
61-90	35	39	39	38	43	38	46	41	42
91-120	28	30	25	34	37	28	23	28	32
121-150	10	11	11	25	24	17	21	21	15
151-180	2	3	2	9	13	9	7	4	12
181+	1	1	1	5	4	2	2	7	4

Height Class (mm)	1997	1998	1999	2000	2001	2002	2003	2004	2005
1-30	123	107	80	66	54	61	35	17	10
31-60	50	30	45	32	38	35	22	20	18
61-90	34	32	12	21	21	19	19	18	19
91-120	18	22	7	9	11	12	13	18	19
121-150	5	10	1	4	5	1	8	9	13
151-180	3	3	1	0	1	0	1	2	2
181+	0	2	0	1	1	1	1	1	2

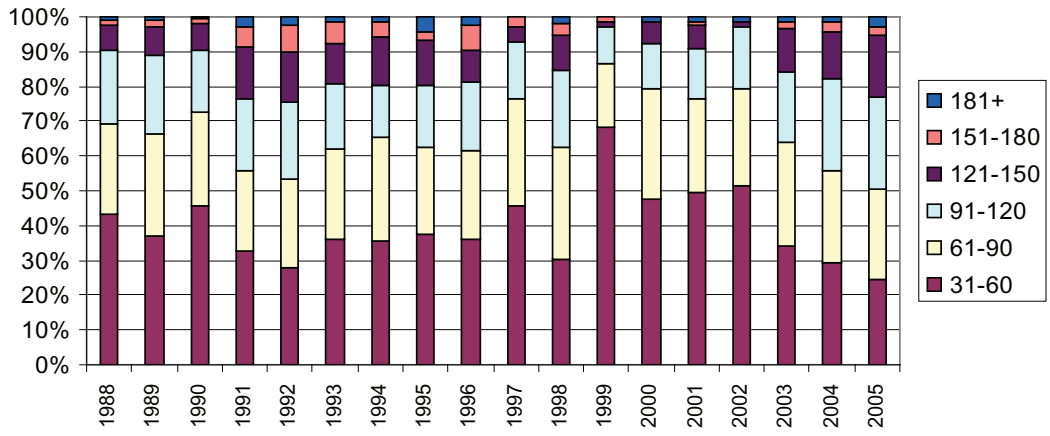

Figure 2-1. Percent composition of acuña cactus size classes from 1988 to 2005, on all monitoring plots combined at Organ Pipe Cactus N.M. 1-30 mm class excluded due to inconsistent sampling.

Table 2-2. All acuña cactus greater than or equal to 25 mm height on monitoring plots at Organ Pipe Cactus N.M.

Year	Plot 0	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Total
1988	8	18	28	19	47	23	143
1989	9	21	31	17	50	24	152
1990	9	23	35	17	50	24	158
1991	15	30	38	17	52	24	176
1992	20	35	41	17	59	24	196
1993	16	35	36	18	48	16	169
1994	18	39	35	18	45	16	171
1995	19	47	41	17	47	15	186
1996	17	44	41	15	48	16	181
1997	16	23	35	11	47	2	134
1998	15	21	30	12	37	1	116
1999	12	20	22	11	16	1	82
2000	13	19	13	15	15	2	77
2001	13	19	14	17	18	5	86
2002	13	19	14	17	17	5	85
2003	10	17	13	13	18	5	76
2004	9	17	11	13	17	5	72
2005	9	17	11	13	20	5	75

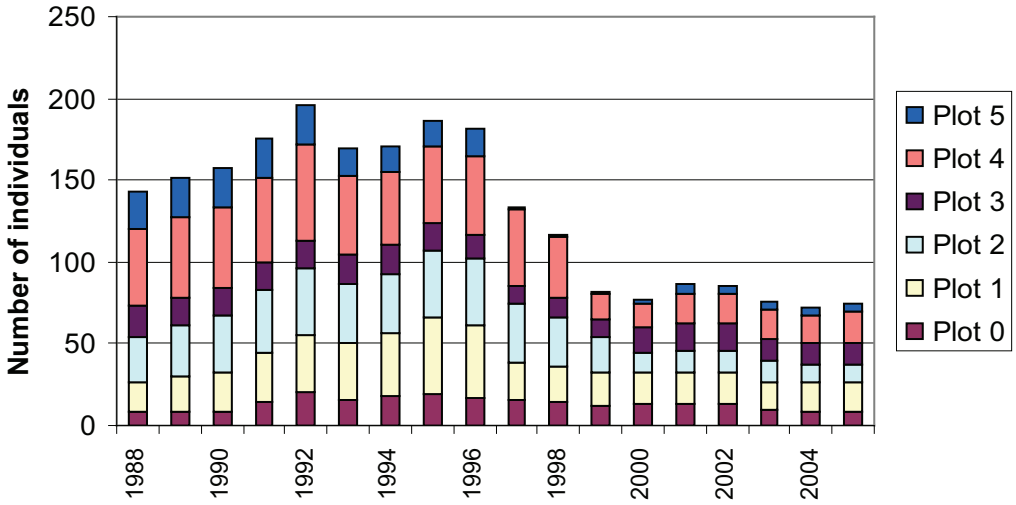

Figure 2-2. All acuña cactus greater than or equal to 25 mm height on monitoring plots at Organ Pipe Cactus N.M. Figure 2-2. All acuña cactus greater than or equal to 25 mm height on monitoring plots at Organ Pipe Cactus National Monument.

Table 2-3. All acuña cactus greater than or equal to 31 mm height on plots 0 and 1 at Organ Pipe Cactus N.M. (1977-1981 data from Buskirk (1981).)

Year	Plot0	Plot1	Year	Plot0	Plot1
1977	34	73	1994	16	33
1978	27	68	1995	14	37
1979	26	75	1996	16	41
1980	24	74	1997	14	16
1981	21	44	1998	11	18
			1999	10	17
1988	7	13	2000	13	16
1989	9	18	2001	12	16
1990	9	20	2002	12	15
1991	12	26	2003	8	16
1992	15	28	2004	9	17
1993	14	29	2005	9	17

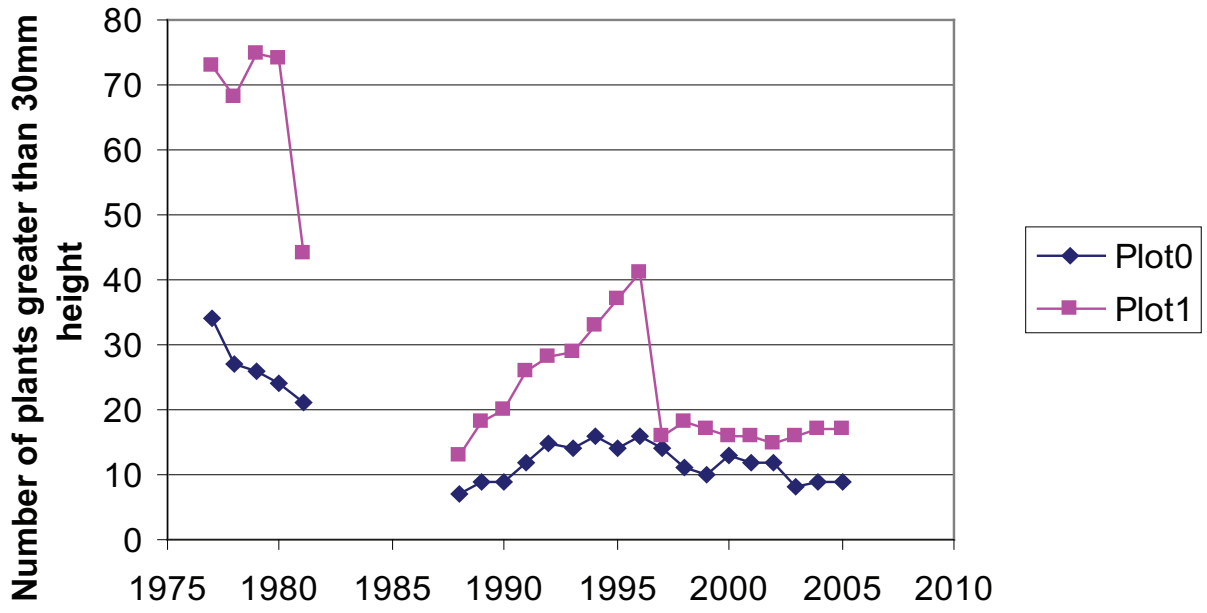

Figure 2-3. All acuña cactus greater than or equal to 31 mm height on plots 0 and 1 at Organ Pipe Cactus National Monument.

Table 2-4. Annual mortality of acuña cactus since previous census on monitoring plots at Organ Pipe Cactus N.M.

From Year	To Year	Alive	Dead	1-10 mm	Alive	Dead	11-40 mm	Alive	Dead	41+ mm
1988	1989	57	5	8.77	75	4	5.33	105	7	6.67
1989	1990	101	24	23.76	85	5	5.88	116	5	4.31
1990	1991	103	5	4.85	99	3	3.03	122	7	5.74
1991	1992	155	59	38.06	148	7	4.73	141	9	6.38
1992	1993	109	45	41.28	157	48	30.57	150	30	20.00
1993	1994	101	25	24.75	114	6	5.26	131	8	6.11
1994	1995	100	27	27.00	101	2	1.98	133	12	9.02
1995	1996	107	53	49.53	107	28	26.17	141	6	4.26
1996	1997	58	16	27.59	88	11	12.50	141	48	34.04
1997	1998	71	23	32.39	72	14	19.44	90	22	24.44
1998	1999	61	27	44.26	52	3	5.77	93	32	34.41
1999	2000	41	6	14.63	56	1	1.79	49	12	24.49
2000	2001	23	7	30.43	56	6	10.71	54	2	3.70
2001	2002	8	1	12.50	54	4	7.41	69	1	1.45
2002	2003	17	8	47.06	54	15	27.78	58	10	17.24
2003	2004	11	9	81.82	35	11	31.43	53	1	1.89
2004	2005	3	2	66.67	23	0	0.00	59	0	0.00

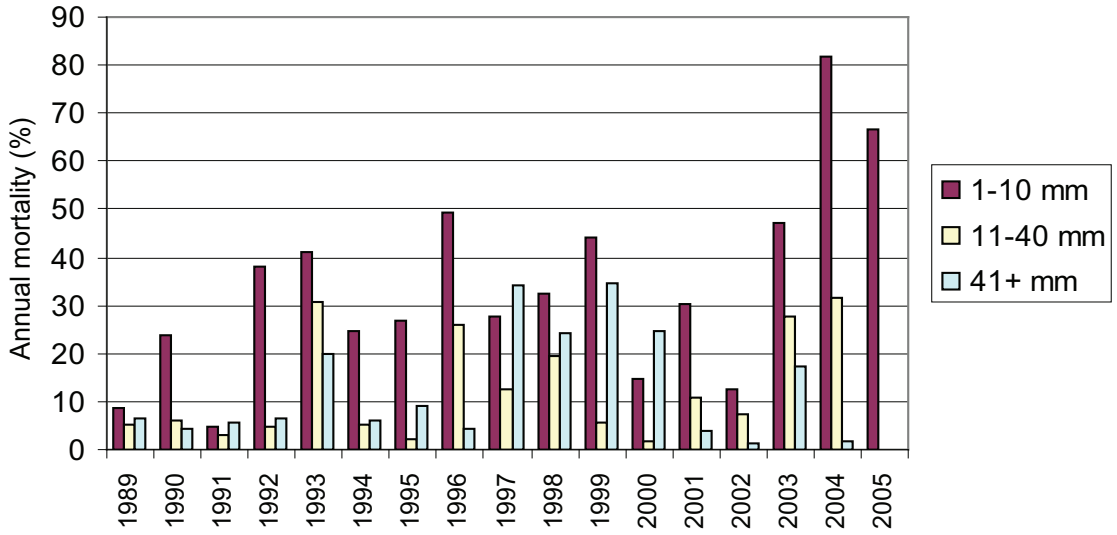

Figure 2-4. Annual mortality of acuña cactus since previous census on monitoring plots at Organ Pipe Cactus N.M.

Table 2-5. Mean number of flowers (a) and fruit (b) at each acuña cactus plot at Organ Pipe Cactus N.M.

Year	Plot 0	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Total
a. Flowers							
1988	2	47	56	95	0	0	200
1989	13	74	77	93	152	168	577
1990	13	59	65	63	131	123	454
1991	22	115	128	93	232	205	795
1992	44	155	154	62	254	233	902
1993	43	149	165	79	187	171	794
1994	9	62	82	44	102	103	402
1995	23	114	139	45	139	154	614
1996	18	111	109	21	113	122	494
1997	8	11	45	2	84	8	158
1998	48	89	175	34	234	0	580
1999	12	8	30	2	15	0	67
2000	23	5	8	6	34	8	84
2001	57	69	60	47	83	9	325
2002	12	5	12	4	28	2	63
2003	28	26	26	17	41	5	143
2004	64	70	70	52	77	20	353
2005	69	81	76	66	103	35	430
b. Fruit							
2004	50	59	41	49	50	16	265
2005	67	65	55	63	85	26	361

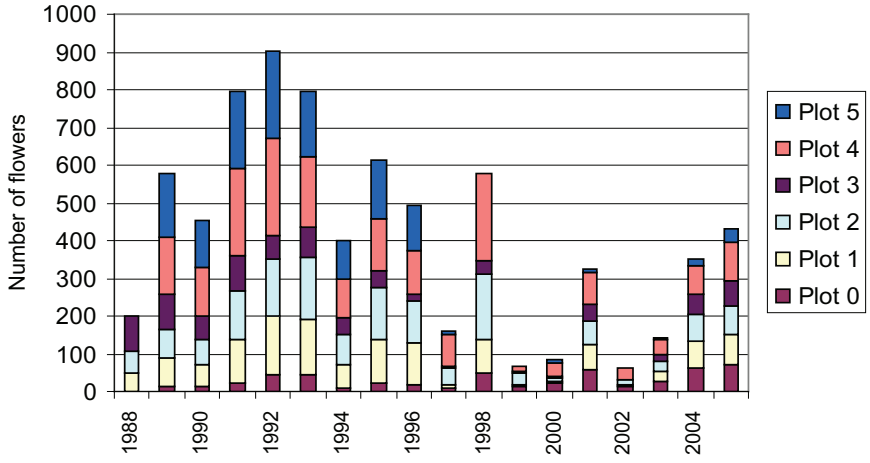

Figure 2-5. Mean number of flowers at each acuña cactus plot at Organ Pipe Cactus N.M. (not counted on plots 4&5 in 1988).

Table 2-6. Mean annual growth of acuña cactus as percent increase in height on monitoring plots at Organ Pipe Cactus N.M.

To Year	Plot 0	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	6-plot mean
1989	36.9%	28.0%	15.1%	11.0%	17.5%	39.4%	24.6%
1990	22.4%	1.8%	7.9%	17.6%	9.7%	-1.9%	9.6%
1991	64.3%	86.2%	51.7%	59.7%	35.2%	61.4%	59.7%
1992	34.5%	15.8%	25.2%	28.9%	29.4%	3.3%	22.8%
1993	18.8%	22.3%	6.5%	15.2%	6.2%	22.0%	15.2%
1994	5.2%	13.2%	12.2%	10.4%	7.9%	8.2%	9.5%
1995	21.5%	23.2%	47.1%	30.5%	18.5%	32.7%	28.9%
1996	15.9%	15.5%	4.0%	14.8%	6.0%	1.5%	9.6%
1997	-7.3%	-6.7%	-13.4%	-14.7%	-1.0%	-0.1%	-7.2%
1998	72.7%	56.4%	60.5%	70.8%	45.9%	75.3%	63.6%
1999	-21.3%	-14.4%	-28.0%	-11.8%	-8.7%	-20.5%	-17.5%
2000	51.3%	44.9%	84.4%	70.7%	42.5%	61.6%	59.2%
2001	24.1%	18.6%	21.4%	24.8%	18.1%	35.2%	23.7%
2002	-12.2%	-13.1%	-14.8%	-9.0%	-9.6%	-18.1%	-12.8%
2003	23.5%	47.4%	3.9%	29.7%	10.9%	50.2%	27.6%
2004	6.8%	10.2%	2.6%	11.5%	12.8%	17.4%	10.2%

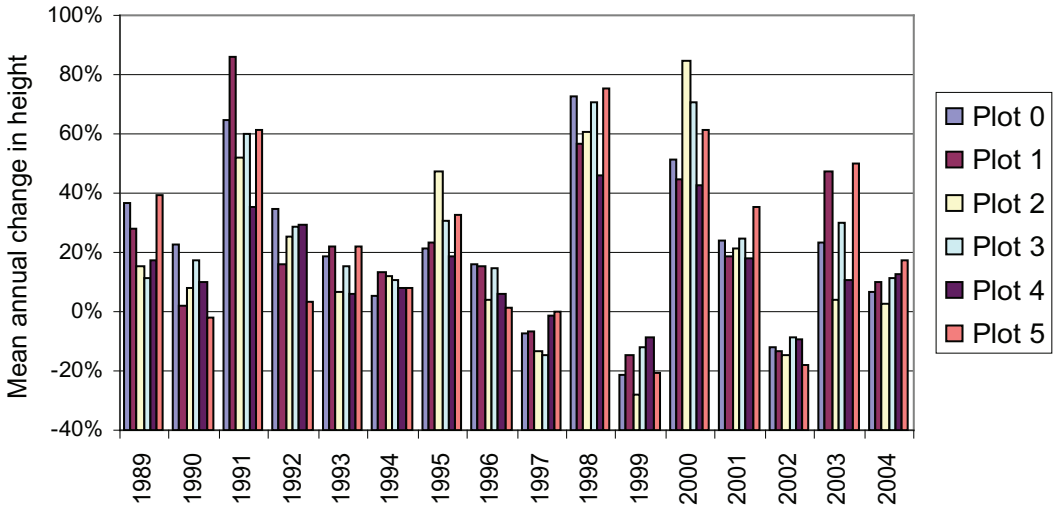

Figure 2-6a. Mean annual growth of acuña cactus as percent increase in height on monitoring plots at Organ Pipe Cactus N.M..

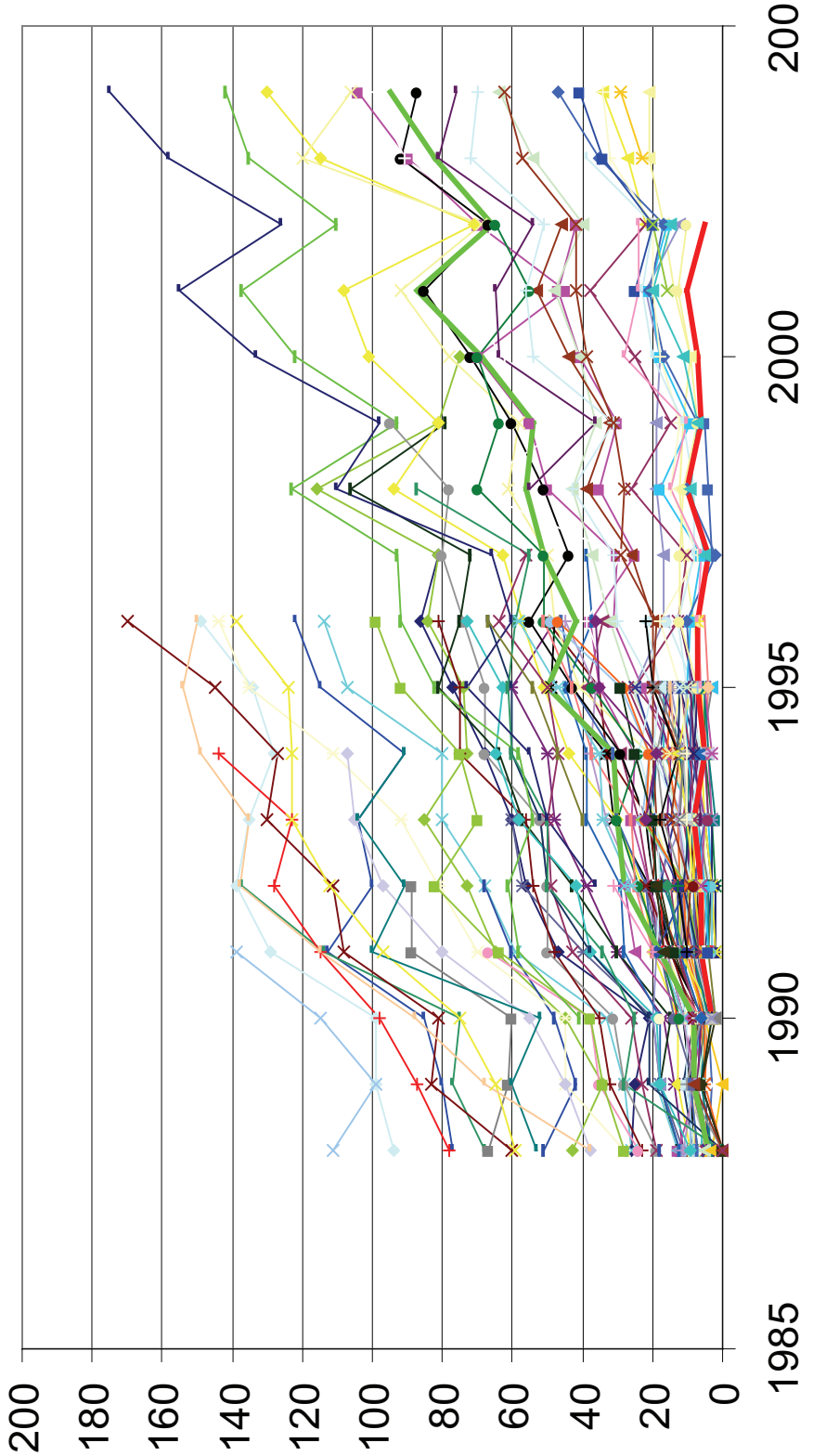

Figure 2-6b. Individual growth trajectories of acuña cactus on plot 1 at Organ Pipe Cactus N.M. Plant 54 indicated by thick green line, plant 73 by thick red line.

Table 2-7. Rainfall since previous census (inches) at the Acuña Habitat climate station, Organ Pipe Cactus N.M.

From Year	To Year	Apr-Sep	Oct-Mar	Apr-Mar
1988	1989	3.8	5.3	9.1
1989	1990	1.6	1.5	3.2
1990	1991	6.7	6.2	12.9
1991	1992	2.0	7.4	9.3
1992	1993	5.7	10.1	15.8
1993	1994	3.0	3.5	6.5
1994	1995	2.2	6.2	8.3
1995	1996	5.0	2.4	7.4
1996	1997	6.7	0.6	7.3
1997	1998	3.5	7.0	10.5
1998	1999	2.8	1.1	3.9
1999	2000	5.3	1.4	6.7
2000	2001	0.7	5.5	6.2
2001	2002	5.1	0.0	5.1
2002	2003	0.3	3.2	3.6
2003	2004	8.1	2.4	10.5
2004	2005	2.8	7.9	10.7

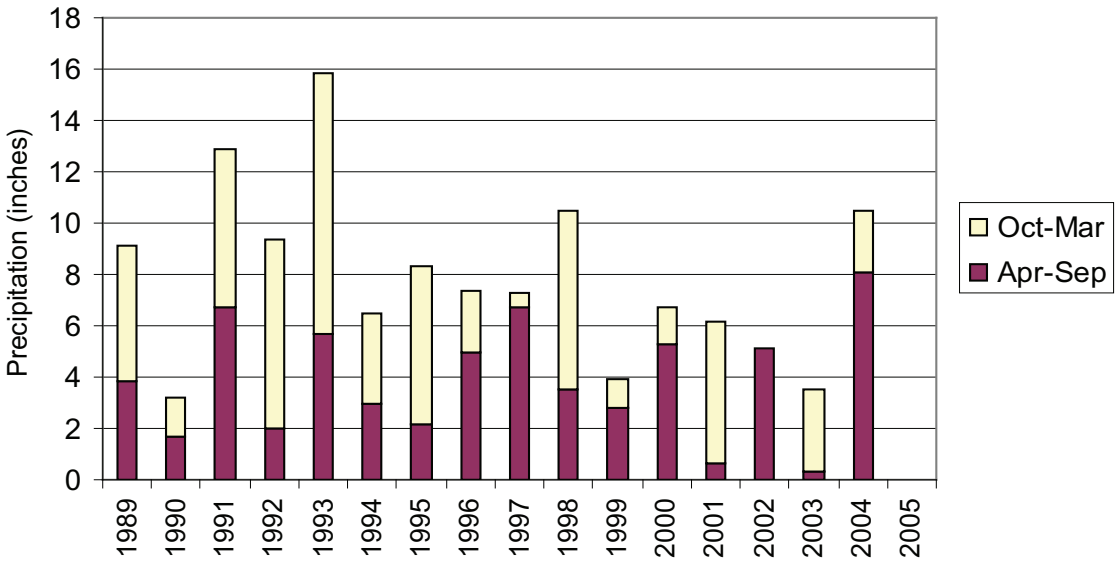

Figure 2-7. Rainfall since previous census (inches) at the Acuña Habitat climate station, Organ Pipe Cactus N.M.

Table 2-8. Example of condition notes and fate of unhealthy acuña cactus individuals at plot 4 in 1997, Organ Pipe Cactus N.M.

Plant #	Height	Condition	Flowers	Fate (between census periods)
20	55	bore hole	no	uprooted (1998-1999)
30	90	bore hole	no	dead (1997-1998)
35	126	bore hole	yes	uprooted (1997-1998)
73	96	bore hole	yes	dead (1997-1998)
19	156	base damaged	yes	dead (1997-1998)
52	89	base damaged	no	dead (1997-1998)
13	81	“dying”	no	dead (1997-1998)

Organ Pipe Cactus and Senita Cactus

Peter Holm

Objectives

The overall objective applied to all special status plant monitoring is to understand population dynamics and provide insight into potential problems or threats faced by species so that efficient and effective management actions can be undertaken (Ruffner Associates 1995). A specific objective for the columnar cacti, articulated more recently, is to determine if productivity (indicated by stem growth) of organ pipe and senita cactus plants is changing over time; if change in productivity is detected, then possible causal agents will be evaluated (Petterson 1998).

Introduction

Organ Pipe Cactus National Monument is fairly unique in the presence of 3 species of columnar cactus including organ pipe (*Stenocereus thurberi*), senita (*Pachycereus schottii*), and saguaro (*Carnegia gigantea*). The organ pipe and senita cactus are of particular interest because they are at their northern distributional limits and because they were instrumental in the establishment of the monument. The organ pipe is widespread on rocky slopes and upper bajadas throughout the monument, with greatest population densities on southwestern, southeastern, and southern slopes where freezing temperatures are least likely to occur (Parker 1987). Senita is restricted to the southern boundary on sandy plains and warm rocky slopes.

Population trends for organ pipe cactus demonstrate that regeneration over the last century has been irregular, with brief episodes of recruitment during anomalous wet periods such as the 1910s and 1920s. Episodes of recruitment have generally corresponded to wet periods with mild winters, and poor regeneration has coincided with prolonged drought (Parker 1993). Concerns for these species have generally included freezing temperatures and land use changes (Johnson et al. 1991).

Flowering peaks and fruit set timing for organ pipe cacti in OPCNM are different than populations further south in Sonora, exhibiting a pollination system adapted to a higher reliance on endangered lesser long-nosed bats (*Leptonycteris curasoae*). Maximum fruit set requires the joint contributions of bats, birds, and bees and if one or more of these pollinators decline, reduction in fruit set could occur (Fleming et al. 2001).

Project History

In 1970, Park Ranger Fred Goodsell selected 31 organ pipe cacti and 9 senita cacti for long-term growth monitoring. The organ pipe cacti were part of a population growing on a steep, south-southeast facing rocky slope in the central Puerto Blanco Mountains near Baker Mine. Eight of the senita cacti plants were located near Lost Cabin Mine and one was located along a wash on the floor of Senita Basin in the southern Puerto Blanco Mountains. These individuals represented a wide range of sizes but were small enough to allow access for stem measurements. Therefore, this sampling effort was biased towards smaller size classes of organ pipe cactus, in particular, plants less than 15-20 m total stem length (Figure 3-1). The individuals were permanently tagged. Monument personnel measured the annual growth of these individuals from 1970 to 1997, 2000, and 2002 to 2003. Monitoring of some individuals in the original study ended sooner due to mortality or severely reduced vigor.

The original organ pipe plot established by Fred Goodsell was placed in characteristic habitat for the species within 8 km of OPCNM headquarters. The plot was located on a steep, S-SE facing hillslope in the central Puerto Blanco Mountains (average slope angle and aspect of 24° and 162° respectively), at 595 – 615 m elevation. The geologic substrate is metaquartz porphyry. The newer Bates Mountains organ pipe plot is located

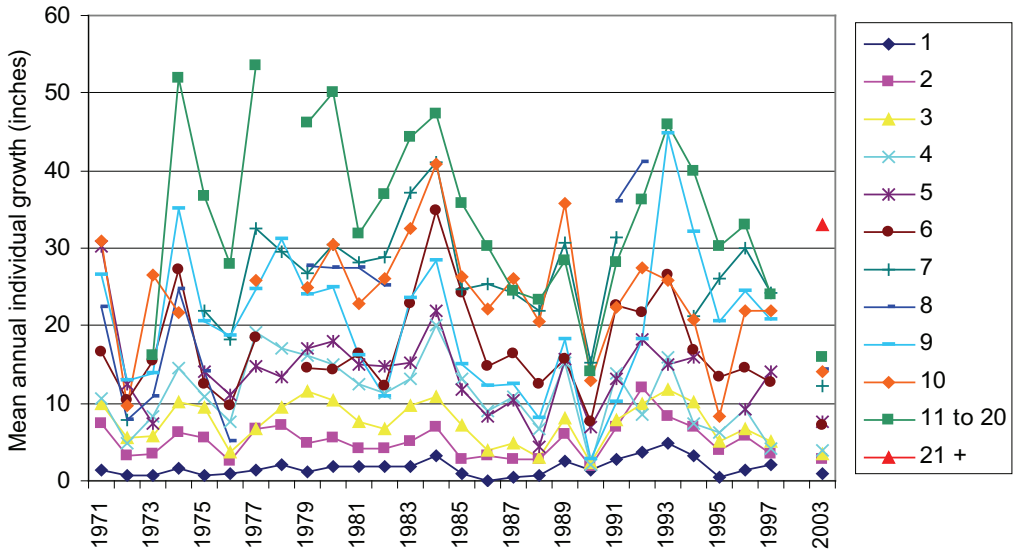

Figure 3-1. Mean annual individual growth of organ pipe cactus, grouped by number of stems, at the Baker Mine plot, Organ Pipe Cactus N.M.

on a S-SE facing hillslope 1.4 km west of Bates Well, at 421 - 468 m elevation on a conglomerate and brecchia substrate.

In 1990, as a part of the Special Status Plants project, additional plots were set up for the purpose of assessing intersite variability in growth rates. A new study plot containing 20 organ pipe cacti was established in the Bates Mountains. Four additional senita cacti were selected for monitoring on the original southern Puerto Blanco Mountains plots, including 2 at Lost Cabin Mine and 2 at Senita Basin. Also, to increase the sample of small organ pipe cacti in the Baker Mine plot, 8 plants under 1 m tall were added to the monitoring program in 1995, and 2 more added in 1996. There were recently 36 organ pipe cactus individuals under investigation at the Baker Mine study site. In 2005, growth monitoring was discontinued in favor of exploring new study designs to address broader ecological questions for columnar cacti in the monument.

Methods

Each stem of every study plant was identified with a tag indicating plant number and arm number. As stems grew, they became too long and/or curved to be measured from the base, so a wooden peg was inserted approximately 1 m (3 ft) from the base, or in a solid, fleshy part of the arm. Each stem was measured to the nearest 0.25 inch, from the base or peg to the stem tip. When new arm buds appeared, their position (e.g., NW), parent stem number, and bud length were recorded. All measurements and condition notes were recorded on a standard data form. Measurement data were entered into a spreadsheet for calculation of annual growth and graphing results. In 1996 and 2002, slides were taken of each plant in each study site for long-term repeat photography.

Rowlands (1999) determined that number of stems was a better factor for predicting growth than was plant size (sum of stem lengths), so stem number is used here to establish size classes. For this report, annual stem growth is defined as the current year's length minus the previous year's length; annual plant (individual) growth is defined as the sum of annual stem growth for all stems on that individual; and number of stems is defined as the number of stems included in the calculation of annual plant growth. Since the 1996 results were reported (Rowlands 1999),

growth measurements of organ pipe and senita cactus were obtained in 1997, 2000 and 2002-2004.

Regression analysis was performed on each stem-number class to determine if there was any significant change over time.

Results

The 3 organ pipe plants monitored at Dos Lomitas were last measured in 1997 and are not included in this summary; nor are the 3 organ pipe specimens at Senita Basin, which were last measured in 2002, because there were no annual growth increments to report. For organ pipe cactus, annual plant growth was averaged across individuals in the same stem number class and presented in Tables 3-1 and 3-2 for the Baker Mine and Bates Mountains sites respectively. Graphical representations of these data reductions (Figures 3-1 and 3-2), provide an easy means to compare growth between years and stem number classes and to scan for extreme events. Annual plant growth for senita cactus is presented in Figure 3-3.

Extreme, low growth events appear in census years 1972, 1976, 1990, 1995, and 2003. High growth events appear in census years 1979, 1984, and 1993. The patterns are less clear for senita cactus due to the small sample size. These extreme growth events can be compared to number of freezing days (Figure 3-4) and amounts of winter and summer precipitation (Figure 3-5) occurring in the previous 1-2 years.

The mean sample size for stem-number classes 1-10 at Baker Mine is 2.54. As individual plants grow and add stems, they move into and then out of a given stem-number class. Changes in the composition of samples probably add some noise to the pattern. However, the extreme events are probably real.

Regression analyses, performed on the Baker Mine data summaries, do not reveal any highly significant trends (Table 3-3). Most, 8 out of 11, stem-number classes show a slight but insignificant decline in growth. The 11-20 stem-number class shows the greatest, but still only marginally significant, decline in growth (R^2=0.15, P=0.055, N=25).

The highest-ever recorded annual stem growth was 16.75" between 1990 and 1991 on a stem at the Baker Mine plot. In general, the newer stems

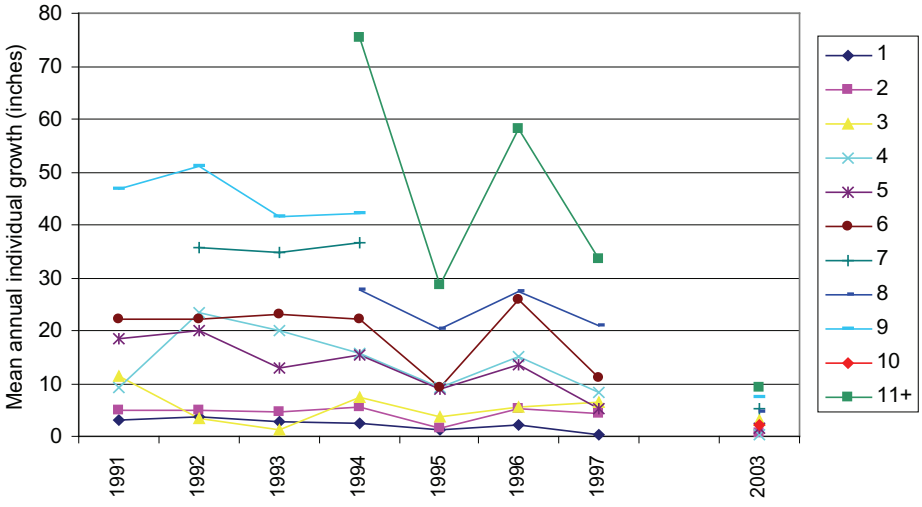

Figure 3-2. Mean annual individual growth of organ pipe cactus, grouped by number of stems, at the Bates Mountains plot, Organ Pipe Cactus N.M.

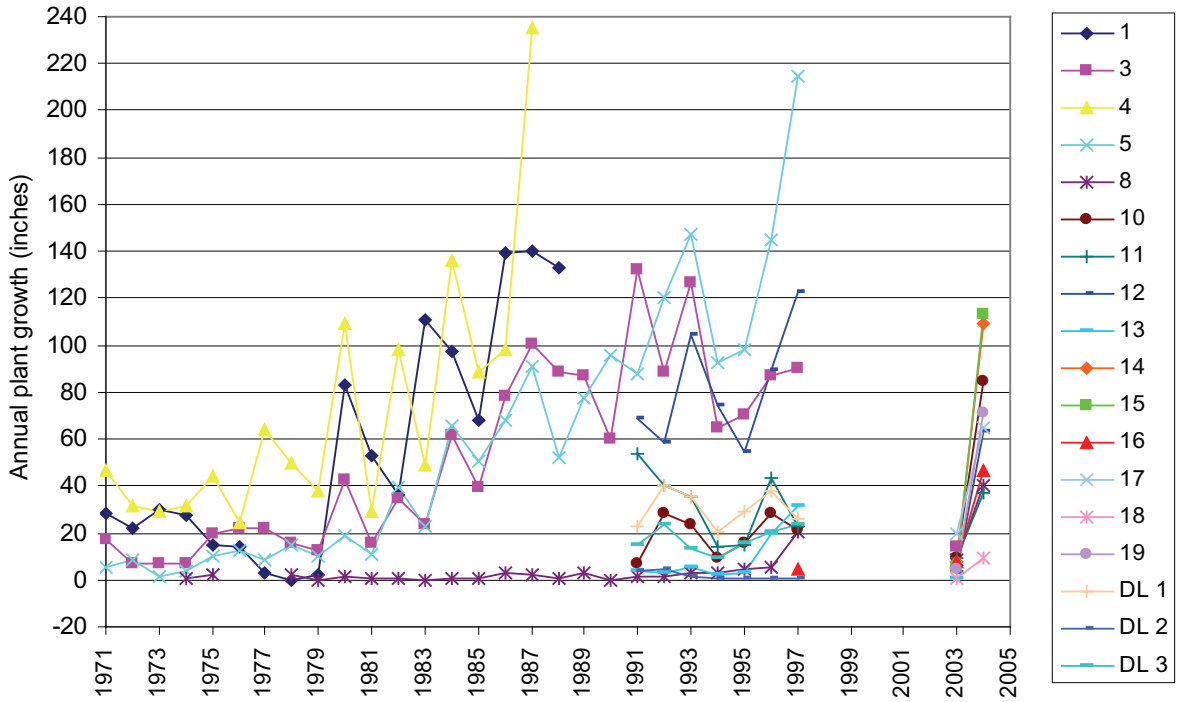

Figure 3-3. Mean annual growth (inches) of individual senita cactus monitored at Organ Pipe Cactus N.M.

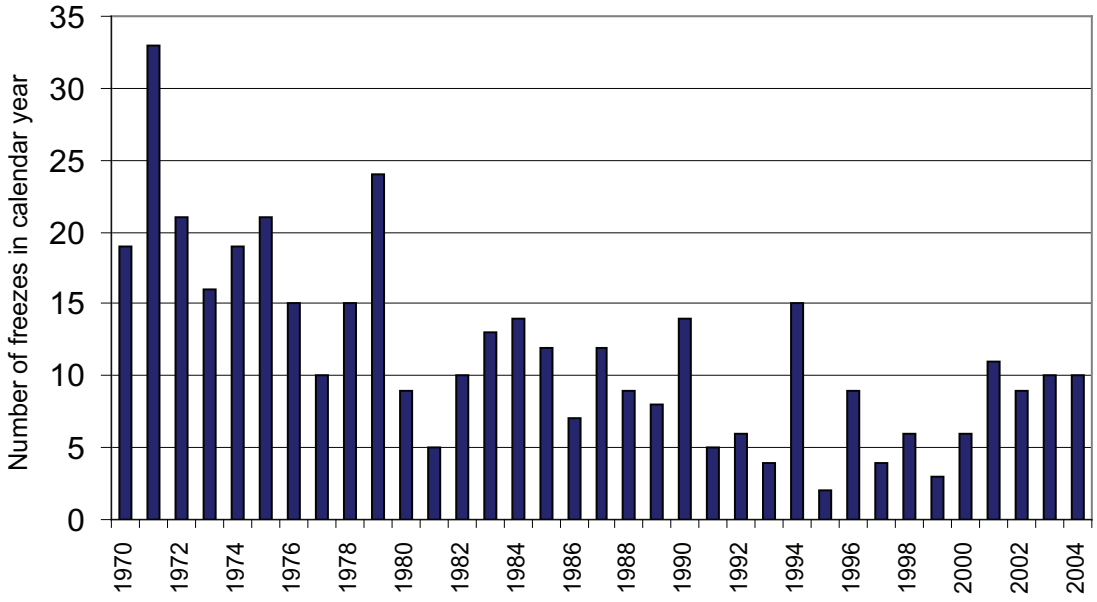

Figure 3-4. Number of days with temperatures at or below freezing at Organ Pipe Cactus N.M. headquarters.

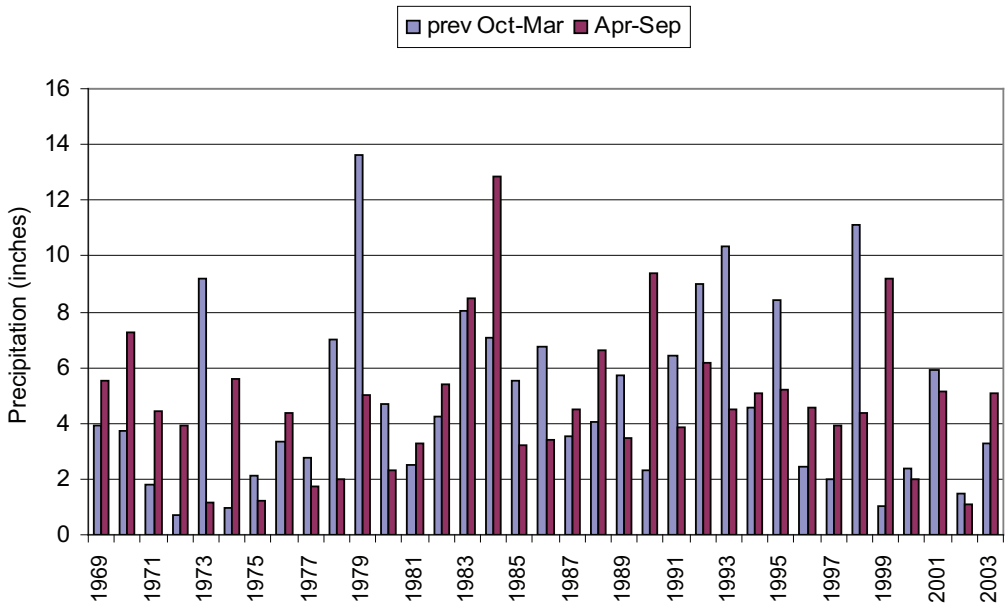

Figure 3-5. Winter and summer precipitation recorded at Organ Pipe Cactus N.M. headquarters. Example: 1980 precipitation values from Oct 1979-Mar 1980; Apr 1980-Sep 1980; compare to growth reported in 1981 census.

grew at a much faster rate than older stems, and frequently accounted for most of the overall plant growth in a year. The new stems generally grow from the base of the plant.

Discussion

Parker (1988) used analysis of variance and regression analysis of the 1970-1983 data to relate growth in organ pipe and senita cactus to plant size, age, and climate. She determined that plant size and number of stems explained much of the variation in annual growth. Variation in mean growth rates between years was positively correlated with previous winter (November-April) precipitation and negatively correlated with number of days with temperatures at or below freezing (November-March). Freezing had a more prolonged effect on senita.

Determining climate relations is not only important for understanding the distribution limits of organ pipe and senita cactus, but also in predicting possible changes in their status and distribution within the monument that may derive from climatic trends. Long-term data on temperature at ORPI indicate a significant decline in the frequency of freezing days (R^2=0.46, P<0.0001, for 1969-2003).

Winter freeze-kill is believed to be the limiting factor for the northern distribution of the organ pipe cactus (Felger and Lowe 1967, Parker 1988). One might very well predict that the species will become more widespread throughout the monument and elsewhere in southern Arizona if the incidence of freezes continues to remain low or decrease even further. However, Felger and Lowe (1967) also suggested that the general decrease in summer as well as annual precipitation from southeast to northwest may limit western distribution.

The marginally significant decline in growth for the 11-20 stem-number class may warrant further statistical analysis. It may be noteworthy that most (8 of 11) stem number classes exhibited declining growth rates, despite the lack of statistical significance for individual classes. A

complete reexamination of the entire data set with both auto and cross-correlation of cactus growth data and climatic variables was suggested by Rowlands (1999).

Growth monitoring may continue at a reduced frequency. The protocol developed by Ruffner Associates (1995) recommended every 5 years. Monument staff have expressed interest in exploring other options for monitoring columnar cacti that would address a wider array of ecological questions.

Recommendations

- Relocate Kathleen Parker's repeat photo sites, and possibly vegetation plots, to assess mortality and recruitment since 1986.

- Use stem growth data, climate data and repeat photos for interpretive displays/ presentations on organ pipe cactus growth patterns and response to precipitation.

- Design a columnar cacti monitoring protocol to determine long-term recruitment and phenology trends on different landscape gradients in the monument. Such a protocol could be linked to the Sonoran Desert Network vital signs phenology monitoring program, and integrated into lesser-long nosed bat pollination studies.

Acknowledgements

Field work and data collection for 1997-2004 was accomplished by Charles Conner and Ami Pate.

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Table 3-1. Mean annual individual growth (inches) from previous year of organ pipe cactus, grouped by number of stems, at the Baker Mine plot, Organ Pipe Cactus N. M. Numbers include mean, standard deviation, and number of plants in each stem class.

	Number of stems																	
	1			2			3			4			5			6		
1971	1.50	1.25	7	7.47	2.59	4	10.00	2.38	3	10.55	2.98	5	30.25		1	16.63		2
1972	0.71	0.39	7	3.30	0.57	5	5.50	2.54	3	4.90	1.51	5	12.50		1	10.50		1
1973	0.69	0.43	4	3.36	1.32	7	5.83	2.75	3	8.20	2.46	5	7.50		1	15.50		1
1974	1.63	0.72	4	6.25	2.70	7	10.08	6.45	3	14.60	3.39	5			0	27.13		2
1975	0.75	0.54	4	5.46	2.21	7	9.42	4.14	3	10.94	5.25	4	14.13		2	12.50		1
1976	0.88	0.66	4	2.57	1.21	7	3.58	4.48	3	7.63		2	11.06	2.68	4	9.75		1
1977	1.50	0.74	4	6.58	3.47	6	6.58	2.67	3	19.13		2	14.81	2.90	4	18.50		1
1978	2.13	0.48	4	7.20	2.19	5	9.44	2.13	4	17.00		2	13.38	1.23	4			0
1979	1.25	0.66	3	4.88	1.97	4	11.45	3.59	5	16.08	7.26	3	17.00	6.97	3	14.50		1
1980	1.92	0.63	3	5.50	2.19	4	10.40	2.34	5	15.08	6.33	3	17.92	4.94	3	14.25		1
1981	1.88		2	4.15	1.29	5	7.70	0.62	5	12.50		2	15.06	6.38	4	16.50		1
1982	1.75		2	4.20	1.27	5	6.70	1.65	5	11.25		1	14.75	5.95	5	12.25		1
1983	1.75		2	5.05	0.82	5	9.80	2.00	5	13.25		1	15.13	4.04	4	22.88		2
1984	3.13		2	6.90	4.70	5	10.94	3.18	4	20.00		2	22.00	2.27	4	34.88		2
1985	0.88		2	2.75		2	7.11	3.86	7	13.25		2	11.75	3.25	3	24.17	12.39	3
1986	0.00		1	3.33	1.81	3	3.90	2.66	5	8.92	2.27	3	8.33	0.29	3	14.88	5.59	4
1987	0.50		1	2.88	1.93	3	4.75	0.95	5	10.75		2	10.33	5.80	3	16.45	6.93	5
1988	0.75		1	2.87	0.33	3	3.10	1.45	5	6.69		2	4.38	2.55	3	12.51	7.02	5
1989	2.50		1	5.96	3.18	3	8.00	2.25	5	15.32		2	15.67	10.45	3	15.65	1.33	4
1990	1.50		1	1.94		2	2.36	1.75	6	1.99		1	6.97	4.24	4	7.69	4.72	4
1991	2.75		1	6.99		1	7.93	4.29	4	13.79	2.44	3	13.08	11.25	3	22.56	11.35	4
1992	3.75		1	12.00		1	9.92	3.50	3	8.44	4.75	4	18.25		2	21.60	9.47	5
1993	4.75		1	8.25		1	11.88		2	15.90	4.40	5	15.00		1	26.63	9.84	6
1994	3.13		2	7.00		1	10.13		2	7.44	3.47	4	16.00		1	16.92	7.07	6
1995	0.38		2	4.00		1	5.13		2	6.31	2.57	4			0	13.43	8.29	7
1996	1.38	0.48	4	5.67	2.50	3	6.58	3.38	3	9.31	5.97	4	9.25		1	14.64	6.69	7
1997	2.15	1.57	5	3.50		2	5.05	2.94	5	4.25	2.61	3	14.13		2	12.75	8.01	7
2003	1.00		1	2.80	2.99	5	3.50		2	4.00		1	7.56	4.37	4	7.14	3.68	7

Table 3-1, continued. Mean annual individual growth (inches) of organ pipe cactus, grouped by number of stems, at the Baker Mine plot, Organ Pipe Cactus N. M. Numbers include mean, standard deviation, and number of plants in each stem class.

	Number of stems																	
	7			8			9			10			11 to 20			21 +		
1971			0	22.38		2	26.63		2	31.00		1			0			0
1972	7.75		1	7.75		1	12.83	1.70	3	9.75		1			0			0
1973			0	10.75		2	13.88		2	26.50		1	16.25		1			0
1974			0	24.75		2	35.13		2	21.75		1	52.00		1			0
1975	22.00		1	14.00		2	20.50		2			0	36.63		2			0
1976	18.25		1	5.00		1	18.67	2.57	3			0	28.00		2			0
1977	32.63		2			0	24.75	12.92	3	25.75		1	53.50		2			0
1978	29.50	6.54	3			0	31.04	11.65	6			0			0			0
1979	26.88		2	27.75		2	24.00		1	24.88		2	46.13		2			0
1980	30.50		1	27.42	14.74	3	25.00		1	30.38		2	50.00		2			0
1981	28.25		1	27.50		2	16.25		2	22.88		2	31.88		2			0
1982	28.75		1	25.25		1	10.75		1	26.19	16.59	4	37.00		2			0
1983	37.25		1			0	23.63		2	32.50	13.24	4	44.25		2			0
1984	41.00		1			0	28.38		2	40.83	24.45	3	47.42	10.79	3			0
1985	24.75		1			0	15.00		2	26.25	16.64	3	35.75	8.95	3			0
1986	25.50		1			0	12.25		2	22.25	19.28	3	30.17	6.95	3			0
1987	24.25		1			0	12.57		2	26.17	11.25	3	24.38	8.36	3			0
1988	21.89		1			0	8.08		2	20.52	8.76	3	23.19	11.53	3			0
1989	30.69		2			0	18.12		2	35.82	9.52	3	28.44	10.14	3			0
1990	15.31		2			0	2.69		2	12.86	6.76	3	14.00	6.41	3			0
1991	31.37		1	36.03	8.04	3	10.18		2	22.31		2	28.18	19.33	4			0
1992			0	41.00		2	18.33	11.66	3	27.50		2	36.17	20.28	5			0
1993			0			0	44.75	7.83	3	25.75	12.10	3	45.92	10.82	6			0
1994	21.25		1			0	32.00		2	20.67	16.41	3	39.82	20.88	7			0
1995	26.00		1			0	20.63		2	8.38		2	30.19	13.89	8			0
1996	30.00		1			0	24.38		2	22.00		2	33.06	18.54	8			0
1997	24.25		1			0	20.75		2	22.00		2	23.91	12.80	8			0
2003	12.25		2	14.42	4.48	3			0	14.00		1	15.81	11.93	8	32.92	16.57	3

Table 3-2. Mean annual individual growth (inches) of organ pipe cactus, grouped by number of stems, at the Bates Mountains plot, Organ Pipe Cactus N. M. Numbers include mean, standard deviation, and number of plants in each stem class.

	Number of stems															
	1			2			3			4			5			6		
1991	3.19	1.98	6	5.06	1.55	4	11.50		2	9.37		1	18.53	4.58	4	22.06		2
1992	3.60	1.91	5	5.05	1.59	5	3.50		1	23.50		2	19.88		2	22.13		2
1993	2.75	1.79	4	4.69	1.23	4	1.25	4.75	3	20.13		2	13.00		1	23.17	5.84	3
1994	2.44	1.14	4	5.50	2.27	4	7.38		2	15.83	12.36	3	15.50		1	22.25		2
1995	1.13		2	1.46	1.22	6	3.58	1.42	3	9.25		2	9.00		1	9.33	2.52	3
1996	2.13		2	5.29	3.09	6	5.50		2	15.17	8.38	3	13.50		1	25.92	4.76	3
1997	0.42	0.29	3	4.17	2.70	3	6.50	1.46	4	8.42	5.08	3	5.25		1	11.17	4.54	3
2003			0	0.75		1	3.08	3.45	3	0.25	0.61	5	1.50	0.90	3			0

Table 3-2, continued. Mean annual individual growth (inches) of organ pipe cactus, grouped by number of stems, at the Bates Mountains plot, Organ Pipe Cactus N. M. Numbers include mean, standard deviation, and number of plants in each stem class.

	Number of stems											
	7			8			9			10			11+		
1991			0			0	46.75		1			0			0
1992	35.75		1			0	51.13		2			0			0
1993	34.75		1			0	41.63		2			0			0
1994	36.75		1	27.75		1	42.25		1			0	75.25		1
1995			0	20.25		1			0			0	28.63		2
1996			0	27.25		1			0			0	58.13		2
1997			0	21.00		1			0			0	33.50		2
2003	5.25		1	4.50		2	7.52		2	2.25		1	9.38		2

Table 3-3. Regression statistics for a) mean annual individual growth of organ pipe cactus, grouped by number of stems, at the Baker Mine plot, and b) annual number of freezings days and winter and summer precipitation near headquarters, Organ Pipe Cactus National Monument.

	Intercept	Slope	R	R^2	Adjusted R^2	N	F	Sig
a) stems								
1	-70.513	0.036	0.287	0.0823	0.0470	28	2.332	0.139
2	-1.435	0.003	0.013	0.0002	-0.0383	28	0.004	0.949
3	163.626	-0.079	0.241	0.0581	0.0218	28	1.603	0.217
4	388.251	-0.190	0.346	0.1195	0.0856	28	3.527	0.072
5	407.599	-0.198	0.317	0.1007	0.0632	26	2.687	0.114
6	126.641	-0.055	0.075	0.0056	-0.0341	27	0.142	0.710
7	159.239	-0.067	0.071	0.0050	-0.0423	23	0.106	0.748
8	-901.683	0.466	0.405	0.1643	0.0884	13	2.163	0.169
9	99.386	-0.040	0.034	0.0012	-0.0388	27	0.030	0.865
10	483.469	-0.231	0.264	0.0699	0.0294	25	1.727	0.202
11 to 20	1122.004	-0.548	0.388	0.1508	0.1139	25	4.085	0.055
b) climate								
Freezes	883.765	-0.439	0.677	0.4584	0.4420	35	27.933	8.0E-06
Winter PPT	-37.277	0.021	0.068	0.0047	-0.0255	35	0.155	0.696
Summer PPT	-31.995	0.018	0.075	0.0057	-0.0245	35	0.188	0.667

Vegetation Structure and Diversity

Peter Holm

Objectives

From the protocol manual (Lowe et al 1995): "The objective of the ORPI EMP project on vegetation structure and diversity is to provide baseline vegetation data, soil texture data, and slope, aspect, and elevation information for 1 or more vegetation plots (quadrats) at each of the specified sites."

Additional guidance for the objectives can be found in the Sensitive Ecosystems Program plan (Bennett and Kunzmann 1987). Criteria for site selection was to include as diverse vegetation types as possible which are representative of all communities, sensitive habitat and/or characteristic habitats, and communities with relict species. Long-term monitoring at those sites was to provide information on community dynamics including species composition, importance, and distribution.

Introduction

Plants are continuously exposed to environmental conditions and are the most readily observable, measurable, and mappable indicators of climate, soil, biotic interaction, and human disturbance (Lowe 1964). Vegetation can be impacted by herbivory, trampling, fire, cutting, uprooting, climate change, soil disturbance, and invasive species.

Vegetation is also a key component of many species' habitats, providing nourishment, shelter, and structural features needed for communication, surveillance, and other activities. Maps and other information about vegetation communities can be correlated with the composition and distribution of animal communities and used to generate habitat models that predict the occurrence of animal species. Documenting changes in vegetation communities will not only provide indicators of vegetation response to various stressors but also provide insight into ecological processes and long-term trends in other components of the ecosystem.

Methods

Project History

As part of the Sensitive Ecosystems Project, Vegetation Structure and Diversity, 26 permanent plots were established at long-term monitoring sites between 1988 and 1991 (Lowe, Wirt, and Rosen, ca 1994). Soil texture data, and slope, aspect, and elevation information were also provided in the project report. Permanent vegetation plots were selected to be representative of the surrounding EMP site. When the EMP site included different vegetation communities, a separate plot was established in each primary (important) vegetation type. The number of plots per EMP site varies from 1 to 3.

With the exception of the Neolloydia Site (aka Acuña Habitat), all plots were re-inventoried between 1994 and 1997 (Table 4-1.). Also, 3 EMP sites were added and 5 new vegetation plots, bringing the total number of plots to 30 (Figure 4-1). The protocol recommended that an inventory of the plots be performed approximately 5 years after the baseline reading, and after that on a 10-year cycle (Lowe, Wirt, and Rosen, 1995).

Survey and Data Reduction

At each plot, the 2 photopoints were relocated and re-photographed. Each plot measures 20 x 50 m (65 x 164 ft) and is subdivided into ten 10 x 10 m (33 x 33 ft) plots. Non-stretchable measuring tapes were placed around the perimeter, along the 50 m midline, and across the 20 m width at 10 m intervals. The tapes were pulled as tight and straight as possible to ensure the most accurate reading. Data were recorded as follows, from the original protocol (Lowe, Wirt, and Rosen, 1995):

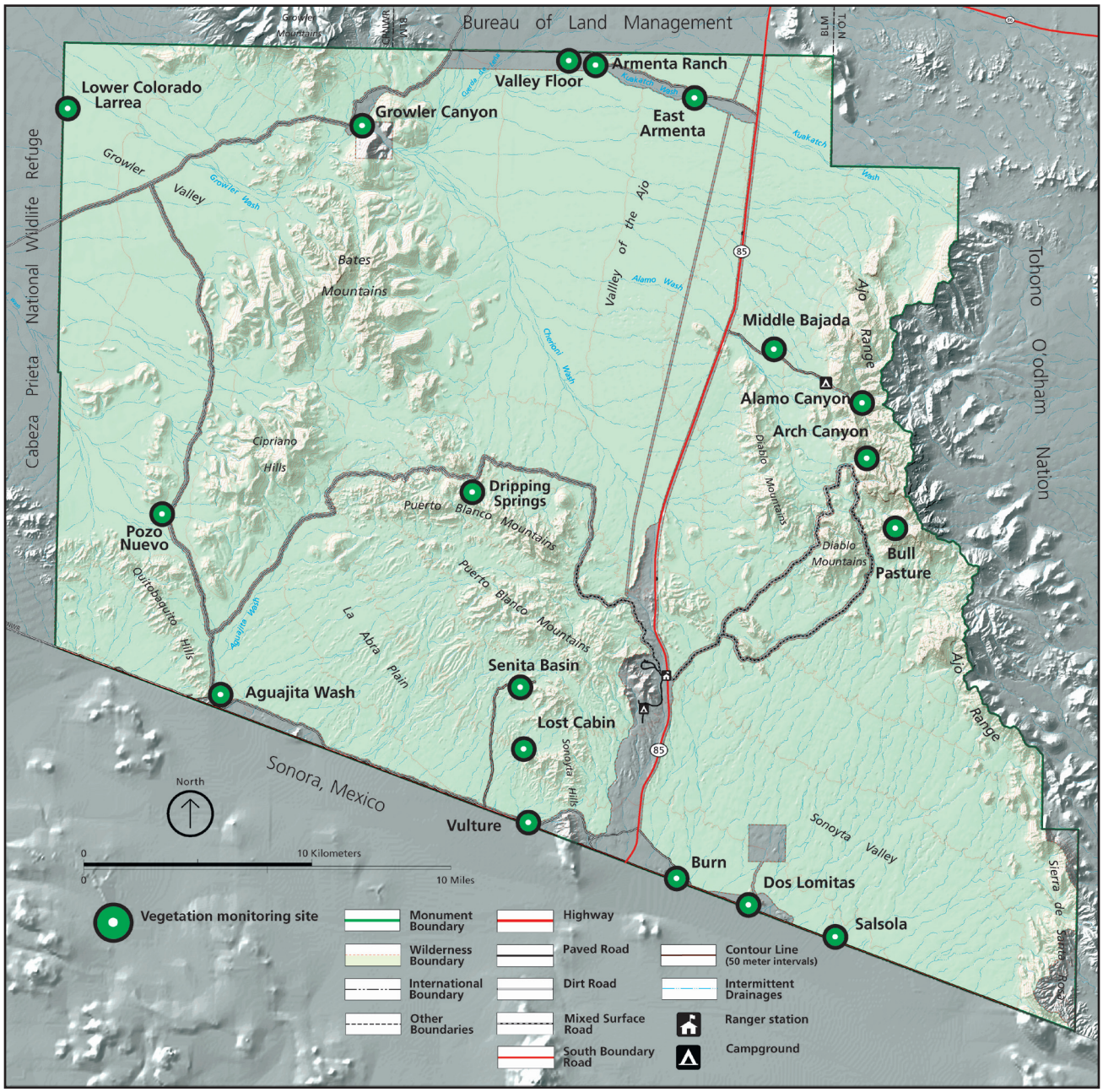

Figure 4-1. Vegetation structure and diversity plots, Organ Pipe Cactus N.M.

Table 4-1. Vegetation structure and diversity plots and years read for Sensitive Ecosystems Project (SEP) and Ecological Monitoring Program (EMP) at Organ Pipe Cactus N.M. (If the inventory of a given plot required multiple visits, spanning 2 calendar years, only the first year is indicated.)

Plot Name	Code	Hydrologic Regime	Soil Gradient Category	Elevation (feet)	SEP	EMP
Aguajita VG01	AGUA1	Xeroriparian	Valley floor	1,140	1989	1994
Aguajita VG02	AGUA2	Upland	Valley floor	1,140	1989	1994
Aguajita VG03	AGUA3	Upland	Valley floor	1,140	1989	1994
Alamo Canyon VG01	ALAM1	Xeroriparian	Rocky slope	2,400	1989	1995
Arch Canyon VG01	ARCH1	Xeroriparian	Rocky slope	3,000	1989	1995
Arch Canyon VG02	ARCH2	Upland	Rocky slope	2,900	1989	1995
Armenta Ranch VG01	ARMR1	Upland	Valley floor	1,565	1990	1996
Armenta Ranch VG02	ARMR2	Degraded xeroriparian	Valley floor	1,565	1990	1996
Bull Pasture VG01	BULL1	Upland	Rocky slope	3,150	1989	1997
Bull Pasture VG02	BULL2	Xeroriparian	Rocky slope	3,150	1989	1997
Burn Site VG01	BURN1	Upland	Valley floor	1,390	1989	1994
Dos Lomitas VG01	DOLO1	Degraded upland	Valley floor	1,400	1989	1994
Dos Lomitas VG02	DOLO2	Degraded upland	Valley floor	1,400	1989	1994
Dripping Springs VG01	DRIP1	Xeroriparian	Rocky slope	2,000	1990	1996
East Armenta VG01	EARM1	Upland	Valley floor	1,720	1989	1994
East Armenta VG02	EARM2	Upland	Valley floor	1,720	1988	1994
Growler Canyon VG01	GROW1	Xeroriparian	Valley floor	1,370	1990	1997
Growler Canyon VG02	GROW2	Wash bed	Valley floor	1,370	1990	1997
Lost Cabin VG01	LOST1	Upland	Rocky slope	1,600	1990	1995
Lower CO Larrea VG01	LOWE1	Upland	Valley floor	1,100		1993
Middle Bajada VG01	MIDB1	Xeroriparian	Bajada	2,110		1995
Middle Bajada VG02	MIDB2	Upland	Bajada	2,110		1995
Neolloydia Site VG01	NEOL1	Upland	Rocky slope	1,600	1989	
Pozo Nuevo VG01	POZO1	Upland	Valley floor	1,240	1989	1994
Salsola Site VG01	SALS1	Xeroriparian	Valley floor	1,480	1990	1997
Senita Basin VG01	SENI1	Upland	Rocky slope	1,665	1990	1995
Senita Basin VG02	SENI2	Xeroriparian	Rocky slope	1,745	1990	1997
Valley Floor VG01	VALL1	Upland	Valley floor	1,540		1995
Valley Floor VG02	VALL2	Xeroriparian	Valley floor	1,540		1995
Vulture Site VG01	VULT1	Upland	Bajada	1,325	1989	1994
Vulture Site VG02	VULT2	Xeroriparian	Bajada	1,325	1989	1994

1. **Presence (P)** was the measure of the number of species present; equivalent to species richness (S), number 4 below. Unknown plants were recorded and a voucher specimen was collected for later identification. In some cases the site had to be revisited to obtain suitable material for identification.

2. **Density (N)** was the number of individuals rooted in a unit area. In this study, the unit area was a 0.1 ha (0.25 a.) plot for perennial plants, and a 1.0 m^2 (10.8 ft^2) plot for ephemerals. Accuracy in making the count for density for a given perennial species in the 0.1 ha (0.25 a.) plot was aided by separate counts for all of the individuals present in each of the ten 10 x 10 m plots (see below), and then summing for the 10. If a single plant had roots/stems in two or more subplots, it was counted only once.

For ephemerals, density counts of abundant taxa (dozens to hundreds of individuals per 1.0 m^2 [10.8 ft^2]) should be summed over conveniently chosen subdivisions (halves, quarters, or other fractions) of the 1.0 m^2 (10.8 ft^2) plot that are used for convenience of counting.

3. **Frequency**, in percentage, for a given species was determined by the number of 10 x 10 m plots occupied by 1 or more individuals of the species rooted in the plot(s). If a species occurs in (is rooted in) 3 of 10 plots, it has a frequency of 30% for that 0.1 ha (0.25 a.) plot. Because the 10 x 10 m plots were contiguous, samples were not independent.

4. **Coverage** of perennial plants was measured by the line intercept method. In line intercept, the distances (lengths) of the plant crowns that intercepted a straight line of meter tape were recorded. The lines of meter tape used for intercept measurements included the plot perimeter of two 50 m (164 ft) tapes and two 20 m (66 ft) tapes, plus the 50 m (164 ft) centerline. The total line length used was 190 m (623 ft).

For a given species, the sum of its crown interception distances (= interception lengths), multiplied by 100, then divided by the total line length yields the percent cover for that species. The sum total meters of distance for all crown interceptions of all species, multiplied by 100, and divided by total line length yields the community coverage percent. Intervals of bare ground (i.e., line segments not intercepted by any plant) can be similarly summed, multiplied by 100, and divided by total line length

5. **Species richness** (S) is the number of species per unit area. The number of species present in a given area provides the species richness values for that area, which area is either a 0.1 ha (0.25 a.) plot (for perennial taxa) or the 1.0 m^2 (10.8 ft^2) plots (for ephemeral taxa). Species richness (S) = species presence (P).

6. **Species diversity** (H') is: $H' = - \sum (p_i * \ln[p_i])$ where p_i is, for each species i, the numerical proportion of that species abundance (N, density) to the total abundance of all plants in the plot or sample, and ln is the natural logarithm. This measure of species diversity, aka the Shannon-Weiner Index, incorporates both species richness (S) and evenness of the abundances of various species. Increasing S will increase H'; conversely, when 1 or a few species tend to overwhelmingly dominate numerically, the value of H' will decrease. These properties make H' a sensitive overall community indicator index.

<u>Additional Criteria</u>

1. Biennials are plants that reproduce during the second year of their life and then die; this also includes plants that may be ephemeral in some years but persist as short-lived perennials in others. Some examples of biennials include trailing four o'clock (*Allionia incarnata*), slimleaf bursage (*Ambrosia confertiflora*), and purple three awn (*Aristida purpurea*). Counts of these plants will fluctuate from year to year. Document the approximate size or height of plants that are counted. For trend analysis, these species must be excluded.

2. Seedlings are plants in their first year of life and have only a slight chance of becoming established. Count established plants and seedlings separately and document the field decisions with photographs and notes. Examples of criteria for judging a plant to be established or not include: presence of a woody stem, presence of branching, overall plant height, and leaf development. Use only established plants in computing density on the plot and for trend analyses.

3. Plants such as creosotebush and big galleta (*Pleuraphis rigidus*) are sometimes difficult to count because of a common base of numerous stems and a continuous crown. Species with overlapping crowns (>15% overlap) can be lumped together as 1 individual. Document decisions.

4. Grasses should be counted as clumps (i.e., bunches, tussocks, or aggregations). Document decisions as necessary. Also count ferns as clumps.

5. Among species which spread via rooting of fragmenting joints, such as jumping cholla (*Cylindropuntia fulgida*), count all plants except when a mass of small plants surrounds the parent plant. Be careful to count only well established joints not part of a parent-based clump.

6. When reading a line-intercept, look down on the line to align the crown margin, then record the beginning and ending of each plant interception along the line. For continuous clumps of 2 or more individuals of a single species, only 1 beginning and ending measurement needs to be taken. However, when 2 species overlap, each must be recorded separately, even though they intercept the same portion of the line. While measuring the length of a line interception of an individual plant crown, the crown is to be visualized as a smooth circle, ellipse, or ellipsoid, and not as a concave polygon, regardless of the degree of openness of the crown. Plants are recorded on the line-intercept regardless of whether they are rooted inside or outside of the plot. Measure line-intercept based on the living part of the plant only.

Only data reductions about percent cover for all woody perennial species combined are reported at this time. A paired t-test was used to evaluate significance of change between first and second surveys for those plots with 2 surveys. Similar data reductions were compiled from the grazing recovery study (Warren and Anderson 1992).

Results

For the 1994-1997 survey, percent cover of perennial vegetation ranged from 3.69 at the Burn Site VG01 to 178.50% at the Alamo Canyon VG01 (Table 4-2). Percent cover, as reported, can exceed 100% because of overlapping canopies among different species. The Alamo Canyon plot actually had 8.2 percent bare ground.

For the 25 plots that were surveyed twice, the mean percent cover increased from 42.99% in 1988-1990 to 52.66% in 1994-1997. This change is significant (t=-4.06, P=0.00045, N=25). A similar comparison can be made with perennial vegetation cover recorded at 20 grazing recover study plots in 1975 and again in 1988 (Warren and Anderson 1992). Percent cover on the grazing recovery plots (Table 4-3) increased from a mean of 18.36% in 1975 to 26.28% in 1988. This increase is significant (t=-5.93, P=0.00001, N=20).

Discussion

Changes in vegetation cover from 1975 to 1988 and from 1988-1990 to 1994-1997 should be interpreted with caution. Annual precipitation during that period, indicated by the 5-year moving average, suggests that both intervals experienced increasing precipitation (Figure 4-2.). A longer series of surveys would be required to determine if the increase truly represents a long-term trend or short-term fluctuation. This lack of a sufficiently long series highlights one of many concerns with the current protocol.

Vegetation monitoring was intended to serve as one of the important integrative links between

Table 4-2. Changes in total perennial vegetation cover at EMP sites, Organ Pipe Cactus National Monument.

Plot	Year 1	Cover (%)	Year 2	Cover (%)	Change Year 1 to Year 2
AGUA1	1989	75.00	1994	83.80	11.7%
AGUA2	1989	62.98	1994	65.83	4.5%
AGUA3	1989	26.88	1994	22.42	-16.6%
ALAM1	1989	152.85	1995	178.50	16.8%
ARCH1	1989	70.65	1995	92.33	30.7%
ARCH2	1989	47.19	1995	87.28	85.0%
ARMR1	1990	8.57	1996	14.57	70.0%
ARMR2	1990	34.66	1996	48.85	40.9%
BULL1	1989	48.96	1997	32.74	-33.1%
BULL2	1989	41.52	1997	51.35	23.7%
BURN1	1989	0.72	1994	3.69	412.5%
DOLO1	1989	11.54	1994	19.19	66.3%
DOLO2	1989	16.64	1994	20.39	22.5%
DRIP1	1990	66.83	1996	77.66	16.2%
EARM1	1989	31.25	1994	27.27	-12.7%
EARM2	1988	31.23	1994	36.77	17.7%
GROW1	1990	52.65	1997	53.16	1.0%
GROW2	1990	41.21	1997	56.94	38.2%
LOWE1			not sampled for perennials		
LOST1	1990	36.83	1995	44.07	19.7%
MIDB1			1995	87.99	
MIDB2			1995	23.11	
NEOL1	1989	28.97			
POZO1	1989	27.97	1994	37.36	33.6%
SALS1	1990	20.74	1997	35.42	70.8%
SENI1	1990	32.76	1995	58.12	77.4%
SENI2	1990	30.65	1997	58.54	91.0%
VALL1			1995	11.22	
VALL2			1995	54.82	
VULT1	1989	19.84	1994	23.17	16.8%
VULT2	1989	84.75	1994	86.99	2.6%

Table 4-3. Changes in total perennial vegetation cover at grazing recovery study sites, Organ Pipe Cactus National Monument. Data from Warren and Anderson (1992).

Plot	Year 1	Cover (%)	Year 2	Cover (%)	Change Year 1 to Year 2
Agua200	1975	3.40	1988	13.50	297.1%
AguaPlot 2E1	1975	10.50	1988	19.70	87.6%
AguaPlot 2E2	1975	16.60	1988	24.00	44.6%
AguaPlot 2E3	1975	9.80	1988	15.50	58.2%
Ajo foothills300	1975	27.60	1988	45.90	66.3%
Ajo foothills3S1	1975	41.40	1988	48.20	16.4%
Ajo foothills3S2	1975	25.30	1988	41.50	64.0%
Ajo foothills3S3	1975	22.50	1988	38.00	68.9%
Ajo foothills3S4	1975	27.40	1988	28.20	2.9%
ArmrControl	1975	10.00	1988	12.70	27.0%
ArmrExclosure	1975	12.30	1988	10.20	-17.1%
DoloControl	1975	7.50	1988	13.20	76.0%
DoloExclosure	1975	16.30	1988	21.00	28.8%
Grow100	1975	10.90	1988	17.80	63.3%
Grow1SE1	1975	15.20	1988	22.20	46.1%
Grow1SE2	1975	7.60	1988	11.30	48.7%
Grow1SE3	1975	20.10	1988	18.60	-7.5%
Seni400	1975	32.70	1988	42.90	31.2%
Seni4W1	1975	21.90	1988	39.40	79.9%
Seni4W2	1975	28.20	1988	41.90	48.6%

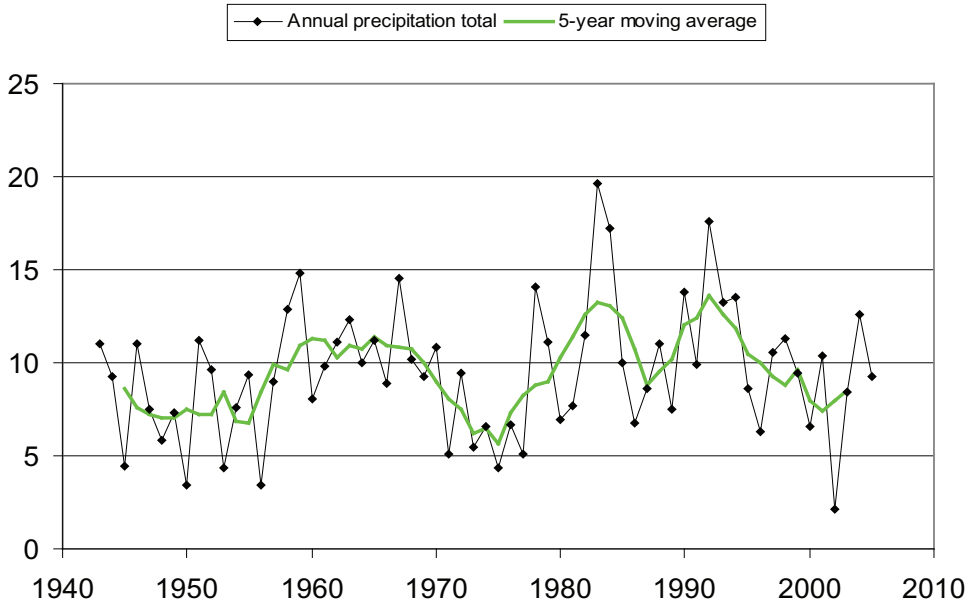

Figure 4-2. Annual precipitation and 5-year moving average recorded at Organ Pipe Cactus National Monument headquarters, 1943-2005.

sub-projects in the EMP at OPCNM (Lowe, Wirt, and Rosen, 1995). There was even a long range vision where vegetation monitoring would provide "(1) intersite variation in composition, structure, and diversity--the community variation in program space, and (2) intrasite change in composition, structure, and diversity--the community change in ecological time."

There are several concerns with the current array of plots and methods for data collection that prevent the protocol from achieving its original goals. Intersecting cover lines and contiguous sub-plots result in non-independence of sub-samples and limit the options for statistical analysis. Some species have zero values in many sub-plots or even whole plots resulting in non-normal distributions. Some plots straddle more than one vegetation community (i.e., they are not homogeneous). Most plots do not overlap animal monitoring plots or transects and some may not even occur in homologous habitat so that direct comparisons cannot be made. Important structural data are not collected such as plant height. The frequency of monitoring is insufficient to measure productivity.

Vegetation monitoring should be a key component in any ecological monitoring program. The Sonoran Desert Network is currently developing new protocols for vegetation monitoring (Mau-Crimmins et al. 2005). Vegetation structure and soil stability (soil aggregate stability and soil compaction) will be monitored on permanent plots every 5 years with all plots being monitored within a park unit in a given year. Vegetation life form abundance, soil quality (soil cover and biological soil crusts), and exotic species status and trends will be monitored together on permanent plots with a rotation that samples some plots every year.

Recommendations

- The original protocol should be abandoned. Improved experimental design and sampling techniques will increase the accuracy and applications of the data collected from each sampling event.
- A committee to develop a new experimental design and sampling techniques should be established and the resulting protocol should be peer-reviewed and amended as necessary.
- While the new protocol is being developed, OPCNM should re-sample some of the cover lines.
- OPCNM should work closely with the Sonoran Desert Network to insure that the new vegetation monitoring protocols and site selection addresses both network and monument needs for resource monitoring and management.

Acknowledgements

Field work was accomplished by Susan Rutman, Ami Pate, Charles Conner, Dennis Casper.

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Rio Sonoyta Mud Turtle

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Objectives

Determine population status and trends; obtain information on life history and natural history to better understand and protect the populations at Quitobaquito and elsewhere.

Introduction

The Sonoyta mud turtle, *Kinosternon sonoriense longifemorale*, is endemic to a small area in southwestern Arizona and northwestern Sonora. The only U.S. population, at Quitobaquito, declined from several hundred in the 1950s to fewer than 100 in the 1980s (Arizona Game and Fish Department 2005). A decline in 1989-90 was attributed to drought and high temperatures. The subspecies is listed as an ESA Candidate (FWS) and is threatened by groundwater pumping, possibly exacerbated by reduction of surface flow by transpiration in dense thickets of exotic saltcedar (*Tamarix ramosissima*) in the Rio Sonoyta. It is not known or thought to be significantly impacted by border-related issues such as pollution, wildfire, off-road traffic, other exotic species, although poaching is known at Quitobaquito and could be a threat.

Staff at Organ Pipe Cactus National Monument (OPCNM) began monitoring the Sonoyta mud turtle in 2001. This chapter reports on the results of monitoring from 2001 to 2005, with an emphasis on population estimates. The strengths and weaknesses of this monitoring are discussed and recommendations are provided.

Methods

The Quitobaquito Springs/Rio Sonoyta Conservation Assessment and Strategy (2004) recommends annual monitoring with two sampling periods to allow intra-year population estimation using mark and recapture. Sampling effort varied between years but was consistent between 2004 and 2005 (Table 5-1). In 2004 and 2005, sampling occurred on two occasions, 2-3 weeks apart in September-October, using 12 hoop and 14 minnow traps baited with sardine and hotdog. Most of the procedures were originally described by Rosen (1992). Each captured turtle is permanently notched, or its existing mark is carefully read and recorded, and the individual is sexed, weighed, and measured (including measurement of plastral growth annuli). Trap station, release time, and any other pertinent notes are also recorded. All 12 hoop traps and 6 minnow traps are deployed in Quitobaquito Pond, while the other 8 minnow traps are set in the channel pools upstream of the pond (Figure 5-1). As part of the climate monitoring program, a rain gauge is maintained at the Quitobaquito EMP site and checked at the end of each month. Water levels are monitored as part of a surface waters monitoring program.

Due to low sample sizes and there being only one sampling effort in 2003, both within-year and inter-year population estimates were generated. The Chapman version of the Lincoln-Peterson Index was used to compute population estimates as follows:

n_1 = # individuals recorded in the 1st survey period
n_2 = # individuals recorded in the 2nd survey period
m = # individuals recorded in the 1st survey period and recaptured in the 2nd survey period

Chapman Estimate = $(n_1 + 1)(n_2 + 1)/(m + 1) - 1$
Standard Error (SE) = square root of $(n_1^2(n_2 + 1)(n_2 - m)/(m + 1)2(m + 2))$

If a survey period includes multiple trap nights, then each individual (indicated by permanent mark) is counted once towards the number of individuals. Within-year estimates were limited

to yearling and older turtles (carapace length > 40 mm) because young of the year may not have been present during the first survey period. For between-year estimates, the second survey was limited to yearling and older turtles because young of the year would not have been present during the first survey period. These adjustments were necessary to insure that recruitment did not violate the assumption of a closed population.

Results

Sampling efforts and total captures for 2001 to 2005 are summarized in Table 5-1. Both the number and spatial arrangement of hoop and minnow traps has changed over the years but was consistent in 2004-2005. In 2001, there were two 2-night trapping sessions and on both occasions the second night had many fewer captures than the first night. In all years, the second night had fewer captures than the first night. While Rosen

Table 5-1. Sample effort and number of captures for the Sonoyta mud turtle at Quitobaquito Pond and Springs, 2001 - 2005, Organ Pipe Cactus N.M.

Year	Date	Captures	Hoop traps	Minnow traps
2001	23-Oct	29	10	18
2001	24-Oct	5	10	18
2001	31-Oct	16	10	18
2001	1-Nov	6	10	18
2002	12-Jun	18	12	8
2002	30-Jul	11	11	9
2002	12-Sep	34	14	11
2002	10-Oct	13	13	10
2003	26-Sep	37	10	12
2004	15-Sep	26	12	14
2004	13-Oct	9	12	14
2005	5-Oct	18	12	14
2005	21-Oct	15	12	14

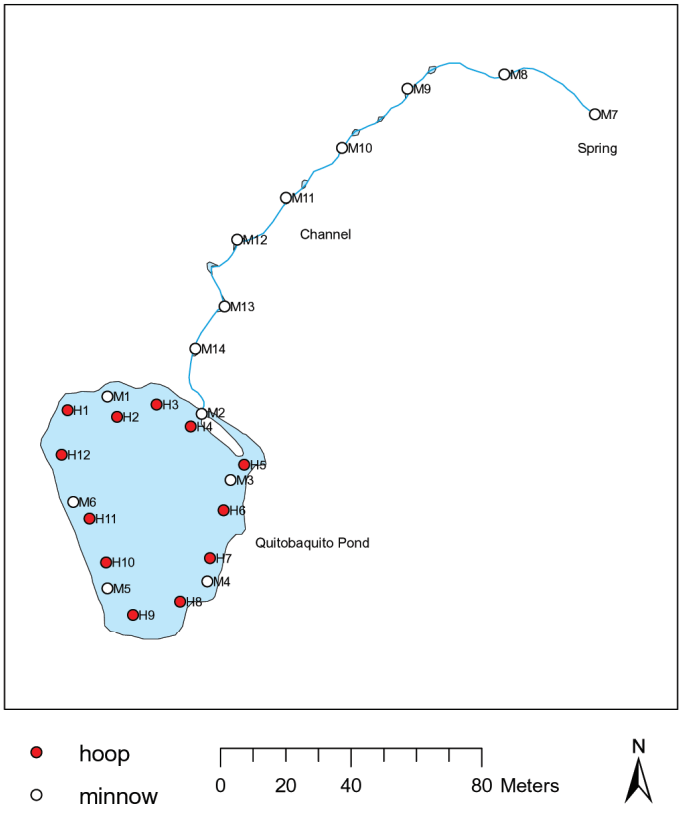

Figure 5-1. Sonoyta mud turtle trap locations at Quitobaquito Pond and Springs, Organ Pipe Cactus N.M.

Table 5-2. Within-year population estimates for yearling and older turtles (carapace length > 40 mm) at Quitobaquito Pond and Springs, 2001-2005, Organ Pipe Cactus N.M. See text for definitions.

Survey1	Survey2	n_1	n_2	m	Year	Estimate	SE
10/23-24/01	10/31-11/1/01	28	19	6	2001	81.9	22.8
6/12-7/30/02	9/12-10/10/02	26	39	6	2002	153.3	47.7
9/26/03		36			2003		
9/15/04	10/13/04	24	4	1	2004	61.5	26.8
10/5/05	10/21/05	14	7	1	2005	59.0	28.0

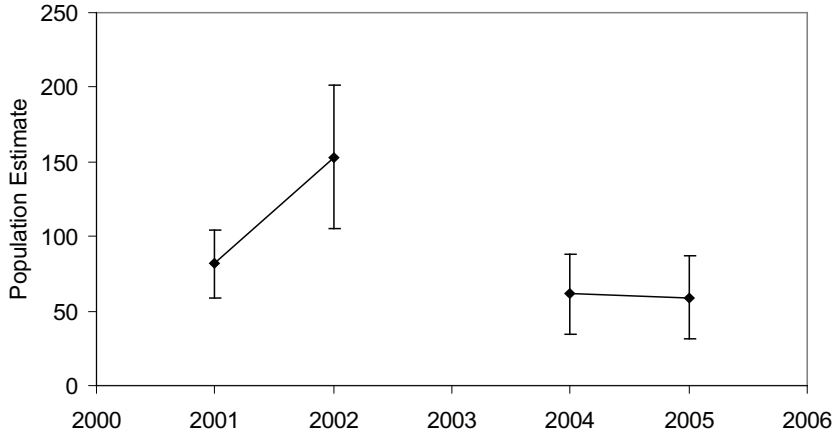

Figure 5-2. Within-year population estimates and standard error for yearling and older turtles (carapace length > 40 mm) at Quitobaquito, 2001 - 2005, Organ Pipe Cactus N.M.

(1992) provides instructions for trapping and processing captures, it does not specify what arrangement of traps to use and when or how often to conduct surveys. A formal monitoring protocol is currently being developed with the aim of standardizing the surveys.

Between 2001 and 2005, the population estimate for yearling and older turtles ranged from 59 to 153 with wide standard errors (Table 5-2, Figure 5-2). However, the estimate peaked in 2002 and has shown a depressed level for 2004 and 2005. A within-year estimate was not possible for 2003 due to the single sample. However, the between-year estimates suggest that the population declined between 2002 and 2003 (Table 5-3, Figure 5-3).

From 1992 to 2002, total annual rainfall at Quitobaqito declined from 14.9 to 1.4 inches and has since rebounded to 11.7, 7.5, and 8.7 inches for 2003, 2004, and 2005, respectively (Figure 5-4). Although there are some gaps in the record, water level with respect to the overflow point in Quitobaquito Pond is depicted in Figure 5-5. For the period 1999-2005, the lowest point of -11.5 inches occurred on 7/28/05. The water level has since fallen to approximately 18 inches below the outflow pipe on June 22, 2006. This is believed to be a result of reduced inflow related to vegetation encroachment and leakage in the channel (OPCNM 2006). Efforts have been undertaken to

Table 5-3. Between-year population estimates for all Sonoyta mud turtles at Quitobaquito, 2001 - 2005, Organ Pipe Cactus N.M.

Survey1	Survey2	n_1	n_2	m	Year	Estimate	SE
2001	2002	48	59	16	2001	171.9	33.8
2002	2003	63	36	7	2002	295.0	86.0
2003	2004	37	24	5	2003	157.3	50.8
2004	2005	30	20	3	2004	161.8	63.4

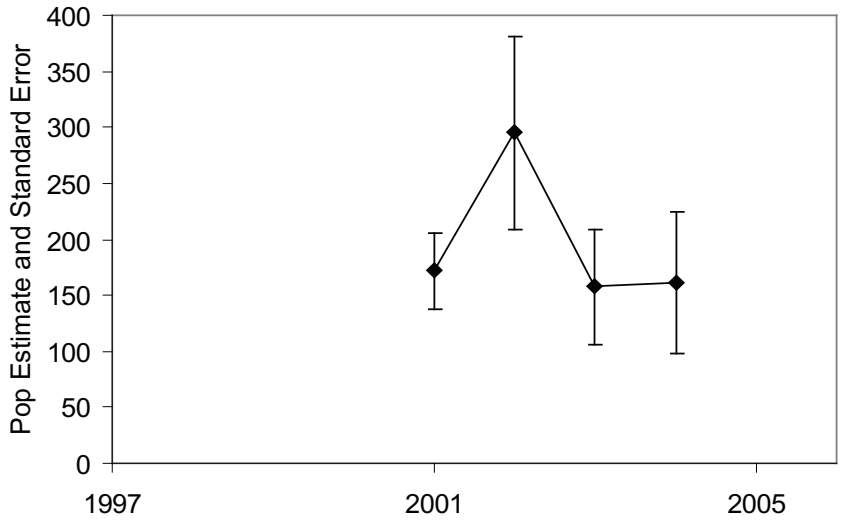

Figure 5-3. Between-year population estimates and standard error for all Sonoyta mud turtles at Quitobaquito, 2001 - 2005, Organ Pipe Cactus N.M.

restore flow and the pond level had recovered to -8.5 inches by September 21, 2006 (OPCNM data).

Discussion

Declining rainfall and pond levels may be directly or indirectly related to the apparent reduction in mud turtle numbers at Quitobaquito. Effects may be realized through higher temperatures, altered food availability, increased competition with pupfish, or some other factor. Specific research would be needed to investigate potential causes of decline. Some discussion of the strength of current population estimates should be considered before launching any new research.

All the population estimates given here are crude and do not account for differential catchability as a function of age. There is an increase in catchability with age and/or size in the Sonoran mud turtle (Rosen 1987) that does not approach a plateau of equal catchability, which is an assumption of these computational methods, until full adult size reached. This "full adult size" is likely around 90-100 mm CL at Quitobaquito, although it has not been specifically evaluated for this population. If recruitment varies with climate, as found by Rosen and Lowe (1996) for Quitobaquito, the age structure and thus the bias of the estimate will vary to give a high estimate in years with good recruitment and low or close to accurate when juveniles are few. The contributions of young age classes may have been especially strong following the peak in 2002. The dataset should be thoroughly reviewed using a modified age-

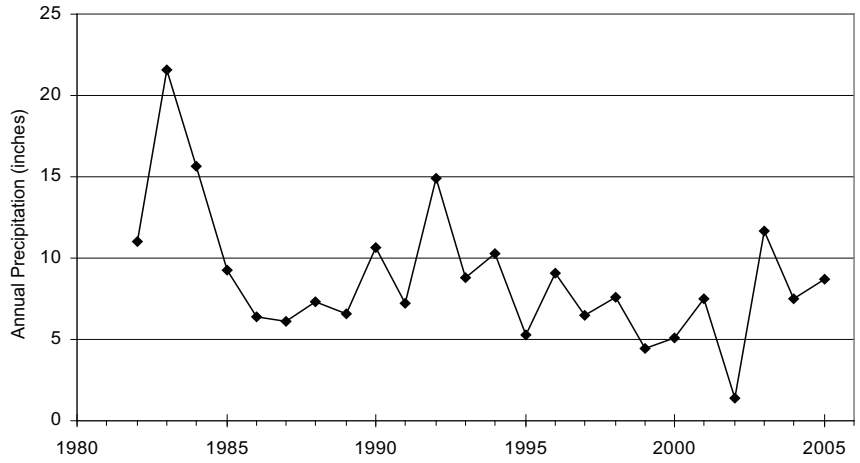

Figure 5-4. Annual precipitation at Quitobaquito rain gauge, 1982 - 2005, Organ Pipe Cactus N.M.

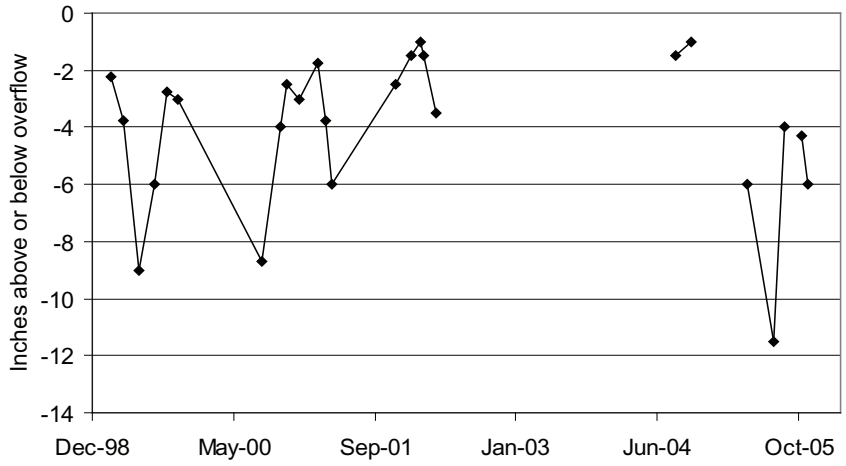

Figure 5-5. Water level at Quitobaquito Pond with respect to overflow point from 1999 to 2005, Organ Pipe Cactus N.M.

stage computational model like the one applied by Rosen and Lowe (1996) to estimate population size and survivorship.

Further, the low estimates for 2004 and 2005 are based on a very small sample sizes for the second survey period. A single night or trapping per survey period may be insufficient if captures are low or greater precision is desired. Results for 2006 and an additional set of computations to compare within-year to between year estimators will be needed to re-examine the low estimates for 2003-2005. Given the problems discussed above, this result should be viewed with suspicion. However, a true value at or below the current estimates of 62 and 59 yearling plus older turtles in 2004 and 2005, respectively, should be viewed as cause for immediate alarm for the Quitobaquito population.

In general, the declining values for population estimates appear to identify a real trend of population decline during the early years of the 21st century. In climatic terms, such a decline is not unexpected. From 1977-1984, the Arizona Upland, and OPCNM in particular, experienced

its strongest rainfall period on record, and during 1990-1995 there were also years of excellent rainfall, after which drought began to grip the region. The 21st century has thus far been very dry, with some years of remarkably severe drought at OPCNM.

Since (1) various connections occur between turtle food supply and terrestrial vegetation, (2) declining water levels from reduced springflow and/or increased evaporation also likely affect turtle food supply, (3) the turtle population appears nutritionally stressed to begin with at Quitobaquito (Rosen and Lowe 1996), (4) energetic limitations likely reduce clutch frequency (Rosen 1987), and (5) dry conditions around aquatic environments could affect egg survivorship by desiccation it is reasonable to expect a decline in the Sonoran mud turtle population during drought. Rosen and Lowe (1996) correlated recruitment with rainfall in preceding years, adding to this expectation.

Therefore the declining population trend suggested by our computations is expected, and is not necessarily unusual. However, the very low estimates since 2002 highlight the importance of sampling in 2006. Sampling in 2006 should be done early, if practical, in case a population collapse is occurring. Even though we should expect a "low normal" result for 2006, the drought minimum population sizes we may document during 2006 and, should drought persist, in subsequent years will offer a clearer picture of the population threat to the Sonoyta mud turtle at Quitobaquito associated simply with low effective population size. This should reinforce the awareness that this population is potentially vulnerable even without abnormal or unnatural population declines or catastrophe. Further, it should also reinforce our awareness that species conservation in the Mexican portion of Rio Sonoyta Valley is a key supplement for U.S. conservation, particularly for aquatic species.

Additional Recommendations

- Until a new protocol is developed, conduct minimum of 2 nights trapping per year, one per survey period. Conduct 2 consecutive nights per survey period if captures are low and/or higher precision is needed. Successive, within-year trapping sessions should be at least 2 weeks apart but no more than one month apart.
- Summarize results of annual surveys and report to Arizona Game and Fish Department, U.S. Fish and Wildlife Service, and Quitobaquito/Rio Sonoyta Workgroup within one month after completion of annual monitoring.
- Develop a monitoring protocol according to National Park Service standards and with input and review by subject area experts and interested agencies.
- Continue water flow monitoring and conduct more frequent water quality monitoring.
- Investigate possible causes of mortality such as predators, disturbance to nest sites, parasites, food, contamination, and poaching.

Acknowledgements

Daren Riedle and Ami Pate assisted with field work.

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Lizards

Charles Conner and Peter Holm

Objectives

To measure population changes in lizards that can be correlated with natural and human caused environmental changes.

Introduction

Long-term lizard monitoring will contribute to an understanding of natural ecological processes at OPCNM. Both abiotic (climate, soils, and geology) and biotic (intra- and inter-specific competition, predation pressure, and vegetation) factors are expected to have a strong influence on the vertebrate community, including the lizards. Long-term data on multiple factors may also aid in detecting and understanding natural and human-caused ecosystem effects, and thus assist management needs that may arise.

Lizards are apparently the most numerous vertebrates on the monument (Rosen and Lowe 1996, Petryszyn and Russ 1996), and it is likely that they are of great ecosystem importance as insectivores and as prey for larger vertebrates such as roadrunners, raptors, foxes, and snakes. Lizards are much less mobile than birds and should respond to variation on a smaller spatial scale. Thus, lizards form an important component within the Ecological Monitoring Program (EMP) at OPCNM that is well-suited to detect biotic effects of global climate change, of local human-caused disturbance, and of natural environmental fluctuation. Long-term lizard monitoring should aid managers by providing for early warning of abnormal conditions, data for comparison with other more altered sites, and enhanced understanding of ecological process. Abnormal conditions may be manifested as a sustained decline in one or more species or diversity index, or as a sustained absence of species that were formerly present.

Lizard populations respond to increased rainfall with increased reproduction (Whitford and Creusere 1977, Dunham 1981, Abst 1987, and Anderson 1994). However, lizard population size is not very well correlated with rainfall, and may be strongly influenced by other factors such as predation, as the existing data indicates (Rosen 2000), and as finally suggested by many years of study at the Nevada Test Site (Turner et al. 1970 and 1982). The literature does not contain data-based studies as long as, or with the breadth of information of, the OPCNM lizard, climate, and other species monitoring.

The EMP lizard monitoring protocol is an original, transect-based method (OPCNM, 1995). The most common, and simplest, lizard monitoring method is pitfall trapping (Campbell and Christman 1982, Vogt and Hine 1982, Karns 1986, but see Medica et al. 1971, Gibbons and Semlitch 1982, and Brenner et al. 1992), which requires little skill in the field and is fairly easily standardized. However, it has two major drawbacks for us: (1) it requires that we leave dug-in traps installed, where they may be found by monument visitors, and (2) they cause mortality through predation within the traps even when the system is optimized. Bounds (1996) found that our transect method worked as well, and was less costly, compared to pitfall trap grids.

Any method, short of direct population census, requires the assumption that changes of observed numbers of lizards reflect primarily changes in abundance, rather than changes in individual activity. Rosen and Lowe (1996) provided two years of validation using mark-recapture and line transects showing that the assumption of population changes seems to hold up. The lizard line transect method we have used is designed to minimize the effects of daily, seasonal, and year-to-year flux in activity level on the result. It requires some skill and care in the field, but

has the absolute minimum effect possible on the monitored individuals and populations. Further, the data we are gathering might later be utilized within the distance-sampling methodology (Buckland et al. 1995), and can be used to estimate actual lizard population density with some limited additional research to determine proportion of lizards that are active during surveys.

Monitoring was initiated during a 4-year (1987–1991) study of OPCNM herpetofauna. During 1990 and 1991, project research personnel worked with and trained OPCNM Resources Management field workers on performance of the lizard line protocol. Most of the 1991 work, and all subsequent monitoring, was done by monument staff. In the beginning, only the Core I sites were visited due to constraints of time and personnel, but by 1993 all sites were visited during both activity seasons. This consistency greatly facilitates analysis and interpretation of the data. This report presents results through 2005.

Methods

Study sites

This project was carried out at 19 study sites, with 1 to 4 transects each (Table 6-1, Figure 6-1). Two of the sites, utilized only for lizard monitoring, include a pair of lines (LIZG1 and LIZG2) just east of the East Armenta EMP site and a single line (CREO1) in the creosotebush community east of Armenta Ranch. The LIZG transects are located in the middle of the snake monitoring site, and were designed to yield data for a direct correlative evaluation against the voluminous lizard data extracted from the snake traps and other work on that site. The CREO1 line was established to complete a comprehensive landscape transect from Ajo Mountain rock slope, to upper bajada, middle bajada, lower bajada, and valley floor. The most recent additions are two transects, ALAM2 and BULL1, which were added in summer 2001 to obtain more data on the sensitive species, *Aspidoscelis burti*.

The sampling design suggested by Rosen and Lowe (1996) called for monitoring in rocky slope, bajada, and valley floor to capture the soil texture gradient. Both the mesic eastern and xeric western portions were represented. Ideally, they included sites with both a xeroriparian line and an upland (i.e., non-xeroriparian) line, although they compromised on some sites for efficiency reasons and some sites have 2 xeroriparian or 2 upland lines (see Table 6-1).

Transect methods

The methods, which are summarized briefly here, have followed the monitoring protocols set forth in detail by the principal investigators (OPCNM, 1995; Rosen and Lowe, 1996). Lizard monitoring was conducted during the spring maximum of lizard activity, late April through May, and again during the summer maximum, late-July through late-September, once the summer monsoon rains had commenced. Lizards were censused on line transects for which the transect centerline, varying in length from 100 to 300 meters, was walked repeatedly during peak lizard activity time and temperature during morning on warm (or hot), sunny, and fairly calm, days. Care is taken with timing and observer behavior on-transect to minimize the probability that lizards may be frightened off the transect. All lizards seen within 7.5 meters of the centerline were included on the monitoring data sheet. The following data were recorded: species, time, distance along transect, lizard distance from centerline at first sighting, and size/age class. Gender was recorded if it could be determined. Eight sites have just 1 line (200-300 m long), while 9 sites have 2 lines each (100-200 m long). Each of these sites can be monitored in one morning by one field worker. The Pozo Nuevo EMP site, which has 4 100-m lines covering the breadth of habitats, requires 2 people or 2 mornings to complete. The design of the protocol is such that a person can walk 2 lines alternately on a single morning.

Generally, each line was walked beginning at the east end so lizards could be readily seen basking in the morning sun, and all lines were

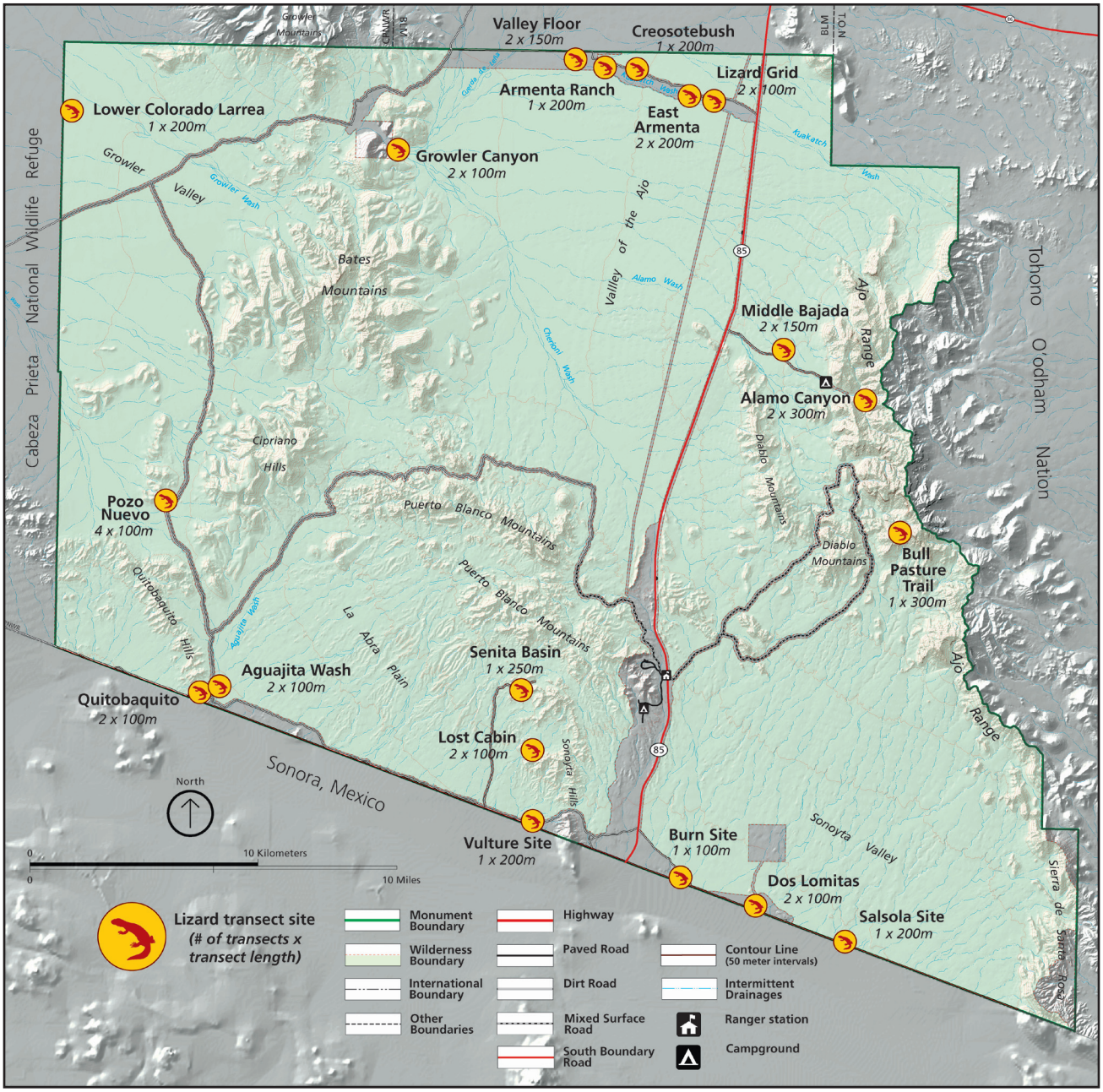

Figure 6-1. Lizard transect sites at Organ Pipe Cactus N.M.

Table 6-1. Classification of lizard lines according to hydrologic regime and soil texture at Organ Pipe Cactus N.M.

Site	Transect	Code	Length (m)	Hydrologic regime	Soil texture	Transect alias
Aguajita Wash	1	AGUA1	100	upland	bajada	Saltbush
Aguajita Wash	2	AGUA2	100	xeroriparian	bajada	Bosque
Alamo Canyon	1	ALAM1	300	xeroriparian	rocky slope	Canyon Bottom
Alamo Canyon	2	ALAM2	300	upland	rocky slope	
Armenta Ranch	1	ARMR1	200	xeroriparian	valley floor	
Bull Pasture	1	BULL1	300	upland	rocky slope	
Burn Site	1	BURN1	100	xeroriparian	valley floor	
Creosotebush	1	CREO1	200	upland	valley floor	
Dos Lomitas	1	DOLO1	100	xeroriparian	valley floor	Inside Exclosure
Dos Lomitas	2	DOLO2	100	xeroriparian	valley floor	Outside Exclosure
East Armenta	1	EARM1	200	upland	bajada	Desertscrub
East Armenta	2	EARM2	200	xeroriparian	bajada	Kuakatch Wash
Growler Canyon	1	GROW1	100	xeroriparian	valley floor	Wash Bed
Growler Canyon	2	GROW2	100	xeroriparian	valley floor	Bosque
Lizard Grid	1	LIZG1	100	upland	bajada	North
Lizard Grid	2	LIZG2	100	upland	bajada	South
Lost Cabin	1	LOST1	100	upland	bajada	Wash Flats
Lost Cabin	2	LOST2	100	upland	rocky slope	Rocky Draw
Lower Colorado Larrea	1	LOWE1	200	upland	valley floor	
Middle Bajada	1	MIDB1	150	xeroriparian	bajada	Wash
Middle Bajada	2	MIDB2	150	upland	bajada	Flats
Pozo Nuevo	1	POZO1	100	upland	rocky slope	Hill Base
Pozo Nuevo	2	POZO2	100	xeroriparian	valley floor	Wash
Pozo Nuevo	3	POZO3	100	upland	valley floor	dumosa Bursage
Pozo Nuevo	4	POZO4	100	upland	valley floor	deltoidea Bursage
Quitobaquito	1	QBQT1	100	upland	rocky slope	Hill
Quitobaquito	2	QBQT2	100	xeroriparian	bajada	Bosque
Salsola Site	1	SALS1	200	xeroriparian	valley floor	
Senita Basin	1	SENI1	250	upland	bajada	
Valley Floor	1	VALL1	150	upland	valley floor	Flats
Valley Floor	2	VALL2	150	xeroriparian	valley floor	Wash
Vulture Site	1	VULT1	200	mixed	bajada	

Table 6-2. Lizard species recorded on transect lines at Organ Pipe Cactus N.M.

Family	Scientific name	Common name	Code
Iguanidae	*Dispsosaurus dorsalis*	desert iguana	DIDO
Crotaphytidae	*Crotaphytus nebrius*	Sonoran collared lizard	CRNE
	Gambelia wislizenii	longnose leopard lizard	GAWI
Phrynosomatidae	*Callisaurus draconoides*	zebratail lizard	CADR
	Phrynosoma platyrhinos	desert horned lizard	PHPL
	Phrynosoma solare	regal horned lizard	PHSO
	Sceloporus clarkii	Clark's spiny lizard	SCCL
	Sceloporus magister	desert spiny lizard	SCMA
	Urosaurus graciosus	brush lizard	URGR
	Urosaurus ornatus	tree lizard	UROR
	Uta stansburniana	side-blotched lizard	UTST
Teiidae	*Aspidoscelis burti*	canyon spotted whiptail	ASBU
	Aspidoscelis tigris	western whiptail	ASTI
Helodermatidae	*Heloderma suspectum*	Gila monster	HESU

walked beginning with first warmth, shortly after sunrise. Air and soil surface temperatures were recorded at the beginning of each walk. Transect walks were timed to coincide with the peaks of activity of each of the various species of lizards present, with particular attention being given to the "indicator species", usually whiptail lizards (genus *Aspidoscelis*--until recently called *Cnemidophorus*), around which the timing and duration of each session are generally determined. This was accomplished by continuous awareness of lizard activity in the area, including away from the transects. Once the number of individuals observed of the indicator species had peaked and was diminishing for 1 or 2 more walks, the transect monitoring session was complete, unless there was reason to suspect that an anomalous event (wind, clouds, small number random events) underlay the result. If so, the transect might be run again; or the data might be abandoned, and the transect re-run on another day to ensure a suitable environmental context for all results accepted. Generally, lizard activity diminished significantly once surface temperatures exceeded 50°C. As usual, the day-to-day weather, especially during the summer monsoon season, necessitated attentiveness, patience, and flexibility in scheduling the monitoring.

This protocol did not sample for nocturnal species such as the western banded gecko (*Coleonyx variegatus*). Also, some species that were more active during the hottest part of the day, such as the desert iguana (*Dipsosaurus dorsalis*), were likely under represented, along with the cryptic and less active horned lizards (*Phrynosoma solare* and *P. platyrhinos*). The chuckwalla (*Sauromalus ater*) has never been recorded on a transect, due to its very specialized habitat of rocky areas with large boulders.

The ability to detect lizards on a transect in a consistent, repeatable manner matching the described protocol is principally a matter of observer experience, especially keeping in mind that morning behavior is dictated principally by thermoregulation. There are other considerations as well. Heavily vegetated sites present a challenge for visual detection, but the timing of walks for basking and activity in the open, along with auditory cues, can overcome these situations. The first detection of a lizard on a transect is frequently by sound, and then it is seen, either running to cover or rustling under a shrub or tree. With experience, the observer will correlate these

sounds with the eventual visual identification of the lizard to the point where it is most often possible to identify the lizard by sound alone, using cues such as location and time of day. Each species of lizard has its own "signature" method of locomotion, much as birds can be identified by the way they fly. All of these cues help in the identification of a lizard, frequently by a combination of locomotion style, sound, and time and location. The large majority of detections and identifications are by simple clear sighting of the lizard, however. Certainly, a fleeting glimpse or auditory detection cannot lead to any determination of gender, although size class can usually be determined. In 1997 for instance, 3 out of 1228 lizard detections were recorded as heard.

Data analysis

In this report, relative abundance is equivalent to the peak value obtained for a species per 100 meters of transect. A species' peak value is the maximum count obtained among all walks of a transect in a given morning. The relative abundance or peak for (all) lizards is the sum of peak values for all species per 100 meters. Species richness is the number of species (sometimes called species diversity). Diversity was calculated using the Shannon function:

$$H' = - \Sigma (p_i \times \ln(p_i))$$

where p_i is the proportion of the i^{th} species.

To use all sites and compare relative abundance, species richness, and diversity among years, each transect was standardized to zero mean and unit standard deviation. Then all transects were averaged for each season and a standard error computed. To provide some insight into possible impacts of adjacent land-use, the sites were divided into interior and border groups; mean and standard error were then computed for each group. Border EMP sites include, from west to east, Quitobaquito, Aguajita Wash, Vulture Site, Burn Site, Dos Lomitas, and Salsola Site; all other sites are interior (Figure 6-1).

Trend analysis was conducted for each species to determine if there was any change in relative abundance. For each species, the peak value for each season at each transect was used. All of the 1988-2005 data were used. Trends were modeled independently for each species by using a generalized linear mixed model (PROC GLIMMIX; SAS) with a year covariate to estimate trend, a season factor (spring or summer) to control for seasonal variation, a random transect effect, and a random year effect. The random year effect captures annual variation that cannot be explained by linear trend alone. A log link function based on a Poisson distribution with overdispersion was specified for the model.

Results

The most commonly observed species, based on the sum of peak values, was *Aspidoscelis tigris* (Figure 6-2). Other common species, in descending order of relative abundance, were *Uta stansburiana*, *Urosaurus ornatus*, *Callisaurus draconoides*, and *Sceloporus magister*.

Data for peak numbers of lizards observed are presented as graphs for each transect in Appendix A. Between 1997 to 2005, 2 transects, VALL1 and GROW1, had zero lizards recorded in spring 2002 and spring 2005, respectively. The highest peak recorded was 22 lizards per 100m at the Burn 1 transect in summer 2000. Most transects exhibited a maximum relative abundance of lizards in summer 1998 and a minimum in spring 2003. This pattern is also apparent in the combined graph (Figure 6-3).

Trend analysis indicated changes in some species during the period 1988-2005 (Table 6-3). The most significant change was a 4.8% average annual increase in *U. stansburiana* ($P<0.001$). That translates to a doubling in abundance in 16 years. The most common species, *A. tigris*, exhibited a 2.5% average annual decrease ($P=0.051$).

Plots of mean, standardized values for border and interior sites does not reveal any sustained departure between the two groups for relative

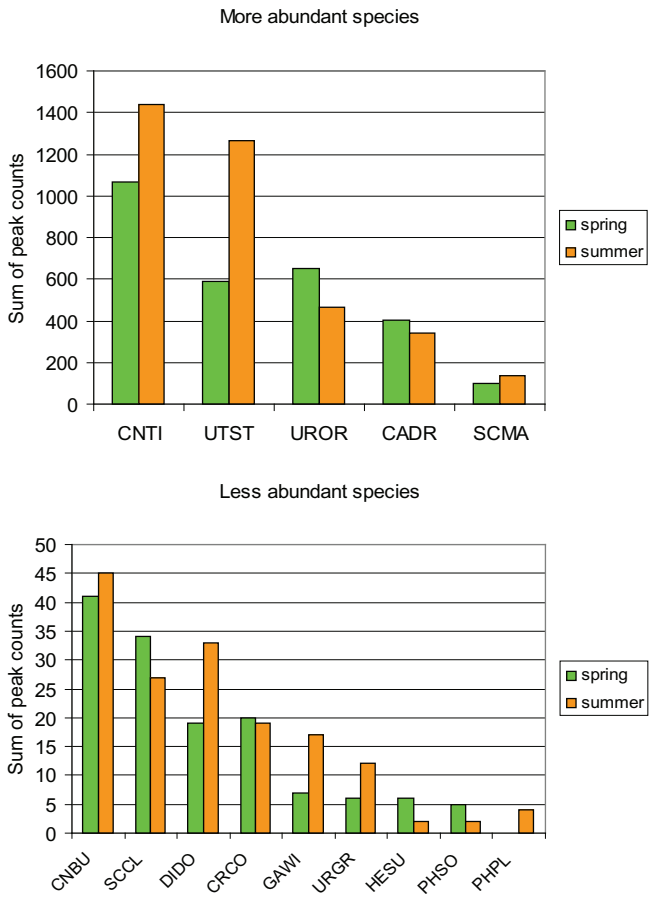

Figure 6-2. Sum of peak counts for lizards on all transects at Organ Pipe Cactus N.M., 1988-2005.

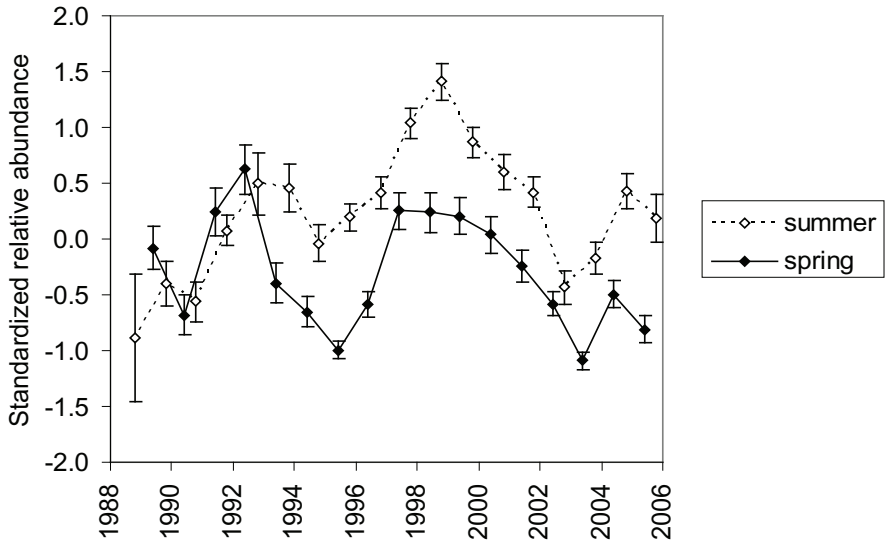

Figure 6-3. Relative abundance of all lizards, standardized for each transect at Organ Pipe Cactus N.M., 1988-2005. Mean and standard error derived from all transects pooled for a given season.

Table 6-3. Estimated annual change, based on trend model, for lizard species on transect lines at Organ Pipe Cactus N.M., 1988-2005.

Species	% Annual Change	Standard Error	95% CI	Significance
Aspidoscelis burti		insufficient data		
Aspidoscelis tigris	-2.5	1.3	(-4.9 to 0.0)	0.051
Callisaurus draconoides	-2.5	2.0	(-6.2 to 1.5)	0.214
Crotaphytus nebrius		insufficient data		
Dispsosaurus dorsalis	-6.9	3.9	(-14.2 to 1.1)	0.088
Gambelia wislizenii	5.4	6.5	(-6.7 to 19.1)	0.394
Heloderma suspectum	6.0	13.6	(-17.7 to 36.4)	0.652
Phrynosoma platyrhinos		insufficient data		
Phrynosoma solare	0.9	15.7	(-25.6 to 36.9)	0.954
Sceloporus clarkii		insufficient data		
Sceloporus magister	-2.1	2.1	(-6.1 to 2.1)	0.320
Urosaurus graciosus	8.4	16.4	(-19.5 to 45.9)	0.594
Urosaurus ornatus	0.3	2.2	(-3.9 to 4.8)	0.884
Uta stansburniana	4.8	1.2	(2.4 to 7.1)	<.001

abundance, diversity, or species richness (Figure 6-4).

Discussion

At most sites, lizards peaked in 1997-1998, fell off dramatically in 2002-2003, and recovered in 2004-2005 (Appendix A and Figure 6-3). This pattern follows the general pattern seen for rainfall in 1997-2005. Since 1996, OPCNM has experienced one wet year (1998), several mediocre rainfall years, and one record-setting dry year in 2002. Monsoon rains have been spotty at best, and there have been long dry spells in the winter and spring. Field workers have reported that insect activity has been relatively low, with many sites being eerily quiet, and there were fewer roadrunners, snakes, and other predators seen as well. Some of this can be quantitatively evaluated using the snake and bird monitoring data.

In the longer-term view (1988-2005), lizards appear to have gone through three cycles with peaks occurring in 1992, 1998, and 2004 (Figure 6-3). Interestingly, the peak in 1998 is greater despite the 1992 peak being associated with a wetter and more prolonged El Niño event. Following 1992, lizards actually declined markedly well before the rainy era ended; Rosen (2000) attributed this to high observed predator activity. Rosen (2000) reported a dramatic and consistent annual increase in predator activity (observed abundance) starting from 1990, and peaking in 1995, and decreasing after 1996. We hypothesize that the magnitude and time-lag of responses to climatic events is modified by other biotic interactions. This is novel in a field that has been largely dominated by ideas of interspecific competition and climate as determinants of lizard community function and population fluctuations.

The results of trend analyses are interesting because it is a terrestrial, small-bodied species, U. stansburiana, that has increased, while the terrestrial, larger-bodied species, A. tigris, appears to have decreased during the period 1988-2005 (Table 6-3). Many small-bodied lizards, including U. stansburiana, mature early (less than one year), produce multiple clutches, and have a short life expectancy. An examination of trends within habitat categories might reveal differences between them with respect to species with different life history strategies.

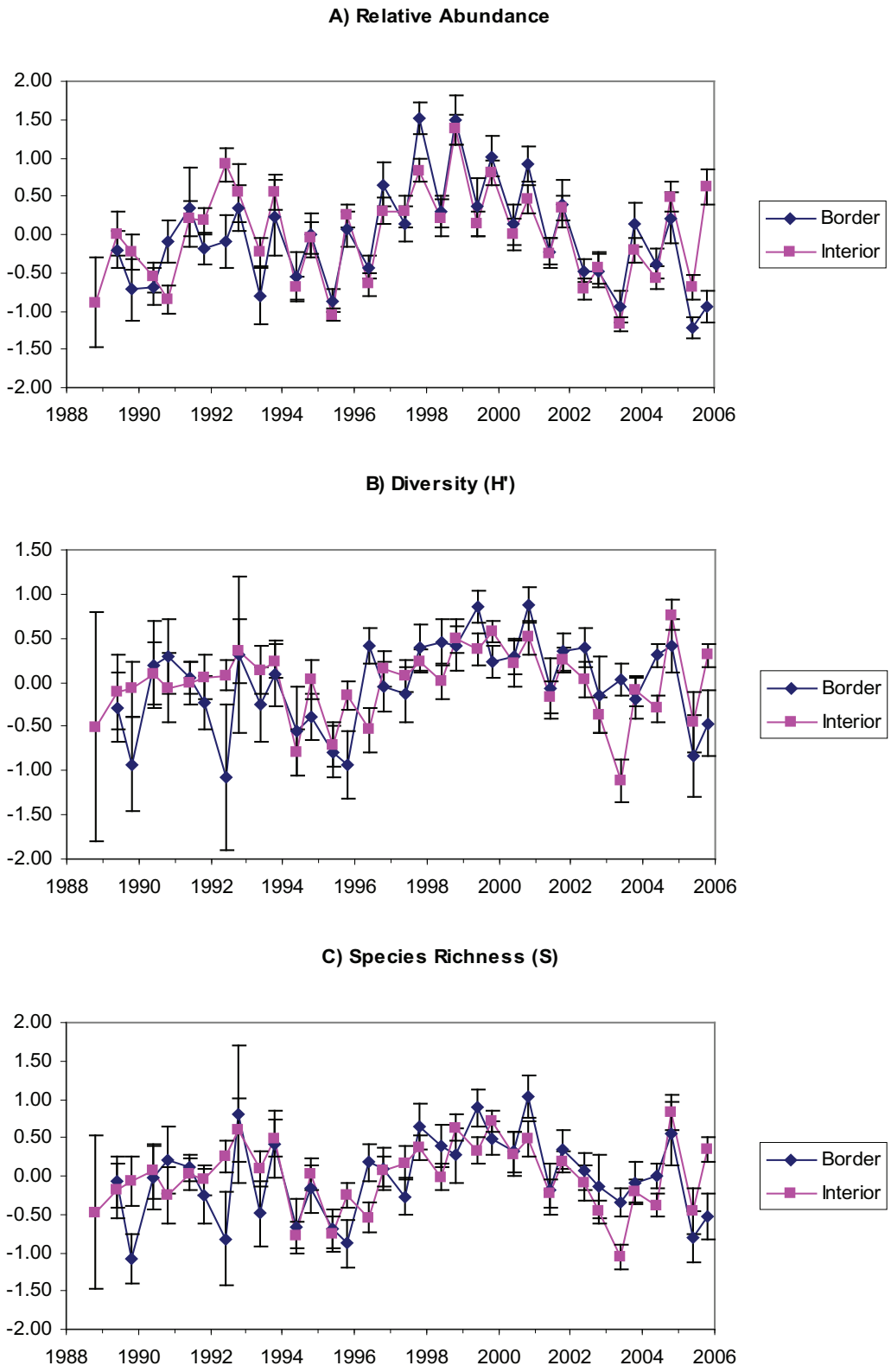

Figure 6-4. Comparison of lizard transect results from 9 border and 21 interior sites at Organ Pipe Cactus N.M. Mean and standard error for A) relative abundance, B) diversity, and C) species richness. Each site standardized to zero mean and unit variance.

Several lizard species at OPCNM are considered as sensitive from a management perspective. The U.S. Fish and Wildlife Service lists *A. burti* and *Sauromalus ater* (chuckwalla) as species of concern; BLM also lists them as sensitive species (AGFD 2006). Rosen and Lowe (1996) recommended four lizard species for the OPCNM Red List, including *A. burti*, *Sceloporus clarkii*, *U. graciosus*, and *Phrynosoma platyrhinos*. Each is at its climatically determined range limit and would be vulnerable to climate change. *A. burti* and *S. clarkii* are characteristic of deep canyons and rocky slopes of the Arizona Upland subdivision of the Sonoran Desert, whereas *U. graciosus* and *P. platyrhinos* are characteristic of valley floor environments in the Lower Colorado Valley subdivision.

While the objective of lizard monitoring at OPCNM is "to measure population changes in lizards that can be correlated with natural and human caused environmental changes," no standard has been set for the desired level of precision. A reasonable goal for detecting trends would be to be able to detect a 10% annual increase or decrease in relative abundance on study sites over a ten year time span, with α=0.10 (Type 1 error) and β=0.20 (Type 2 error). Preliminary analyses by the EMP coordinator (unpublished) suggested that 5 of the 14 species detected on lizard transects have sufficient power to detect change. These 5 species are *A. tigris*, *C. draconoides*, *S. magister*, *U. ornatus*, and *U. stansburiana*. These are common and widespread species. One common species, *C. draconoides*, prefers open ground with loose soil such as washes, dirt roads, and clearings; it may be good indicators of frequent disturbance, especially if combined with low overall lizard diversity. *Uta stansburniana* is capable of 100% annual turnover and would also be expected in recently disturbed sites that are in early stages of recovery.

This simple power analysis indicates that several key indicator species may be efficiently studied using the OPCNM EMP lizard monitoring protocol, although some less abundant species may require more effort. However, this power analysis is preliminary, and does not account for variance that can be explained by covariates of lizard abundance, such as climate and predation, for example, which will add statistical efficiency and ecological realism to the trend analyses, increasing power in both the narrow and broad sense.

Lizard species that are at their climatically determined distributional limits would be good indicators of climate change, except that they tend to be less common. To detect trends in *A. burti* and *S. clarkii,* 10 lizard lines would be needed in the Ajo Range. However, only 3 lines currently exist there. The Lower Colorado Valley species, *U. graciosus* and *P. platyrhinos,* are too uncommon to be monitored with current protocols without a large increase in effort. *Sauromalus ater* is not recorded on any of the current lizard lines and would likely require a different technique.

Recommendations

- Consider shifting some of the current lizard monitoring effort to focus more on sensitive species such as *Aspidoscelis burti* and *Sceloporus clarkii* in the Ajo Range. Develop interpretive materials for these and other species characteristic of mesic communities in larger desert mountain ranges. Educate the public about the vulnerability of these small and isolated communities to climate change.

- Lizards are a conspicuous part of the Sonoran Desert and play an important role in many food chains. Although the current protocol appears to provide a good, unbiased indicator of status and trends in lizard communities, lizards do not play as wide a range of ecological roles as do rodents or birds. In addition to being consumers and prey, rodents excavate burrows affecting soils, vegetation, and diverse wildlife habitat and they are important for seed dispersal. Birds serve as consumers (at multiple trophic levels), prey, agents of dispersal, and pollinators. The full utility of lizard data needs to be examined to determine

to what extent one can correlate changes in the lizard communities with natural and human caused environmental changes and help address current monument and regional natural resource issues.

Acknowledgements
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Snakes

Charles Conner, Phil Rosen and Peter Holm

Objectives

The snake monitoring is following the protocol established by Rosen (2000) and in communication with Rosen, but no formal NPS protocol has been established yet. The objectives as currently understood are (1) monitor snakes as one major element in the predator assemblage at ORPI that affects other monitored components, particularly lizards, rodents, and small birds (see below), (2) maintain the continuity of a notably long-running (1987-2006) monitoring record for snakes, which have only been so monitored at one or a few other sites worldwide, and (3) collect significant baseline information on natural history and demographics, which are largely unrecorded for most of the species present. At present, the ongoing monitoring is confined to one site, on which other intensive monitoring is ongoing for other EMP elements. Some additional monitoring data is available for Highway 85, Armenta Road, Armenta Ranch, and Pozo Nuevo, although some of this is quite limited in temporal scope and total effort.

Introduction

Snakes are a diverse component of Sonoran Desert communities. A total of 26 snake species have been recorded at OPCNM (Rosen and Lowe 1996). At OPCNM, snakes are abundant and are likely major predators of lizards, small mammals and of bird eggs and nestlings. Some species are predators of arthropods but their significance is unknown. They are also important predators on each other, and their predator importance makes them likely competitors for predatory mammals and raptorial birds. Snakes are likely abundant enough at ORPI that they also comprise a significant part of the diet of certain larger predators that would be leading candidates for top-down regulation of ecosystem structure, such as red-tailed hawks, coyotes, and foxes.

Snakes are conspicuous casualties of highway and even backcountry motor vehicle traffic. Between 1988 and 1991, Rosen and Lowe (1994) estimated that ca 1000 snakes were killed annually between Why and Lukeville on State Highway 85. The Organ Pipe shovel-nosed snake may be particularly vulnerable because its known range and habitat in the United States is close to Highway 85. Other threats to OPCNM snakes include poaching, especially of the rosy boa and shovel-nosed snakes, and climate change effects on species near their range limit (Rosen and Lowe 1996).

Long-term ecological studies of snakes are few. The most notable is reported by Fitch (1999, and many references therein) for 50 years of annual snake monitoring at the University of Kansas Natural History Reservation and adjacent lands. Snake monitoring at ORPI is a continuation of dissertation research initiated in 1987 by Rosen (2000). At 20 years in 2006, this is the longest running snake monitoring study in the Sonoran Desert, and all told, 1093 individual captures have been registered on the local monitoring site.

The primary reason snake monitoring was continued by the NPS was to provide additional information about predators that may be affecting lizards and rodents at the East Armenta EMP Site. Birds have also been monitored at this site and are the only other monitored group that includes some predator species. Rosen (2000) reported that trends in some snake species or groups were related to climate, prey populations, and predator populations during his study of this site in 1987-1998.

It would be preferable to have two or more additional snake monitoring sites, but overly dispersing the effort could also reduce the important details provided by the protocol described below. The East Armenta site has the benefit of being fairly ordinary and representative

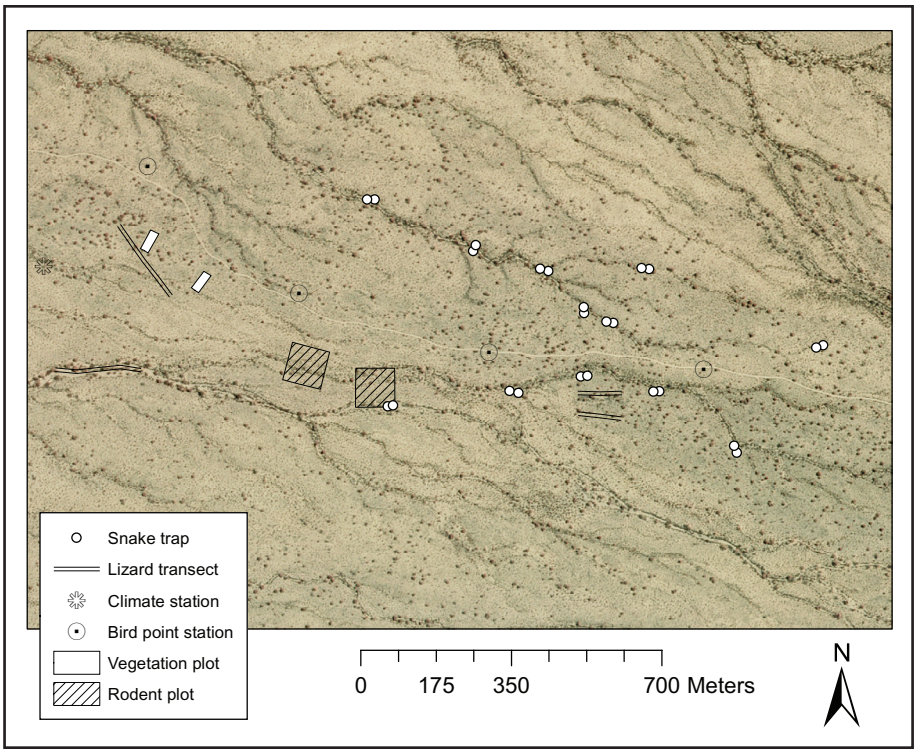

Figure 7-1. Snake monitoring study site map, Organ Pipe Cactus N.M.

while being accessible and support reasonably high diversity and abundance of snakes.

Methods

Snake monitoring at ORPI is conducted on an approximately 1km² study site adjacent to the East Armenta EMP site (Figure 7-1). Traps were installed in a variety of microhabitats, positioned so that they were likely to capture snakes and not expose captured animals to excessive heat. There are currently 12 trap stations (of the original 22), each consisting of 2 submerged buckets separated by a 12-18 m drift fence. Each drift fence consists of 3mm (1/8 inch) mesh hardware cloth, standing 75cm tall and sunk 15cm into the ground. At each end is a hardware cloth funnel trap, from which snakes enter and are trapped in a submerged plastic trash bucket with lid. The top 12cm of the bucket are above ground. Plywood boards, measuring approximately 30cm long and 25cm high are placed at the outer edges of the first funnel and at a 45° angle with the fence, to further guide animals into the funnel. Buckets are 75 or 110 liter capacity, with the entrances and screened vents approximately 50mm above ground, at minimum, to prevent flooding. The bucket lids are covered with a large piece of plywood to prevent overheating. Two false bottoms of screen (1 inch and 1/2 inch mesh) are installed to minimize predation within the trap buckets. Traps are checked once each day.

Each snake is permanently marked (with a unique, subcaudal scale clip), sexed, weighed, measured (including rattle segments), and examined for reproductive condition, food bolus, and injuries. Trap station, release time, and any pertinent notes such as banding pattern or color are also recorded. Snakes encountered outside traps are also processed. Snake traps are usually operated on 4 consecutive nights, once per month, from April to October. Monitoring has generally been scheduled to correspond to the dark moon phase and warm weather when possible. Snake monitoring also records species, age/size class, and trap location for all incidental captures of

small mammals, lizards, amphibians, and large invertebrates. Data are recorded on field forms and later entered onto a spreadsheet.

All animals are released on site, with snakes being released into appropriately-sized burrows or other safe cover, or in the trap area at sunset. All necessary safety measures are taken when handling rattlesnakes and other biting animals. Trap entrances are blocked with the funnel edge boards when not in use, and the bucket lids are left slightly ajar, with sticks protruding just above the rim from the trap bottoms to facilitate the escape of any animals that may still get in.

Relative abundance was computed as the number of captures per trap night. Trap nights were computed as the number of nights multiplied by the number of traps. If traps were opened on mid-day Monday and closed on mid-day Friday, there would be 4 X 12 = 48 trap nights.

Results

Snake monitoring began in 1987 and has been conducted primarily by ORPI staff since 2000. There have been 3 known snake mortalities out of 365 captures between 2000 and 2005. One was eaten by another snake, one was apparently killed by ants, and one died during processing, presumably from excessive heat. Many animals other than snakes were also caught in the traps and some are killed. Most mortalities were due to predation, despite the use of false bottoms to separate animals of different sizes. There have been 45 documented lizard mortalities out of 2664 captures, 59 small mammal mortalities out of 1356 captures, 2 bird mortalities out of 4 captures, and 1 toad mortality out of 7 captures.

Monitoring activities for 2000-2005 are

Table 7-1. 2000-2005 sampling history at the snake study area, Organ Pipe Cactus N.M.

Start date	End date	Trap Nights	Start date	End date	Trap Nights
6/30/2000	7/7/2000	7	5/21/2003	5/25/2003	4
8/2/2000	8/6/2000	4	6/28/2003	7/3/2003	5
8/26/2000	9/3/2000	8	7/21/2003	7/28/2003	7
10/2/2000	10/6/2000	4	8/16/2003	8/21/2003	5
3/22/2001	3/27/2001	5	9/26/2003	9/30/2003	4
4/18/2001	4/23/2001	5	10/20/2003	10/24/2003	4
5/18/2001	5/23/2001	5	3/13/2004	3/16/2004	3
6/16/2001	6/20/2001	4	4/10/2004	4/15/2004	5
7/21/2001	7/25/2001	4	5/14/2004	5/18/2004	4
8/11/2001	8/15/2001	4	7/17/2004	7/21/2004	4
9/12/2001	9/17/2001	5	8/7/2004	8/12/2004	5
10/10/2001	10/13/2001	3	9/8/2004	9/14/2004	6
3/21/2002	3/23/2002	2	9/27/2004	9/29/2004	2
4/10/2002	4/13/2002	3	4/8/2005	4/11/2005	3
6/2/2002	6/6/2002	4	5/10/2005	5/13/2005	3
7/14/2002	7/18/2002	4	6/12/2005	6/15/2005	3
8/9/2002	8/11/2002	2	7/5/2005	7/9/2005	4
9/6/2002	9/11/2002	5	8/8/2005	8/13/2005	5
9/30/2002	10/3/2002	3	9/2/2005	9/6/2005	4
4/1/2003	4/4/2003	3	9/26/2005	9/29/2005	3
4/25/2003	4/29/2003	4			

Table 7-2. Relative abundance of snakes trapped on the snake study area, Organ Pipe Cactus N.M.. 1988-1998 data from Rosen (2000).

Scientific name	Species Code	Relative Abundance		Total Captures	
		2000-2004	1988-1998	2000-2004	1988-1998
Masticophis flagellum	Mafl	0.344	0.341	116	258
Hypsiglena torquata	Hyto	0.122	0.139	41	105
Crotalus atrox	Crat	0.128	0.106	43	80
Rhinocheilus lecontei	Rhle	0.083	0.114	28	86
Crotalus scutulatus	Crsc	0.033	0.074	11	56
Arizona elegans	Arel	0.098	0.033	33	25
Salvadora hexalepis	Sahe	0.065	0.041	22	31
Pituophis catenifer	Pica	0.030	0.032	10	24
Crotalus cerastes	Crce	0.039	0.025	13	19
Phyllorhynchus decurtatus	Phde	0.027	0.026	9	20
Micruroides euryxanthus	Mieu	0.006	0.026	2	20
Leptotyphlops humilis	Lehu	0.012	0.015	4	11
Phyllorhynchus browni	Phbr	0.009	0.008	3	6
Chilomeniscus cinctus	Chci	0.006	0.008	2	6
Lampropeltis getula	Lage	0.000	0.011	0	8
Chionactis palarostris	Chpa	0.000	0.001	0	1

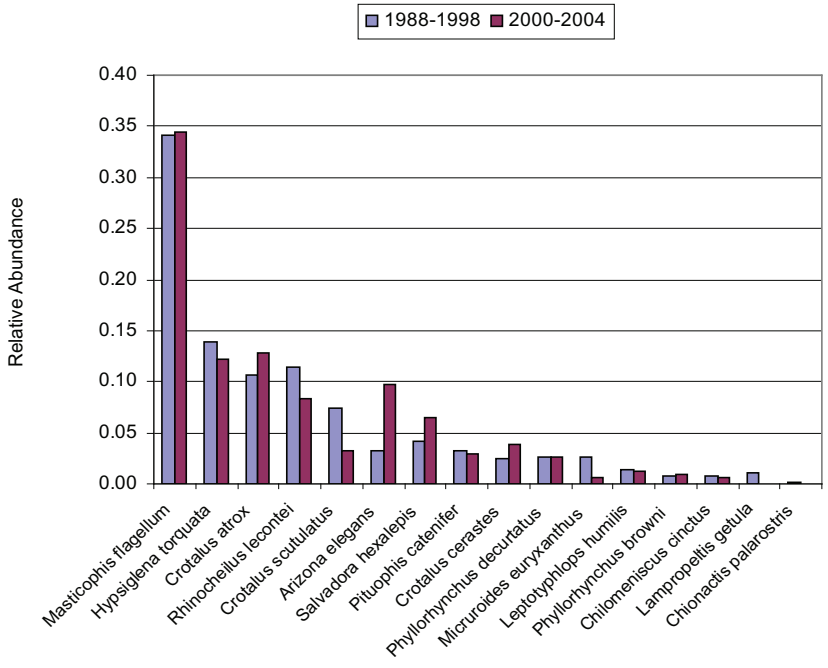

Figure 7-2. Relative abundance of snakes trapped on the snake study area, Organ Pipe Cactus N.M. 1988-1998 data from Rosen (2000).

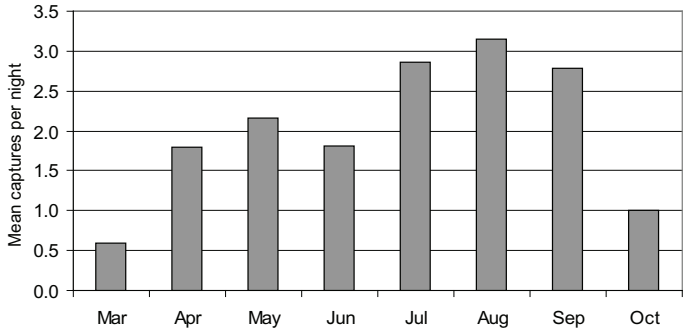

Figure 7-3. Mean snake captures per trap night by month on the snake study area, Organ Pipe Cactus N.M.

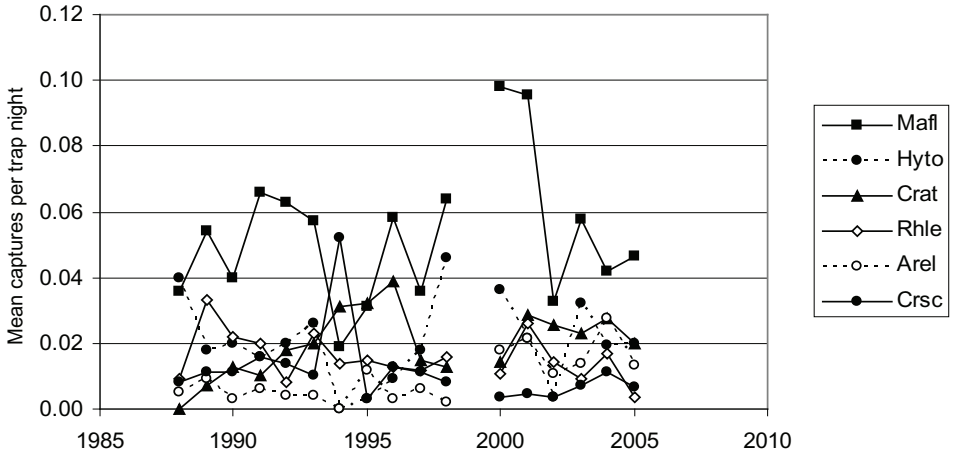

Figure 7-4, Mean snake captures per trap night for six common species on the snake study area, Organ Pipe Cactus N.M. 1988-1998 data are adjusted differently; see Rosen (2000).

summarized in Table 7-1. A total of 14 species of snakes have been recorded at the study site (Table 7-2). Changes in the relative abundance of some species between the periods1988-1998 and 2000-2004 are apparent in Figure 7-2. Species apparently declining are *Crotalus scutulatus*, *Micruroides euryxanthus*, and *Lampropeltis getula*, while increasing are *Arizona elegans*, *Salvadora hexalepis*, and possibly *Crotalus cerastes* and *Rhinocheilus lecontei*.

Overall, the composition of the snake community at the study site appears relatively similar between the two periods. No marked decline in overall snake abundance, as indicated by captures per trap night, is evident over the duration of this monitoring record.

Discussion

Monthly variation in capture rate (Figure 7-3) suggests that activity is depressed during the pre-monsoon drought in June, although dry springs have markedly depressed snake capture rates and normal and wet springs probably have capture rates similar to summer rates. Sampling would be optimized by limiting the trapping period to April through September (or early October if warm conditions persist). It would not be an efficient use of human resources to sample snakes during cooler months when few or no captures would be obtained.

By far, the species caught with the greatest frequency was *Masticophis flagellum*, no doubt due to its unique character as a widely ranging and

active predator as well as its abundance. Many individuals of this species have been caught repeatedly over the years, with some surprising distances having been covered.

Figure 7-4 provides a glimpse at possible long-term trends. The 2002 decline likely reflects a decrease in activity during severe drought, as well as a population decline that seems to have persisted for most species in the year or two immediately after the drought.

Relative abundance has remained fairly constant. Some snakes have shown an apparent increase in abundance, most notably *Arizona elegans* and *Salvadora hexalepis*. *Crotalus cerastes* may also have increased, and the three species that may be increasing are ones found widespread and abundant in the hyperarid quarters of the Lower Colorado Valley and Gran Desierto west and southwest of ORPI.

Species seeming to decline on the site were *Crotalus scutulatus*, *Micruroides euryxanthus*, and *Lampropeltis getula*. The reason that *C. scutulatus* may be declining is not clear: although it is not common in the arid deserts, as suggested above, neither is *C. atrox*, which did not decline. However, both *M. euryxanthus* and *L. getula* are generally associated with relatively mesic conditions, especially in arid lands, and the first has never been found in the arid Lower Colorado Valley Sonoran Desertscrub.

Monitoring results for 2000-2005 are surprising in showing relatively stable rates of observed snake activity and abundance comparable to those seen in 1987-1998. As the drought has extended, and in some years deepened, snake populations have not collapsed, but have remained as a relatively stable predator group. Nonetheless, the results suggest the drought may be having an impact on species abundance patterns by favoring relatively more arid-associated (and presumably arid-adapted) species. These kinds of results are essential for comparison to less natural, more impacted areas such as Tucson and Avra Valley, where unstable snake communities may be expected, and where species losses have been noted (Rosen 2003).

A special case of interest is *Crotalus cerastes*, which is rarely caught in the traps but is by far the most commonly seen snake on the sandy dirt road (Armenta Road) that cuts through the study area. *Crotalus cerastes* prefers the loose sandy substratum encountered along the road, especially the edges, and can frequently be found sidewinding or crawling along the interior road edges at night, presumably hunting for prey. This behavior could be resulting in an increased number of mortalities, as Law Enforcement and other vehicle traffic have climbed dramatically in recent years.

Recommendations

Life history and natural history data

A substantial set of baseline data has been collected for snakes at this Sonoran Desert site. The use of unique marks allows the accumulation of individual life history data including growth, reproductive condition, injuries, and movement. The East Armenta EMP site and snake study area is the only site where rodents, birds, snakes, lizards, large invertebrates, and, on 2 occasions, vegetation have been monitored. It is a unique opportunity to examine interactions between species and trophic groups because no other EMP site has a snake trap array. Even though this suite of monitoring elements is limited to one site, the results should contribute to our understanding of desert ecosystems and provide valuable material for interpretation. The necessary analyses have not yet been conducted with recent data (see Rosen, 2000 for results of his analysis of the 1987-1998 data). To realize the value of this information the data will either have to be analyzed by NPS or provided to others for analysis.

Highway mortality

Rosen and Lowe (1994) estimated that approximately 1000 snakes were killed per year between Why and Lukeville. If resources

are available, the monument could employ a combination of trap stations and road surveys for snakes to provide information specifically designed to quantify the amount and distance from highway of road mortality impacts. This design would also establish a broader and thus firmer basis for estimates of predation pressure that are probably essential to interpreting monitoring trends in other groups, notably lizards and small mammals.

Sidewinder mortality on Armenta Road
Conduct evening road surveys of sidewinders along the Armenta Road for comparison with data collected in the 1990s by Rosen to determine if increased traffic is having an impact.

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Birds

Tim Tibbitts

Objectives

The original objective of the avian monitoring program at Organ Pipe Cactus National Monument was "...to detect changes in abundance and/or distribution of birds that may be influenced by, or are the result of, changes in monument resources, adjacent land use, or management practices." (Johnson 1995).

Introduction

At OPCNM, as elsewhere, bird communities provide a valuable subject for long-term ecological monitoring. As a group, bird species span a wide range of ecological functions, from ecological generalists of broad geographic distribution to specialists of very limited distributions. In the Sonoran Desert in southwestern Arizona, bird species range from nectivores weighing several grams to predators weighing over 5 kg. Between those extremes are many species of insectivores, granivores, predators, and omnivores, exploiting niches on the ground, in all vegetation, in rocks, and high in the air. Birds' ability to fly and to construct nest sites allow them to forage widely, and use mechanisms to cope with extreme heat that are not available to less mobile organisms. Finally, birds as a group are a relatively conspicuous fauna, as a result of their mobility and vocal behaviors. This is especially true in the relatively open habitat of Sonoran desertscrub. As a result of all these factors, birds present a valuable group for gaging the productivity, diversity, and complexity of ecosystems.

Interest in quantifying bird populations has increased recently, due to a concensus that declines in some Neotropical migrants are occurring (Robbins et al. 1989, Finch 1991, Sauer and Droege, 1992, Rappole and McDonald 1994, Peterjohn et al., 1995). Decline in a particular species of Neotropical migrant (species that migrate from wintering grounds at low latitude to breeding grounds at higher latitude) is likely due to a combination of factors. These factors are in general associated with human land use practices and resulting impacts on habitat quality and quantity on the breeding and wintering grounds. Opinions vary as to whether impacts on wintering grounds or summering grounds are experiencing the most significant impact (Rappole and McDonald 1994, Sherry and Holmes 1995).

Although quantification of avian populations has been the subject of much study (see, for example, Ralph and Scott 1981, Sauer and Droege 1990, Ralph et al. 1993), there are no universally applicable standard techniques to determine bird population numbers (Verner 1985, Bibby et al. 1992). However, over the last 20 years the ornithological community has given considerable attention to the use of point-counts as a means of monitoring birds, with two major symposia being held regarding this survey method (Ralph and Scott 1981, Ralph et al. 1995). Point counts have emerged as the method of choice when monitoring objectives are to gauge relative abundances of the diurnal breeding bird community over large geographic areas.

Paradoxically, although it is relatively easy to observe desert birds, they are difficult to accurately count because: 1) vocalizations carry great distances in the open landscape, making estimating distances and pinpointing locations problematical, 2) some species maintain large home ranges, making double-counting a possibility, 3) some species are small, cryptically colored, vocally and/or behaviorally inconspicuous, making detection difficult.

Avian population trends are often difficult to detect with only 3 or 4 years of data. Short-term data sets are usually inadequate to determine

long-term trends that are often masked by year to year variability; long-term studies are required to identify population trends (Ralph et al 1981, Perrins et al. 1991; Bibby et al. 1992). Possible long-term declines in some neotropical migrants cannot be easily detected until many years of data have been collected (Verner 1985; Ralph et al. 1993).

This report covers a new method of point counts introduced to OPCNM in 1997. The previous method of belt transects (Johnson 1995) was discontinued after 1995. The methods section of this report provides extensive descriptions of the new point count methods, study sites, and concerns about the protocol.

History of Avian Monitoring Studies at Organ Pipe Cactus National Monument

There are about 280 species of birds known to occur, either presently or historically, within OPCNM. Of that number, 75 species are known to breed here (Groschupf et al. 1988, and Monument records). Modern bird studies in OPCNM began with Huey's (1942) annotated checklist of 150 species. Subsequent studies focused on the ecology and general habitat relationships of breeding birds within OPCNM (Philips and Pulich 1948; Hensley 1959). Other studies were conducted through the early 1980s, examining the ecology and distribution of selected species or populations (Cole and Whiteside 1965, Beck et al. 1973, Inouye et al. 1981). A contracted project titled "Ecology of Special Status Avian Species" documented 75 species of birds, which were thought to represent the majority of permanent and summer residents in OPCNM (Johnson and Hiett 1992). From that project, a monitoring protocol was developed for 15 "indicator" species and 7 "sensitive" species based on walking belt transects (Johnson and Hiett 1992). This protocol was implemented in 1994-1995. In 1995 and 1996, other contracted researchers investigated the distribution and ecology of brown-headed cowbirds (*Molothrus ater*) in OPCNM (Halterman et al. 2000). That project included sampling 95 point-count stations distributed across 8 transects in xeroriparian habitats. Also during the 1990s, the Monument was included in the state-wide Arizona Breeding Bird Atlas surveys, carried out by the Arizona Game and Fish Department, with some field work completed by monument staff. Finally, from 1992 to the present, monument personnel have continued to inventory and monitor the endangered cactus ferruginous pygmy-owl (*Glaucidium brasilianum cactorum*).

Avian Monitoring Protocol, 1997-2004

No avian monitoring was done in 1996, due to changes in staff, work priorities, and questions regarding the monitoring protocol. In 1997, a new avian monitoring protocol was developed. This change in technique was motivated by two factors: 1) a desire to move closer to the more broadly-accepted standard of point-count transects, and; 2) concerns that the previous belt-transect protocol was ill-suited to Sonoran desertscrub avian communities. The revised monitoring protocol was developed by OPCNM staff biologists with ornithological backgrounds (J. Petterson, T. Tibbitts, and L. Dickson). The revised protocol was carried out as a pilot project in 1997, then slightly adjusted in both 1998 and 1999. A summary of the genesis and evolution of avian monitoring protocols is presented in Table 8-1. Expanded discussion of the methods used from 1997 to 2001 follows Table 8-1.

Methods

The methods presented below describe the final form of the protocol, as it was implemented unchanged from 1999 through 2004.

1997-1998

Eight transects were established in 4 major habitat types: mountain slopes, xeroriparian corridors, bajadas, and valley floors. Two transects were placed in each habitat type. These were placed through or adjacent to existing Ecological Monitoring Program sites where possible; at Growler Canyon, East Armenta, Bull Pasture, Senita Basin, and Middle Bajada. Three transects (Growler Canyon, Cuerda de Leña, Kuakatch)

Table 8-1. History of methods for general avian monitoring at Organ Pipe Cactus N.M., Arizona.

Years	Methods
1994-1995	Protocol of Johnson and Hiett (1992 and 1995) implemented: 7 belt transects located at "Core I" Ecological Monitoring Program sites. Observers walked transects of up to 1.5 km in length, continually counting all birds seen or heard along route, within a variable width of 20 m to 60 m. Three replicates of each transect were sampled during the spring breeding season.
1996	No monitoring was done, due to staffing shortages.
1997	New protocol developed by ORPI staff (see text for full discussion). Eight transects were established in 4 major habitat types: mountain slopes, xeroriparian, bajadas, and valley floors. Two transects were placed in each habitat type, overlaying existing EMP sites where possible. Each transect consisted of 16 point-count stations spaced at 250 m intervals. Each point-count was an unlimited-radius count of 5 minutes' duration. Bird detections were separated into two distance categories: those less than 50 m from observer and those greater than 50 m. Point-count transects were begun at (or within 10 minutes after) sunrise, and all stations within a transect were completed consecutively, separated only by walking time between them. Each transect was sampled only twice in 1997, due to the late date at which new personnel reported to work.
1998	The 1997 protocol modified as follows (see text for full discussion): 1. The detection distance separation was increased to 100 m, because few birds are detected within 50 m of the observer 2. Each transect/point-count station was sampled three times, to span the majority of the long Sonoran Desert breeding season (late February to early May).
1999-2004	1997-1998 protocol modified as follows (see text for full discussion): 1. The interval between point-count stations was increased from 250 m to 500 m, and the number of point-counts per transect reduced from 16 to 8. These changes were made due to time constraints and double-counting some individual birds at closer intervals between point-counts. 2. The segregation of detections into distances from observer was changed to distance bands of: <50m, 50m-100m, 100m-150m, >150m, and birds flying overhead in transit. 3. One valley floor transect was discontinued, and an additional transect established in each of the mountain slope, xeroriparian, and bajada habitat strata. These changes made to maintain adequate data collection for statistical analysis. 4. Point-count duration was lengthened from 5 to 7 minutes. 5. Final protocol: 10 transects of 8 point-counts each, sampled 3 times per spring

used the transects established by Halterman et al. (2000), to allow some degree of continuity with a pre-existing data set, and for the logistical advantage of using point-count stations that had already been marked and mapped. Each transect consisted of 16 point-count stations spaced at 250 m intervals. Each point count was an unlimited-radius count of 5 minutes' duration Reynolds et al. 1980, Hutto et al. 1986). In 1997, bird detections were separated into two distance categories: those occurring less than 50 m from the observer and those greater than 50 m. In 1998, this distance separation was increased to 100 m, due to the low numbers of birds typically detected within 50 m. Point-count transects were begun at (or within 10 minutes of) sunrise, and all stations within a transect were completed consecutively, separated only by walking time between them. Counts were not conducted during rain or with winds >10 mph. Each transect was sampled twice in 1997 (due to the late date at which new personnel reported to work) and three times in 1998. The three visits of 1998 and later years were timed to span the majority of the long Sonoran Desert breeding season (late February to early May) (Table 8-2).

1999-2004

The methods of 1997-1998 were modified slightly in 1999, and then continued unchanged through 2004. Experiences in 1997-1998 showed that the 250 m interval between point-counts was too close, resulting in double-counting many individual birds. Also, the 16-point transects took so long to sample that the later point-count stations in each transect were sampled after morning bird activity had substantially declined. Therefore, beginning in 1999, only every-other point-count station was sampled in each transect. This resulted in transects of 8 point-counts at

Table 8-2a. Sampling periods and observers, 1997-2004 avian monitoring, Organ Pipe Cactus N.M.

	Visit 1	Visit 2	Visit 3	Observers
1997		Apr 30 to May 22	May 23 to Jun 5	Petterson, Tibbitts & Dickson
1998	Feb 18 to Mar 3	Mar 23 to Apr 10	May 12 to Jun 1	Petterson, Tibbitts & Dickson
1999	Feb 22 to Mar 1	Mar 17 to Mar 29	Apr 28 to May 9	Petterson & Tibbitts
2000	Feb 25 to Mar 10	Mar 22 to Apr 1	Apr 23 to May 2	Tibbitts
2001	Feb 21 to Mar 9	Mar 23 to Apr 13	Apr 28 to May 9	Tibbitts
2002	Feb 21 to Mar 7	Mar 22 to Apr 3	Apr 25 to May 4	Tibbitts
2003	Feb 22 to Mar 7	Mar 21 to Apr 7	Apr 26 to May 9	Tibbitts
2004	Feb 24 to Mar 7	Mar 23 to Apr 7	Apr 25 to May 5	Tibbitts

intervals of 500 m. Another related modification was the addition of an additional transect in each of the mountain slope, xeroriparian, and bajada habitat strata, to maintain a total number of point-count stations that would generate adequate data for statistical analysis. Also, one valley floor transect was discontinued, because bird detections in that habitat type were too low for statistical treatment. Point-counts were also lengthened to 7 minutes, after a trial period indicated this longer period more accurately sampled bird species and numbers. Finally, detections were segregated into nested distance bands, concentric radii centered on the observer. Distance bands were <50m, 50m-100m, 100m-150m, and >150m. Birds flying over the observer and appearing to be in transit to or from areas lying outside a 200 m radius from the observer were tallied separately. Thus, from 1999-2004, the protocol consisted of the following key elements:

- 10 transects, distributed across four habitat types (Figure 8-1; see descriptions below).
- Each transect consists of 8 point-count stations at 500m intervals.
- Each point-count sampled for 7-minutes' duration per visit.
- Each transect sampled three times each spring. In each of these three sampling periods, all 10 transects are done in as few consecutive mornings as possible (Table 8-2) The ideal of sampling all 10 transects in 10 consecutive days (assuming only one observer) is usually not achieved, typically due to windy conditions.
- 80 point-counts sampled three times per year for a grand total of 240 point-count station samples per year.

Data collection did not occur in 2005, due to higher-priority activities for staff, and border-related safety issues. The second and third visits (out of 3) to Senita Basin could not be accomplished in 2004 due to border-related safety concerns.

Additional guidelines for carrying out OPCNM avian monitoring point counts:

1. Do not do sampling in inclement weather (raining or winds > 8 mph). Birds will tend to be much less vocal, plus your ability to hear them is diminished.
2. Do not wear a broad-brimmed hat – these obscure and/or deflect sound. Wear a ball cap, visor cap, or no hat. It helps to clip a broad-brimmed hat on your daypack, so you can wear it after the line is completed, while you're walking back to the vehicle.
3. If there is a breeze, face 90 degrees away from it. Breeze creates a lot more sound in your ears, from turbulence, if you are facing directly into or away from it. If you turn 90 degrees from the breeze, it is blowing straight into one ear, instead of blowing across both. It is much quieter that way.
4. In practice, it is usually most productive to census birds by ear for the first 5 minutes

of the point, then scan visually the last 2 minutes. In many habitats, it will take most of 5 minutes to sort out all the audible birds. Then in the final 2 minutes, you can scan with binoculars, picking up birds that are less vocal but more visually conspicuous (Phainopeplas perched high and exposed, or flying; loggerhead shrikes, perched high and exposed; red-tailed hawks and kestrels, perched on top of saguaros; ravens and turkey vultures, flying at up to great distances; black-throated sparrows quietly moving around in foreground).

5. Wear cotton clothing, not nylon or other synthetic Gore-Tex type fabrics. These can be very noisy, creating "swish" sounds every time you move. Even minor foreground sounds like that can substantially reduce what birds you can hear.
6. Point counts are best done alone. If another person is present, they must stand still and quiet while the observer records detections. The sounds created by shifting feet, opening zippers on packs, whispering, eating food, etc., can all mask bird vocalizations.
7. Transects located in xeroriparian areas can be very cold at sunrise, even during the 2nd survey visit. Dress in layers and remember gloves.
8. Record data at each point count, then move quickly to next point. In most cases, the 500m between points can be walked in 4 to 5 minutes. Thus each point takes 12 minutes – 7 to survey the point and 5 to walk to the next. After surveying the 8th (final) point at each transect, sit down and transcribe all data from the front of each data sheet to the back. Doing this immediately reduces transcription errors, because each point is still fresh in memory. This method also assures that the transcription gets done in a timely manner.

Data Recording, Compiling, Entry, and Quality Control

Data consistency was maximized, and observer variation was minimized, by several means. To the maximum extent possible transects were sampled within the same time period for each of the three visits, across all years (Table 8-2.). Also, to the maximum extent possible transects were sampled in the same order (lowest elevation to highest) during each sample period. Variations in these two strategies occurred, due mainly to weather conditions. For example, windy weather could result in a morning's sampling being postponed, or that morning's efforts being redirected to a transect known to be less windy. For 2000 through 2004, one observer sampled all transects on all visits, resulting in very low observer variation. For 1997-1999, three observers of comparable abilities sampled the transects – including the observer who sampled from 2000 – 2004.

Data are recorded onto a standard data sheet. Four-letter codes for birds are written on the data sheet in a spatial representation of where they are detected within the area of each point count. This allows the observer to track where individuals are, to reduce double-counting and to record species as they are detected. At the end of each transect (8 point counts), the observer sits down and transcribes data from the spatial representation on the front page, to a summary on the reverse page, which tallies each species by number of individuals detected within each distance band. During this field transcription, for each sheet (point) the observer checks for transcription errors by any of several methods. The total number of birds listed on the front and back of the data sheet may be compared. Or as a random and partial quality check, the total number of birds in one or more distance bands on page one will be compared with the total number listed in the tally on page two. A similar alternative is that the total numbers for a given species (all distance bands) may be compared. This sometimes partial field data checking was backed up by a complete checking for data transcription and entry errors, at the time of data entry. After data entry, total numbers for each species, for each distance band, for each point were compared. The final totals in the database were compared with the totals reported on both

sides of the data sheets. Where discrepancies were found, the front page of the data sheet was taken to be the true number. This quality checking detected an error of approximately one bird per 8 to 12 point counts. (This translates into about 1 bird of 100 to 200 counted, or an error rate of about 0.5% to 1%) In virtually all cases, the error was a transcription error made when data were transferred from the front page to the back. This error of one bird per 8 to 12 points took one of several forms: a) bird missed - not included on page two; b) extra bird reported on page two; c) bird tallied in wrong distance band on page two; d) bird tallied under wrong species on page two.

Data Analysis

In this report, annual monitoring results for each transect are summarized for 1999-2004. Summaries for 1997-1998 are not comparable without conversion and will be treated in a later report. Equal detectability among sites and years was assumed for all analyses and equal detectability among species was also assumed for analyses involving total detections, species richness, and diversity. Concerns with equal detectability are discussed below under Protocol: Challenges, Limitations, and Potential Biases. Summaries for total detections, species richness, and diversity were calculated as described below.

Total detections – All birds detected during the 7 minute observation period at each point count station. This includes both auditory and visual detections.

Species richness – The number of species detected on a given transect during a given visit.

Diversity - $H' = - \sum (p_i * \ln[p_i])$

where p_i is, for each species i, the total detections for that species divided by the sum of total detections for all species , and ln is the natural logarithm.

To use all sites and compare relative abundance, species richness, and diversity among years, each transect was standardized to zero mean and unit standard deviation. Then all transects were averaged for each season and a standard error computed.

Trend Analysis - For each species, total counts for each visit at each transect were calculated. Only the 1999-2004 data were used. Trends were modeled independently for each species by using a generalized linear mixed model (PROC GLIMMIX; SAS) with a year covariate to estimate trend, a visit factor (1, 2, or 3) to control for seasonality, and a random transect effect. The model was specified to have a log link function based on a Poisson distribution with overdispersion.

For some relatively common migratory species, the algorithm failed to converge when all observations were concentrated at one or two visits, with sparse occurrences at the other two or one visits. To determine the trend for those species, we excluded certain visit(s) from the modeling of that species. For example, WWDO was observed 4, 2, and 1607 times during visits 1, 2, and 3, respectively, and the algorithm failed to determine a trend based on the three visits; therefore we determined a trend based on visit 3 only. Similarly, we determined trends for BCFL, BHCO, WETA, and TOWA based on visit 3, trends for HOOR, TUVU, WEFL, PYRR, BHGR based on visits 2 and 3, a trend for DEJU based on visits 1 and 2, and trends for LASP and HOLA based on visit 2.

Habitat Types and Study Sites

Four general bird habitat types were identified, based on differences in vegetation associations, physiography, and other factors affecting the makeup of avian communities. Bird transect site locations are shown in Figure 8-1.

Mountain and rocky slopes - Areas with steep, upland slopes with very shallow, rocky soil and bedrock outcrops varying in elevation from 511 m to 1036 m. Three transects were established at separate sites:

1. Bull Pasture. The transect follows the Bull

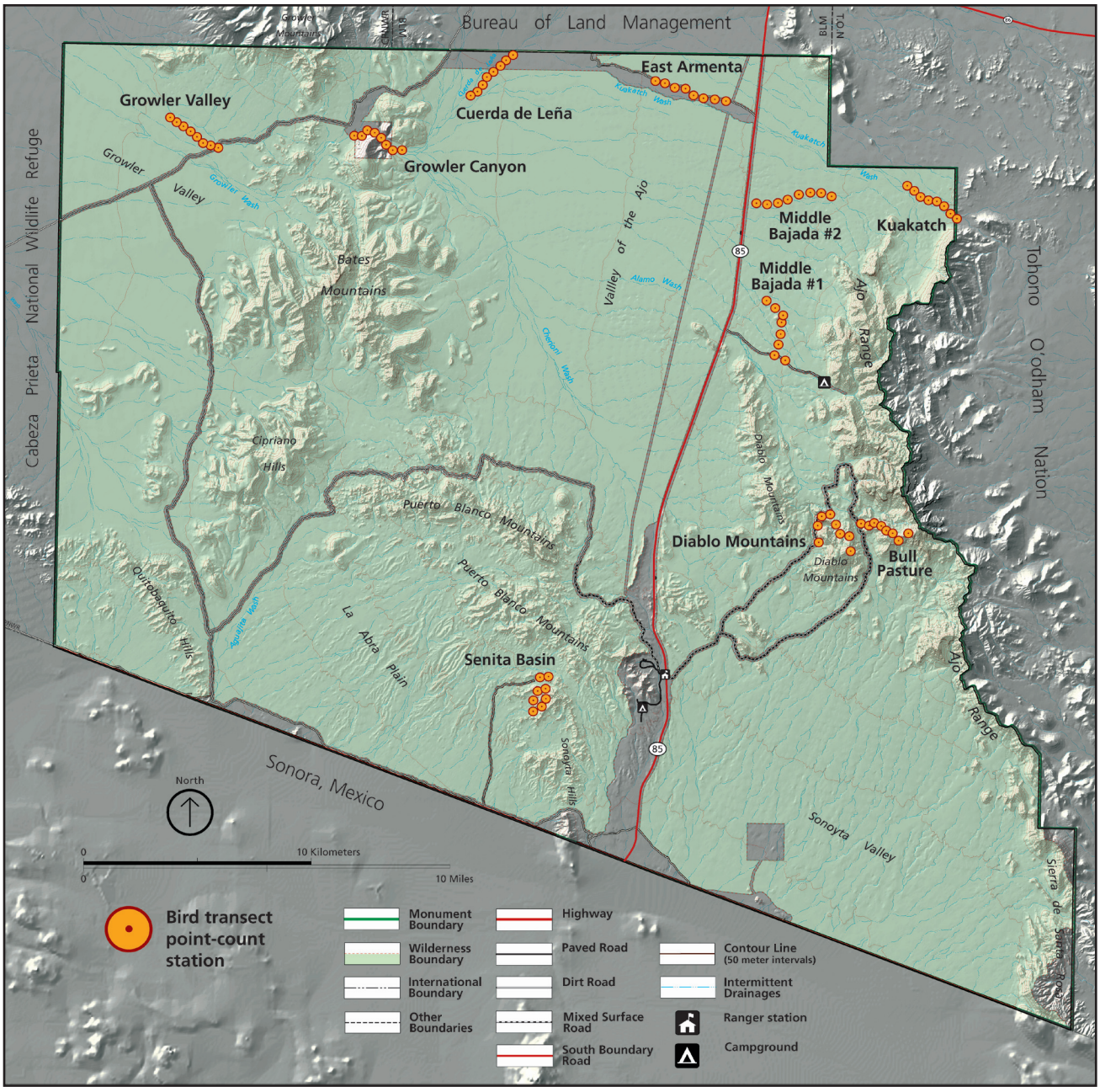

Figure 8-1. Bird transect locations, Organ Pipe Cactus N.M.

Pasture Trail from its origin, continuing approximately 4 km and passing through the Bull Pasture EMP site. The area is characterized by steep mountain slopes, extensive rock outcrops and bouldery areas. Vegetation community is Arizona Uplands desertscrub, with prominent presence of jojoba, jumping bean, agaves, grasses. Notable and distinguishing bird species include: rock wren, canyon wren, Say's phoebe, rufous-crowned sparrow, prairie falcon.

2. Diablo Mountain. The transect begins on the Ajo Mountain Drive approximately one-half mile south of the mouth of Diablo Canyon. The transect then follows the Ajo Mountain Drive to Stop 12 near Wild Horse Tank, then ascends along ridgelines, following the east rim of Diablo Canyon. The area is characterized by steep mountain slopes, extensive rock outcrops and bouldery areas. Vegetation community is Arizona Uplands desertscrub, with prominent presence of of jojoba, jumping bean, agaves, grasses. Notable and distinguishing bird species include: rock wren, canyon wren, Say's phoebe, rufous-crowned sparrow, prairie falcon.
3. Senita Basin. The transect begins just east of the Senita Basin EMP site, at the terminus of the Senita Basin Road. From that point it follows the Victoria Mine Trail eastward approximately 500 m. Then the transect follows a southerly route over the north end of the Sonoyta Hills, eventually curving west and then north again. Vegetation consists of Arizona Uplands Sonoran Desertscrub, with much jatropha, elephant tree, and brittlebush. Notable and distinguishing bird species include: rock wren, canyon wren, Say's phoebe.

Xeroriparian corridors - Identified by major ephemeral desert washes, some with multiple channels, draining large watersheds. Greater availability of water results in extensive stands of large individuals of ironwood, palo verde, catclaw acacia, and mesquite. Large phreatophytic shrubs such as desert broom and canyon ragweed are also present. Vegetation structure of this strata is more diverse than other habitat types, with bird communities being more diverse also. The three point-count transects are:

4. Kuakatch. The transect begins in Kuakatch Wash near OPCNM's northeastern corner, then continues downstream approximately 4 km. The area is characterized by an extensive xeroriparian woodland, passing through middle-bajada desertscrub communities with high densities of saguaro cactus. Avian community is one of the highest density and diversity of all transects. Notable and distinguishing species include: hooded oriole, crissal thrasher, Bell's vireo, Lucy's warbler, numerous neotropical migrants, ferruginous pygmy-owl, zone-tailed hawk, high densities of brown-crested flycatchers.
5. Cuerda de Leña. The transect begins in Cuerda de Leña Wash near the point where this drainage enters OPCNM from the north, then continues downstream approximately 4 km. The area is characterized by well-developed xeroriparian woodland, passing through creosote flats. Avian community is relatively diverse. Notable and distinguishing species include: hooded oriole, crissal thrasher, Bell's vireo, Lucy's warbler, neotropical migrants, and vermilion flycatcher.
6. Growler Canyon. The transect begins in Growler Wash in Growler Canyon, at a point just south of the Bates Well ranch house, then continues upstream approximately 4 km. The area is characterized by a well-developed xeroriparian woodland passing between basalt hills. Avian community is correspondingly diverse, with high abundances of many species. Notable and distinguishing species include: hooded oriole, crissal thrasher, Bell's vireo, Lucy's warbler, numerous neotropical migrants. Ferruginous pygmy-owl often detected nearby if not on transect.

Bajadas - Consists of broad alluvial deposits with an east-west elevational gradient that drain to the

Valley of the Ajo in the west from their upslope connection to the Ajo Mountains in the east. Soils are well drained and vegetation is dominated by palo verde-bursage-mixed cactus association. The three transects are:

1. East Armenta. The transect begins on the Armenta Road, approximately 500 m west of the powerline, and continues west along the Armenta Road approximately 4 km. The area is characterized by deep sandy loam soils, and a very arborescent expression of Arizona Uplands desertscrub. Avian community is very diverse, with high abundances of many species. Notable and distinguishing species include: purple martin, loggerhead shrike, ferruginous pygmy-owl, Harris' hawk, high densities of cactus wren, ash-throated and brown-crested flycatcher.
2. Middle Bajada #1. The transect begins on the Alamo Road, near the rehabilitating old road to Copper Mountain. The transect follows this old road northward through the "Middle Bajada" EMP site, passing just to the east of Copper Mountain, then curving northwest, and ending approximately 1 km northwest of Copper Mountain. Vegetation community consists of classic Arizona Uplands desertscrub, with extensive saguaro stands. Avian community is relatively diverse, with high abundances of many species. Notable and distinguishing characteristics of avian community are: high densities of all "cactus forest" species: cactus wren, ash-throated flycatcher, brown-crested flycatcher, Gila woodpecker, northern flicker, verdin, black-throated sparrow.
3. Middle Bajada #2. The transect begins approximately 300 m east of Highway 85, on the rehabilitating old road starting at highway mile 61.75 ("Wall's Well Road"). The transect follows this old road eastward approximately 4 km. Vegatation community consists of classic Arizona Uplands desertscrub, with extensive saguaro stands. Avian community is relatively diverse, with high abundances of many species. Notable and distinguishing characteristics of avian community are: high densities of all "cactus forest" species: cactus wren, ash-throated flycatcher, brown-crested flycatcher, Gila woodpecker, northern flicker, verdin, black-throated sparrow

Valley Floor – Consist of flat topography, sandy loam soils, and low density and diversity of vegetation, typically a simple creosote-bursage community.

1. Growler Valley. The transect begins at the junction of the Bates Well Road and the rehabilitating Paloverde Camp Road, approximately 7.2 km west of Bates Well. The transect follows the Paloverde Camp Road northwestward into Growler valley for a distance of approximately 4 km. Habitat is structurally simple, dominated by a creosote bush-bursage vegetation association (Lower Colorado River subdivision). Most cactus and trees are limited to shallow arroyos which dissect the plain. Avian community is relatively simple, with low abundances of most species. Notable and distinguishing species are: black-throated sparrow; mixed flocks of wintering sparrows. Greater roadrunners often detected here at great distances (>1 km), due to lack of bird sounds within 200 m.

Protocol: Challenges, Limitations, and Potential Biases

No method for sampling organisms in their natural habitat is wholly accurate, nor is any without inherent weaknesses and potential biases. This avian monitoring protocol is no exception. However, the value of an imperfect protocol is increased when the limitations, potential biases, and challenges are identified and acknowledged. The following discussion highlights some of the confounding factors to take into account when implementing this protocol, and when analyzing the results.

Challenges

Like all point-count systems, this protocol relies

heavily on accurate hearing and identification of birds. Over 80% of all detections are made by ear alone, so observers must have normal (or corrected to normal) hearing, and must be competent in identifying vocalizations of all species that breed, winter, or migrate through the study area.

Myiarrchus flycatchers: One of the greatest challenges in identifying Sonoran desert birds is distinguishing the vocalizations of ash-throated (*Myiarrchus vociferans*) and brown-crested flycatchers (*M. tyrannulus*). Observers should take extensive training and practice in making this distinction before using this protocol. This is important because both species are very common in the study area, in part of the breeding season. In most years, only ash-throated flycatchers are present up until the end of March. However, by the 3rd sampling visit in April-May, brown-crested flycatchers may equal or outnumber ash-throated flycatchers in many areas.

Large finch distinctions: Another demanding distinction between species' vocalizations is distinguishing the northern cardinal (*Cardinalis cardinalis*) and the pyrrhuloxia (*C. sinuatus*). Once again, observers should invest extensive study time with tapes or other recordings to learn to distinguish the vocalizations of these species. To a lesser extent, one of the call vocalizations of the canyon towhee (*Pipilo fuscus*) can also be confused with the cardinal and pyrrhuloxia, particularly for less-experienced observers. Finally, the green-tailed towhee (*P. chlorurus*) is a common migrant in some areas (e.g. Kuakatch, Growler) and can be confused with the resident canyon towhee. Calls of the rare vagrant catbird (*Dumetella carolinensis*) may be mistaken for the green-tailed towhee.

Mockingbird noise: In some years, northern mockingbirds (*Mimus polyglottus*) are very common, a combination of both resident breeders and migrants. During these years, mockingbirds can substantially confound this and any other aural-based protocol. Mockingbirds sing loudly, incessantly, and may mimic vocalizations of virtually any resident bird, migrants, and birds that essentially never occur in the Sonoran Desert. As few as 2 or 3 mockingbirds within 100 m of the observer can result in a "wall of sound" effect that drowns out the vocalizations of most other birds. Furthermore, the mockingbird's repertoire creates the hazard of mistaking its imitated calls with those of the real species.

Limitations

This protocol takes advantage of the ability to detect numerous bird species during the dawn hours, when their vocalizations and general behavior make them relatively obvious. However, nocturnal birds such as owls, nighthawks, and poorwills are sampled poorly by this protocol, if at all. Those species (approximately 9 total) range from uncommon to very common. Some, such as elf owls (*Micrathene whitneyi*) and lesser nighthawks (*Chordeiles acutipennis*), occur at fairly high densities and are probably of substantial ecological influence.

Some diurnal birds are detected infrequently, either because of low population densities and/or life history characteristics. Of recurring interest is the question of gaging populations of resident raptors, e.g. red-tailed hawk (*Buteo jamaicensis*), Harris' hawk (*Parabuteo unicinctus*), American kestrel (*Falco sparvarious*), prairie falcon (*F. mexicanus*), turkey vulture (*Cathartes aura*), and golden eagle *(Aquila chrysaetos*). Also, several raptors are present in the Monument for 6 months or more each year, as winter residents and/or migrants. These include: sharp-shinned hawk (*Accipiter striatus*), Cooper's hawk (*A. cooperi*), red-tailed hawk (*B. jamaicensis*), and northern harrier (*Circus cyaneus*). In general, both resident and migrant raptors occur at fairly low densities and are not vocally conspicuous, except in the immediate nest area. All are detected by the current protocol, but infrequently. As predators and scavengers, these birds exert significant ecological influence, and should be of interest in long-term ecological monitoring. This ability of this protocol to accurately sample raptors has not been tested.

Potential Biases

Most potential biases associated with this protocol arise from probabilities of detection that vary beween species, and between survey conditions. Several examples follow.

Gnatcatcher undercounts. The black-tailed gnatcatcher (*Polioptila melanura*) is among the most common and abundant species in OPCNM. However, its vocal characteristics probably result in it being undercounted or underestimated in aural surveys. The gnatcatcher is detected at virtually all 80 point-count stations, on all visits. But it's relatively soft vocalizations do not carry well, especially through other, louder vocalizations and background noise. As a result, several individuals of this species are typically detected within the 50-meter distance band, but few or none beyond that. In reality, gnatcatchers probably occur at relatively high densities throughout the area covered by each point, but are only detectable close to observers.

Roadrunner population "dynamics" .The greater roadrunner (*Geococcyx californianus*) is irregularly detected using this protocol. We have become aware of a general trend in the pattern of detections. The converse of the black-tailed gnatcatcher, the "cooing" call of the roadrunner is a low-frequency sound that carries in excess of a kilometer under quiet, calm conditions. However, this sound is often masked when the acoustic foreground is busy with loud, highly various vocalizations of other birds. As a result, the roadrunner is detected fairly often on the Growler Valley transect, where bird densities are low and there is little interfering noise. Conversely, the roadrunner is rarely detected in more productive habitats where the density and diversity of other birds are high. Even though the roadrunner would be expected to be more abundant in the more productive habitats, the data would suggest it is less common. Perhaps illustrating this effect further is the observation that in very dry years (e.g. 2002, unpubl. data), when all transects had greatly reduced bird detections, the detections of roadrunners actually increased. This may be because roadrunners simply become more detectable under any conditions where there are fewer general bird vocalizations near the observer.

Black-throated sparrow undercounts: The black-throated sparrow is among the most common and abundant birds on virtually all transects. And although it is usually detected readily, this species tends to vocalize more through the heat of the day (after transects have been completed) than at dawn. For this reason, and also acoustic factors similar to those for the black-tailed gnatcatcher, this protocol may under-represent true densities of black-throated sparrows.

Results

A summary of transect completion is presented in Tables 8-2a and 8-2b. We sampled 11 transects a total of 216 times from 1997 through 2004. One transect (Growler Valley 2) was discontinued after 1998. Three transects (Diablo, East Armenta, Kuakatch) were not initiated until 1999. Apart from these modifications, sampling was missed on only 4 occasions over the 8 years. The 3rd sample visits were missed at both Growler Valley transects in 1997, possibly due to timing (too late in the year). In 2004, the 2nd and 3rd sample visits to Senita Basin were cancelled due to high levels of border-related illegal activity in the area. Our efforts to complete all transects in as few days as possible, for each of the three annual visits, were successful considering weather and other limitations. Our efforts to complete each of the three annual visits on approximately the same dates from year to year were similarly successful.

Average detections, species richness, and diversity are summarized in Table 8-3 for each transect for each year. Total bird detections increased slightly through those years, with a low point in 2002 (Figure 8-2). Bird species richness and diversity were fairly constant from 1999 through 2004 (Figure 8-3 and 8-4).

Discussion

This monitoring protocol has been in place for

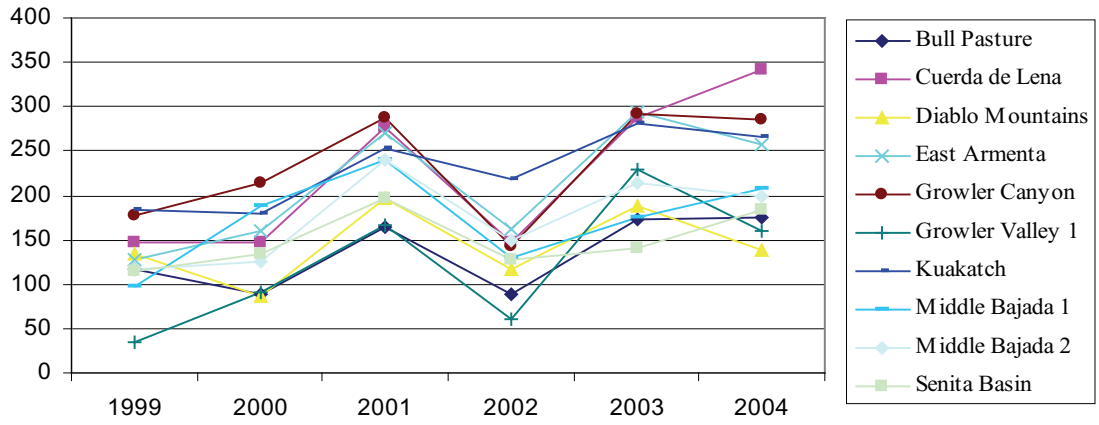

Figure 8-2. Mean detections among 3 visits to avian monitoring transects at Organ Pipe Cactus N.M.

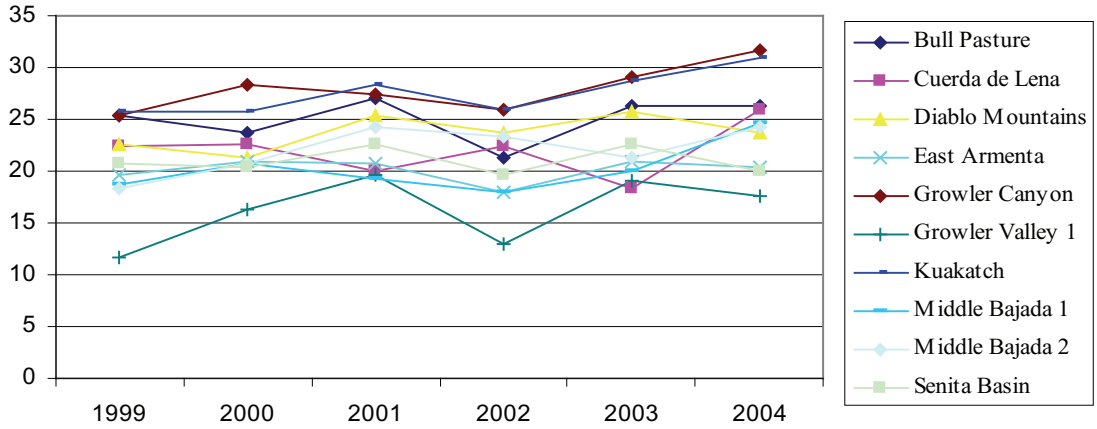

Figure 8-3. Mean species richness among 3 visits to avian monitoring transects at Organ Pipe Cactus N.M.

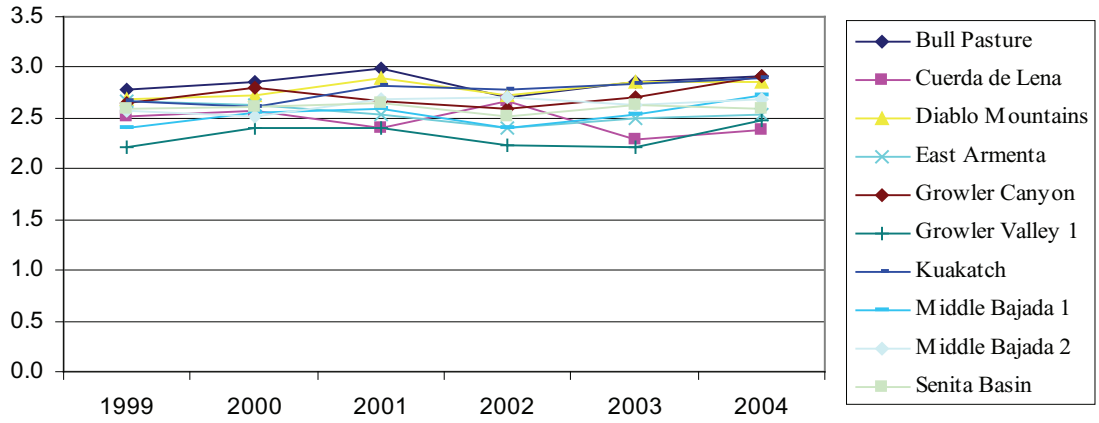

Figure 8-4. Mean diversity among 3 visits to avian monitoring transects at Organ Pipe Cactus N.M.

a relatively short period of time. We are still in the process of building baseline information. Long-term population trends cannot be identified yet, however good examples of year-to-year variation are accumulating. Fortunately, observer consistency has been very high (Table 8-2), so observer variation between transects and between years is correspondingly low. As a result, year-to-year changes in abundances of some species should already be identifiable.

Selecting the four broad habitat types for sampling did result in the transects yielding patterns in bird species composition. The total number of bird detections varied considerably between transects and habitat types (Figure 8-2). Not surprisingly, transects located in areas with greater density and diversity of vegetation yielded greater avian density and diversity. The greatest number of total detections were in xeroriparian areas (Growler Canyon, Kuakatch, Cuerda de Leña), followed closely by bajada habitats (East Armenta, Middle Bajada 1 and 2) (Figure 8-2). The lowest numbers of detections were generally in Growler Valley, although rocky mountain slope habitats were also low (Senita Basin, Diablo Mts, Bull Pasture). Detection numbers in the most productive habitats were generally about three times those for the least productive sites.

Species richness varied considerably between transects (Figure 8-3). The variation followed a pattern similar to that of total detections, with an interesting difference. The open, structurally simple, sparsely vegetated habitat of the Lower Colorado River Subdivision on the Growler Valley transect had the lowest species richness. Conversely, the large, well-developed Arizona Upland xeroriparian habitats (Growler Canyon, Kuakatch) yielded the highest species richness. Interestingly, although rocky mountain slope habitats (Bull Pasture, Diablo, Senita Basin) yielded low total detections, species richness on those transects usually equaled or exceeded that of the highly-productive bajada habitats. In fact, species richness on the rocky slope transects equaled and sometimes exceeded that of the smaller xeroriparian transect (Cuerda de Leña). High species richness of the rocky mountain slope habitats is likely because they often contain almost all the species present on bajadas (just in lower numbers), but then also support other species that are closely associated with the rocky habitat and are not present on bajadas (e.g. rock wren, canyon wren, rufous-crowned sparrow, Say's phoebe). Species richness at the highest-ranking sites was approximately twice that of the lowest ranking sites.

Mean diversity also varied among transects (Figure 8-4). Two of the three rocky mountain slope transects (Bull Pasture, Diablo) ranked highest for mean diversity. The reason for this is likely the same as for species richness; the rocky slope transects detected most bajada species plus some that occur exclusively on rocky slopes. The Growler Canyon and Kuakatch xeroriparin transects ranked just below rocky slopes in mean diversity. And again, the valley-floor habitat of the Growler Valley transect ranked lowest.

Data from 1997-2004 indicate an increase in total bird detections over those years. This apparent increase is difficult to evaluate without a better measure of the typical year-to-year variance. Additional years of data collection, spread over years of varying climatic conditions, would better define the normal variance. Even so, it appears that increased detections are statistically significant, for some species (Table 8-4.) Before discussing possible increases, it should be noted that increased detections may or may not equate to increased numbers of real birds on the transects. The fact that a single observer sampled all transects in 2000 through 2004 probably reduced observer variation. However, if the observer's skills increased over time (likely), that may have resulted in greater numbers of detections. For example, "Unknown bird" detections declined by 65.6% annually. It is likely there was a corresponding increase in the number of birds successfully identified to species. This alone could account for some apparent increase in bird detections.

Among the species showing a pronounced increase were Brewer's sparrow, white-crowned sparrow, lesser goldfinch, green-tailed towhee, and ferruginous pygmy owl. Considering the sheer numbers involved, the increases in Brewer's and white-crowned sparrows are likely real (Figure 8-7). These wintering seedeaters appeared to respond to the two moist winters following the extreme drought year of 2002 (See Climate chapter), by wintering in OPCNM in large numbers. While the increase in lesser goldfinches was statistically significant, the real increase was from about 40 detections in 1999 to about 70 in 2004. This is not a large number of detections from which to make conclusions about the species' status. Similarly, the 89.4% annual increase in green-tailed towhees (Table 8-4) was statistically significant, but may not have been ecologically significant. The real increase was from almost no detections in 1999 to slightly fewer than 50 in 2004. Once again, these are not many detections from which to draw conclusions. Increasing observer skills could have resulted in increased detections of this species (see above). Also, like many other wintering and migrant birds, this one typically occurs in a few fairly specific habitats (xeroriparian in this case). Occurrence of migrant birds in such habitat patches on a given day is likely affected by numerous factors such as weather, landscape-scale habitat conditions, random chance, and other factors independent of conditions on that transect on that particular day. Migratory species also tend to exhibit wider variation between visits within each year.

A species' natural history must also be considered in interpreting trend data. The 79.4% annual increase in ferruginous pygmy-owls is statistically significant and sounds substantial. However, that apparent trend is based on fewer than 15 detections in the final year, after that significant increase. In reality, the appearance of one new territory near a transect in 2004 resulted in some increased detections, and was perhaps a positive indicator of this sensitive species increasing in numbers. But at the same time, pygmy-owl males tend to be more vocal, for longer in the spring, if they are having poor success attracting mates. So increased aural detections, particularly in April and May, might actually suggest trouble for the local population.

The monument's avifauna can be separated into three major categories of birds, according to residency status. These are:

- Permanent residents: Present year-round and breed here.
- Migrant breeders: Species that breed here but migrate out of the monument for part of the year.
- Migrants: Species that migrate through the monument and/or winter here, but do not breed here.

These categories are useful for considering changes in the avian community over time. However, these categories are not perfectly discrete. Some species fall into more than one of these categories. For example, some species include both individuals that breed here, and also some that occur in the monument in winter and/or migration, but breed farther north. These species include: red-tailed hawk, northern mockingbird, loggerhead shrike, northern cardinal, turkey vulture, Bell's vireo, phainopepla, mourning dove, and others.

These residency categories may be useful to gage changes in the monument's ecosystems. For example, global climate change or other habitat changes may affect the migratory or residency behaviors of some species. Residency categories provide a useful framework to consider the year-to-year variations in detections recorded between 1999 and 2004.

The most apparent pattern in the avian monitoring data is for the year 2002, when total detections, mean detections, species richness, and (to a lesser extent) mean diversity all declined (Figures 8-2, 8-3, 8-4). A recent, severe drought peaked in 2002 (see "Climate" chapter). In 2002,

birds may have avoided the drought-affected region that year, due to the severe conditions. Numbers of permanent residents, migrant breeding birds, and migrant/wintering birds were lower in 2002, probably due to a combination of real reductions in presence and reduced activity levels among birds. Reduced activity, particularly singing, would make birds less likely to be detected. Birds may be present but not vocalizing or engaging in other obvious activities, making them largely undetectable by point count methods.

Permanent residents also strongly showed a decline in detections in 2002 (Figure 8-5). This group includes many of the most common species in OPCNM. The decline in 2002 was observed for almost all permanent residents. One apparent trend was that the decline was perhaps less pronounced in species detected in the lowest numbers. Presented graphically (Figure 8-5), the decline appears most severe in the most abundant species (e.g. Gambel's quail, mourning dove, phainopepla). Many of these species experienced declines to approximately one-third the number of detections in other years.

Few permanent residents appeared to have an opposite trend, with detections increasing or remaining constant in 2002 (e.g. cactus wren and black-tailed gnatcatcher). This may have been an artifact of the acoustic environment. When the overall number and variety of bird sounds are greatly reduced, several types of vocalizations become more audible. These include low-frequency calls at great distance (common raven, greater roadrunner), and soft, high-frequency calls nearby (black-tailed gnatcatcher). We suspect detection rates for some of these species were enhanced in 2002 by this effect, possibly even to the point of masking actual declines in these species in that year. A greater proportion of common permanent residents exhibited a downward spike in detections in 2002, compared to migratory breeders and wintering/migrant species (Figures 8-5 to 8-7). This may be intuitive in that, as permanent residents, they were in the monument throughout the drought, experiencing physiological stresses without departing to other areas for relief.

A smaller proportion of common migrant birds that breed in OPCNM exhibited a downward spike in detections in 2002, compared permanent residents (Figure 8-6). As noted above, migratory species may have been able to cope with the drought better because they can move to other areas, perhaps less drought-stricken, for a large part of the year. The two migratory breeders with the greatest declines in 2002 were white-winged dove and brown-crested flycatcher. Both species are very closely tied to saguaro cactus, so their status might be of particular interest in long-term drought continues. The white-winged dove is one of the most abundant species in the monument during the months it is present, with detections comparable to Gambel's quail and mourning dove. This is also a relatively large bird, meaning it accounts for a substantial portion of bird biomass through the spring-summer months. White-winged doves appeared to have rebounded in 2003.

Several migrant-breeder species apparently increased in 2002 and/or in the years after. These included turkey vulture, Lucy's warbler, ladder-backed woodpecker, and Scott's oriole. Turkey vultures may have increased because of the availability of drought mortality of many wildlife species. However, turkey vulture detections include migrants that do not breed in OPCNM. So sighting a single kettle of 50 migrant vultures could have substantially affected this apparent trend. The increase in Lucy's warbler is of considerable interest. This species is almost completely restricted to mesquite habitats (Corman and Wise-Gervais 2005). Mesquite may be recovering in some parts of OPCNM, following the cessation of livestock grazing in the late 1970s. However, mesquite mortality is also being observed throughout the monument as a result of the continuing drought. Lucy's warblers thrive in mesquite stands that include standing dead trees. The relationship between

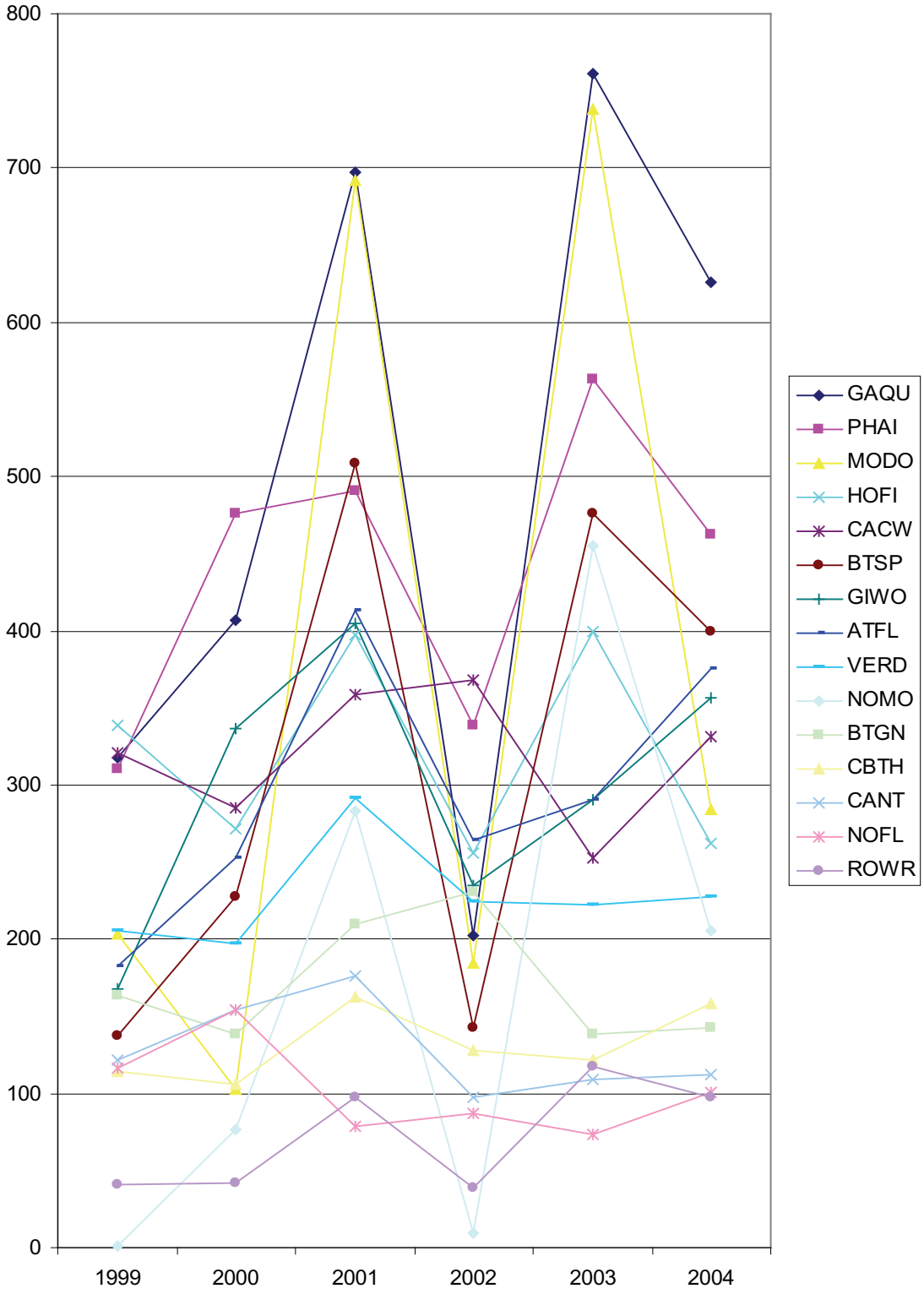

Figure 8-5. Total detections of the 15 most common permanent resident bird species on avian monitoring transects at Organ Pipe Cactus N.M., 1999-2004.

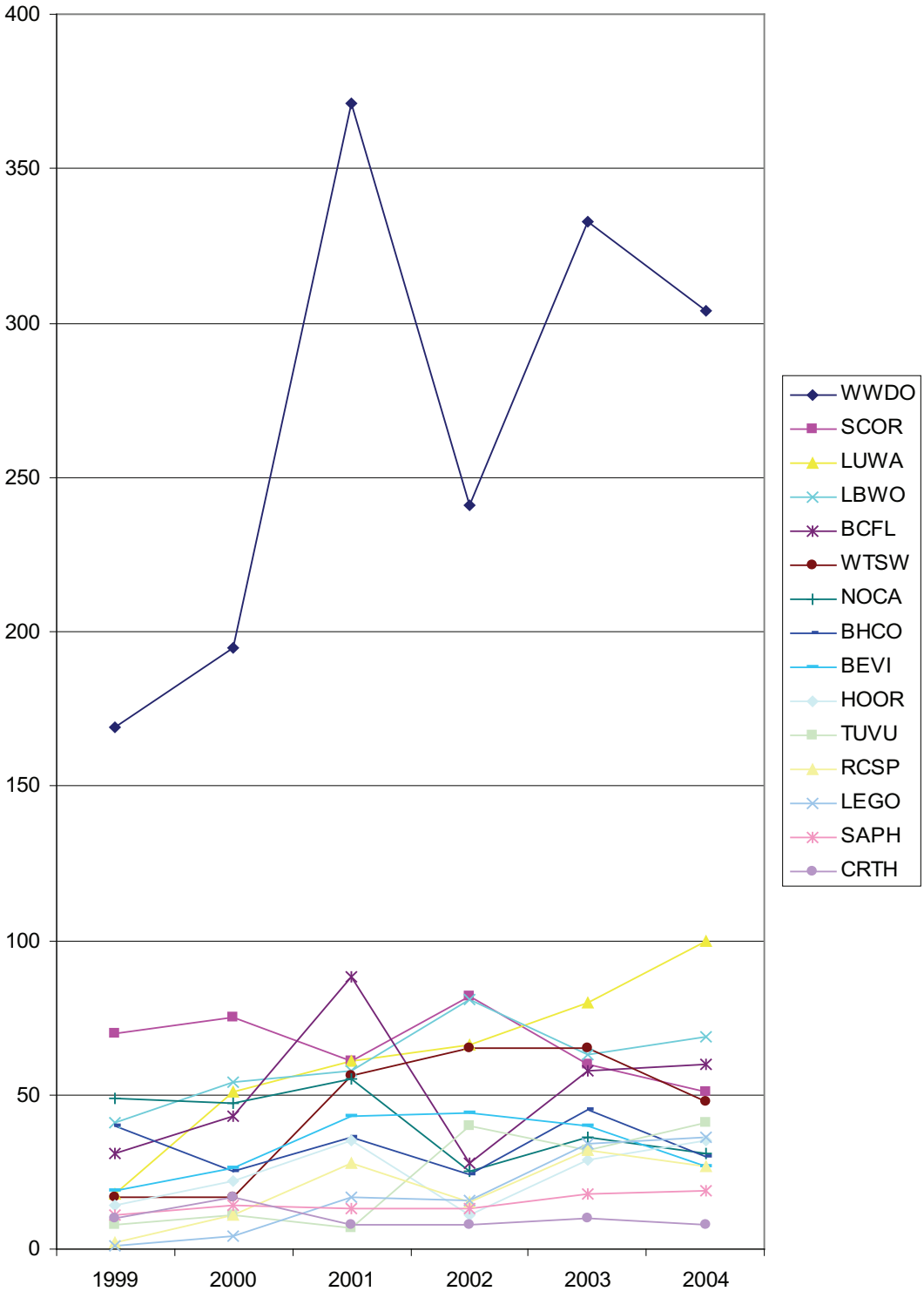

Figure 8-6. Total detections of 15 migrant breeding bird species on avian monitoring transects at Organ Pipe Cactus N.M., 1999-2004.

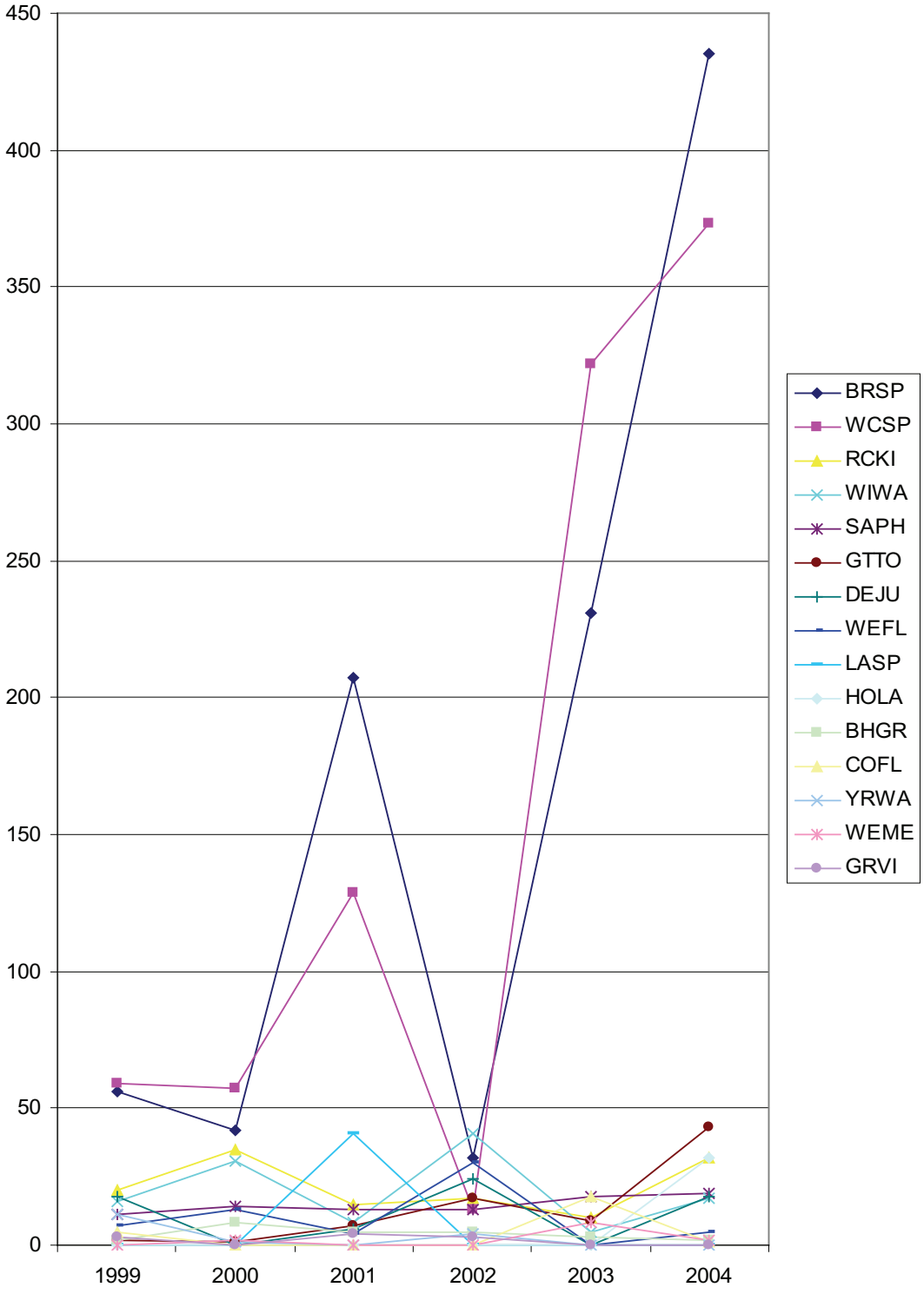

Figure 8-7. Total detections of the 15 most common migrant wintering bird species on avian monitoring transects at Organ Pipe Cactus N.M., 1999-2004.

the trend of mesquite and Lucy's warbler in OPCNM could be a very interesting component of long-term change in vegetation and climate. Finally, the increased detections of Scott's oriole and ladder-backed woodpecker in 2002 elicit no obvious explanations. Neither increase is readily explained by the acoustic factors discussed above, and there are no apparent characteristics of habitat or natural history to explain the increases.

With two notable exceptions, wintering/migrant birds that do not breed in OPCNM did not decline in 2002 (Figure 8-7). Almost all wintering/migrant species were detected fewer than 50 times in any year. Most showed no change or modest increases, all of which could be explained by the normal variance in migration. The two exceptions were Brewer's sparrow and white-crowned sparrow. These two finches can winter in large numbers in OPCNM. Ironically, they favor open, lower-bajada and valley-floor habitats where overall bird detections, species richness, and diversity are lowest. These sparrows are typically detected in large numbers on the Growler Valley transect, and the Cuerda de Leña xeroriparian transect which is framed by open creosote flats. In these settings, these sparrows appear to be attracted to the expansive growths of low-stature winter annual plants (e.g. *Plantago insularis*) that appear after adequate winter rains. As wintering birds, they can opportunistically occupy areas that have winter annual growth, and avoid those without. It is not surprising then that they exhibit a typical boom-and-bust occurrence (Figure 8-7), almost absent in dry years but abundant in years of adequate winter rains (e.g. 2001, 2003, 2004).

Sonoran Desert Network

Terrestrial bird monitoring was selected as one of 25 vital signs by the Sonoran Desert Network (Mau-Crimmins 2005). Network and OPCNM staff met in October 2005 to discuss integration of the EMP with the regional network. A copy of OPCNM bird data was provided to SODN to aid in protocol development. It is possible that SODN may use point counts along with mist netting and banding, nest searching and monitoring, and periodic vegetation sampling. Monument biologists will continue to work with the network on protocol development and integration of EMP and SODN bird monitoring projects. Network objectives for bird monitoring include:

1. Determine annual changes in species composition and abundance of land birds in grassland, riparian, and upland communities in SODN parks.

2. Determine annual changes in the productivity of land birds in SODN parks.

3. Determine if trends in land bird species composition or abundance in SODN parks differ from regional trends.

Recommendations

1. Complete data analysis and interpretation.

2. Evaluate whether the existing data and protocol meets management and monitoring objectives.

3. Establish transects along and near the south boundary, to monitor for increases in nonnative and/or anthropogenic species associated with human activities in Mexico (e.g. European starling, English sparrow, brown-headed cowbird, great-tailed grackle, domestic fowl, black vulture).

4. Establish monitoring programs for other species most likely to be affected by changes (e.g. common raven, turkey vulture).

5. Establish monitoring programs for species most closely tied to the monument's fundamental purposes (Sonoran Desert): brown-crested flycatcher, elf owl, white-winged dove, verdin, Harris' hawk, gilded flicker, Gila woodpecker, cactus wren.

Acknowledgements

The avian monitoring program reported here

was established largely by former OPCNM Ecological Monitoring Program Manager Jim Petterson (1997-1999). This monitoring protocol was patterned after, and uses some of the same transects as, a study carried out in the mid-1990s by researcher Lara Dickson. During her subsequent tenure as an OPCNM Biological Technician in 1997-1998, Lara also assisted with field data collection. Volunteers Beverly and Luther Walls did extensive data entry and data checking in 2005. Julie Yee (Statistician, U.S. Geological Survey, Western Ecological Research Center) provided the trend analysis.

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Figure 8-2b. Date of each visit to each avian monitoring transect at Organ Pipe Cactus N.M., 1997-2004.

Year-visit	Bull Pasture	Cuerda de Lena	Diablo Mountains	East Armenta	Growler Canyon	Growler Valley 1	Growler Valley 2	Kuakatch	Middle Bajada 1	Middle Bajada 2	Senita Basin
1997-2	Apr 30	May 8			May 4	May 8	May 11		May 7	May 14	May 22
1997-3	May 23	May 23			Jun 1				May 17	May 26	Jun 5
1998-1	Mar 3	Feb 25			Feb 18	Feb 23	Feb 18		Feb 25	Feb 19	Feb 25
1998-2	Apr 10	Mar 23			Mar 28	Mar 27	Apr 3		Apr 7	Mar 27	Mar 24
1998-3	Jun 1	May 17			May 19	May 29	May 12		May 18	May 15	May 11
1999-1	Mar 1	Feb 24	Feb 28	Feb 25	Feb 26	Feb 22		Mar 1	Feb 24	Feb 23	Feb 25
1999-2	Mar 24	Mar 20	Mar 29	Mar 27	Mar 19	Mar 17		Mar 28	Mar 23	Mar 25	Mar 22
1999-3	May 7	Apr 28	May 4	Apr 28	May 9	May 3		May 9	May 7	Apr 30	May 8
2000-1	Mar 1	Mar 4	Mar 10	Feb 25	Mar 3	Mar 5		Feb 27	Mar 9	Feb 26	Mar 2
2000-2	Apr 1	Mar 26	Mar 31	Mar 24	Mar 23	Mar 27		Mar 25	Mar 28	Mar 22	Mar 30
2000-3	May 3	Apr 21	May 2	Apr 24	Apr 28	Apr 29		Apr 30	Apr 26	Apr 23	Apr 25
2001-1	Mar 8	Feb 25	Mar 9	Feb 21	Mar 5	Mar 4		Mar 6	Feb 23	Feb 22	Feb 26
2001-2	Apr 11	Apr 4	Apr 12	Mar 26	Mar 30	Mar 27		Apr 13	Apr 1	Mar 23	Mar 28
2001-3	May 9	Apr 30	May 8	May 5	Apr 29	Apr 28		May 6	May 3	May 4	May 1
2002-1	Mar 7	Feb 23	Mar 6	Feb 25	Feb 22	Feb 21		Mar 3	Feb 27	Feb 8	Feb 26
2002-2	Apr 3	Mar 25	Apr 2	Mar 26	Mar 24	Mar 22		Apr 1	Mar 30	Mar 27	Mar 31
2002-3	May 4	Apr 27	May 3	Apr 28	Apr 26	Apr 25		May 2	May 1	Apr 30	Apr 29
2003-1	Mar 7	Feb 26	Mar 6	Feb 27	Feb 23	Feb 22		Mar 2	Mar 3	Feb 28	Mar 1
2003-2	Apr 7	Mar 23	Mar 31	Mar 24	Mar 22	Mar 21		Mar 27	Mar 25	Mar 26	Apr 1
2003-3	May 9	Apr 28	May 7	Apr 29	Apr 27	Apr 26		May 8	May 2	Apr 30	May 1
2004-1	Mar 7	Feb 26	Mar 2	Feb 28	Feb 25	Feb 24		Mar 6	Feb 29	Feb 27	Mar 1
2004-2	Apr 7	Mar 25	Apr 5	Mar 26	Mar 24	Mar 23		Apr 4	Apr 1	Mar 30	
2004-3	May 5	Apr 28	May 4	May 1	Apr 26	Apr 25		May 3	May 2	Apr 30	

Table 8-3. Annual summaries (average of 3 visits) of total detections, species richness, and diversity from avian point count transects at Organ Pipe Cactus N.M., 1999-2004.

	Year	Bull Pasture	Cuerda de Lena	Diablo Mountains	East Armenta	Growler Canyon	Growler Valley 1	Kuakatch	Middle Bajada 1	Middle Bajada 2	Senita Basin*
Total detections											
	1999	117.7	147.3	133.0	128.0	176.3	34.3	183.7	97.0	116.0	115.0
	2000	89.3	147.0	87.3	161.0	213.0	90.3	179.3	189.0	125.0	134.7
	2001	164.3	277.3	197.0	270.0	287.3	166.3	252.0	239.3	241.0	196.0
	2002	88.3	148.0	116.7	162.3	143.0	61.3	217.7	129.3	149.3	128.0
	2003	173.0	287.7	187.3	294.0	292.0	228.7	280.7	176.0	215.0	139.7
	2004	176.0	341.0	138.7	258.3	284.3	159.0	265.0	207.0	200.0	184
	Mean	134.78	224.72	143.33	212.28	232.67	123.33	229.72	172.94	174.39	149.56
Species richness											
	1999	25.3	22.3	22.7	19.7	25.3	11.7	25.7	18.7	18.3	20.7
	2000	23.7	22.7	21.3	21.0	28.3	16.3	25.7	20.7	20.7	20.3
	2001	27.0	20.0	25.3	20.7	27.3	19.7	28.3	19.3	24.3	22.7
	2002	21.3	22.3	23.7	18.0	26.0	13.0	26.0	18.0	23.3	19.7
	2003	26.3	18.3	25.7	21.0	29.0	19.0	28.7	20.0	21.3	22.7
	2004	26.3	26.0	23.7	20.3	31.7	17.7	31.0	24.7	24.3	20
	Mean	25.00	21.94	23.72	20.11	27.94	16.22	27.56	20.22	22.06	21.00
Diversity											
	1999	2.78	2.52	2.68	2.67	2.65	2.22	2.67	2.40	2.58	2.59
	2000	2.86	2.58	2.73	2.63	2.80	2.41	2.62	2.56	2.53	2.61
	2001	2.98	2.40	2.90	2.54	2.68	2.39	2.82	2.59	2.69	2.65
	2002	2.71	2.67	2.72	2.41	2.60	2.23	2.78	2.40	2.71	2.51
	2003	2.86	2.28	2.86	2.50	2.71	2.22	2.84	2.54	2.63	2.64
	2004	2.91	2.38	2.86	2.54	2.92	2.48	2.90	2.72	2.69	2.60
	Mean	2.850	2.471	2.790	2.550	2.724	2.325	2.771	2.534	2.637	2.598

* Only one visit in 2004.

Table 8-4. Estimated percent annual change in the 50 most common bird species on point count transects at Organ Pipe Cactus N.M., based trend model.

Species	4-letter Code	Annual Change (%)	Standard Error	95% Confidence Interval	Significance (p)
American Kestrel	AMKE	4.4	7.8	-10.0 to 21.1	0.564
Ash-throated Flycatcher	ATFL	11.8	2.8	6.4 to 17.4	<.001
Bell's Vireo	BEVI	7.5	4.2	-0.5 to 16.0	0.066
Black-tailed Gnatcatcher	BTGN	-0.6	2.7	-5.8 to 5.0	0.840
Black-throated Sparrow	BTSP	18.5	3.9	11.1 to 26.4	<.001
Brewer's Sparrow	BRSP	55.9	11.5	34.8 to 80.4	<.001
Brown-crested Flycatcher	BCFL	9.7	5.8	-1.4 to 22.1	0.088
Brown-headed Cowbird	BHCO	0.7	6.1	-10.9 to 13.7	0.914
Cactus Wren	CACW	1.3	2.7	-3.8 to 6.7	0.627
Canyon Towhee	CANT	-5.2	2.7	-10.3 to 0.2	0.060
Canyon Wren	CANW	11.1	4.6	2.3 to 20.6	0.013
Common Raven	CORA	11.0	6.7	-1.5 to 25.1	0.085
Costa's Hummingbird	COHU	0.9	4.4	-7.4 to 9.9	0.835
Crissal Thrasher	CRTH	-8.4	5.2	-18.1 to 2.5	0.125
Curve-billed Thrasher	CBTH	6.4	3.3	0.0 to 13.2	0.049
Dark-eyed Junco	DEJU	4.9	14.4	-20.1 to 37.7	0.728
Ferruginous Pygmy Owl	FEPO	79.4	18.6	46.2 to 120.2	<.001
Gambel's Quail	GAQU	13.3	3.1	7.3 to 19.7	<.001
Gila Woodpecker	GIWO	7.9	2.7	2.8 to 13.3	0.002
Greater Roadrunner	GRRO	37.2	10.0	18.8 to 58.5	<.001
Green-tailed Towhee	GTTO	89.4	16.1	60.2 to 123.9	<.001
Hooded Oriole	HOOR	13.1	6.5	0.9 to 26.6	0.034
House Finch	HOFI	0.5	3.1	-5.3 to 6.8	0.859
Ladder-backed Woodpecker	LBWO	10.9	4.2	3.0 to 19.4	0.006
Lark sparrow	LASP	-15.9	16.3	-43.1 to 24.2	0.377
Lesser Goldfinch	LEGO	64.0	15.0	36.9 to 96.5	<.001
Loggerhead Shrike	LOSH	-0.1	6.7	-12.5 to 13.9	0.986
Lucy's Warbler	LUWA	26.7	3.9	19.2 to 34.7	<.001
Mourning Dove	MODO	16.3	4.8	7.1 to 26.3	<.001
Northern Cardinal	NOCA	-9.2	4.4	-17.5 to -0.0	0.049
Northern Flicker	NOFL	-8.0	3.2	-14.0 to -1.5	0.017
Northern Mockingbird	NOMO	40.0	7.4	26.2 to 55.4	<.001
Phainopepla	PHAI	6.0	2.4	1.3 to 10.9	0.011
Pyhrruloxia	PYRR	4.6	9.0	-11.8 to 24.1	0.604
Red-tailed Hawk	RTHA	7.3	9.2	-9.4 to 27.2	0.412
Rock Wren	ROWR	22.5	4.6	13.8 to 31.8	<.001
Ruby-crowned Kinglet	RCKI	-1.7	4.9	-10.8 to 8.5	0.737
Rufous-crowned Sparrow	RCSP	32.0	7.2	18.6 to 47.0	<.001
Say's Phoebe	SAPH	11.1	6.7	-1.2 to 25.1	0.079
Scott's Oriole	SCOR	-3.7	3.1	-9.7 to 2.6	0.245
Townsend's Warbler	TOWA	-13.4	8.1	-28.3 to 4.5	0.131
Turkey Vulture	TUVU	43.8	16.0	15.3 to 79.2	0.001
Unknown Bird	UNK	-65.6	8.8	-79.3 to -43.0	<.001
Verdin	VERD	2.7	2.1	-1.3 to 6.8	0.190
Western flycatcher	WEFL	-6.4	6.2	-17.9 to 6.7	0.316
Western Tanager	WETA	-7.5	10.6	-26.5 to 16.5	0.501
White-crowned Sparrow	WCSP	58.3	12.3	35.8 to 84.5	<.001
White-throated Swift	WTSW	22.4	6.2	10.8 to 35.3	<.001
White-winged Dove	WWDO	12.2	3.9	4.6 to 20.3	0.002

Bats

Ami Pate

Objectives

The protocol does not provide an explicit objective. However, it states that the sampling tactics "should provide data that reflect, given a long enough time series, gross changes in bat diversity and numbers" (Petryszyn 1995).

Introduction

Bats comprise the second largest taxonomic group of mammals in the world; only the Order Rodentia has more species. The 28 species of bats recorded in Arizona represents the most diverse bat fauna of any state in the United States, other than Texas. Bats are an important component of ecological systems in the southwest U.S. The abundance and diversity of bats and their trophic position as secondary and primary consumers adds to the complexity in food webs in all but the driest of desert ecosystems. However, low reproductive rates and the need to seek specific conditions and microclimates for roosting and hibernating make bat populations vulnerable to declines (O'Shea, T.J. et al. 2003).

The bat monitoring program at OPCNM provides managers with information about what bat species are present in the monument; relative abundance and diversity at waterholes; gross differences between waterholes or changes over time, given either a long time series or drastic change; and baseline information on life history and natural history. Also, increased long-term development and alteration of roosting and foraging habitat in southwest Arizona and Mexico may change bat distribution and migration patterns. Protected lands such as OPCNM are important wildlife refuges, and can serve as reference points for altered landscapes in the surrounding region. A drastic or sustained decline in relative abundance or diversity would alert managers to abnormal conditions at OPCNM, or possibly elsewhere in the case of migratory species.

Twenty-six of the 28 species of Arizonan bats are insectivorous, with the other 2 species being nectar/fruit eaters (Hoffmeister 1986). The nectar/fruit eating bats serve as important pollinators for several species of large columnar cacti that are unique to the Sonoran desert, including saguaro, organ pipe, and senita cactus (Fleming 1996).

Twelve species of bats were found to occur in OPCNM as a result of surveys conducted during 1978–80 (Cockrum 1981). E. Lendell Cockrum described bat species occurrences, life histories, and habitats for the following: California leaf-nosed bat *(Macrotus californicus)*, western pipistrelle *(Pipistrellus hesperus)*, California myotis *(Myotis californicus)*, cave myotis *(Myotis velifer)*, big brown bat *(Eptesicus fuscus)*, hoary bat *(Lasiurus cinereus)*, Townsend's big-eared bat *(Corynorhinus townsendii)*, pallid bat *(Antrozous pallidus)*, Underwood's mastiff bat *(Eumops underwoodi)*, pocketed free-tailed bat *(Nyctinimops femorosaccus)*, and Brazilian free-tailed bat *(Tadarida brasiliensis)*. In addition, a large maternity colony of the lesser long-nosed bat *(Leptonycteris curasoae)* was discovered. The western mastiff bat *(Eumops perotis californicus)* and the Mexican long-tongued bat *(Choeronycteris mexicana)* were not yet verified in the monument at the time of the report, but were confirmed during later mist-netting projects to bring the total to 14 known bat species at OPCNM (Table 9-1).

Of these 14 species, one is designated as endangered under the U.S. Endangered Species Act (U.S. Fish and Wildlife Service, 2001)—*Leptonycteris curasoae*. Six of these species are designated as Species of Concern (former Category 2 candidates for listing under the Endangered Species Act): *Choeronycteris mexicana, Corynorhinus townsendii, Eumops perotis californicus, Eumops underwoodi, Macrotus*

Table 9-1. Bat species by family, acronym, and Endangered Species Act status, Organ Pipe Cactus N.M.

Phyllostomidae (American leaf-nosed bats)	Species	Acronym	ESA Status
Mexican long-tongued bat	*Choeronycteris mexicana*	CHME	Species of Concern
Lesser long-nosed bat	*Leptonycteris curasoae*	LECU	Endangered
California leaf-nosed bat	*Macrotus californicus*	MACA	Species of Concern
Vespertilionidae (Vespertilionid bats)			
Pallid bat	*Antrozous pallidus*	ANPA	
Townsend's big-eared bat	*Corynorhinus townsendii*	COTO	Species of Concern
Big brown bat	*Eptesicus fuscus*	EPFU	
Hoary bat	*Lasiurus cinereus*	LACI	
California myotis	*Myotis californicus*	MYCA	
Cave myotis	*Myotis velifer*	MYVE	Species of Concern
Western pipistrelle	*Pipistrellus hesperus*	PIHE	
Molossidae (Free-tailed bats)			
Western mastiff bat	*Eumops perotis californicus*	EUPE	Species of Concern
Underwood's mastiff bat	*Eumops underwoodi*	EUUN	Species of Concern
Pocketed free-tailed bat	*Nyctinimops femorosaccus*	NYFE	
Brazilian free-tailed bat	*Tadarida brasiliensis*	TABR	

californicus, and *Myotis velifer.*

Several factors make bats difficult creatures to study, resulting in limitations to gaining a detailed understanding of basic information pertaining to changes in abundance, life history parameters, and species diversity. Counting bats in a day roost or during evening exit flights from a day roost are a traditional method of monitoring bat populations. However, for many bat species this is not practical because (1) locations of roosts may not be known, (2) some species do not concentrate in large roosts, (3) some species move to other locations when disturbed, (4) some species move from roost site to roost site on a regular basis, (5) some species have sexually segregated roosts, and (6) often a roost may be used at the same time by several species. Many species that occur at OPCNM are known to roost singly or in small groups in cavities and crevices in rocks and plants, and may frequently change roost sites. Potential roost sites of this variety are countless in the rocky desert scrub and mountains of the monument. Therefore for western crevice and cavity-roosting bats, understanding life history and roosting behavior is very challenging (Bogan et al. 2003).

Although bats have fairly high urine-concentrating abilities, research on daily water budgets has shown that insect diets are not high enough in water content to preclude desert bats' reliance on free water (Carpenter 1969, Bassett 1982). Therefore, because bats need to drink water frequently, this allows for a means of sampling bat species diversity and relative abundance by using mist nets as traps, strung at water sources where bat activity is concentrated (Petryszyn 1995). Compared to other Southwest areas with local perennial streams and rivers, the lower Sonoran desert environment is well-suited to using waterhole mist-netting for capturing bats since during the hot spring and summer months, there are very few available surface water sites. Extended foraging times in the warm season by most desert bat species also maximizes the chances of capture (O'Shea 1977).

During Cockrum's 1978–80 survey, many water sources associated with livestock developments were mist-netted. Cattle grazing was allowed in OPCNM between 1915 and 1978, and with it came the associated wells and water developments (Brown et al. 1981). Although cattle were removed in the late 1970s, the NPS continued to supply water to several concrete troughs for wildlife use until the mid-1980s. The elimination of these artificial water sources and the closing of abandoned mines may have had some effect on bat distribution in the monument. At the present time surface water sources consist primarily of tinajas: natural bedrock tanks in drainages recharged by rainfall and run-off. Approximately 45 tinajas large enough to maintain water year-round have been inventoried, but most are intermittent or ephemeral, depending on location and annual precipitation.

In 1993, Yar Petryszyn was contracted to assess the current abundance and diversity of bats at OPCNM and to develop a long-term monitoring protocol. Six geographically dispersed, reasonably accessible water sources were chosen for long-term monitoring sites. Several, such as Wild Horse Tank and Tinaja Estufa, are natural tinajas with man-made enhancements (concrete dikes). Two permanent water sources exist in OPCNM, Quitobaquito Pond and Dripping Springs. Isolated intermittent tinajas with the capacity for retaining water in the hottest part of the year were chosen, where high concentrations of bats might be encountered. Quitobaquito pond was also mist-netted bimonthly 1993–1996 by Petryszyn as an independent research project on *E. underwoodi*.

Although mist-netting has its shortfalls, it provides about the only method (other than roost and flight counts) of determining the diversity and relative abundance of bats in a specific area. Even though the warm desert landscape of OPCNM may be conducive to productive mist-netting, it is important to realize the shortcomings of such a practice. Some of these are:

1. Not all species of bats have the same propensity to be netted. The echolocation ability of bats varies greatly from species to species, and some are more likely to pick up the presence of a net.

2. The ability to use certain water sources varies among bat species. Some are capable of using the smallest of waterholes, while those with narrow wings need a sizable expanse of water from which to drink.

3. The number of available water sources may change as variation in rainfall from year to year affects how much water is present. Presumably, the dispersion of bats increases with a greater number of water sources.

4. Variation in netting conditions may affect results. For example, changes in temperature, wind, barometric pressure, moonlight, and storms can effect bat foraging activity. There may be some conditions that cause many bats to remain

in their roost. Additionally, even a slight breeze can billow the nets, increasing the likelihood of detection by bats and therefore, decreasing the effectiveness of netting.

While these factors appear to preclude any chance of gathering data that are meaningful, they can be minimized to initiate a viable monitoring program that results in useful findings. The key concept in obtaining meaningful data is consistency, i.e., netting the same water source during the same period of time under the same conditions as much as possible. These tactics, coupled with using the same number and size of nets should provide data that reflect, given a long enough time series, gross changes in bat diversity and relative abundance. In order to minimize the unpredictable sampling variability because of these and other unknown factors, long-term monitoring methods were standardized as much as possible (Petryszyn 1995).

Other useful data from mist-netting includes life history information, including reproductive status, presence of parasites, injuries and scars, and foraging indicators such as presence of pollen or insect parts on bat fur. This information is especially useful in tracking the status of the maternity colony of the endangered *Leptonycteris curasoae*. Although *Leptonycteris* consume large quantities of cactus flower nectar and fruit, they appear to supplement this fluid intake by visiting tinajas. The species has been caught at every bat tinajas. This species has been caught at every netting site, and is especially numerous at Bull

Figure 9-1. *Leptonycteris curasoae* with yellow agave (*Agave deserti*) pollen on head and body, Bull Pasture, May 2004.

Pasture tinajas (Figure 9-1).

Methods

Six geographically dispersed, reasonably accessible water sources were chosen for long-term monitoring sites (Figure 9-3). Mist nets (2.6-m tall, black nylon , 4-shelf, 38 mm mesh) were used to capture bats at all study sites. Nets ranging from 2.4 to 9.1 m in length were placed at the edge of water or in a flyway near water at tinajas and pools. At Quitobaquito, a boat was used to set up a 36.6-m net across the middle of the pond. Nets were set in similar numbers and locations each year, at the driest time of year (May - July) during nights with little or no moonlight (see exceptions below). When possible, breezy nights were avoided, since bats can more easily detect mist nets when the netting material billows in the wind. Nets were opened at dusk, kept open 3-4 hours, and closed between 11 p.m. and midnight. Starting in 1997, netting conditions for each monitoring night were classified in 4 categories: Excellent (E) = no adverse conditions (wind, rain, moon), Good (G) = 1 adverse condition for less than 25% of net time, Fair (F) = 1 or more adverse condition less than 50% of net time, and Poor (P) = 1 or more adverse condition more than 50% of net time.

Nets were checked every few minutes throughout the evening and all captured bats were removed from the net and released on site after species identification, sex, age, weight, forearm and ear lengths, presence of ectoparasites and reproductive condition were recorded. Bats were processed and released as carefully and quickly as possible, to reduce stress or injury. From 1993 to 2005, only 4 mortalities out of a total of 3099 captures were recorded (0.1 %).

In 1996, two netting sessions were conducted; late spring/summer and post-monsoon. Although increased humidity and insect activity over water holes after monsoon rains can result in increased bat foraging, the effect of monsoon rains from year to year was found to be too unpredictable for long-term bat monitoring in the fall season.

Not only are water sources dispersed, but storm patterns can cause poor netting conditions. From 1997 – 2005, bat monitoring was scheduled only in late spring/early summer; when water was limited to larger tinajas, and before monitoring sites dried up. One site, Estufa Tinaja frequently dries up in early spring, so it is sometimes netted in September during the post-monsoon dry period.

One site, Wild Horse Tank, was netted bimonthly over the course of a year (1997-98) to track bat activity in fall and winter months. In 1999-2001, selected sites were netted for 2 consecutive nights to measure the range of variability between nights.

All data were recorded on to standard field forms and later transferred to an electronic data base (MS Access). In this report, results may be expressed as total captures or captures per hour. The latter provides an index (i.e., relative abundance) that does not measure actual population numbers or density, but allows for examination of change over time. For a given monitoring occasion, the number of species recorded is equivalent to species richness and is the only index of diversity used in this report.

Study sites

The same geographic locations for mist netting have remained consistent since 1993, although minor shifts in location were made at 2 sites—Alamo Canyon and Bull Pasture—in order to find more reliable surface water (see methods). The sites represent the range of water source types and locations in the monument. Jacuzzi tinaja is a scoured rhyolite bedrock pool in an open section of South Alamo canyon (Figure 9-2); Bull Pasture is a very sheltered wide, shallow pool in the Ajo Mountains; Wild Horse Tank is an improved large capacity water source in the mountain foothills; Tinaja Estufa is an improved small capacity water source in the Bates Mountains; and Dripping Springs is a permanent pool in a cave in the Puerto Blanco Mountains. The non-spring sites have reliably held water until early summer,

Figure 9-2. Mist net at Jacuzzi Tinaja, South Alamo Canyon, June 2005.

except after the driest winters. The exception is Tinaja Estufa, which is exposed and frequently dries up by May, but is important because of its geographic location in the northwest part of the monument.

South Alamo Canyon
The site of the "Jacuzzi tinajas" is approximately 1 mile upstream of the confluence of the North and South forks of Alamo Canyon in the Ajo Mountains. A 5.5 m net is set with 3 poles forming a "V" at the front edge of the pool. In 2004 and 2005, a 2.4 m net was set with 2 poles (Figure 9-2).

This site replaced North Alamo Canyon's "Paisley tinaja" as a permanent monitoring site in 1998, because the South Alamo site is a higher capacity tank which holds water more reliably in the heat of summer.

Wild Horse Tank
This Diablo Mountains water source is a semi-permanent pool below a cliff with an artificial dam built in historic ranching days. The tank is half filled with gravel from storm run-off, which protects water from evaporation in the hot summer months. When full, the surface diameter of the pool is 10x17 m, the largest bat monitoring site outside of Quitobaquito Pond. The tank is in a very open flyway area.

Bull Pasture
Several protected tinajas are found in this lush middle elevation area of the Ajo Mountains. Sampling was conducted at tinajas in a drainage that empties into Estes Canyon. "Estes Canyon #2" was netted 1993-1996. In June 1997 this pool was nearly dry, and staff placed a net at the more protected "Estes Canyon #1" (informally known as "Deer Drop Tinaja"), situated below a 30 m pour-off below "Estes Canyon #2."

Bates Valley
The Bates Mountain Range in the northwestern corner of the monument contains 2 principal tinaja sites, Tinaja Estufa and Hidden Gorge Tinajas. Tinaja Estufa is located in an open drainage, and water dries up here more quickly than in the Ajo Mountains. Because of its remote location (the only site that requires an overnight backpack) and unreliable water levels, this site

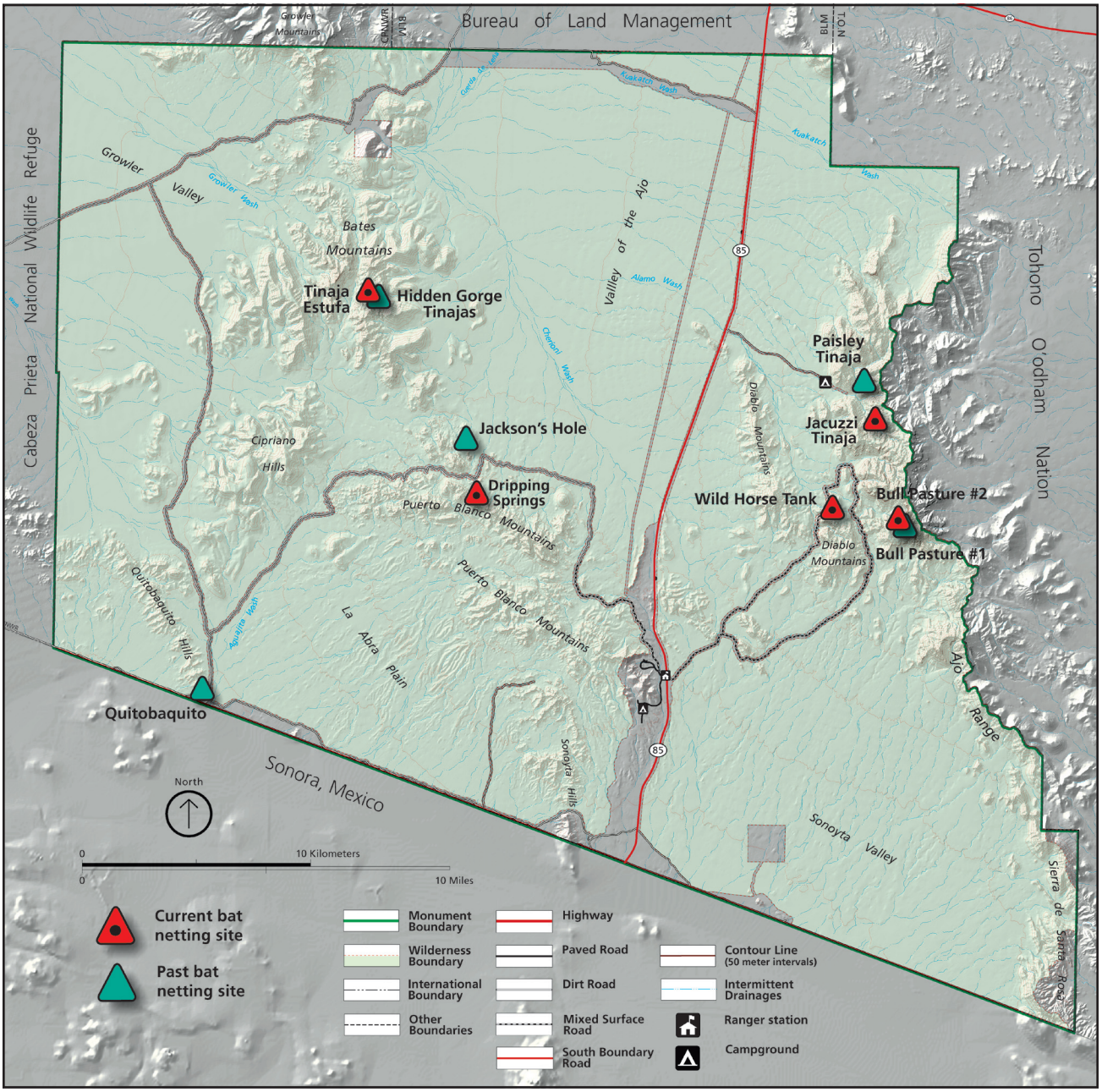

Figure 9-3. Bat mist netting sites at Organ Pipe Cactus N.M.

has not been netted in some years, or netted in the fall after monsoon rains. Attempts have been made to set mist nets at the nearby protected plunge pools of the Hidden Gorge Tinajas, but the terrain is too steep to support a successful net set over water.

Dripping Springs
This permanent seep under a rock overhang on a mountainous slope in the Puerto Blanco Mountains is difficult to sample because of the dense shrubby vegetation growth around the pool. The cave entrance is approximately 1.2 m wide and 2 m high, with the pool volume of 10 m^3. From 1993-1996, one 5.5-m net was oriented diagonally across the overhang opening, with 1 pole set uphill on top of a small cliff face. Starting in 1997, the 5.5-m net was set with 3 poles in a "V," with half the net across the front of the cave opening, and the other half close to the canyon slope. This alterned net set appeared to improve capture success. Due to the site's location on a heavily-used migrant and smuggling trail, water fouling and security issues have affected netting efforts over the years.

Quitobaquito Pond
This site is located at a 0.22 ha spring-fed pond. At this large open water site, bats in the Molossid (Freetail) family account for over 90% of the captures, while these free-tailed species are rarely caught at the other bat netting sites. At these southern Arizona locations, *E. underwoodi* has been observed and captured as it visits open ponds to drink on the wing. For this large, fast-flying bat, relatively large, open bodies of water may be important resources for drinking. Quitobaquito Pond is one of very few locations in the arid border area of south-central and southwestern Arizona where such water resources exist.

From 1993-2000, the pond was netted with a 36.6-m net and checked by boat. Also, bimonthly netting was conducted by Yar Petryszyn 1994-1995 for a banding project (Petryszyn et al. 1997). In June 2000, 4 Underwood's mastiff bat were fitted with small luminescent tags and observed by staff on nearby hilltops. In 2001-2002 the pond was netted extensively for an Underwood's mastiff bat radio telemetry project to determine foraging and roosting habitat (Tibbitts et al. 2002). Quitobaquito pond has not been netted since 2002 due to staff shortages and border security concerns.

Results

Tables 9-1 through 9-12 summarize bat mist net captures at all sites, 1993-2005. Only May-July netting sessions were used for analysis, for consistent comparison. Species composition has not varied significantly over 12 years of mist netting, except for Townsend's big-eared bat (*Corynorhinus townsendi*). This was a rarely caught species 1994-1996, but from 1997-2005 it was caught more frequently at all sites except for Estufa Tinaja and Quitobaquito (Figure 9-4).

Percent of total captures for all years by species is presented in Table 9-2. In general, the most numerous bats caught at non-Quitobaquito netting sites were the pallid bat (*Antrozous pallidus*), the big brown bat (*Eptesicus fuscus*), the lesser long-nosed bat (*Leptonycteris curasoae*) and the western pipistrelle (*Pipistrellus hesperus*).

Capture numbers for some individual species varied substantially from year to year, while others remained more stable. Notably, the big brown bat (*Eptesicus fuscus*) had a peak capture rate in 1999 and 2000 (Figure 9-4), especially at Bull Pasture, Dripping Springs and Estufa Tinaja. The most frequently caught bat, the western pipistrelle (*Pipistrellus hesperus*), had a peak capture rate in 2005; perhaps due to an all-time capture record per night of 68 individuals at Wild Horse Tank. Other species may be increasing. The California leaf-nosed bat (*Macrotus californicus*) started a gradual increase in capture rate in 1998, especially at Estufa Tinaja. The lesser-long nosed bat (*Leptonycteris curasoae*) has also been increasingly captured at mist net sites. In 2005, a record number of *Leptonycteris* were caught at the Bull Pasture site (N = 25). A record number of

Table 9-2. Percentange of total captures for all species at selected sites, all captures combined, 1993 - 2005, Organ Pipe Cactus N.M.

SITE:	BULL PASTURE	DRIPPING SPRINGS	TINAJA ESTUFA	NORTH ALAMO	SOUTH ALAMO	WILD HORSE
Total captures:	582	350	148	161	181	1,069
SPECIES	% of total:	% of total:	% of total:	% of total:	% of total:	% of total:
Antrozous pallidus	6	15	13	10	4	5
Choeronyteris mexicana	0	0	0	1	1	0
Corynorhinus townsendi	1	3	0	1	6	3
Eptesicus fuscus	19	21	28	5	4	10
Leptonycteris curasoae	29	4	5	15	7	8
Macrotus californicus	1	8	14	6	9	3
Myotis californicus	3	2	1	2	15	5
Myotis velifer	4	5	2	1	4	9
Pipistrellus hesperus	32	42	37	60	50	55
Tadarida brasiliensis	5	0	0	0	0	2

Leptonycteris were counted at the maternity roost in 2005.

From 1997-1998, Wild Horse Tank was netted in all 4 seasons to investigate bat activity in the cooler months (Figure 9-7). Several species were active in the winter of 1997-1998; in November 1997 *Antrozous pallidus, Corynorhinus townsendi, Eptesicus fuscus, Macrotus californicus* and *Pipistrellus hesperus* were captured (ending air temperature was 9° C); and in January 1998 *Antrozous pallidus, Corynorhinus townsendi, Eptesicus fuscus, Pipistrellus hesperus* and *Tadarida brasiliensis* were caught (temperatures were in the low 4° degrees C during this netting session).

In 1999-2001, Wild Horse Tank and Bull Pasture were netted for 2 consecutive nights to measure the range of variability between nights (also 2 consecutive nights at Dripping Springs in 1999 and at Tinaja Estufa in 2000). Resulting species composition and capture numbers were fairly similar between the consecutive nights (Figure 9-8), so the protocol was changed back to a single netting night to conserve staff time.

Sex ratios, for all sites and years combined, are summarized in Figure 9-10 and Table 9-4. Analysis of sex ratios per site (Tables 9-6, 9-8, 9-11, 9-12, 9-14, 9-16, 9-18) for all years combined can be useful to identify spatial preferences for foraging and roosting activity. For example, the predominance of *Myotis velifer* females at Wild Horse Tank and Dripping Springs, and *Macrotus californicus* females at North Alamo Canyon and Tinaja Estufa may indicate important maternity colonies in the area.

Capture time comparisons for all species combined and selected species are summarized in Figure 9-9. All non-Quitobaquito May and June netting nights were combined, 1994-2001. Captures dropped dramatically from 2300 – 0000. Since the majority of captures occur by 2300, staff has recently stopped netting slightly earlier than 0000 for backcountry travel safety; however, nets are opened for at least 3 hours. Four species had peak captures very early in the evening—*Pipistrellus hesperus, Myotis velifer, Myotis californicus, and Corynorhinus townsendi*. *Eptesicus fuscus* tended to be captured later in the evening. *Leptonycteris curasoae* peak captures occurred from 2100 – 2200.

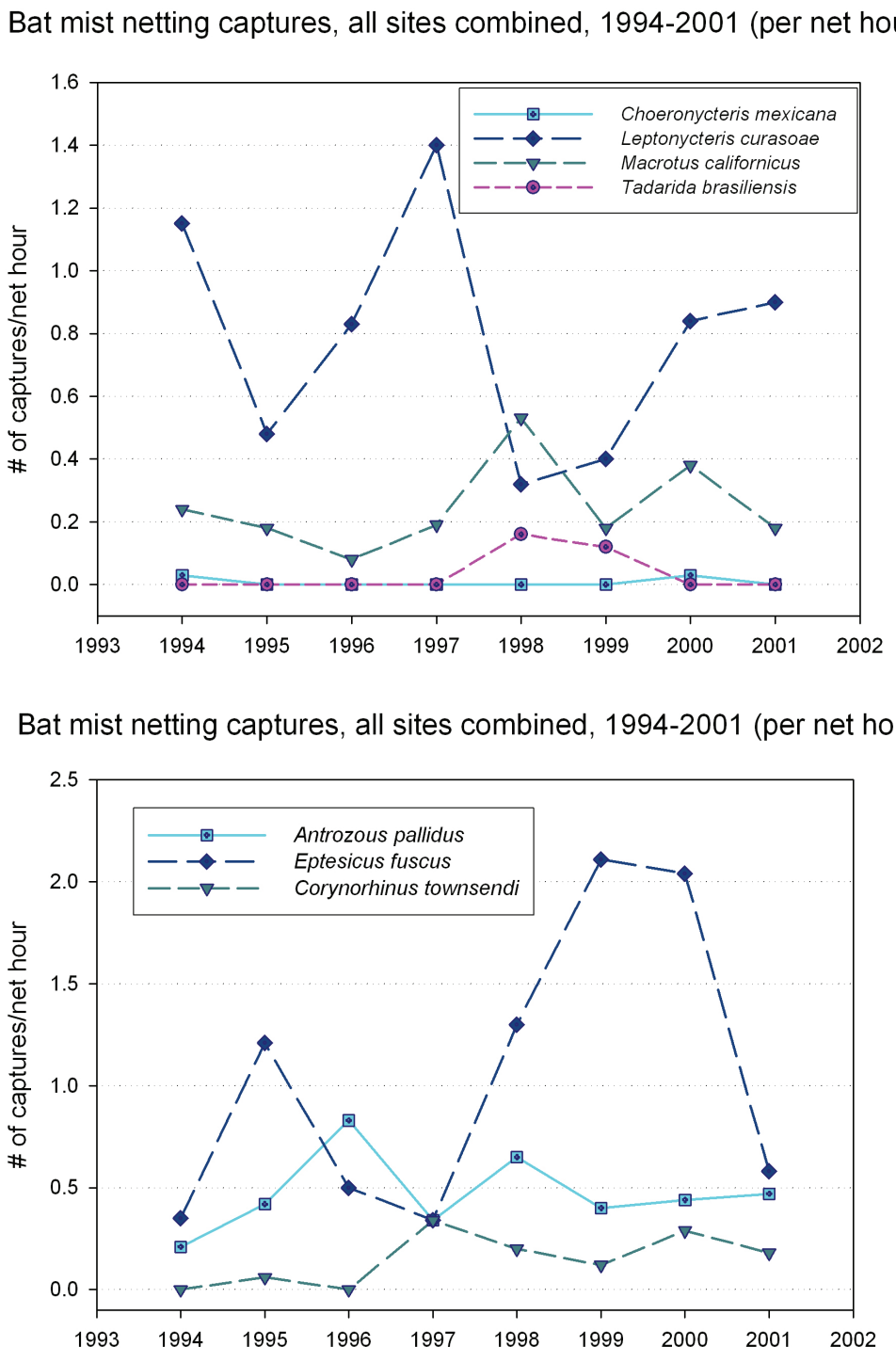

Figure 9-4. Bat mist netting captures for 7 species, per net hour, 1994-2005, Organ Pipe Cactus N.M. All sites outside of Quitobaquito Pond included in summary.

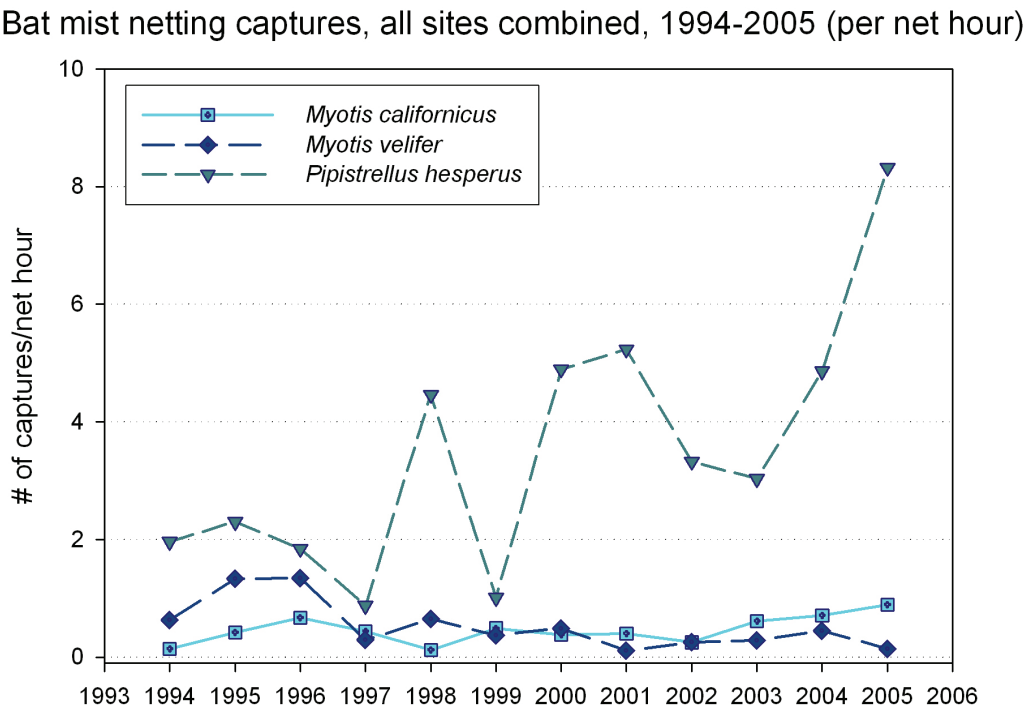

Figure 9-5. Bat mist netting captures for 3 species, per net hour, 1994-2005, Organ Pipe Cactus N.M. All sites outside of Quitobaquito Pond included in summary.

Discussion

SPECIES

Trends and observations for selected bat species are discussed in the following paragraphs.

Lesser long-nosed bat (Leptonycteris curasoae)

Females of the endangered nectar-feeding lesser long-nosed bat migrate to southern Arizona from central Mexico in April-May, following a corridor of flowering plants, and join other pregnant females in large maternity colonies. One of the largest colonies in the United States was discovered at OPCNM in 1969, and has been monitored by Arizona biologists and monument staff since the 1980s. In mid to late June young begin flying, and contribute to the nightly emergence flight. The colony usually reaches its peak size in late June and early July, when most adult females and their offspring are present. In July and August numbers fall off, as adults and young apparently disperse to other local roosts, and/or make more significant movements eastward and to higher elevations to feed on agaves, as saguaro and organ pipe food resources decline. A 2004-2005 study showed that 3 marked bats from the OPCNM roost moved eastward and were located in southeastern Arizona (Krebbs et al. 2005). This was the first evidence that bats from the southwestern corner of Arizona are moving to the mountains of southeastern Arizona in late summer.

The colony has increased substantially since the late 1980s and early 1990s. Colony size in that time period was estimated at 7,000-12,000 (Fleming et al. 1998). In 1997, June exit counts began increasing, with a peak of 37,800 in 2005.

Unlike other desert bat species, *L. curasoae*'s kidneys are not adapted to water conservation, due to a diet with high water content (Arizona Game and Fish Department 2003). Although this diet is thought to allow the species to be independent of free water, mist netting efforts

at water sources in OPCNM have consistently captured *L.curasoae*. They have been caught at every water source, and constituted a large percentage of captures (29%) at one site, Bull Pasture in the Ajo Mountains. Some of the water sites are in natural flyways, but others are not, and the bats appear to be seeking drinking water during their visits there.

Most of the *L. curasoae* captures are lactating females in late-May/June, and often have fur marked with pollen and fruit from foraging. Juvenile males are sometimes caught in late June and July. Frequently when an individual is caught in the net, one or two other *L. curasoae* will keep flying nearby (evident by the species' distinctive wing flapping), which may be evidence of group foraging.

L. curasoae captures increased significantly 2000-2005, with a peak in 2004-2005, which may be due to the increase in colony size, or possibly due to a shift in foraging territory: the capture increase was mostly from the Bull Pasture site in the Ajo Mountains. A widespread reduction in saguaro and organ pipe blooms was documented informally by Arizona biologists in 2004, and many of the *L. curasoae* captures at Bull Pasture were covered in bright yellow, coarse textured, somewhat sticky *Agave deserti* pollen, instead of the more typical saguaro flower pollen which is a pale yellow, finer-grained and drier. As agave density increases in the higher elevations of the Ajo Mountains, more bats may have been seeking this resource in the absence of saguaro nectar and fruit. A 2004 radio telemetry project by Karen Krebbs of the Arizona-Sonoran Desert Museum also documented radio-tagged bats moving along bajadas on the west side of the Ajo Mountains, and ascending canyons (Krebbs 2005).

As a prolonged drought in the southwest may possibly influence cactus phenology, *L. curasoae* may experience stress from the high energetic cost of locating isolated patches of resources, and increased competition at these sites. A radio-telemetry study of the *L. curasoae* in southeast Arizona over a two-year period with a large change in flowering *Agave palmeri* found that the bats spent 120% more time foraging and 66% less time night roosting/resting during the year that the food resources were less plentiful (Ober et al. 2005). Increased energetic costs of increased foraging distances and decreased roosting may be even more stressful on pregnant and lactating females, and in the long-term may influence night and day roost site selection in the region.

Mexican long-tongued bat (Choeronycteris mexicana)

This species of nectar-feeding bat occurs at the extreme northern limit of its range in southern Arizona, with gravid females migrating from Mexico in May and June. Unlike *L. curasoae*, this species does not form large colonies, but roosts in rock shelters and small caves in groups of 15 or less; and they are known to be very sensitive to disturbance. In Arizona, it is considered a rare species and its range is primarily in higher elevations in the southeast portion of the state (Arizona Game and Fish Department 2003). In OPCNM, *C. mexicana* has been caught only 3 times: June 1994 (North Alamo Canyon), May 2000 (South Alamo Canyon), and May 2006 (South Alamo Canyon); all were lactating females.

California leaf-nosed bat (Macrotus californicus)

Studies in 1999-2000 at the nearby Barry Goldwater Air Force Range (partially now managed by the Sonoran Desert National Monument) documented year-round roosting in natural caves and abandoned mines by Macrotus californicus, and a maximum foraging range of 10 kilometers (Dalton 2001). Capture rates for this species began to increase gradually in 1998, and is most numerous at Estufa Tinaja in the Bates Mountains. Park staff have observed small colonies of Macrotus day roosting in historic ranch structures on the U.S./Mexico border, and in abandoned mines.

Females congregate in maternity colonies of varying size in May and June, and roosting bats are sensitive to disturbance (Arizona Game and

Fish Department 2001). Most all of the females caught at OPCNM sites in May – July months were gravid, lactating, or post-lactating which suggests long-term use of monument habitat for maternity colonies.

Townsend's big-eared bat (Corynorhinus townsendi)
This was a rarely caught species 1994-1996, but from 1997-2005 it was caught more frequently at all sites except for Estufa Tinaja and Quitobaquito (Figure 9-4). Only males have been caught at OPCNM. Females are known to congregate in maternity colonies in the spring and summer, while males tend to be more solitary (Monday 1993). Individual males were also caught in November 1997 and January 1998 during a special year-long netting effort at Wild Horse Tank.

Hoary bat (Lasiurus cinereus)
Only 2 hoary bats have been caught in the monument, a female in North Alamo Canyon in August 1995, and a male at Quitobaquito Pond in September 1997. These were probably migrating individuals; this species is associated with coniferous and deciduous forests and woodlands (Arizona Game and Fish Department 2004).

Underwood's Mastiff Bat (Eumops underwoodi)
The regionally uncommon species of *E. underwoodi* is encountered commonly in OPCNM, at Quitobaquito Pond. Underwood's is a little-studied bat of Mexico and Central America (Kiser 1995). The northernmost subspecies, *E. u. sonoriensis*, is limited in distribution to southern Arizona and Sonora, Mexico. In the U.S. it is known only from OPCNM and several other locales southwest of Tucson (Cockrum and Gardner 1960, Hoffmeister 1986, Petryszyn et al. 1996 and 2000). A two year banding study in 1994-1995 by Petryszyn indicated that Underwood's mastiff bat may be a small local population.

In 2000, OPCNM staff carried out a light-tagging project to gain preliminary indications of where the *Eumops* bats frequenting Quitobaquito are foraging and roosting. Visual observations suggested the bats were foraging over a fairly wide local area, including the Quitobaquito area, adjacent Aguajita Wash, desertscrub and hill slopes in both the United States and Mexico, the Rio Sonoyta, and along Mexico Highway 2. In the latter case, bats were observed foraging low over the highway, sometimes in the headlights of the busy truck traffic.

In 2001-2002, OPCNM staff initiated a radio-telemetry tracking project to determine foraging and roosting areas. Scientific literature on *Eumops* roosting behavior led staff to suspect that the large narrow-winged bats would possibly roost in high cliffs, where they could gain flight through a necessary 10m vertical drop. With the assistance of staff from the neighboring Pinacate Biosphere Reserve in Sonora, Mexico, three bats were tracked, with observers stationed or mobile on both sides of the border. Instead of the expected distant cliff roosts that staff expected to discover, all three bats were found to roost in saguaro cavities in the western part of the Rio Sonoyta valley, one to three miles south or southeast of Quitobaquito, near the northeastern corner of Pinacate Biosphere Reserve (Appendix G). The three bats also displayed comparable home ranges and foraging areas. All three ranged eastward and southward during probable foraging movements and traveled along the axis of the Rio Sonoyta valley, but ranged north and south onto adjacent bajadas and mountain slopes. All three incorporated the border town of Sonoyta, Sonora (a probable reliable source of insects drawn by urban lighting) in their home ranges (Tibbitts et al. 2002).

During the 2001-2002 radio telemetry project, staff netted Quitobaquito Pond 7 summer nights in order to capture *Eumops* for radio outfitting. Only 4 *Eumops* were captured during the 7 night netting effort, a very low amount compared to 1993-2000 monitoring results (Figure 9-6). Increased capture of the non-target Molossid *Nyctinomops femorosaccus* and associated activity

at the net may have decreased the ability to capture *Eumops*, or the species may have experienced a true decline from 1994-1995. Quitobaquito Pond has not been mist-netted since 2002 due to border security concerns, as well as the logistical difficulty of processing 100s of *Nyctinomops femorosaccus* at a long net over water.

Possible future methods to determine current *Eumops* foraging and roosting status in the area without using mist nets include acoustic monitoring of echolocation calls with Anabat detector; also, *Eumops* emits a loud vocalization at a frequency audible to humans. Additionally, monument staff and Pinacate Biosphere Reserve personnel could annually relocate the roosting saguaros found during the telemetry project and check for dusk emergence at these plants and other saguaros with high cavities.

Brazilan free-tailed bat (Tadarida brasiliensis)
This Molossid species was rarely caught at tinaja sites in the monument. The narrow-winged high-flying species is less maneuverable than other insectivorous bats and requires a fairly large body of water for drinking. The Bull Pasture tinaja and Wild Horse Tank have a large water surface area at some times of the year, apparently large enough to attract *T. brasiliensis*. At Bull Pasture, 4 individuals were caught in early June 1999, a record 17 caught in late May 2003, and 9 were caught in late May 2004. At Wild Horse Tank, the species was caught in September 1997, January 1998, March 1998, May 1998 and August 1998. Out of a total of 51 individuals, only one female was captured. *T. brasiliensis* males may occur in southwest Arizona during seasonal migration movements, or on long-distance foraging visits from roosts in the region (McCracken 2003).

Human Disturbance
In recent years, disturbance to backcountry water sites by illegal migrants and smugglers has been an increasing worry to resource managers. Some illegal routes bypass water sources where trash is deposited and wildlife may be deterred from natural visitation. No evidence of migrants has been seen at Bull Pasture, Alamo Canyon and Tinaja Estufa sites, although Tinaja Estufa is located only 1 kilometer from a major migrant and smuggler trail. Wild Horse Tank occasionally receives illegal visitation, but no impairment to water quality has been observed. Dripping Springs is currently the most vulnerable wildlife water site in the monument, located on the path of a well-traveled migrant trail, and the site of repeated "lay-up" or rest area use.

During the June 2001 bat netting visit, resource management staff found the springs site in a severely degraded condition with large quantities of migrant and smuggler refuse around the springs, and the spring pool level one meter lower than normal (possibly due to groundwater conditions and/or migrant use of water for drinking). The surface of the water was completely covered with dead bees to a depth of several centimeters, along with decomposing organic matter, floating milk jugs and a large piece of plastic sheeting. The results from the bat netting demonstrated avoidance by bats due to the degraded condition of the water; capture success was much lower than in previous years, as was species richness: only 6 bats and 3 species were caught. (Summer 2001 bat netting results at other sites were consistent with previous years.) Staff returned to the springs in July 2001 for a site clean-up. By August 2001, the water level had risen significantly and bats were netted again. Captures were much higher than in June, with 14 bats and 6 species. In 2002, 55 bats consisting of 8 species were caught; this implies that bats were not deterred from returning to this important water site which in the hottest months may be the only water source within 270 square miles. Recent security restrictions have prevented staff from regular monitoring of spring conditions, and in 2004 and 2005, netting results were poor due to monsoon storms. Migrant traffic at the springs appears to be declining from 2001-2003 levels.

Conclusions
In conclusion, mist netting results from 1993-

2005 have shown consistent species composition and capture rates at all sites, which suggests that bat populations are likely stable at the monument. Protocol changes and experimentation over the years have resulted in a pared down, inexpensive mist net sampling design. Currently, the core 5 sites/1x per spring/summer schedule can help track gross changes in species richness, and relative abundance, as well as serve as a long-term inventory to detect rare or migrating species. A sustained decline or total absence of one or more species may point to anthropogenic or natural change in the monument's bat populations. As funding allows, this program can be augmented spatially or temporally to address new objectives and questions. Also, acoustic sampling would help monitor bat activity for individuals or species less prone to mist net capture, as well as allow monitoring of bat activity in foraging areas away from mountain water sources (O'Farrell 1999, Ellison 2005).

Recommendations

- Develop clear objectives for bat monitoring at OPCNM.

- Work with the Arizona bat group to develop and incorporate OPCNM bat data into a regional program for analyzing and interpreting bat monitoring data. This will increase the use of OPCNM data, provide a valuable context for and supplement to the data, and assist OPCNM with data analysis and interpretation.

- Work with the interpretation division to develop one or more stories using OPCNM bat data to educate the public about bat natural history and conservation.

- Incorporate acoustic (Anabat) recording in a revised bat monitoring strategy. Southwest biologists have compiled echolocation reference libraries of bat species vocalizations that can be used for acoustic identification. An Anabat ultrasonic detector linked to a laptop can detect bats that fly outside of the sampling capabilities of mist nets (O'Farrell 1999). Also, Anabat could be used to monitor bat activity on a larger landscape scale, in selected vegetation zones across the monument, using points or line transects (Ellison 2005). Both the Anabat II (frequency division) and Pettersson D240x (time expansion) ultrasonic bat detectors can be used during monitoring projects. Real-time recordings can quantify bat foraging activity and time-expanded recordings can identify bat species.

- Inspect and test water quality at Dripping Springs regularly during the hot spring months when water is critical to wildlife. Clear any illegal migrant or smuggler trash from area, and skim any decaying biological matter from the water.

- Inventory potential bat roosts (i.e. large natural caves and abandoned mines) in areas that may be impacted by migrant and smuggler activity, i.e. near low mountain passes in the Puerto Blanco and Ajo Mountains, and along major trails. Any significant colony sites should be targeted for extra resource protection and monitoring.

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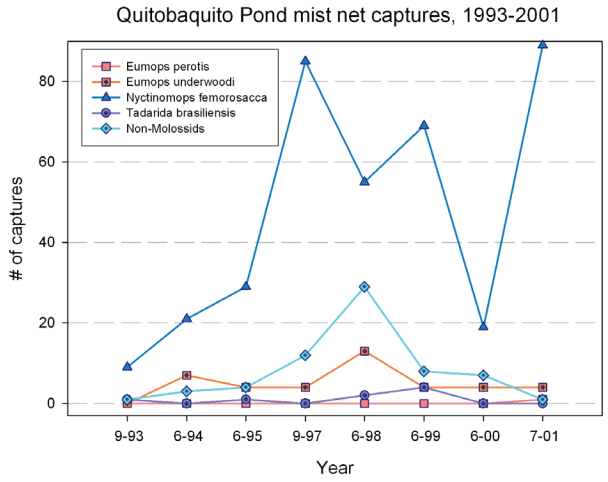

Figure 9-6. Quitobaquito Pond mist-netting captures, 1993-2001, Organ Pipe Cactus N.M.

Table 9-3. Percentage of total captures for all species at Quitobaquito Pond, all captures combined, 1993-2001, Organ Pipe Cactus N.M.

Quitobaquito species	Total captures	% of total
Antrozous pallidus	19	3.4
Eptesicus fuscus	22	3.9
Eumops perotis	1	0.2
Eumops underwoodi	52	9.2
Lasiurus cinereus	1	0.2
Macrotus californicus	1	0.2
Myotis californicus	9	1.6
Myotis velifer	4	0.7
Nyctinimops femorosaccus	420	74.5
Pipistrellus hesperus	26	4.6
Tadarida brasiliensis	9	1.6

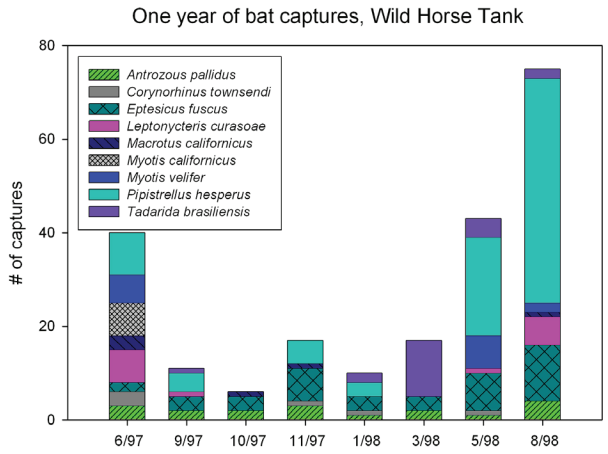

Figure 9-7. One year of bat captures at Wild Horse Tank, Organ Pipe Cactus N.M.

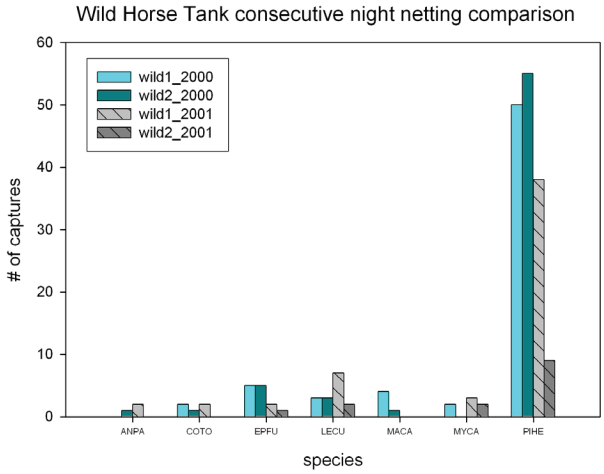

Figure 9-8. Comparison of consecutive night bat captures at Wild Horse Tank, 2000-2001, Organ Pipe Cactus N.M.

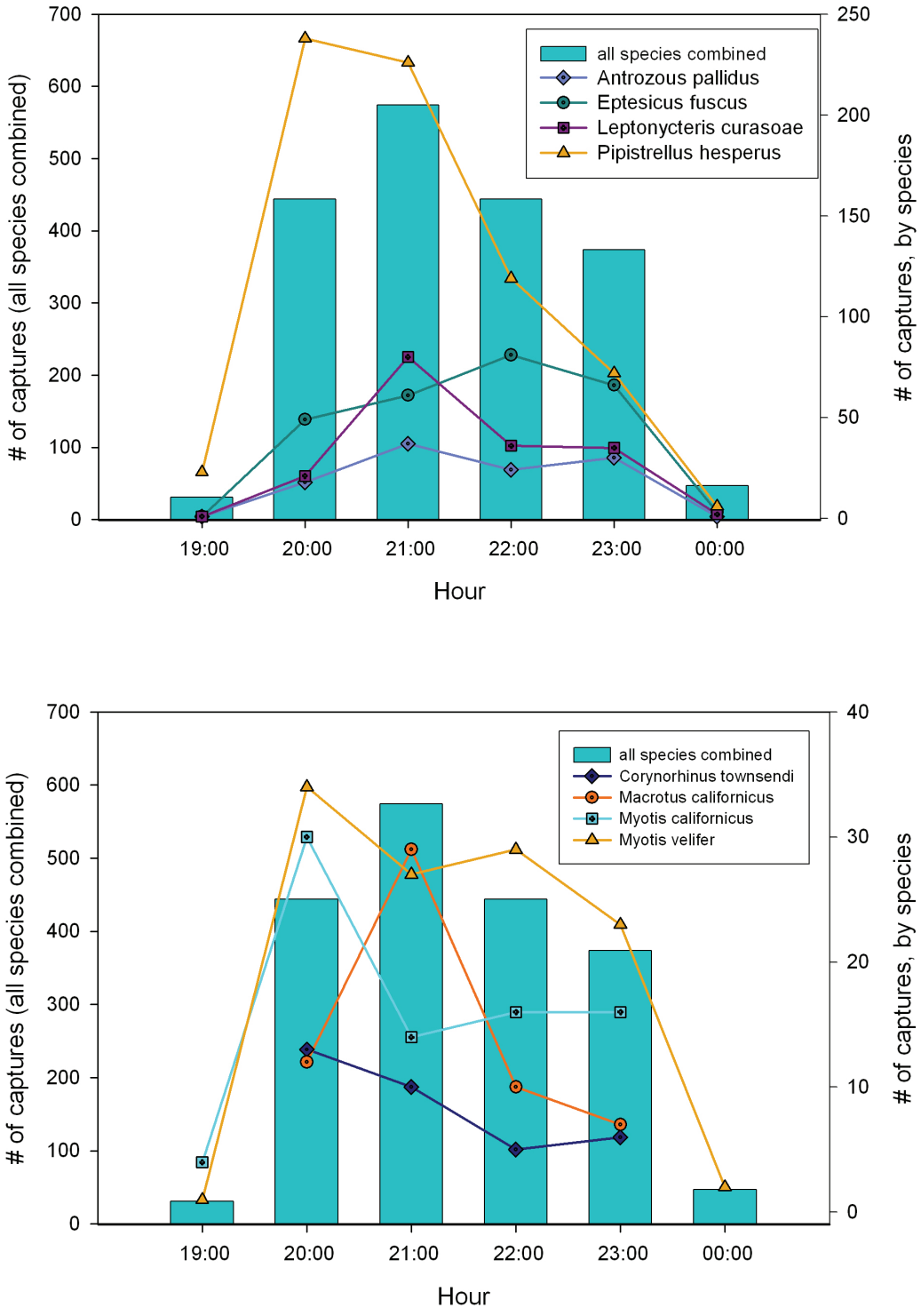

Figure 9-9. Capture time comparison, all species combined and selected species, 1994-2001 (all non-Quitobaquito Pond sites combined), Organ Pipe Cactus N.M.

Table 9-4. Sex ratios of 14 bat species for all sites, 1993-2005, Organ Pipe Cactus N.M.

SPECIES	Total	Female %	Male %
Antrozous pallidus	206	26	74
Choeronycteris mexicana	2	100	0
Corynorhinus townsendi	64	8	92
Eptesicus fuscus	372	32	68
Eumops perotis	1	100	0
Eumops underwoodi	52	50	50
Lasiurus cinereus	2	50	50
Leptonycteris curasoae	306	87	13
Macrotus californicus	109	54	46
Myotis californicus	123	62	38
Myotis velifer	153	66	34
Nyctinimops femorosaccus	420	59	41
Pipistrellus hesperus	1168	39	61
Tadarida brasiliensis	59	2	98

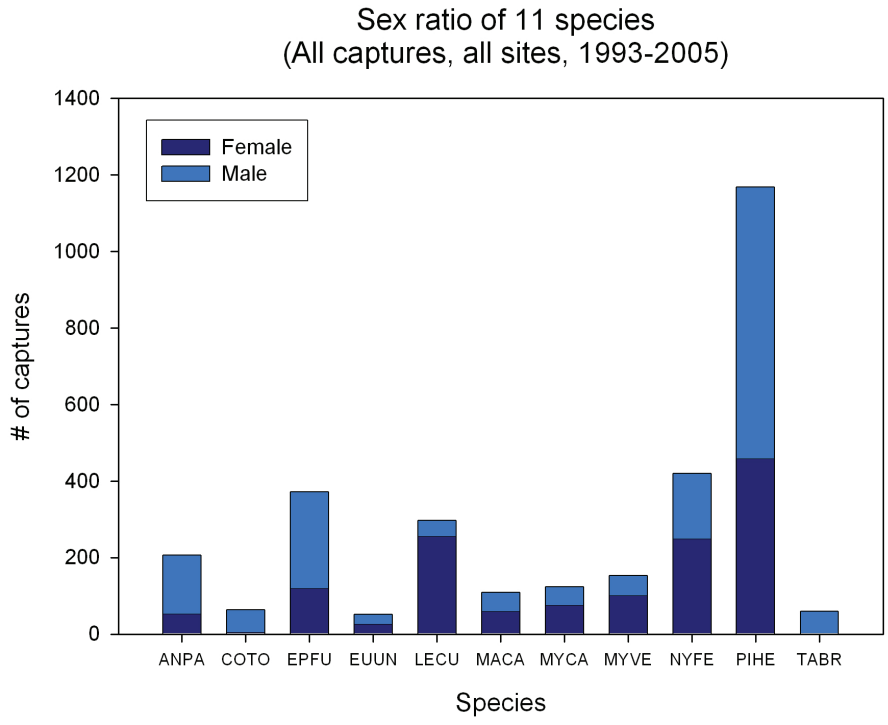

Figure 9-10. Sex ratios of 11 bat species for all sites, 1993-2005, Organ Pipe Cactus N.M.

Table 9-5. Bat mist netting results at Bull Pasture, 1993-2005, Organ Pipe Cactus N.M.

DATE	ANPA	COTO	EPFU	LECU	MACA	MYCA	MYVE	PIHE	TABR	Total
"Estes Canyon #2" Tinaja, above pour-off (Bull Pasture site #1)										
8/8/1993	2	0	1	19	0	0	12	20	0	54
6/6/1994	0	0	0	18	0	0	2	1	0	21
6/23/1995	4	0	3	4	0	2	5	21	0	39
6/18/1996	2	0	3	6	0	2	1	3	0	17
"Estes Canyon #1" Tinaja (aka "Deer Drop" Tinaja), below pour-off (Bull Pasture site #2)										
6/5/1997	3	1	1	21	0	0	0	1	0	27
6/25/1998	0	0	14	5	0	0	2	32	0	53
6/8/1999	1	1	14	5	1	0	0	2	1	25
6/9/1999	2	0	15	4	0	0	0	2	3	26
6/7/2000	3	0	12	6	0	1	0	15	0	37
6/8/2000	1	1	14	13	0	0	1	5	0	35
6/21/2001	4	1	8	6	1	4	0	37	0	61
6/22/2001	5	0	3	6	0	0	0	33	0	47
6/2/2002	1	0	9	13	0	1	0	2	0	26
5/21/2003	3	3	7	6	0	1	1	1	17	39
5/25/2004	2	0	4	11	1	0	0	2	9	29
6/4/2005	0	0	5	25	0	6	0	10	0	46
Total	33	7	113	168	3	17	24	187	30	582

Table 9-6. Sex ratios for Bull Pasture bat captures, 1993-2005, Organ Pipe Cactus N.M.

SPECIES	Total	Female %	Male %
Antrozous pallidus	32	3	97
Corynorhinus townsendi	7	0	100
Eptesicus fuscus	112	12	88
Leptonycteris curasoae	166	94	6
Macrotus californicus	2	0	100
Myotis californicus	16	75	25
Myotis velifer	23	35	65
Pipistrellus hesperus	181	44	56
Tadarida brasiliensis	29	0	100
Grand Total	568	47	53

Table 9-7. Bat mist netting results at Dripping Sprins, 1993-2004, Organ Pipe Cactus N.M.

DATE	ANPA	COTO	EPFU	LECU	MACA	MYCA	MYVE	PIHE	Total
5.5 m net, 2 poles, diagonal upslope net set across front of springs									
9/9/1993	5	0	2	0	0	0	1	4	12
6/7/1994	2	0	8	2	0	0	2	11	25
6/22/1995	2	0	2	0	1	0	2	10	17
6/11/1996	6	0	1	0	0	2	2	7	18
9/10/1996	1	0	3	2	0	0	0	1	7
5.5 m net, "V" set with 3 poles									
6/4/1997	0	2	2	0	0	1	0	7	12
6/22/1998	5	3	4	0	10	0	1	33	56
6/5/1999	2	1	19	1	1	0	5	10	39
6/6/1999	3	0	3	0	0	1	2	3	12
7/3/2000	5	3	12	2	3	2	0	26	53
6/19/2001	2	0	2	0	0	0	0	2	6
8/24/2001	3	2	1	4	2	0	0	2	14
7/1/2002	11	1	9	2	6	1	1	24	55
7/24/2003	5	0	2	1	2	0	0	8	18
Poor netting conditions, monsoon storm in 2004									
7/24/2004	1	0	3	0	2	0	0	0	6
Total	53	12	73	14	27	7	16	148	350

Table 9-8. Sex ratios for Dripping Springs bat captures, 1993-2004, Organ Pipe Cactus N.M.

SPECIES	Total	Female %	Male %
Antrozous pallidus	51	31	69
Corynorhinus townsendi	12	17	83
Eptesicus fuscus	72	65	35
Leptonycteris curasoae	14	57	43
Macrotus californicus	27	56	44
Myotis californicus	7	43	57
Myotis velifer	16	94	6
Pipistrellus hesperus	145	66	34
Total	344	59	41

Table 9-9. Bat netting results at Tinaja Estufa, 1993-2005, Organ Pipe Cactus N.M.

DATE	ANPA	EPFU	LECU	MACA	MYCA	MYVE	PIHE	Total
9/6/1993	0	4	1	1	1	1	1	9
9/7/1993	3	6	1	4	0	0	12	26
9/12/1996	2	5	0	2	0	0	1	10
5/3/2000	4	9	0	0	0	1	3	17
5/4/2000	0	11	0	2	0	0	5	18
9/22/2003	1	0	2	8	0	1	0	12
9/10/2005	9	6	3	4	0	0	28	50

Table 9-10. Bat netting results at Paisley Tinaja, North Alamo Canyon, 1993-1997, Organ Pipe Cactus N.M.

DATE	ANPA	CHME	COTO	EPFU	LECU	MACA	MYCA	MYVE	PIHE	Total
6-20-1995 = pool below Jacuzzi tinaja										
6/20/1995	0	0	0	2	1	2	0	7	3	15
6/23/1998	4	0	1	0	0	2	2	0	14	23
*5-18-99, 5-16-01, 5-19-03, 6-14-05 = fair netting conditions										
5/18/1999*	2	0	1	2	0	3	3	0	4	15
5/19/1999	1	0	0	1	2	0	4	1	2	11
5/28/2000	1	1	3	2	2	3	8	0	9	29
5/15/2001	0	0	2	0	1	2	2	0	13	20
5/16/2001*	0	0	0	0	3	2	0	0	13	18
5/19/2003*	0	0	1	0	0	1	2	0	4	8
6/17/2004	0	0	0	0	4	0	1	0	14	19
6/14/2005*	0	0	2	0	0	1	5	0	15	23
Total	8	1	10	7	13	16	27	8	91	181

Table 9-11. Sex ratios for Tinaja Estufa bat captures, 1993-2005, Organ Pipe Cactus N.M.

SPECIES	Total	Female %	Male %
Antrozous pallidus	18	39	61
Eptesicus fuscus	39	62	38
Leptonycteris curasoae	7	100	0
Macrotus californicus	21	76	24
Myotis californicus	2	100	0
Myotis velifer	3	100	0
Pipistrellus hesperus	52	46	54
Total	142	58	42

Table 9-12. Sex ratios for Paisley Tinaja, North Alamo Canyon, bat captures, 1993-1997, Organ Pipe Cactus N.M.

SPECIES	Total	Female %	Male %
Antrozous pallidus	15	47	53
Choeronyteris mexicana	1	100	0
Corynorhinus townsendi	1	0	100
Eptesicus fuscus	8	50	50
Lasiurus cinereus	1	100	0
Leptonycteris curasoae	24	71	29
Macrotus californicus	8	88	13
Myotis californicus	3	67	33
Pipistrellus hesperus	90	64	36
Total	153	65	35

Table 9-13. Bat netting results at Jacuzzi Tinaja, South Alamo Canyon, 1995-2005, Organ Pipe Cactus N.M.

DATE	ANPA	CHME	COTO	EPFU	LECU	MACA	MYCA	MYVE	PIHE	Total
6-20-1995 = pool below Jacuzzi tinaja										
6/20/1995	0	0	0	2	1	2	0	7	3	15
6/23/1998	4	0	1	0	0	2	2	0	14	23
*5-18-99, 5-16-01, 5-19-03, 6-14-05 = "fair" netting conditions										
5/18/1999*	2	0	1	2	0	3	3	0	4	15
5/19/1999	1	0	0	1	2	0	4	1	2	11
5/28/2000	1	1	3	2	2	3	8	0	9	29
5/15/2001	0	0	2	0	1	2	2	0	13	20
5/16/2001*	0	0	0	0	3	2	0	0	13	18
5/19/2003*	0	0	1	0	0	1	2	0	4	8
6/17/2004	0	0	0	0	4	0	1	0	14	19
6/14/2005*	0	0	2	0	0	1	5	0	15	23
Total	8	1	10	7	13	16	27	8	91	181

Table 9-14. Bat sex ratios for Jacuzzi Tinaja, South Alamo Canyon, 1995-2005.

SPECIES	Total	Female %	Male %
Antrozous pallidus	8	0	100
Choeronycteris mexicana	1	100	0
Corynorhinus townsendi	10	10	90
Eptesicus fuscus	7	57	43
Leptonycteris curasoae	13	92	8
Macrotus californicus	15	47	53
Myotis californicus	27	56	44
Myotis velifer	8	63	38
Pipistrellus hesperus	90	30	70
Total	179	40	60

Table 9-15. Bat netting results at Quitobaquito Pond, 1994-2001, Organ Pipe Cactus N.M.

DATE	ANPA	EPFU	EUPE	EUUN	LACI	MACA	MYCA	MYVE	NYFE	PIHE	TABR	Total
6/2/1994	0	1	0	7	0	0	0	0	21	2	0	31
6/5/1994	0	1	0	6	0	0	0	0	22	0	0	29
6/21/1995	0	1	0	4	0	0	0	0	29	3	1	38
6/6/1997	0	1	0	2	0	0	1	0	2	0	1	7
9/3/1997	4	5	0	4	1	0	1	0	85	1	0	101
6/24/1998	6	6	0	13	0	1	3	0	55	17	2	103
6/10/1999	0	2	0	4	0	0	3	2	69	1	4	85
6/28/2000	2	2	0	4	0	0	1	2	19	0	0	30
6/29/2000	3	3	0	4	0	0	0	0	20	0	0	30
7/22/2001	4	0	1	4	0	0	0	0	89	1	0	99
Total	19	22	1	52	1	1	9	4	411	25	8	553

Table 9-16. Sex ratios for Quitobaquito Pond bat captures, 1993-2001, Organ Pipe Cactus N.M.

SPECIES	Total	Female %	Male %
Antrozous pallidus	19	95	5
Eptesicus fuscus	22	64	36
Eumops perotis	1	100	0
Eumops underwoodi	52	50	50
Lasiurus cinereus	1	0	100
Macrotus californicus	1	100	0
Myotis californica	9	100	0
Myotis velifer	3	33	67
Nyctinomops femorosaccus	420	59	41

Table 9-17. Bat mist netting results at Wild Horse Tank, 1993-2005, Organ Pipe Cactus N.M.

DATE	ANPA	COTO	EPFU	LECU	MACA	MYCA	MYVE	PIHE	TABR	Total
8/9/1993	4		2	14	4	2	5	58	0	89
9/9/1993	7	1	3	0	0	0	0	20	0	31
6/4/1994	0	0	1	4	3	3	14	38	0	63
5/26/1995	1	1	13	3	0	5	8	4	0	35
6/13/1996	2	0	2	4	1	4	13	12	0	38
9/9/1996	1	0	1	0	1	0	1	2	0	6
6/3/1997	3	3	2	7	3	7	6	9	0	40
9/4/1997	2	0	3	1	0	0	0	4	1	11
10/1/1997	2	0	3	0	1	0	0	0	0	6
11/3/1997	3	1	7	0	1	0	0	5	0	17
1/28/1998	1	1	3	0	0	0	0	3	2	10
3/24/1998	2	0	3	0	0	0	0	0	12	17
5/28/1998	1	1	8	1		0	7	21	4	43
8/20/1998	4	0	12	6	1	0	2	48	2	75
5/10/1999	0	1	4	0	0	7	2	5	0	19
5/11/1999	2	0	11	1	1	1	2	5	0	23
6/5/2000	0	2	5	3	4	2	10	50	0	76
6/6/2000	1	1	5	3	1	0	5	55	0	71
5/23/2001	2	2	2	7	0	3	3	38	0	57
5/24/2001	0	0	1	2	0	2	0	9	0	14
7/21/2001	2	0	1	10	2	0	0	20	0	35
5/13/2002	1	10	0	0	0	1	2	14	0	28
5/20/2003	5	1	4	6	0	8	3	42	0	69
5/26/2004	4	0	0	0	0	1	5	14	0	24
7/7/2004	3	5	5	9	8	9	2	45	0	86
6/13/2005	3	5	6	0	0	2	2	68	0	86
Total	56	35	107	81	31	57	92	589	21	1069

Table 9-18. Sex ratios for Wild Horse Tank bat captures, 1993-2005.

SPECIES	Total	Female %	Male %
Antrozous pallidus	55	5	95
Corynorhinus townsendi	34	6	94
Eptesicus fuscus	105	11	89
Leptonycteris curasoae	79	80	20
Macrotus californicus	30	40	60
Myotis californicus	56	57	43
Myotis velifer	92	71	29
Pipistrellus hesperus	573	26	74
Tadarida brasiliensis	21	5	95

Nocturnal Rodents

Peter Holm

Objectives

The monitoring protocol handbook (Petryszyn 1995) states: "to document general trends in nocturnal rodent population size on an annual basis across a representative sample of habitat types present in the monument".

Introduction

Nocturnal rodents constitute the prey base for many snakes, owls, and carnivorous mammals. All nocturnal rodents, except for the grasshopper mouse, are primary consumers. Whereas heteromyids constitute an important guild of granivores, murids feed primarily on fruit and foliage. Rodents are also responsible for considerable excavation and mixing of soil layers (bioturbation), "predation" on plants and seeds, as well as the dispersal and caching of plant seeds.

Rodents are common in all monument habitats, are easily captured and identified, have small home ranges, have high fecundity, and respond quickly to changes in primary productivity and disturbance (Petryszyn 1995, Petryszyn and Russ 1996, Petterson 1999). Other groups of primary consumers such as invertebrates, iguanid lizards, birds, and larger mammals are either more difficult to monitor, have larger home ranges, migrate, or are less abundant. Rodents provide the most cost-effective indicator for monitoring the primary consumer component of monument ecosystems. Long-term monitoring of nocturnal rodent communities contributes to resource management goals by providing information about status and trends in the condition of monument ecosystems, early warning of abnormal conditions, reference data for comparison with more altered sites, and enhanced understanding of ecological processes.

Two families dominate the nocturnal rodent communities at OPCNM. Pocket mice (*Chaetodipus* spp. and *Perognathus* spp.) and kangaroo rats (*Dipodomys* spp.) belong to the family Heteromyidae (heteromyids), while the white-throated woodrats (*Neotoma albigula*), Arizona cotton rat (*Sigmodon arizonae*), cactus mouse (*Peromyscus eremicus*), and grasshopper mouse (*Onychomys torridus*), belong to the family Muridae. *Sigmodon arizonae*, a native riparian species relatively new to OPCNM, has been recorded at the Dos Lomitas and Salsola EMP sites, adjacent to Mexican agricultural fields. Botta's pocket gopher (*Thomomys bottae*) is the lone representative of the family Geomyidae. See Petryszyn and Russ (1996), Hoffmeister (1986), Petterson (1999), Rosen (2000), and references therein, for a thorough review.

As part of the Sensitive Ecosystems Project, Petryszyn and Russ (1996) conducted a baseline study originally titled, *Special Status Mammals of Organ Pipe Cactus National Monument*. They surveyed for nocturnal rodents and other mammals in various habitats throughout the monument and found that murids dominated rocky slopes, while heteromyids dominated bajadas and valley bottoms. They also confirmed the Arizona cotton rat (*Sigmodon arizonae*), on the monument for the first time in December 1988, and recorded Merriam's mouse (*Peromyscus merriami*) monument for the first time since 1894. Current monitoring efforts are guided by the protocol developed for small nocturnal mammals by Petryszyn (1995).

This report provides the following summaries and data reductions:

- Classification of rodent grids by habitat.
- Number of nights of monitoring at each site for each year, 1991-2005.
- List of species and common names for each family.
- Mean annual relative abundance of each

species at each grid.
- Mean adult body mass for each species.
- Relative abundance of nocturnal rodents monument-wide, 1991-2005.
- Trend analysis for each species 1991-2005.
- Appendix B tables (30), one for each grid, 1997-2005:
    - Relative abundance of murids at each grid in each year.
    - Total biomass of murids at each grid in each year.
    - Relative abundance of heteromyids at each grid in each year.
    - Total biomass of heteromyids at each grid in each year.
    - Species richness at each grid in each year.
    - Diversity (H') at each grid in each year.
    - Capture success, night 1.
    - Capture success, night 2.
    - Recaptures.
- Appendix B graphs (30), one for each grid, 1991-2005:
    - Relative abundance of each species at each grid in each year.

Methods

Study Sites

Rodents are monitored annually, in summer, on two consecutive nights. There are 30 grids at 16 EMP sites (Figure 10-1); two sites, Bull Pasture and Dripping Springs have 1 grid, the others have 2 grids (Table 10-1). At most study sites, the 2 grids were located in different micro-habitat types (i.e., Armenta Ranch, Alamo, Dos Lomitas, Growler, Middle Bajada, Pozo Nuevo, Salsola, Senita Basin, Quitobaquito, and Valley Floor), whereas at other locales the 2 grids were placed in homologous micro-habitats and could be considered replicates (Aguajita, East Armenta, Lower Colorado Larrea, and Vulture).

Trapping and Processing Techniques

Grid corners are permanently marked with rebar stakes. Each grid consists of 49 traps arranged in a 7X7 array. Folding Sherman traps, measuring 3x3.5x9in(7.6 x 8.9 x 22.9cm), are used at some rocky sites (Bull Pasture, Alamo), while longer 12in (30.5cm) traps are used in valley and bajada sites where larger species of kangaroo rats may be captured. The traps are placed at 15m intervals, resulting in a 90 x 90m grid. Trap stations on each grid are given permanent alphanumeric designations of A1 - G7 (A1 = southwest grid corner; G7 = northeast grid corner). This designation was useful in tracking species microhabitat selection and species distribution over time. Adding a 15m buffer, which corresponds to the average rodent home range radius, results in an effective sampling area of 1.4ha (3.5a).

Traps were baited with a mixture of rolled oats and sterile bird seed, and opened at dusk for 2 consecutive nights at each site, thereby yielding 98 trap-nights of effort for each grid. Information recorded at time of capture included trap station, species, body mass (g), sex, age, and reproductive condition. From 1991-1996, each new capture (except on the last morning) was marked on the ventral surface with a black permanent ink felt-tip pen. Beginning in 1997, each new capture was marked with a unique combination of color marks to permit individual identification within year. Processing of captures began near dawn on the morning following baiting and finished before the sun had risen high enough to heat the traps appreciably.

In 1997-1999, 7-10 sites were trapped for 4 nights instead of 2 (Table 10-2). In this report, analyses will be limited to results from the first 2 nights of trapping. In 1998, ALAM1, EARM1, LOWE1, and MIDB1 grids were sampled with a 12x12 array with traps spaced at 10 m intervals. The same arrangement was repeated in 1999 except at the ALAM1 grid. The results of trapping with the 12x12 arrangement will be presented in a later report.

Data Analysis

For each grid, an annual abundance index (total

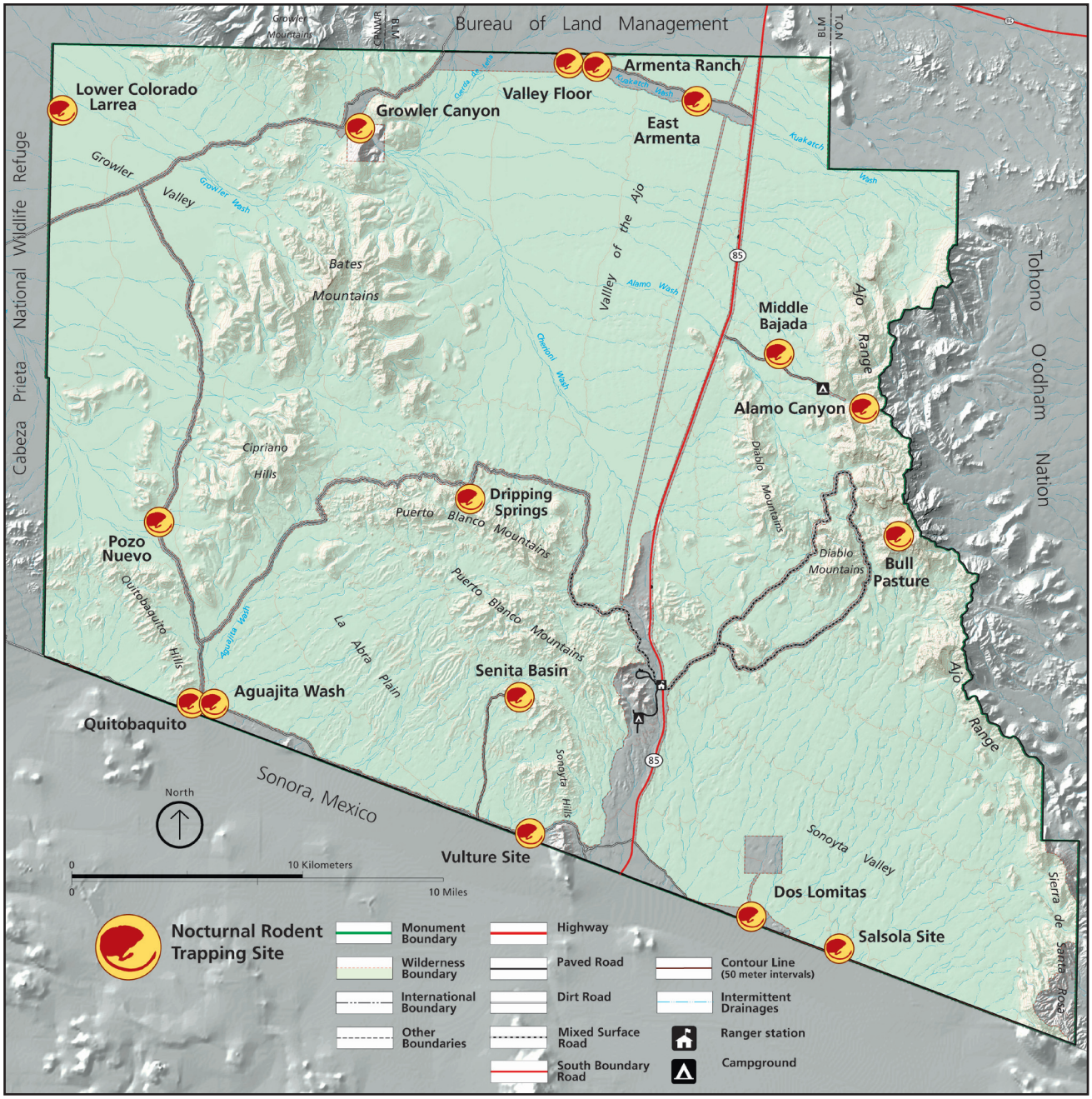

Figure 10-1. Nocturnal rodent trapping sites, Organ Pipe Cactus N.M.

Table 10-1. Classification of rodent grids according to hydrologic regime and soil texture at Organ Pipe Cactus N.M.

Site	Grid	Code	Hydrologic regime	Soil texture
Aguajita Wash	1	AGUA1	xeroriparian	valley floor
Aguajita Wash	2	AGUA2	mixed	valley floor
Alamo Canyon	1	ALAM1	upland	rocky slope
Alamo Canyon	2	ALAM2	xeroriparian	rocky slope
Armenta Ranch	1	ARMR1	mixed	valley floor
Armenta Ranch	2	ARMR2	upland	valley floor
Bull Pasture	1	BULL1	upland	rocky slope
Burn Site	1	BURN1	mixed	valley floor
Burn Site	2	BURN2	upland	valley floor
Dos Lomitas	1	DOLO1	mixed	valley floor
Dos Lomitas	2	DOLO2	mixed	valley floor
Dripping Springs	1	DRIP1	upland	rocky slope
East Armenta	1	EARM1	mixed	valley floor
East Armenta	2	EARM2	mixed	valley floor
Growler Canyon	1	GROW1	xeroriparian	valley floor
Growler Canyon	2	GROW2	xeroriparian	valley floor
Lost Cabin	1	LOST1	mixed	rocky slope
Lost Cabin	2	LOST2	mixed	rocky slope
Lower Colorado Larrea	1	LOWE1	upland	valley floor
Lower Colorado Larrea	2	LOWE2	upland	valley floor
Middle Bajada	1	MIDB1	mixed	bajada
Middle Bajada	2	MIDB2	upland	bajada
Pozo Nuevo	1	POZO1	upland	valley floor
Pozo Nuevo	2	POZO2	upland	valley floor
Quitobaquito	1	QBQT1	mixed	rocky slope
Quitobaquito	2	QBQT2	xeroriparian	bajada
Salsola Site	1	SALS1	mixed	valley floor
Salsola Site	2	SALS2	xeroriparian	valley floor
Senita Basin	1	SENI1	mixed	rocky slope
Senita Basin	2	SENI2	upland	rocky slope
Valley Floor	1	VALL1	upland	valley floor
Valley Floor	2	VALL2	mixed	valley floor
Vulture Site	1	VULT1	mixed	bajada
Vulture Site	2	VULT2	mixed	bajada

Table 10-2. Number of nights of rodent monitoring on each grid for each year at Organ Pipe Cactus N.M. Each site has two grids except for BULL and DRIP which each have one.

Site	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
AGUA	2	2	2	2	2	2	**4**	**4**	**4**	2	2	2	2	2	2
ALAM	2	2	2	2	2	2	**4**	**4**	**4**	2	2	2	2	2	2
ARMR			2	2	2	2				2	2	2		2	2
BULL					2	2	2	2	2	2	2	2	2	2	2
BURN					2	2									
DOLO	2	2	2	2	2	2	**4**	**4**	**4**	2	2	2	2	2	2
DRIP					2	2	2			2	2	2	2	2	2
EARM	2	2	2	2	2	2	**4**	**4**	**4**	2	2	2	2	2	2
GROW	2	2	2	2	2	2	**4**	2	2	2	2	2	2	2	2
LOST				2	2	2									
LOWE			2	2	2	2	**4**	**4**	**4**	2	2		2	2	2
MIDB					2	2	**4**	**4**	**4**	2	2	2	2	2	2
POZO	2	2	2	2	2	2	**4**	2	2	2	2	2	2	2	2
QBQT			2	2	2	2	2	2	2	2	2	2	2	2	2
SALS			2	2	2	2	2	**4**	**4**	2	2	2	2	2	2
SENI	2	2	2	2	2	2	**4**	2	2	2	2	2	2	2	2
VALL					2	2	**4**	2	2	2	2	2	2	2	2
VULT					2	2	2	2	2	2	2	2	2	2	2

captures) was calculated for each species by counting each individual once and ignoring recaptures. The results are graphed in Appendix 2. Total captures, capture success and recapture rates, and biomass data were summed for each of the two taxonomic groups of rodents, heteromyids and murids; species richness (number of species) and diversity were also calculated and tabulated in Appendix 2. Diversity was calculated using the Shannon function:

$$H' = - \Sigma (p_i \times \ln(p_i))$$

where p_i is the proportion of the i^{th} species.
To use all sites and compare relative abundance, species richness, and diversity among years, each grid was standardized to zero mean and unit standard deviation. Then all grids were averaged for each season and a standard error computed.
To provide some insight into possible impacts of adjacent land-use, the sites were divided into interior and border groups: mean and standard error were then computed for each group. Border EMP sites include, from west to east, Quitobaquito, Aguajita Wash, Vulture Site, Burn Site, Dos Lomitas, and Salsola Site; all other sites are interior (Figure 10-1).
Monument-wide trend analyses were performed on each species as follows. Trends were modeled independently for each species by using a generalized linear mixed model (PROC GLIMMIX; SAS) with a year covariate to estimate trend, and a random quadrat effect and a random year effect. The random year effect captures annual variation that cannot be explained by linear trend alone. The model was specified to have a log link function based on a Poisson distribution with overdispersion. All of the 1991-2005 data were used, except for grids employing the 12x12 arrangement.
Based on a visual scan of the graphs in Appendix 2, single grids were selected for linear regression analyses if individual species or families appeared to show trends. This was only done for Alamo Canyon to provide an example.

Results

In the period 1991-2005, there have been 48 trap mortalities out of 21,647 captures or 0.22%. Overall, mean abundance for each species is

Table 10-3. Rodent species recorded on monitoring plots at Organ Pipe Cactus N.M.

Family	Species	Common name	Code
Heteromyidae	*Chaetodipus baileyi*	Bailey's pocket mouse	CHBA
Heteromyidae	*Chaetodipus intermedius*	rock pocket mouse	CHIN
Heteromyidae	*Chaetodipus penicillatus*	desert pocket mouse	CHPE
Heteromyidae	*Perognathus amplus*	Arizona pocket mouse	PEAM
Heteromyidae	*Perognathus longimembris*	little pocket mouse	PELO
Heteromyidae	*Dipodomys merriami*	Merriam's kangaroo rat	DIME
Heteromyidae	*Dipodomys spectabilis*	banner-tail kangaroo rat	DISP
Muridae	*Neotoma albigula*	white-throated woodrat	NEAL
Muridae	*Onychomys torridus*	grasshopper mouse	ONTO
Muridae	*Peromyscus eremicus*	cactus mouse	PEER
Muridae	*Peromyscus merriami*	mesquite mouse	PEME
Muridae	*Sigmodon arizonae*	Arizona cotton rat	SIAR

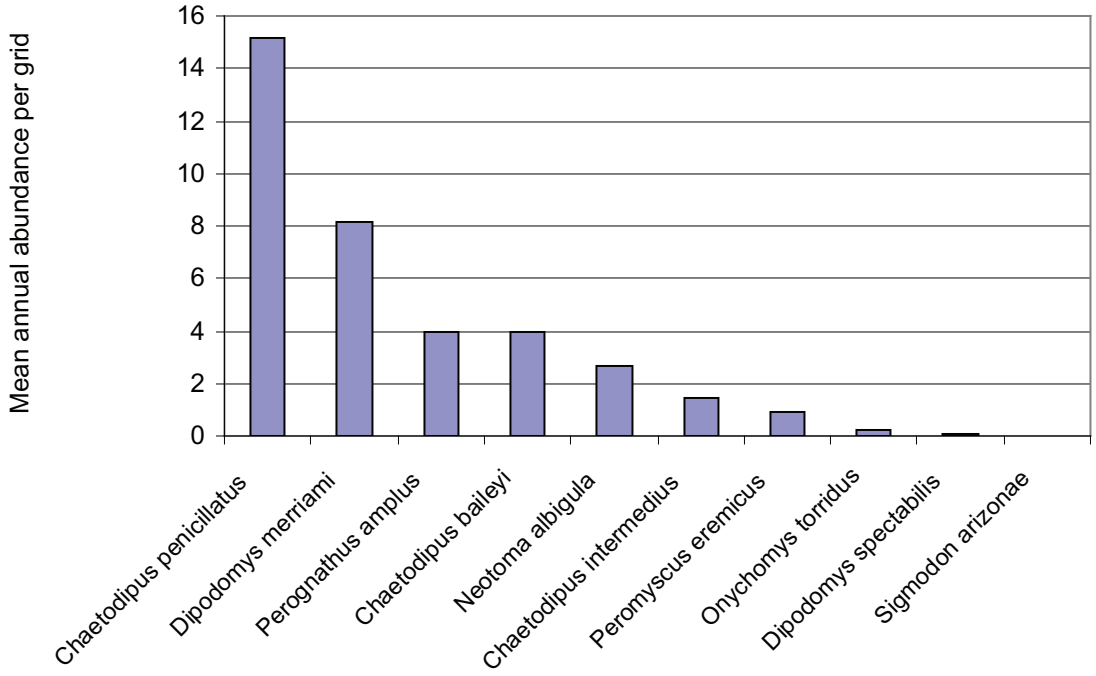

Figure 10-2. Mean abundance, averaged by year and grid, for each nocturnal rodent species on monitoring grids at Organ Pipe Cactus N.M.

Table 10-4. Mean annual abundance of rodent species at each grid at Organ Pipe Cactus N.M. Abundance is total registered over two nights of trapping. See text for definition of site and species codes.

Site code	CHBA	CHIN	CHPE	PEAM	DIME	DISP	NEAL	ONTO	PEER	SIAR	All spp.
AGUA1	0.5	0.1	29.8	3.3	4.5	0.0	2.8	0.5	0.5	0.0	42.0
AGUA2	0.1	0.0	19.4	6.1	9.3	0.0	1.8	0.8	0.0	0.0	37.5
ALAM1	5.4	10.2	7.9	0.0	0.0	0.0	10.1	0.0	5.4	0.0	38.9
ALAM2	11.5	2.1	6.0	0.0	0.0	0.0	7.7	0.0	5.0	0.0	32.4
ARMR1	2.1	0.0	13.5	2.5	11.5	0.1	0.1	0.0	0.0	0.0	29.9
ARMR2	1.4	0.0	12.5	3.6	17.5	0.0	0.1	0.0	0.6	0.0	35.8
BULL1	10.0	3.6	1.5	0.0	0.0	0.0	8.6	0.0	4.4	0.0	28.1
DOLO1	0.2	0.0	15.4	1.3	18.2	0.0	0.4	1.3	0.2	0.6	37.6
DOLO2	0.2	0.1	24.2	1.5	14.0	0.0	0.8	0.3	0.1	0.0	41.2
DRIP1	20.3	6.8	6.8	0.0	0.0	0.0	7.8	0.0	1.8	0.0	43.3
EARM1	0.1	0.0	21.9	9.2	11.9	0.4	3.9	0.0	0.1	0.0	47.5
EARM2	0.1	0.0	13.1	12.1	13.4	0.1	3.6	0.1	0.0	0.0	42.5
GROW1	0.3	0.0	40.5	0.5	10.9	0.0	0.6	0.1	0.0	0.0	52.8
GROW2	1.6	0.0	39.7	0.9	7.4	0.0	1.0	0.1	0.1	0.4	51.2
LOWE1	0.2	0.0	3.7	8.4	17.5	0.0	0.1	0.1	0.0	0.0	30.0
LOWE2	0.1	0.0	2.0	11.5	18.0	0.3	0.0	0.3	0.0	0.0	32.2
MIDB1	18.6	3.8	5.2	2.9	0.3	0.0	1.5	0.0	0.5	0.0	32.8
MIDB2	21.1	0.0	1.0	6.0	4.3	0.0	1.1	0.1	0.0	0.0	33.6
POZO1	0.4	0.7	3.7	5.9	12.5	0.0	0.0	0.1	0.2	0.0	23.5
POZO2	0.2	0.0	6.9	8.6	16.4	0.0	0.1	0.0	0.1	0.0	32.4
QBQT1	1.0	11.4	13.1	0.1	0.1	0.0	12.8	0.0	6.3	0.0	44.8
QBQT2	0.4	0.0	17.5	0.4	4.3	0.0	7.8	0.7	2.8	0.0	33.9
SALS1	0.1	0.0	27.3	2.7	12.5	0.3	0.0	0.7	0.0	0.0	43.5
SALS2	0.6	0.0	42.2	0.6	7.4	0.0	1.1	0.6	0.0	0.1	52.5
SENI1	10.9	1.3	4.7	3.5	3.1	0.0	1.0	0.0	0.0	0.0	24.6
SENI2	9.0	3.8	8.4	1.6	2.3	0.0	1.1	0.0	0.2	0.0	26.4
VALL1	0.1	0.0	3.0	10.8	11.1	0.0	0.0	0.0	0.0	0.0	25.0
VALL2	1.0	0.0	23.2	4.8	7.0	0.0	1.0	0.2	0.0	0.0	37.2
VULT1	0.4	0.0	17.1	6.1	3.5	0.0	1.8	0.0	0.0	0.0	28.9
VULT2	0.7	0.1	23.3	4.1	4.5	0.0	2.2	0.2	0.0	0.0	35.1
Mean	3.95	1.46	15.15	3.96	8.12	0.04	2.69	0.21	0.94	0.03	36.56

Table 10-5. Summary statistics for adult body mass (log transformed) of each nocturnal rodent species on monitoring grids at Organ Pipe Cactus N.M.

	Murids				Heteromyids					
	NEAL	SIAR	ONTO	PEER	DISP	DIME	CHBA	CHPE	CHIN	PEAM
Mean	2.124	1.827	1.338	1.250	1.961	1.562	1.413	1.207	1.111	1.051
Standard Error	0.004	0.046	0.009	0.005	0.023	0.001	0.003	0.001	0.003	0.002
Median	2.146	1.760	1.342	1.255	1.996	1.568	1.415	1.210	1.114	1.041
Mode	2.204	1.716	1.301	1.279	2.004	1.591	1.447	1.230	1.114	1.041
Standard Deviation	0.116	0.195	0.088	0.086	0.110	0.067	0.092	0.093	0.071	0.073
Sample Variance	0.014	0.038	0.008	0.007	0.012	0.005	0.008	0.009	0.005	0.005
Kurtosis	9.916	-1.338	0.722	-0.078	2.979	1.118	0.119	0.081	5.415	0.833
Skewness	-1.708	0.139	-0.448	-0.020	-1.617	-0.725	-0.148	-0.262	1.516	0.037
Range	1.410	0.588	0.450	0.497	0.474	0.533	0.611	0.876	0.599	0.665
Minimum	1.041	1.539	1.079	1.021	1.626	1.238	1.079	0.778	0.903	0.748
Maximum	2.452	2.127	1.529	1.519	2.100	1.771	1.690	1.654	1.502	1.413
Sum	2100.5	32.9	119.1	447.4	47.1	4890.4	1885.3	6741.4	633.5	1654.8
Count	989	18	89	358	24	3131	1334	5587	570	1574

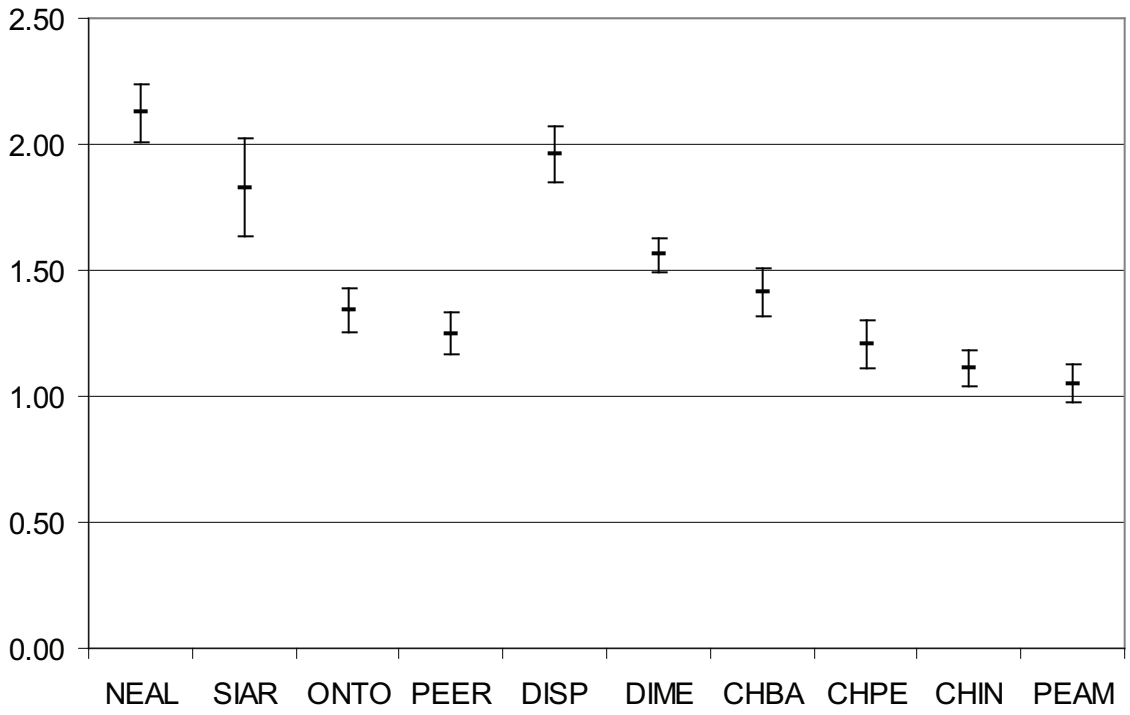

Figure 10-3. Mean and standard deviation of adult body mass (log transformed) for each nocturnal rodent species on monitoring grids at Organ Pipe Cactus N.M.

presented in Figure 10-2. Mean annual abundance for each species at each grid is presented in Table 10-4. *Chaetodipus penicillatus* is the most abundant species with a mean annual abundance ranging from 1.0 captures at MIDB1 to 42.2 captures at SALS2. For all species combined, mean annual abundance among sites ranged from 24.6 at SENI1 to 52.8 at GROW1.

Among years 1997-2004 (Appendix B), the total number of rodents registered in 2 nights of trapping ranged from 2 at VULT2 in 2002 to 76 at EARM2 in 1999. Species richness ranged from 1 species at VULT2 in 2002 to 6 at various sites over the years. Diversity (H') ranged from 0 at VULT2 in 2002 to 1.564 at MIDB1 in 2003.

Eight species, *Chaetodipus baileyi*, *C. intermedius*, *C. penicillatus*, *Perognathus amplus*, *Dipodomys merriami*, *Neotoma albigula*, *Onychomys torridus*, *Peromyscus eremicus*, were captured at one or more sites every year; two species, *Dipodomys spectabilis* and *Sigmodon arizonae* were often not captured at any site in a given year.

Total rodent biomass ranged from 48g at VALL1 in 1998 to 3135g at Dripping Springs in 2004. Overall, the smallest and largest species are *Perognathus amplus* and *Dipodomys spectabilis* among heteromyids, and *Peromyscus eremicus* and *Neotoma albigula* among murids (Table 10-5 and Figure 10-3).

Periods of high rodent abundance occurred in 1992-1993, 1999, and 2004 (Figure 10-4). These correspond with the last 3 El Niño events. Despite wide short-term variation in rodent abundance, the 15-year record suggests systematic decline either monument-wide or for the border sites, specifically. The same is true for diversity and species richness (Figures 10-5 and 10-6).

Trend analysis detected significant changes in 2 pocket mouse species, *Chaetodipus baileyi* and *Perognathus amplus* (Table 10-6). Other trends are detectable by linear regression at specific sites. For example, at Alamo Canyon, murids exhibit a significant decline (R^2=0.71, N=14, P=0.0001), while heteromyids increase (R^2=0.28, N=14, P=0.0501).

Discussion

Petryszyn and Russ (1996) classified sites as mountain canyon, small hills, or bajada/valley floor. A better classification to distinguish rodent communities may be to combine rocky sites (mountain canyons, small hills, and bajadas) into one class and divide valley sites into xeroriparian (dominated by washes or floodplains) and upland (i.e., not xeroriparian) classes. In practice, this

Table 10-6. Estimated percent annual change in rodent species at Organ Pipe Cactus N.M., based trend model.

Species	Percent Change	Standard Error	95% Confidence Interval	Significance
Chaetodipus baileyi	10.8	3.8	(3.7 to 18.5)	0.003
Chaetodipus intermedius	9.9	6.2	(-1.6 to 22.7)	0.095
Chaetodipus penicillatus	-1.4	1.8	(-4.9 to 2.2)	0.443
Dipodomys merriami	-0.8	2.4	(-5.3 to 4.0)	0.743
Dipodomys spectabilis	6.5	12.7	(-15.7 to 34.7)	0.597
Neotoma albigula	-2.4	2.8	(-7.8 to 3.3)	0.399
Onychomys torridus	3.4	4.5	(-5.2 to 12.7)	0.450
Perognathus amplus	4.8	1.5	(1.9 to 7.8)	0.001
Peromyscus eremicus	-4.6	3.6	(-11.5 to 2.8)	0.212
Sigmodon arizonae	-25.1	17.7	(-52.9 to 19.1)	0.221

is difficult because many of the grids include a mix of xeroriparian and upland habitat (Table 10-1). Nevertheless, it is apparent that *Chaetodipus baileyi*, *C. intermedius*, *Neotoma albigula*, and *Peromyscus eremicus* prefer rocky sites, *Chaetodipus* penicillatus prefers xeroriparian flats, and *Dipodomys merriami* and *Perognathus amplus* prefer upland flats (Tables 10-1 and 10-4; see also Cockrum and Petryszyn 1986, Petryszyn and Russ 1996). Grids that are mixed (e.g., VALL2) typically have rodent communities that are intermediate between xeroriparian and upland (e.g., compare to GROW1&2 and LOWE1&2).

The low mean abundance of *Neotoma albigula* at Senita Basin compared to other rocky slope sites is perplexing. A closer examination of this site might reveal a scarcity of one or more limiting resources for this species or a high abundance of predators, competitors, or disturbance. The low abundance of another rocky slope species, *Chaetodipus baileyi,* at Quitobaquito poses similar questions.

In Alamo Canyon, there appears to have been a general decline in murids, *Neotoma albigula* and *Peromyscus eremicus*, and increase in heteromyids, *Chaetodipus baileyi*, *C. intermedius*, and *C. penicillatus* (see Appendix B). It was 2 heteromyid species, *C. baileyi* and *Perognathus amplus*, that exhibited a significant increase, based on monument-wide trend analysis. It would be interesting to see if these changes are short-term (several years) or more lasting.

Several long-term studies of rodents have linked population dynamics to climate, biotic interactions, and disturbance. A 13-year study of rodents with extensive field manipulations in the semiarid thornscrub of northern Chile found a pattern of rainfall-induced vegetation and rodent productivity, followed by increased herbivory and predation (Meserve et al. 2003). Long-term studies of rodents in the Chihuahuan Desert near Portal, Arizona, revealed that many, but not all, El Niño events lead to increases in rodent populations (Valone and Brown 1996, Ernest et al. 2000, Brown and Ernest 2002).

Predators would first exhibit a functional response to higher rodent abundance with a behavioral increase in the rate of predation. The higher intake of prey would lead to an increase in reproductive output among predators, which would further increase predation pressure on rodents. These responses, with their species-specific time lags, may account for the steep decline in rodents at OPCNM from 1992 to 1995 despite high annual rainfall from 1992 to 1994.

There is certainly much more analysis that can be done with the data than has been presented here. Rodent communities differ from each other based on soils, vegetation, and other habitat characteristics. The monument has excellent maps in its GIS data base. Future analyses could partition the data according to habitat categories of interest.

The protocol clearly is able to document general trends in rodents at OPCNM. Perhaps, the data reduction with the greatest management value is that presented in figures 10-4 to 10-6. These figures provide a look at three indicators (relative abundance, diversity, and species richness) of nocturnal rodent communities at OPCNM. All three indicators show some fluctuation but no sustained decline. Therefore, the protocol contributes valuable information about progress toward meeting the goal of preserving a representative portion of the Sonoran Desert ecosystem.

Recommendations

Inventory

There is much variation in geology and vegetation at OPCNM and it would be impossible to monitor rodents in every type of habitat. However, some areas, not presently monitored, may be of interest. Some high elevation areas (more than 1200m) in the Ajo Range have temperate vegetation with oak and juniper in canyons that resembles Madrean woodland or shrub and grass-dominated communities on more gentle

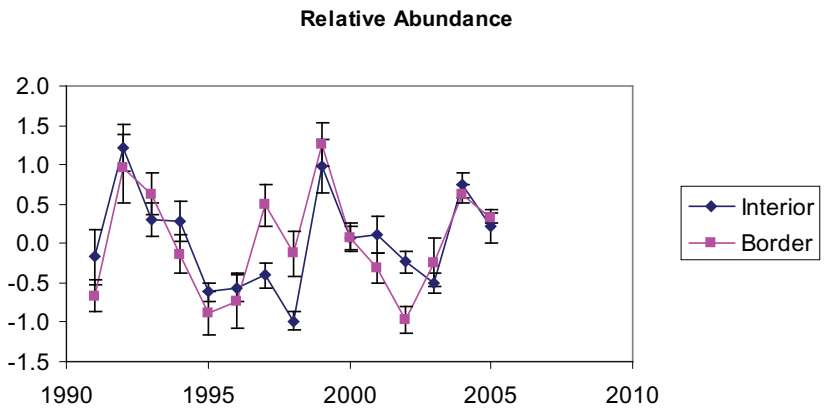

Figure 10-4. Relative abundance of all rodents, standardized for each grid at Organ Pipe Cactus N.M., 1991-2005. Mean and standard error derived from interior and border grids pooled separately for a given season.

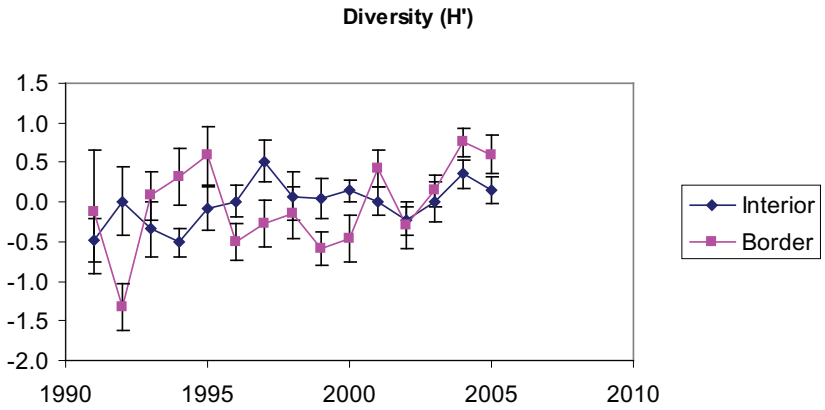

Figure 10-5. Diversity of rodents, standardized for each grid at Organ Pipe Cactus N.M., 1991-2005. Mean and standard error derived from interior and border grids pooled separately for a given season.

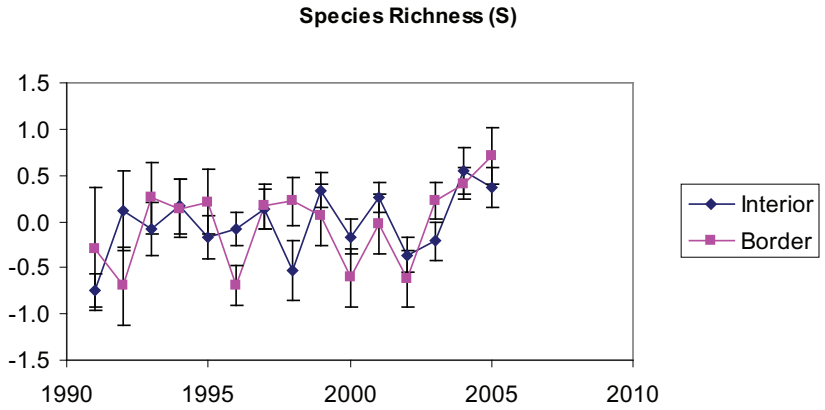

Figure 10-6. Species richness of rodents, standardized for each grid at Organ Pipe Cactus National Monument, 1991-2005. Mean and standard error derived from interior and border grids pooled separately for a given season.

slopes. Some of these areas should be sampled to determine if any species have been overlooked in the monument. Botta's pocket gopher (*Thomomys bottae*) may be common in some of the level basins of the Ajo Range where soil has accumulated. High elevation species may be particularly vulnerable to climate change.

Organ Pipe Cactus N.M. is one of few protected areas and the only NPS unit with intact saltbush (*Atriplex spp.*) communities. Baseline information about these communities, including the rodents, will be valuable for any future restoration effort.

Except for a single lizard transect, no other EMP monitoring has been accomplished on the dark basaltic hills in the western portion of OPCNM. The desert woodrat (*Neotoma lepida*) has been recorded from the Bates Mountains (Hoffmeister 1986) and may be present elsewhere.

Our knowledge of rodent communities in some habitats could be enhanced, if staffing resources are available, by conducting one-time inventories using the standard rodent sampling protocols in the following habitats:

- Temperate communities in the Ajo Range
- Pure saltbush community in the Rio Sonoyta floodplain
- Basalt hills in the western monument

Large Kangaroo Rats

No *Dipodomys deserti* (desert kangaroo rat) have been recorded at EMP sites 1991-2005. This species was not reported either by Warren and Anderson (1987) or Petryszyn and Russ (1996), despite extensive trapping efforts. Museum specimens exist from Quitobaquito, 1 mile east of Quitobaquito, the junction of Puerto Blanco Drive and Pozo Nuevo roads, Bates Well, and the north boundary of OPCNM (Cockrum and Petryszyn 1986, Hoffmeister 1986). The other large kangaroo rat, *D. spectabilis,* is probably more widespread at OPCNM but rarely recorded during monitoring; it has been recorded on 5 grids.

We may be underestimating the relative abundance and distribution of large kangaroo rats, mainly *D. spectabilis*. This species is rarely recorded in part because its burrows are more widely spaced. To adequately sample large kangaroo rats, we should consider counting their distinctive mounds in a larger plot (e.g., 1 hectare) that includes the regular grid. Sampling large kangaroo rats is recommended because the large species, with their characteristic large burrows, may be more vulnerable to impacts from heavy sources such as off-road vehicles and livestock.

Experimental Restoration

Rodents and lagomorphs (cottontails and jackrabbits) no doubt have a significant impact on the successful establishment of plants. They have been largely responsible for the 100% mortality of young trees and shrubs that appeared in great abundance following major rainfall events in 2003-2005 near Ajo, Arizona (Holm, personal observation). Curtin et al. (2000) conducted experimental removal of rodents in the northern Chihuahuan Desert and determined that rodents inhibit the expansion of vegetation patches. Holmgren and Scheffer (2001) suggested that high rainfall events associated with El Niño episodes provide a unique opportunity to greatly enhance seedling establishment if herbivores are controlled.

In heavily-impacted and barren areas, such as near Armenta Ranch and Dos Lomitas, experimental exclosures could be erected to exclude rodents and lagomorphs and allow the establishment of perennial vegetation. This would facilitate further restoration of the vegetation community and reduce erosion potential. Monitoring climate, vegetation, and small mammals would be key to successful planning, implementation, and determining the effectiveness of such a project.

Woodrats

The white-throated woodrat, also known as packrat (*Neotoma albigula*), ranges throughout the deserts and woodlands of southwestern North America. It is a common inhabitant of rocky areas

and areas where cholla and prickly pear cactus are abundant. Woodrats nest in crevices and under boulders and, in less rocky areas, build an above-ground house (midden) consisting of a pile of sticks and cactus joints at the base of a cactus or shrub. The woodrat diet consists mainly of cactus, but foliage, bark, and seeds (especially mesquite) may also be consumed.

Although woodrats are a natural component of Sonoran Desert ecosystems, they occasionally get noticed for the damage they do to property. Woodrats may chew on electrical wires, construct their nests in inconvenient places, or steal small items to place in their nests. Visitor comments from the 2005-2006 season included complaints about woodrats at the main campground.

A special grid was sampled in 2006 to investigate the campground rodent population. The methods and results will be reported separately. However, preliminary results indicated that woodrat density was the third highest ever recorded in the monument in 437 sampling occasions. Long-terms trends in rodent abundance (Figure 10-4) indicate a recent spike in rodent numbers.

A quick look at the campground revealed an abnormally high density of prickly pear cactus. An obvious recommendation for management would be to remove some of the prickly pear cactus. It would also be advisable to remove some of the cholla cactus joints and dry sticks lying on the surface. These actions would reduce the microhabitat sites and materials used for nesting and restore the campground area to a more typical configuration for woodrat habitat on a bajada landscape.

Some interpretive materials here should be helpful in educating visitors about what is going on and satisfying some of their concerns. We can inform visitors about woodrat ecology and population dynamics at OPCNM and we can remind them not to leave containers open and small valuables lying around.

Acknowledgements

Field work was conducted primarily by Charles Conner and Ami Pate; the trend analysis was conducted by Julie Yee of the Western Ecological Research Center of the U. S. Geological Survey office in Sacramento.

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Climate

Peter Holm and Charles Conner

Objectives

The protocol manual indicates that climate monitoring was to serve as "the primary integrative components of the Ecological Monitoring Program" (OPCNM 1995). Initial site selection for weather stations was based on the following criteria (Bennett and Kunzmann 1987):

1. identification of sensitive species habitat where a better understanding of climate related habitat factors is needed for protection of a species;
2. identification of habitat areas associated with long-term monitoring projects to establish climate parameters that may affect changes in naturally occurring populations;
3. identification of specific habitats (major vegetation types) where future research can utilize data collected as baseline and germane to the research project;
4. identification of major airsheds.

Introduction

Climate, particularly the spatial and temporal distribution of moisture and temperature, is a major forcing factor in determining the composition and dynamics of ecosystems (i.e., ecosystem driver). The distribution, productivity, and activity of plants and animals respond to climate variation through the genetically determined tolerances of each species. Detailed information about climate will help us to detect short and long-term changes in climate, identify climate-related variation in multiple biological and physical indicators, and better understand ecological processes including the local consequences of global climate change.

Climate of Southern Arizona

Like much of the Southwest, OPCNM has a bimodal annual rainfall distribution with winter precipitation peaking in December to March and summer precipitation peaking in August. Pronounced seasonal droughts occur in the spring and fall, although the latter may be ameliorated by occasional tropical storms.

During the winter, winds over Arizona are generally out of the west to northwest. Winter precipitation depends on the path, moisture content, and duration of low pressure systems that may be associated with westerly cold fronts or cut off from major steering winds. Winter storms may be enhanced by an influx of tropical moisture such as from the Pacific Ocean subtropical jet stream.

During the summer, winds shift to a more south to southeast source. Summer precipitation, or the Mexican Monsoon, is largely dependent on high pressure systems over the Four-corners area and to the east (including the Bermuda high) to steer upper level moisture from the Gulf of Mexico to Arizona. Low level moisture, from the eastern Pacific and Gulf of California, is drawn into Arizona by low pressure.

Arizona climate, particularly winter precipitation, is associated with the El Niño Southern Oscillation, Pacific Decadal Oscillation, and Madden-Julian Oscillation, and ultimately linked to other global patterns.

Methods

Program History

The histories and configurations of weather stations and rain gauges are summarized in Tables 11-1 and 11-2. Work began in 1987 on the installation of 9 automated weather stations at sites in the monument designated as ecological monitoring sites. These stations, which used Omnidata "Datapod" recorders, were all operational by early 1988. Eight Forester rain gauges are also located throughout the

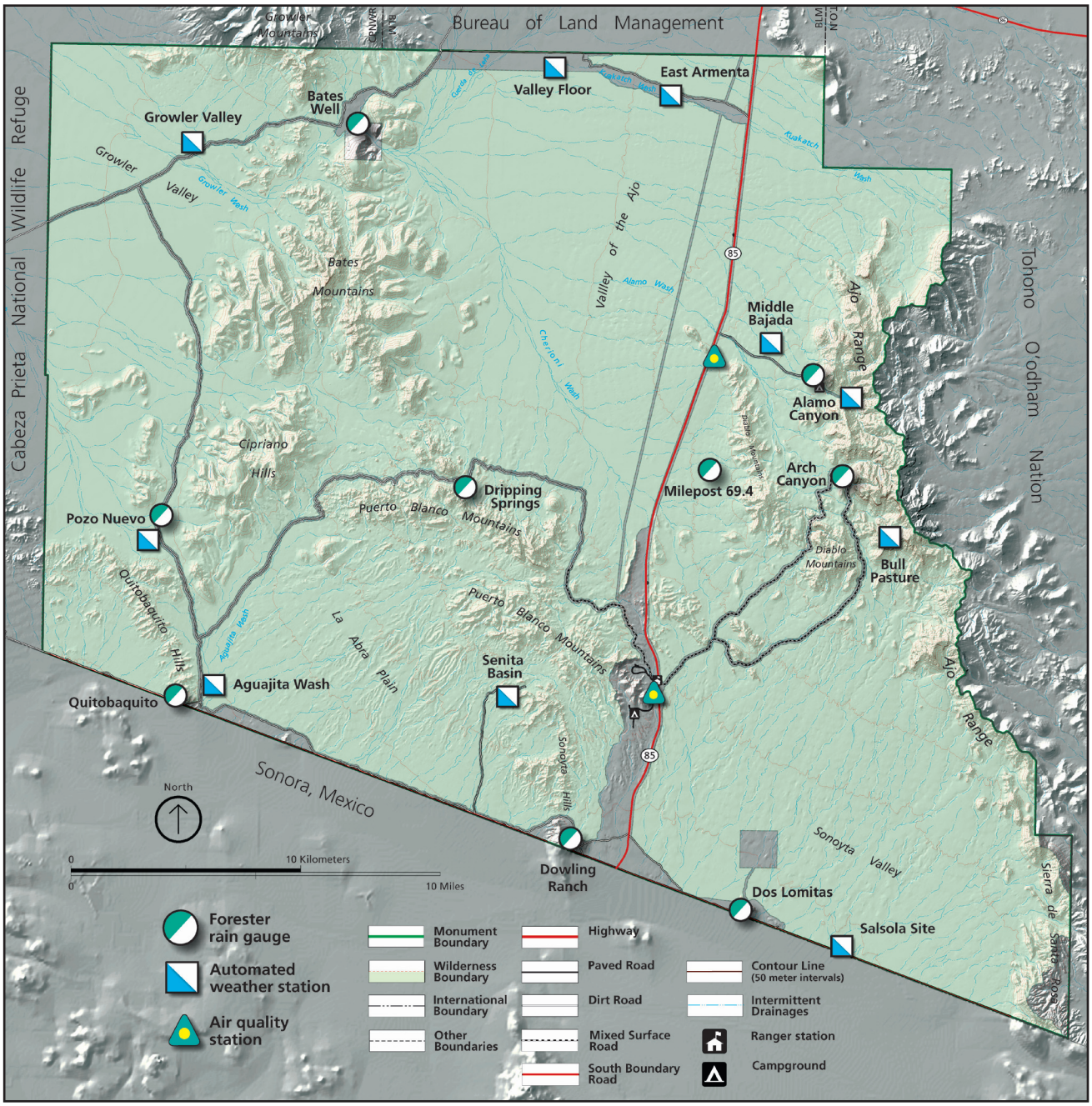

Figure 11-1. Climate monitoring sites, Organ Pipe Cactus N.M.

Table 11-1. History and configuration of automated climate stations deployed at Organ Pipe Cactus N.M. A = wind speed/direction, B = air temp/RH @48in, C = solar radiation, D = air temp @15cm, E = precipitation, F = soil temp @10cm, G = soil temp @25cm, H = soil temp @50cm, I = soil moisture @10cm, J = soil moisture @25cm, K = soil moisture @50cm, L = soil moisture @100cm.

Site	Station Code	Version 1 DataPod			Version 2 Handar			Version 3 Handar		
		Parameters	From Date	To Date	Parameters	From Date	To Date	Parameters	From Date	To Date
Acuna Habitat	ACUN	CDEF	29-Mar-88	9-Aug-95	ABCDE	9-Aug-95	current			
Aguajita Wash	AGUA	ABCDEF	8-Oct-87	25-Aug-95	ABCDE	25-Aug-95	3-Jan-97	ABCDEFGHIK*	3-Jan-97	current
Alamo Canyon	ALAM				ABCDE	2-Apr-96	7-Jan-97	ABCDEFGHIJK	7-Jan-97	current
Bull Pasture	BULL	ABDE	21-Nov-87	13-Sep-95	ABCDE	13-Sep-95	current			
East Armenta	ARME	ABDE	27-Oct-87	30-Mar-95	ABCDE	30-Mar-95	22-Dec-96	ABCDEFGHIJKL	22-Dec-96	current
Gachado Well	GACH	BDE	23-Oct-87	17-Aug-95						
Growler Valley	GROW	ABDE	27-Oct-87	17-May-95	ABCDE	17-May-95	5-Jan-97	ABCDEFGHIK	5-Jan-97	current
Headquarters	HEAD	ABDE	28-Oct-87	22-Aug-95						
Middle Bajada	MIDB				ABCDE	21-Mar-96	9-Jan-97	ABCDEFGHIJK	9-Jan-97	current
Pozo Nuevo	POZO				ABCDE	14-Feb-96	current			
Salsola Site	SALS	ABDE	22-Oct-87	12-May-95	ABCDE	12-May-95	current			
Senita Basin	SENI	ABCDEF	22-Oct-87	4-May-95	ABCDE	4-May-95	3-Jan-97	ABCDEFGHIJK**	3-Jan-97	current
Valley Floor	VALL				ABCDE	17-Mar-96	29-Dec-96	ABCDEFGHIJKL	29-Dec-96	current

*Aguajita Wash weather station was discovered stolen 11-Mar-99, reinstalled in new location 05-Jul-02, new configuration = BE
**Senita Basin weather station was discovered stolen 30-Oct-02, reinstalled in new location 27-Dec-02, new configuration = ABDE

Table 11-2. History of Forrester type rain gauges deployed at Organ Pipe Cactus N.M.

Site	Letter Code	From Date	To Date	Notes
Alamo Canyon	ALAM	Jan-82	present	near campground
Arch Canyon	ARCH	Jan-82	present	near parking area
Bates Well	BATES	Jan-82	Dec-87	operated by VIP's, who left (age)
Bates Well	BATES	Feb-98	present	at mouth of Growler Canyon, near mammal grids
Dos Lomitas	DOLO	Jan-82	Sep-96	rain gauge relocated from here due to theft
Dos Lomitas	DOLO	Nov-96	present	new rain gauge location, near old
Dowling Ranch	DOW	Jan-82	present	west of ranch
Dripping Springs	DRIP	Jan-82	present	near road
Armenta Ranch	ARMR	Jan-88	Dec-94	removed
Growler Valley	GROW	Jan-82	Oct-87	replaced with weather station
Mile Post 69.4	MP69	Jan-82	present	~1 mile to east
Pozo Nuevo	POZO	Oct-92	Feb-96	replaced with weather station
Quitobaquito	QBQ	Jan-82	present	west of pond

monument. Rain gauges have been in use at some sites since the early 1960s, though not consistently until 1982.

In 1995 and 1996, the array and composition of the 9 automated weather stations was upgraded. The new array consisted of 11 stations at or near the 11 Core I sites (see chapter about Study Sites). Two weather stations were eliminated (Headquarters and Gachado Well), seven weather stations were converted from Datapod recorders to Handar (now Vaisala) recorders at existing station sites (Aguajita Wash, Bull Pasture, East Armenta, Growler Valley, Acuña (=Neolloydia) Habitat, Salsola Site, and Senita Basin), and four stations were installed at new locations at Core I sites (Alamo Canyon, Middle Bajada, Pozo Nuevo, and Valley Floor. The instruments and recorders were all replaced with new late generation equipment, and all stations were set up with a full complement of meteorological instruments. The above-ground configuration of instruments was identical from site to site; below-ground sensors for soil moisture and temperature were added to 7 sites in 1996-1997 (see Table 11-1 for site to site variation). The data at each station were recorded on one logger, the Handar 555A, and power was supplied by a solar panel and internal battery.

Data Collection

Each weather station recorded hourly data for all parameters (Table 11-1). Above-ground data collection included wind speed and direction at 3 m above ground surface, air temperature and humidity at 48 inches (122 cm) above ground surface, solar radiation, air temperature at 15 cm above ground surface, and precipitation. Below-ground sensors recorded soil moisture and temperature at various depths (Table 11-1).

Servicing a weather station consisted of downloading data onto a palmtop computer and checking for damaged or malfunctioning equipment. Data were downloaded from the palmtop to a PC at the office and entered into an Excel spreadsheet. Summary data were then generated for daily maximum, minimum, and average values for all relevant parameters, with monthly summary figures also generated. All data were backed up on disks and stored in a fire-proof vault.

Monthly rainfall data were gathered from the Forester rain gauges by measuring the amount of pre-measured transmission fluid (which prevented evaporation of water) and rain water in the bucket and subtracting the known quantity of transmission fluid. Then, fresh transmission fluid was measured and placed in the bucket. Water was separated out of the used transmission fluid so the fluid could be used again. Data from these rain gauges were entered into an Excel spreadsheet. Daily and monthly rainfall summaries were provided to monument staff seasonally and within a few days of the new year for a given year.

Regional climate data were obtained from Hastings and Humphrey (1969); Sellers, Hill, and M. Sanderson-Rae (1985); and from the Western Regional Climate Center web site (WRCC 2005) to compare with OPCNM stations. Sites included for elevation profiles included Ajo, Anvil Ranch, Arivaca, Casa Grande, El Riito (Sonora), Eloy, Gila Bend, Kitt Peak, Puerto Penasco (Sonora), Ruby, Santa Rosa School, Sasabe, Sells, Tacna, and Yuma (Citrus Station).

Results

Long-term precipitation and temperature data for the headquarters area are presented in Figures 11-2, 11-3, and 11-4. A 10-year moving average (Figure 11-2) indicates that annual total precipitation has gone through 2 multi-decade cycles, and we appear to be in a major drought phase. The driest year in the 1943-2005 record was 2002 with 2.16 inches (55 mm), compared to the wettest year in 1983 with 19.64 inches (499 mm) of rain. Mean annual precipitation for the period of record is 9.468 inches (240.5 mm).

Mean annual temperature has increased gradually over the period of record and so have the mean cold month (January) and warm month (July) temperatures (Figure 11-3 and Table 11-3). The coolest year on record was 1951 with an average temperature of 67.7 °F (19.8 °C) and the warmest was 1995 with an average 72.7 °F (22.6 °C). The number of freezing days has declined over the years (Figure 11-4), with a maximum of 34 occurring in 1949 and minimum of 2 occurring in 1995.

Annual and monthly summaries for precipitation and temperature are provided for each monitoring station and rain gauge, in Appendices C and D. Figure 11-5 provides a view of annual rainfall at 12 sites. Several significant rainfall events occurred from 1997 to 2005. Tropical Depression Marty stalled over the northern Gulf of California on September 23-25, 2003 and delivered 2.22 inches (56 mm) at Middle Bajada and 5.58 inches (142 mm) at Alamo Canyon. The spring 2005 wildflower season was exceptional because October 2004 – February 2005 rainfall sums ranged from 5.05 inches (128mm) at Growler Valley to 11.75 inches (298mm) at Arch Canyon. On average, these sites receive 3.78 inches (96mm) and 5.78 inches (147mm) for the period October – February.

Spatial variation is also evident within OPCNM and in comparison with other sites in the region. Annual rainfall increases with elevation (Fig. 11-5) and there is a general decline in rainfall at OPCNM from east to west. Based on Figure 11-5, annual rainfall between 15 and 20 inches (380 and 500mm) might be expected on Mount Ajo (elevation 1465m). Figure 11-6 shows mean annual temperatures declining with increasing elevation. Bull Pasture, the highest station in OPCNM, is warmer in winter than many valley bottom sites (Appendix D).

Table 11-3. Summary of regression statistics for climate trends at Organ Pipe Cactus N.M. headquarters. X = year for all.

	N	R	R^2	Adjusted R^2	F	Sig
Number of days at or below 32 °F, 1949-2005 Y = 641.445 - 0.317X	57	0.649	0.4210	0.4105	39.991	0.0000
January average temperature, 1949-2005 Y = 0.084X - 113.101	57	0.462	0.2130	0.1987	14.887	0.0003
Annual average temperature, 1949-2005 Y = 0.051X - 30.455	57	0.623	0.3886	0.3775	34.960	0.0000
July average temperature, 1948-2005 Y = 0.029X + 30.571	58	0.331	0.1094	0.0935	6.881	0.0112
Annual precipitation, 1943-2005 Y = 0.033X - 55.368	63	0.172	0.0296	0.0137	1.858	0.1778
Annual precipitation, 1943-1999 Y = 0.059X - 106.540	57	0.280	0.0782	0.0614	4.663	0.0352

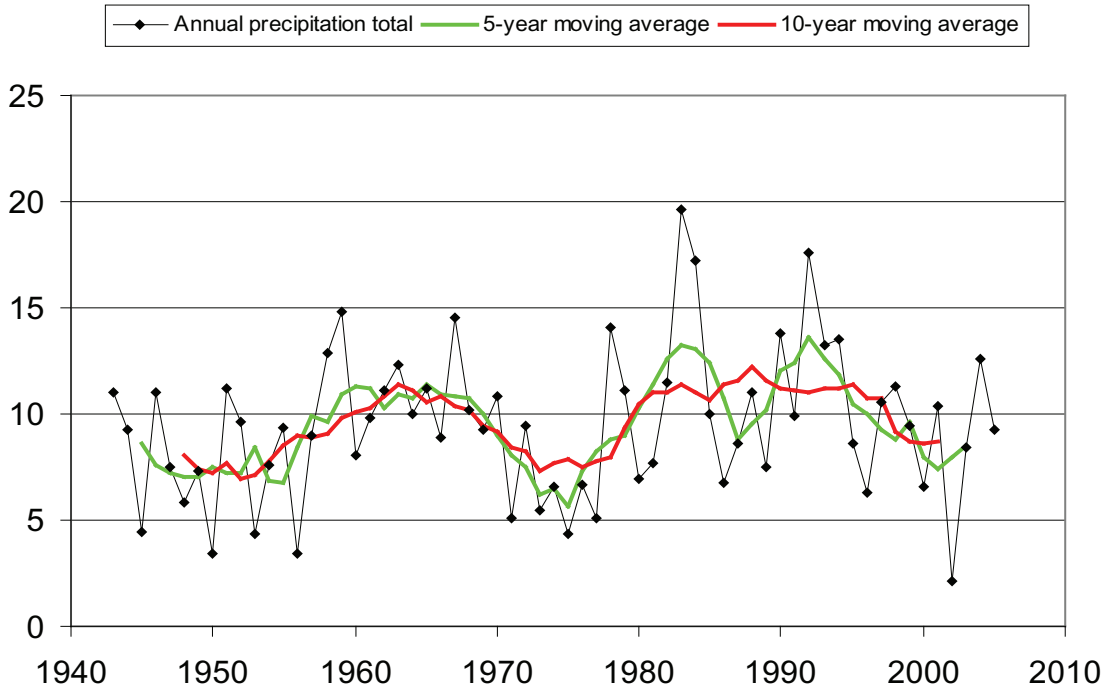

Figure 11-2. Annual precipitation (inches) recorded at Organ Pipe Cactus N.M. headquarters, 1943-2005.

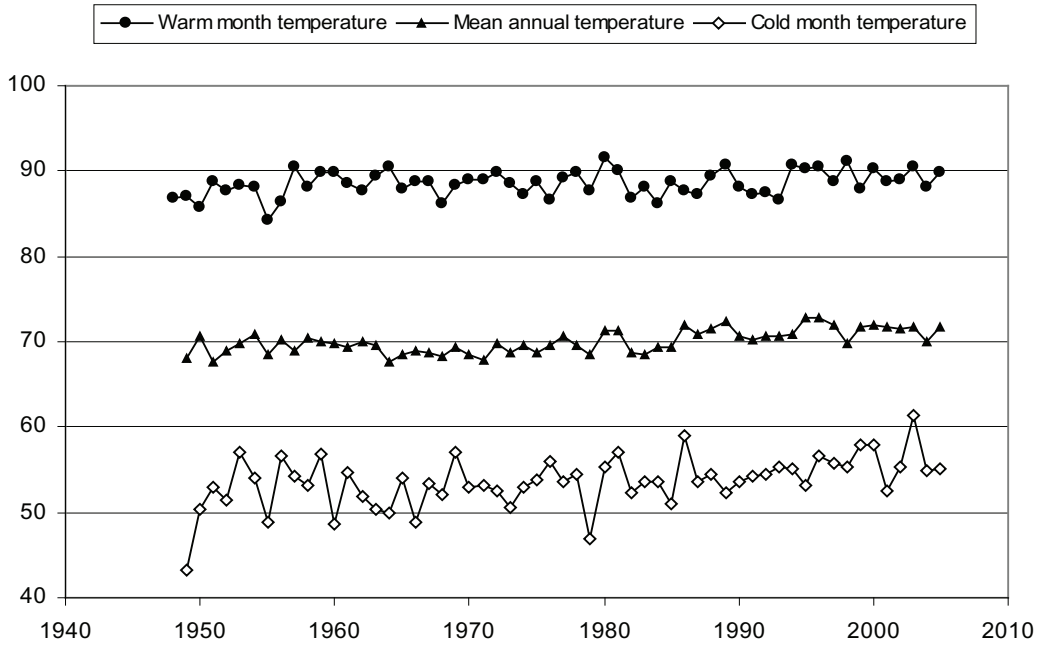

Figure 11-3. Warm month, mean annual, and cold month temperatures (°F), recorded at Organ Pipe Cactus N.M.headquarters since 1948-49.

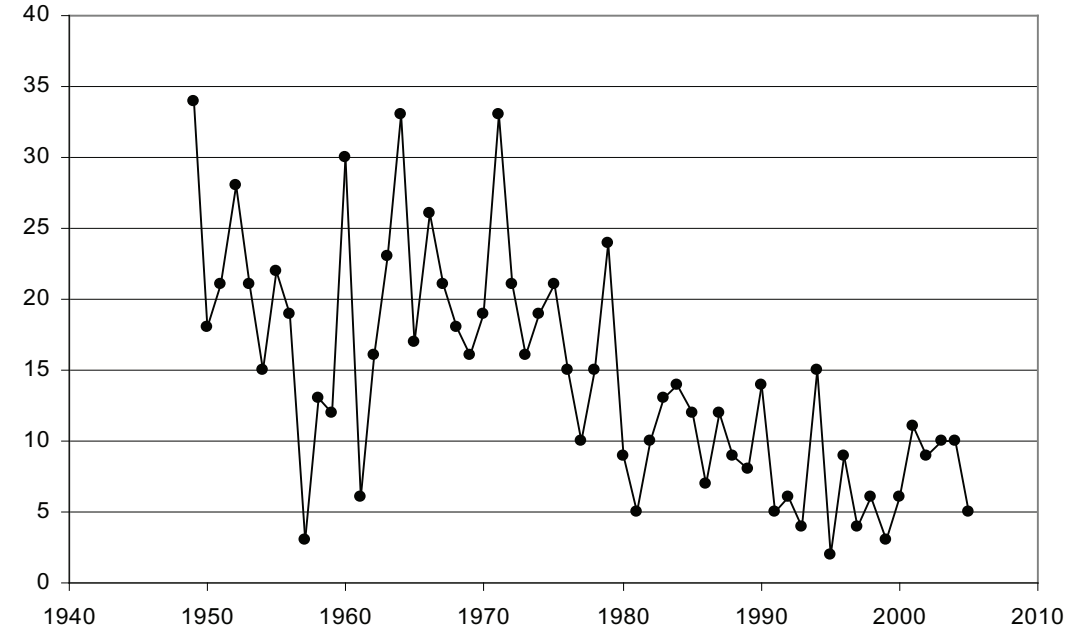

Figure 11-4. Annual number of freezing days (minimum temperatures of 32°F or less), recorded at Organ Pipe Cactus N.M.headquarters since 1949.

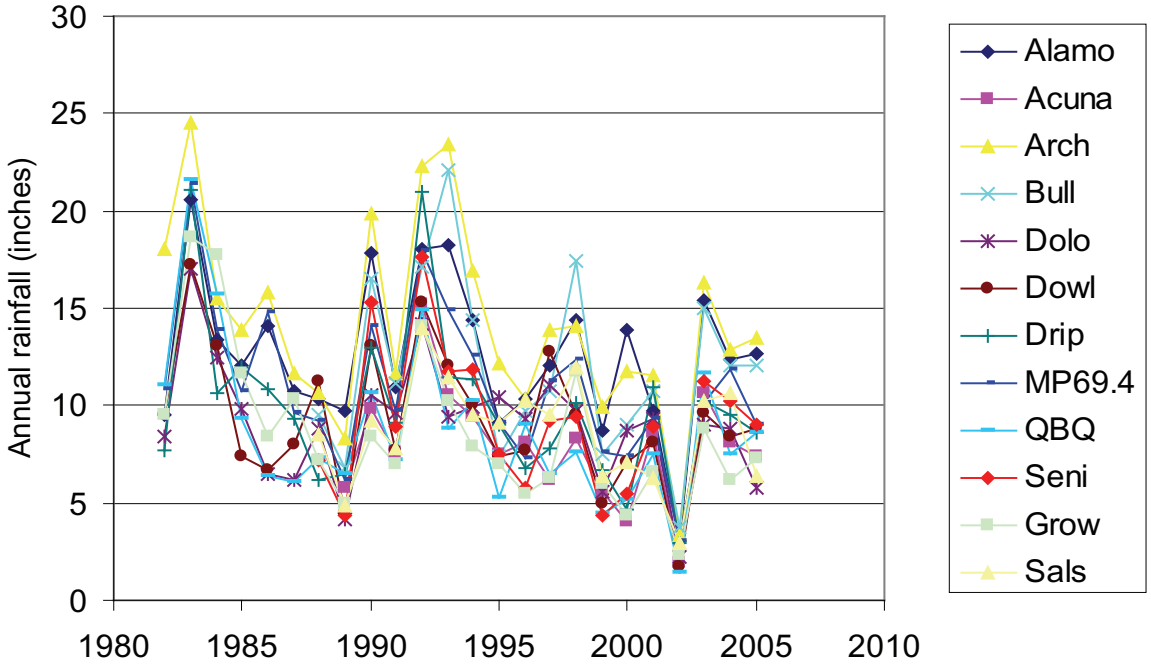

Figure 11-5. Annual rainfall at 12 monitoring sites with the longest record at Organ Pipe Cactus N.M.

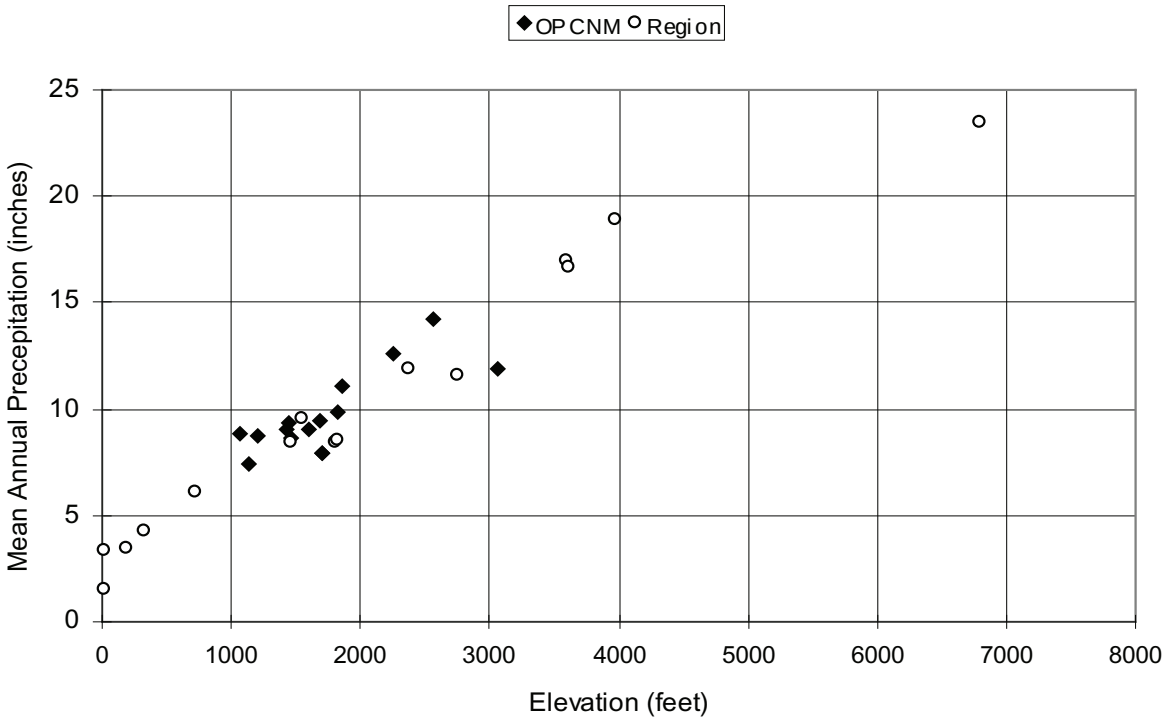

Figure 11-6. Mean annual precipitation and elevation at Organ Pipe Cactus N.M. and region. The highest elevation site is Kitt Peak.

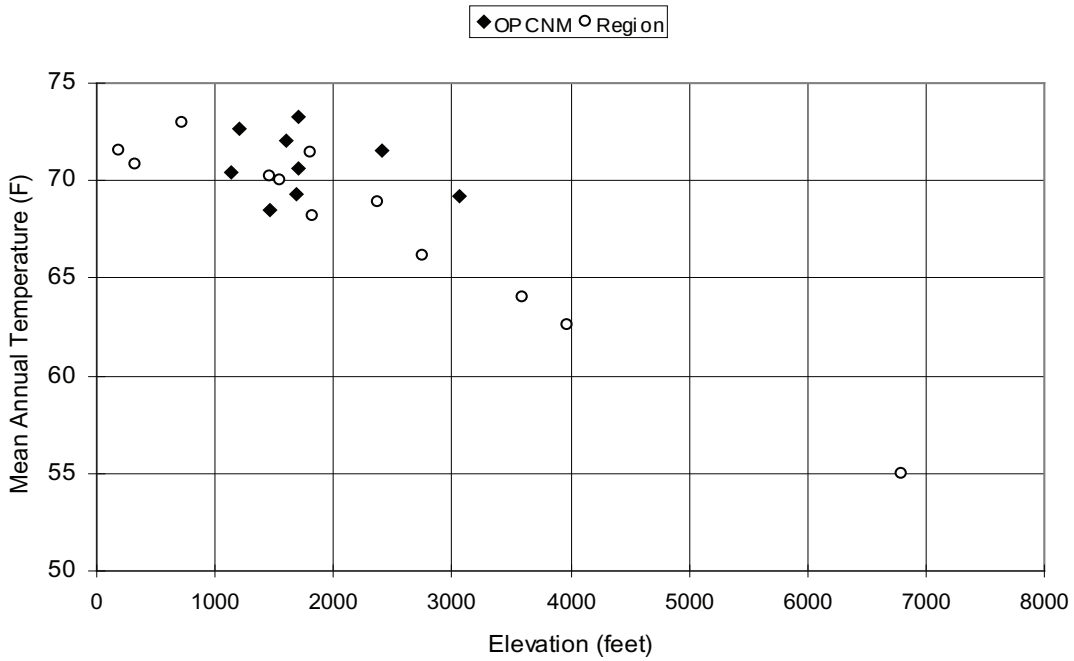

Figure 11-7. Mean annual temperature and elevation at Organ Pipe Cactus N. M. and region. The highest elevation site is Kitt Peak.

Discussion

Climate data, especially rainfall, relates to many other resources of interest, including growth rates in cacti, relative abundance in wildlife populations, and groundwater levels (see other report chapters). Anecdotal information also relates climate to wildflower blooms (e.g., spring 2005, following wet winter of 2004-2005) and wildfire events (e.g., spring-summer 2005).

Climate data from all OPCNM stations provide a unique opportunity to develop high resolution models of climate variability. Such models, (e.g., Comrie and Broyles, 2002) can help understand and predict abrupt spatial variation related to local convection patterns.

Trends in precipitation, temperature, and number of freezing days were previously analyzed by Rowlands (2002). Using regression analysis, he obtained a significant increase in annual precipitation for the period 1943-1999 at monument headquarters. Since 1999, OPCNM has experienced a drought and a regression analysis of the 1943-2005 data does not yield a significant increase (Table 11-3).

Organ Pipe Cactus N.M. lies in the transition between Arizona Upland and Lower Colorado Valley subdivisions of the Sonoran Desert. It also lies approximately 150 km north of the Central Gulf Coast subdivision and is well known for the high number of species characteristic of that desert. A comparison of OPCNM climate with regional stations suggests that OPCNM receives slightly less warm-season precipitation than the Central Gulf Coast and receives much more cool-season precipitation (Figure 11-7). Cold month temperatures are generally lower and warm month temperatures, generally higher, at OPCNM compared to the Central Gulf Coast (Figure 11-8).

The long-term changes in temperature and number of freezing days will ultimately affect the flora and fauna of this region. Frost-sensitive species, such as senita (*Pachycereus schottii*) and ashy jatropha (*Jatropha cinerea*), may expand their geographic distributions northward. Temperate

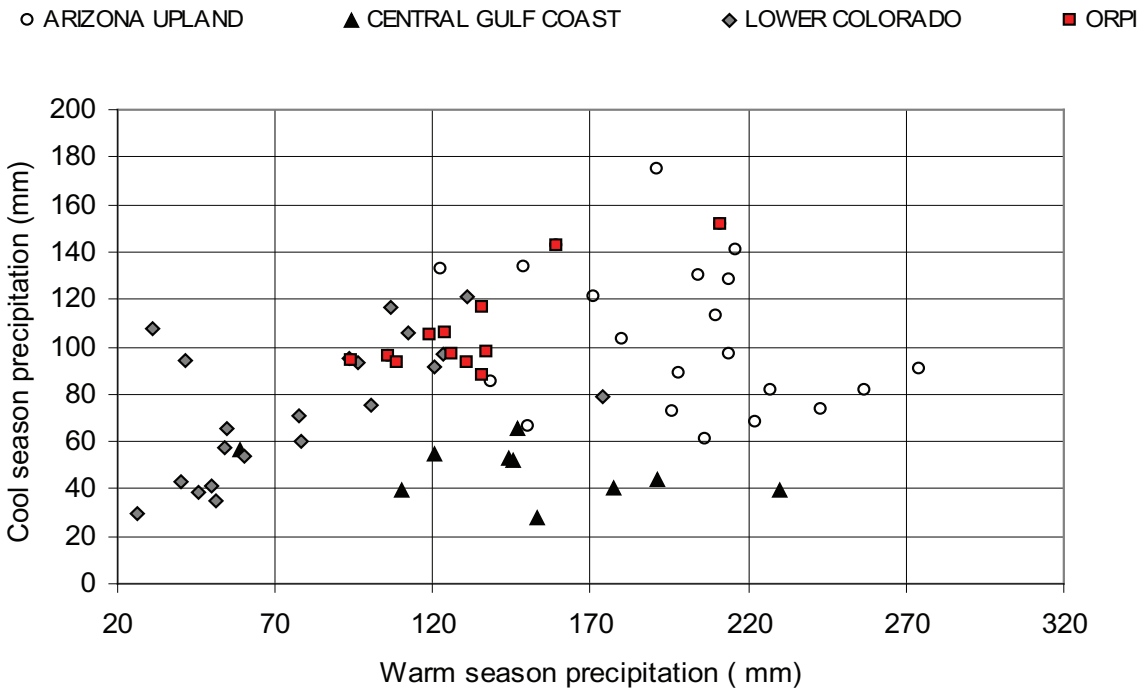

Figure 11-8. Mean annual cool season (Oct-Mar) vs warm season (Apr-Sep) precipitation at Organ Pipe Cactus N.M. and other Sonoran Desert stations.

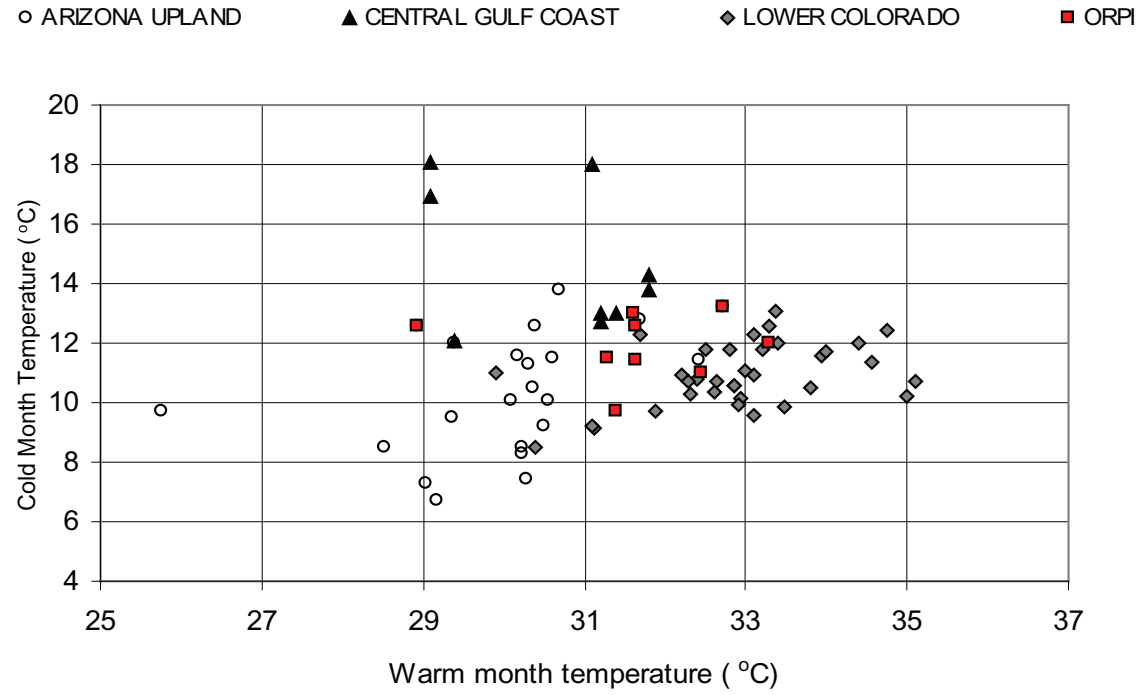

Figure 11-9. Mean annual cold month vs warm month temperature (°C) at Organ Pipe Cactus N.M. and other Sonoran Desert stations.

zone species may disappear from the small mountain-top communities in southwestern Arizona. Most vulnerable, may be populations with an age structure and biogeographic distribution that is distinctly relictual. Some populations of redberry juniper (*Juniperus coahuilensis)* consist entirely of ragged-looking old adults and are confined to protected north-facing slopes at high elevations where the most cool-mesic environments occur. Documenting such trends could help increase public awareness of the effects of global climate change on local ecosystems.

Sonoran Desert Network (SODN)

Climate is one of 25 vital signs selected by the network for a regional monitoring program (Mau-Crimmins et al. 2005). An excerpt from the SODN Phase III Monitoring Plan summarizes the significance and objectives of broad and meso-scale climate monitoring:

Broad-scale Climate

The climate of a region drives ecosystem processes, dictating species' distributions, governing nutrient cycling, and driving changes in other abiotic components of the system.

1. Determine long-term trends in temperature, precipitation, and synthetic variables (PET, drought indices, etc) in the Sonoran Desert region.

2. Determine how broad-scale climate is related to other vital signs.

Meso-scale Climate

The local (mesoscale) climate within a park drives localscale ecosystem processes, dictating species' distributions, governing nutrient cycling, and driving changes in other abiotic components of the system.

1. Evaluate spatial and temporal trends in temperature, precipitation, wind speed, wind direction, relative humidity, snow depth, and variables appropriate for understanding other vital signs in SODN parks.

2. How do local weather conditions influence biotic and abiotic processes (e.g., leaf-out, flowering, invasion by nonnative species, fire threat?)

3. How do climatic variables vary over complex topography within the scale of a park unit?

In October 2005, OPCNM and SODN staff met to discuss integration of EMP and network projects. Several goals were identified including the development of metadata and protocols that meet current NPS standards. The existing OPCNM climate data set is vast and will require extensive analysis to realize its full utility and determine the best configuration for future climate monitoring. The network was provided with a complete copy of the data set and the integration process is moving forward.

Recommendations

- Continue to integrate EMP climate monitoring with the Sonoran Desert Network. Work with the network to determine how many climate monitoring sites are needed and develop procedures for routine data analysis and reporting. Also, evaluate current and future needs for upgrade of climate monitoring equipment.
- Climate monitoring has generated a large data set that has not been thoroughly analyzed. The data should be formatted for analysis and placed on a website where it can be accessed by researchers.
- Monitor selected species and communities at high elevation, cool-mesic sites to track impacts of global warming. Long-term changes are expected to be slow and monitoring can take place at wide intervals, such as every 10 years.

Acknowledgements

Field assistance was provided by Ami Pate.

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Air Quality

Ami Pate

Objectives

Determine seasonal and inter-annual trends in nitrogen deposition, sulfur deposition and visibility reducing pollutants.

Introduction

Federal land management areas are classified as Class I, II, or III areas to facilitate implementation of the Clean Air Act. Mandatory Class I areas, the most protected from increases in air pollution, were designated by Congress in 1977. The Class I areas consist primarily of national parks and national forest lands with designated wilderness. Since Organ Pipe Cactus National Monument (OPCNM) became a wilderness area in 1978, the monument falls under Class II status. Class II areas also receive protection under the act, but to a lesser degree. The Sonoran Desert Inventory & Monitoring Network has identified several sensitive air quality related values for OPCNM: visibility, vegetation, surface waters, soils and fish and wildlife.

Visibility is an important air quality related value to NPS visitors. Air and light pollution affect the visual experience of wilderness vistas, landscape features and dark night skies. Impairment occurs as a result of the scattering and absorption of light by particles and gases in the atmosphere. Emissions of sulfur dioxide (SO_2) into the atmosphere and resulting fine particulate (less than 2.5 microns) formation are a major cause of visibility impairment, and contribute to deposition to sensitive terrestrial and aquatic ecosystems.

Atmospheric deposition of nitrogen and sulfur compounds affects ecosystems in a variety of ways, including acidification, fertilization, and eutrophication. In the Sonoran Desert Network, nitrogen deposition and its fertilization effects can cause changes in soil that affect microorganisms, plants, and trees, ultimately leading to changes in plant community structure and diversity (NPS 2005).

Although a copper smelter 24km north of the monument in the town of Ajo was closed in 1983 and local visibility-impairing emissions were reduced, new threats to air resources are increasing. Agricultural activities on the Mexican border affecting air quality include field burning, garbage burning, pesticide and herbicide use, and truck traffic on dirt roads. New industrial and urban developments are planned in the Sonoyta, Sonora area and increasing tourist and truck traffic through the monument have the potential to dramatically increase air pollutants. OPCNM is also affected by regional haze sources such as urban southern California, the industrialized Gulf coasts of Mexico and Texas and the smelter regions of Arizona and New Mexico (Baron 1991). More proximate sources of air pollution include metropolitan Phoenix and Hermosillo, Sonora, and a power plant at Puerto Libertad, Sonora.

Cooperative Agencies

Currently the monument operates sites for the National Atmospheric Deposition Program and the Arizona Department of Environmental Quality, to monitor aspects of air quality. Additionally, OPCNM participated in a NPS Air Resources Division passive ozone monitoring study 1996-2003. The monument also funded a visibility camera, 1997-2004.

National Atmospheric Deposition Program (NADP)

This program was initiated in 1978 to track geographical patterns and temporal trends in the chemical climate of North America. Rain samples are collected weekly at sites throughout the country and chemistry measurements are performed both in the field and at a Central Analytical Laboratory. It is administered by the National Atmospheric Deposition Program/

National Trends Network (NADP/NTN) Coordination Office at Colorado State University. Various cooperating agencies across the country provide personnel and equipment for the program. OPCNM, 1 of 4 current NADP sites in Arizona, began sampling in 1980.

Arizona Department of Environmental Quality (ADEQ)

ADEQ regulates air quality as mandated by the Federal Clean Air Act and Arizona State Statutes. Environmental Protection Agency plans for air quality standards are followed by the Department. Among ADEQ projects is ambient monitoring of airborne particulates with a dichotomous (dichot) sampler. Sites monitored by ADEQ include areas with urban-related pollution, emissions from industrial facilities, and dust from agricultural operations and also areas distant from these sources, such as National Park Service sites. A dichot sampler, measuring coarse and fine particulates less than 10 microns in diameter (PM_{10}), was in place at OPCNM until 2002 (Before that, a high volume air sampler measured particulates with less resolution than the dichot method.) In 2003 an IMPROVE (Interagency Monitoring of Protected Visual Environments) site was installed.

IMPROVE

The Interagency Monitoring of Protected Visual Environments (IMPROVE) program is a cooperative air quality monitoring effort between federal land managers; regional, state, and tribal air agencies; and the Environmental Protection Agency. The IMPROVE monitoring program was established in 1985 to aid in the implementation of the 1977 Clean Air Act goal of preventing future and remedying existing visibility impairment in Class I areas. The network began operating in 1988 and currently consists of 175 monitoring sites. The network is working towards reducing regional haze by establishing current visibility conditions and identifying the chemical species and emission sources responsible for existing visibility impairment.

In 2004, a nephelometer was installed at the IMPROVE monitoring shed. Nephelometers measure the amount of light scattered by particles and gases in the atmosphere. This measurement combined with estimates of the obsorption coefficient (from aerosol monitoring filters) can be used to determine the average total light extinction.

National Park Service Gaseous Pollutant Monitoring Program

In 1996, the NPS Air Quality Division initiated a passive ozone sampling program as a low cost method to monitor ozone levels. The samplers were designed to provide basic information on ozone exposures and provide a baseline by which the need for additional, more intensive monitoring could be judged. Monitoring involved exposing the passive samplers for one week period during the 3-5 month summer "ozone season," retrieving the samplers, and mailing them to the analysis contractor. This program was discontinued in 2004 due to budget cuts.

From 1997-2004, Organ Pipe Cactus National Monument operated an automatic visibility camera to document baseline vista conditions on the U.S./Mexico border near Lukeville, AZ and Sonoyta, Sonora. In 2000, the monument cooperated with the Pinacate Biosphere Reserve to install an automatic visibility camera in the reserve, also to document baseline visibility conditions on the U.S./Mexico border.

Methods

National Atmospheric Deposition Program

The OPCNM NADP site equipment consists of an Aerochem Metrics wet/dry precipitation collector and a Belfort Universal rain gauge with event pen. During precipitation events, the wet-side collection bucket was automatically uncovered, then covered when the event had ended. Cumulative weekly rain samples were collected. The Belfort Universal rain gauge recorded precipitation event times and precipitation amount on chart paper. In the OPCNM lab, the bucket was weighed to determine precipitation

amount. If rainfall was of sufficient volume, measurements of pH and specific conductance were then made (These field chemistry measurements were discontinued in 2005). The samples were sent to the NADP Central Analytical Lab in Champaign, Illinois, where more extensive chemistry measurements were performed: specific conductance, ph, hydrogen, ammonium, calcium, magnesium, sodium, potassium, sulfate, nitrate and chloride.

Arizona Department of Environmental Quality

The dichotomous particulate (PM_{10}) sampler at Organ Pipe was located near the NADP sampling equipment. Two filters collected coarse and fine particulate samples for a 24-hour period every six days. The filters were sent to ADEQ for gravimetric and optical density analysis. This sampler was discontinued in 2002 with the installation of a more comprehensive IMPROVE particulate sampling site.

IMPROVE

The IMPROVE particle monitor consists of four independent sampling modules. Three modules collect only fine particles (PM2.5), while the fourth collects both fine and coarse particles (PM10). The IMPROVE monitor measures mass, chemical elements, sulfate, nitrate, organics, and elemental carbon. The samplers run for 24 hours every third day collecting the particulate matter on filters. These filters are retrieved once a week and sent to contracted laboratories for physical and chemical analyses.

The nephelometer is mounted on a north-facing 14-foot tower at the IMPROVE monitoring site. The nephelometer draws ambient air into a chamber where light of known intensity is emitted over a a path parallel to a photodiode detector. A direct estimate of atmoshpheric scattering is made by measuring the light scattered from the front, back and sides of the optical chamber. Data is logged by a Campbell Scientific logger, and transmitted by phone modem to data managers.

National Park Service Gaseous Pollutant Monitoring Program

The passive ozone samplers consisted of cylinders containing 2 nitrite-coated filter pads and a clip-on badge support. Each sampler was placed at a height of 3 m beneath a rain shield and exposed to ambient air for 7 days. When the devices were exposed to air, ozone oxidized the nitrite coating on the filters to nitrate. After exposure, the devices were returned to a laboratory where ion chromatography was used to determine the amount of nitrate formed and hence the overall ozone exposure.

The OPCNM visibility camera was installed 15 miles north of the U.S./Mexico border to capture a southern vista of the Sierra Cubabi in Sonora. A timer-activated camera took slides daily at 1500. Slides were processed and qualitative visibility analysis was performed by NPS contractor Air Resource Specialists, Inc. The Pinacate Biosphere Reserve camera was installed approximately 20 miles south of the U.S./Mexico border, with a vista target of the Sierra Pinta in southwestern Arizona.

Results

National Atmospheric Deposition Program

The data from these sites were included in national summary maps of weighted mean concentrations and deposition estimates for various ions. These national summary maps along with annual, seasonal, and weekly data summaries for each site in the NADP network are available from the program website: http://nadp.sws.uiuc.edu/

Arizona Department of Environmental Quality

Dichot particulate sampler results through 1997 were sent to OPCNM. It is unknown whether 1998-2002 data summaries are available.

IMPROVE

Data summaries are available at the IMPROVE website: http://vista.cira.colostate.edu/IMPROVE/

National Park Service Air Quality Division
Summaries from the NPS passive ozone program are available at the NPS website: http://www2.nature.nps.gov/air/Studies/Passives.cfm

Representative visibility conditions for the monument, 1997-2004, are shown in Figure 1.

Discussion

National Atmospheric Deposition Program
NH_4, NO_3, SO_4 and pH results for 1997-2004 precipitation samples (Figures 12-19 through 12-26) followed a pattern similar to previous years. At OPCNM, climate is characterized by 2 rainfall seasons, winter storms generally originating from the Pacific Ocean, and summer/fall monsoons from the Gulf of Mexico and Gulf of California. Consistently, precipitation samples have higher pH and lower NO_3 and SO_4 concentrations for February–March winter rainfall samples, and much lower pH (more acidic) during summer and fall winter months, with associated higher NO_3 and SO_4. NADP annual trend plots from 1980-2004 show a post-Ajo copper smelter peak of sulfate levels in the period of 1996-1999, and a corresponding lower pH. Trends for NO_3 and NH_4 are increasing.

IMPROVE
Comparing 1991-1997 dichot results for PM_{10} and SO_4 with 2003-2004 IMPROVE particulate sampler results for the same parameters shows slightly higher concentrations in 2003-2004 (Figures 12-3 and 12-4). Also, peak values for both parameters are much higher than earlier years. The seasonal patterns were similar as well, with the lowest concentrations usually in the winter months, and elevated concentrations in spring and summer. Since the fine particulates present in PM_{10} can impair visibility, these results may explain the monument's generally good winter visibility and frequently impaired summer and fall visibility. In the desert Southwest, sulfates account for approximately 60% of visibility impairment (Malm 1992).

Also, 2003-2004 IMPROVE results for SO_4, NO_3, organic carbon, soil, and $PM_{2.5}$ (very fine particulate matter) were compared between OPCNM, Saguaro National Park, and Chiricahua National Monument. (Figures 12-5 through 12-14). SO_4 concentrations were much higher at OPCNM than at the southeastern Arizona sites.

A study showed that Arizona/Sonora copper smelters and southern California refining, generating, and auto emissions were the most probable sources of sulfates at Chiricahua (Malm 1999). However, with recent smelter closures and reduction of sulfur levels in California fuels, a decline in sulfate levels in the southwest should be occurring. A study of temporal trends in the U.S. showed a decrease in sulfate concentrations in monitoring sites west of the Rocky Mountains (Malm et al. 2002). Further data analysis and source attribution modeling would be useful in explaining the trend of increasing SO_4 at OPCNM.

Nitrate levels were more pronounced for OPCNM in the late summer- winter months than at the other sites. All sites recorded a spike in organic carbon concentrations in late October 2003, coinciding with the southern California fire events.

Passive ozone
From 1997 to 2003, weekly ozone concentrations followed a trend of higher values in early summer than late summer (Figures 12-1 and 12-2). In 1999, the highest and lowest values were measured: 59.8 parts per billion in late May, and 18.7 parts per billion in late August.

Visibility
The Pinacate visibility camera recorded many more layered haze events than the OPCNM visibility camera (Tables 12-1 and 12-2). The Pinacate camera captured a vista farther to the west, which may be influenced by agriculture and development in Yuma, Arizona and San Luis R.C., Sonora. Figure 12-31 shows a regional haze event in June 2002 at OPCNM. Figure 12-32 shows a layered haze event in December 2002 at the

Pinacate Biosphere Reserve.

Recommendations

OPCNM's air quality monitoring program has documented many air quality seasonal trends and poor air quality events. Using OPCNM climate and air quality data in a back trajectory analysis would be one way to determine sources for visibility impairment and acidic rainfall events. This information could be used in interpretive displays to promote sustainable practices. The NPS Air Resources Division and the Arizona Department of Environmental Quality would be possible sources of assistance for this analysis.

Acknowledgements

Charles Conner

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Table 12-1. Qualitative 35mm slide analysis, Pinacate visibility camera. Slides were taken daily at 1200. “Uniform” haze condition includes sky condition codes “clear,” “scattered clouds,” “overcast,” and “haze concealed.”

Pinacate Biosphere Reserve	Uniform (Dataset includes atmospheric conditions)	Ground Based Layered Haze	Elevated Layered Haze	Multiple Haze Layers	Weather Obscures Scene	Cannot Be Determined
Fall 2000	85.4%	12.2%	--	--	2.4%	--
Win 2001	62.9%	25.8%	2.2%	2.2%	1.1%	5.6%
Spr 2001	97.8%	2.2%	--	--	--	--
Sum 2001	100%	--	--	--	--	--
Fall 2001	98.9%	--	1.1%	--	--	--
Win 2002	79.8%	13.5%	3.4%	3.4%	--	--
Spr 2002	100%	--	--	--	--	--
Sum 2002	98.6%	1.4%	--	--	--	--
Win 2003	67.8%	17.8%	3.3%	2.2%	8.9%	--
Spr 2003	93.9%	3%	--	--	--	3%
Sum 2003	100%	--	--	--	--	--
Fall 2003	90.6%	1.2%	2.4%	1.2%	3.5%	1.2%
Win 2004	90.1%	1.1%	3.3%	3.3%	2.2%	--
Spr 2004	34%	--	--	--	--	66%
Sum 2004	46.8%	--	--	--	6.5%	46.8%

Table 12-2. Qualitative 35mm slide analysis, Organ Pipe Cactus N.M. visibility camera. Slides were taken daily at 1500. “Uniform” haze condition includes sky condition codes “clear,” “scattered clouds,” “overcast,” and “haze concealed.”

Organ Pipe Cactus N.M.	Uniform (Dataset includes atmospheric conditions)	Ground Based Layered Haze	Elevated Layered Haze	Multiple Haze Layers	Weather Obscures Scene	Cannot Be Determined
Fall 1997	94.3%	0.6%	--	--	5.2%	--
Win 1998	86.9%	6.3%	--	--	5.6%	1.3%
Spr 1998	94.0%	0.5%	--	0.5%	4.9%	--
Sum 1998	99.4%	--	--	--	--	0.6%
Fall 1998	99.4%	--	--	--	--	0.6%
Win 1999	91.9%	1.2%	0.6%	--	--	6.4%
Spr 1999	98.8%	0.6%	--	--	--	0.6%
Sum 1999	99.4%	--	--	--	--	0.6%
Fall 1999	94.4%	5.6%	--	--	--	--
Win 2000	86.0%	14.0%	--	--	--	--
Spr 2000	100%	--	--	--	--	--
Sum 2000	100%	--	--	--	--	--
Fall 2000	100%	--	--	--	--	--
Win 2001	97.8%	2.2%	--	--	--	--
Spr 2001	68.5%	1.1%	--	--	--	30.4%
Sum 2001	67%	2.2%	--	--	1.1%	29.7%
Fall 2001	100%	--	--	--	--	--
Win 2002	97.5%	2.5%	--	--	--	--
Spr 2002	97.8%	2.2%	--	--	--	--
Sum 2002	100%	--	--	--	--	--
Fall 2002	97.8%	--	--	--	2.2%	--
Win 2003	89.3%	3.6%	--	--	7.1%	--
Spr 2003	94.2%	2.9%	--	--	2.9%	--
Sum 2003	95.6%	3.3%	--	--	1.1%	--
Fall 2003	94.3%	1.4%	--	--	4.3%	--
Win 2004	97.8%	2.2%	--	--	--	--

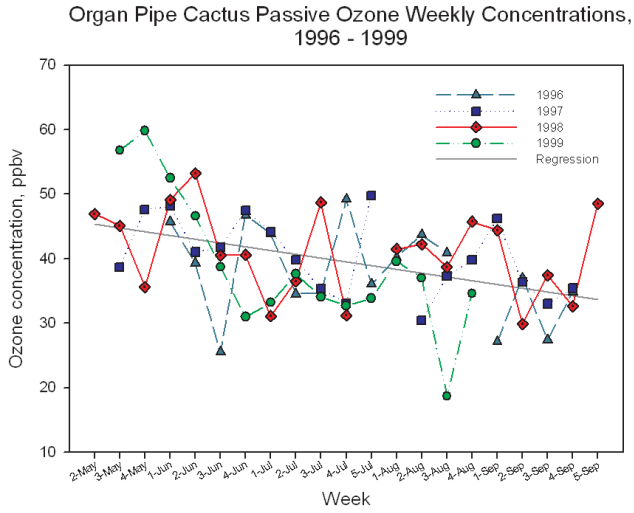

Figure 12-1. Passive ozone monitoring results, 1996-1999, Organ Pipe Cactus N.M.

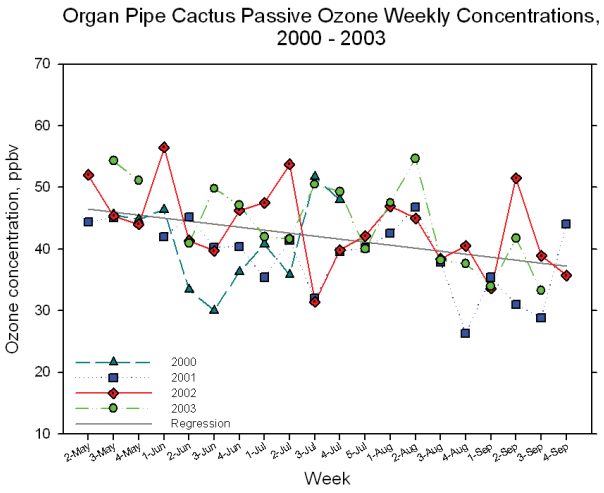

Figure 12-2. Passive ozone monitoring results, 2000-2003, Organ Pipe Cactus N.M.

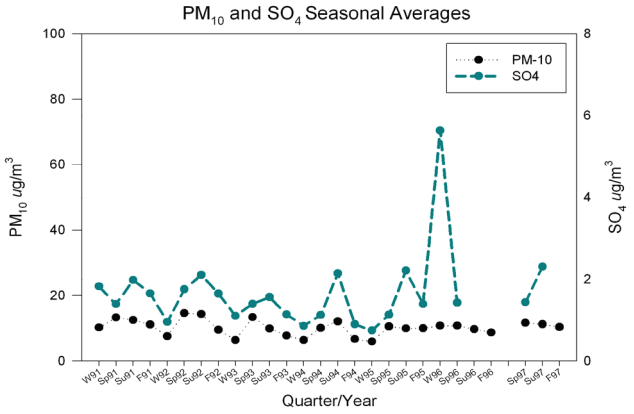

Figure 12-3. PM_{10} and SO_4 concentrations from dichot particulate sampler, 1991-1997, Organ Pipe Cactus N.M.

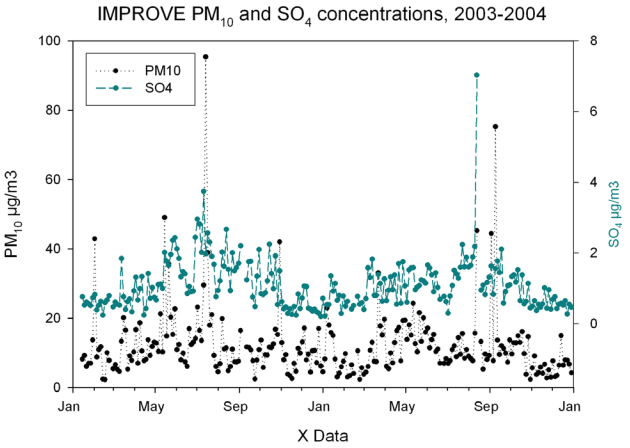

Figure 12-4. PM_{10} and SO_4 concentrations from IMPROVE particulate sampler, 2003-2004, Organ Pipe Cactus N.M.

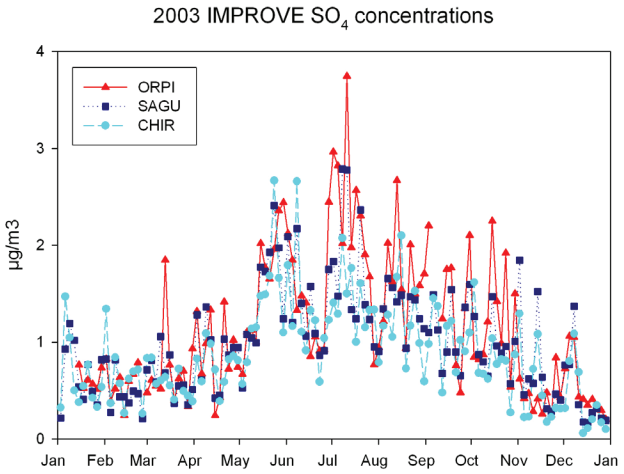

Figure 12-5. 2003 SO_4 concentrations for Organ Pipe Cactus National Monument, Saguaro National Park and Chiricahua National Monument. Data from IMPROVE particulate sampler.

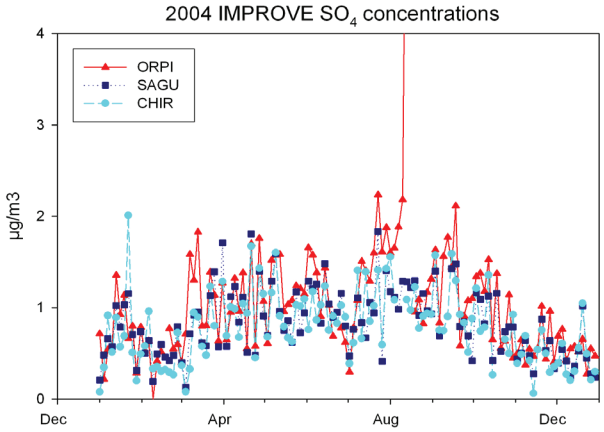

Figure 12-6. 2004 SO_4 concentrations for Organ Pipe Cactus National Monument, Saguaro National Park and Chiricahua National Monument. Data from IMPROVE particulate sampler. (Value out of range = 7.03 µg/m^3 on August 13, 2004.)

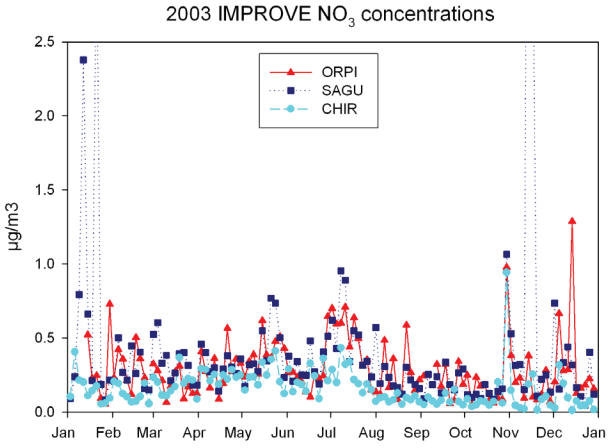

Figure 12-7. 2003 NO_3 concentrations for Organ Pipe Cactus National Monument, Saguaro National Park and Chiricahua National Monument. Data from IMPROVE particulate sampler. (Values out of range = 3.27 µg/m^3 on January 21, 2003 and 3.13 µg/m^3 on November 17, 2003.)

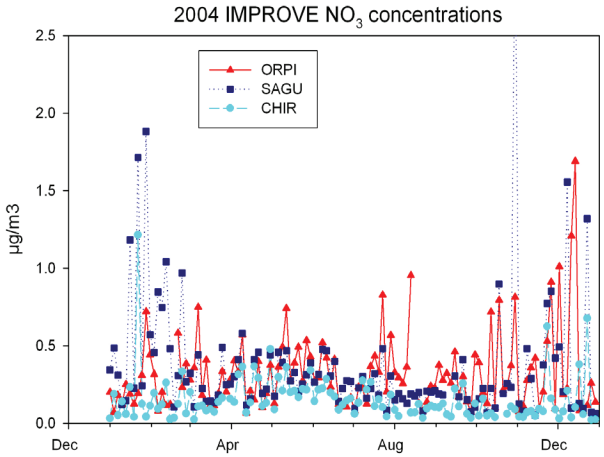

Figure12-8. 2004 NO_3 concentrations for Organ Pipe Cactus National Monument, Saguaro National Park and Chiricahua National Monument. Data from IMPROVE particulate sampler. (Value out of range = 3.38 µg/m^3 on October 30, 2004.)

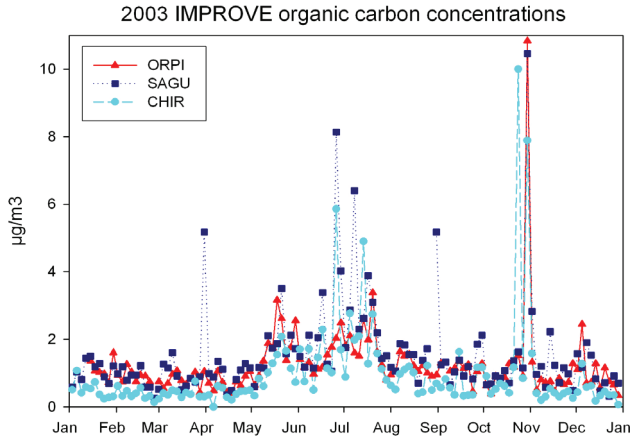

Figure 12-9. 2003 organic carbon concentrations for Organ Pipe Cactus National Monument, Saguaro National Park and Chiricahua National Monument. Data from IMPROVE particulate sampler.

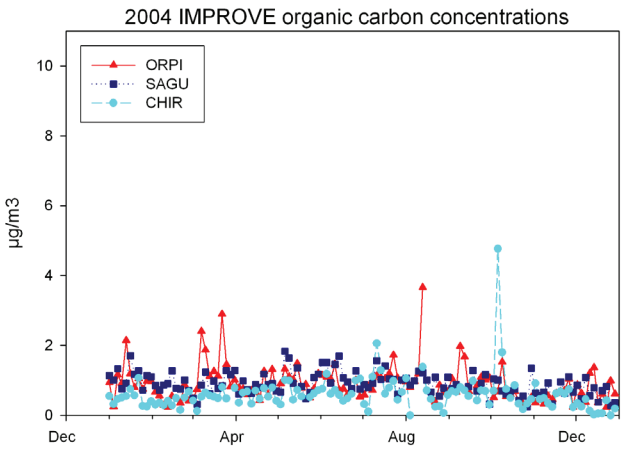

Figure 12-10. 2004 organic carbon concentrations for Organ Pipe Cactus National Monument, Saguaro National Park and Chiricahua National Monument. Data from IMPROVE particulate sampler.

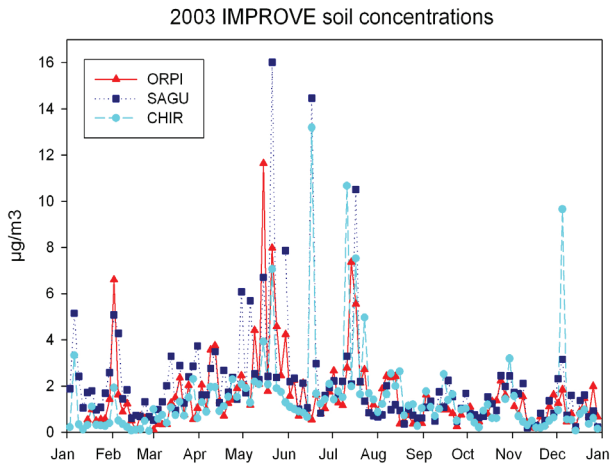

Figure 12-11. 2003 soil concentrations for Organ Pipe Cactus National Monument, Saguaro National Park and Chiricahua National Monument. Data from IMPROVE particulate sampler.

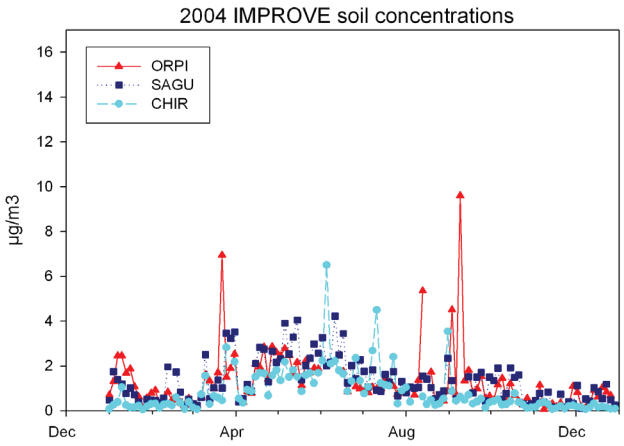

Figure 12-12. 2004 soil concentrations for Organ Pipe Cactus National Monument, Saguaro National Park and Chiricahua National Monument. Data from IMPROVE particulate sampler.

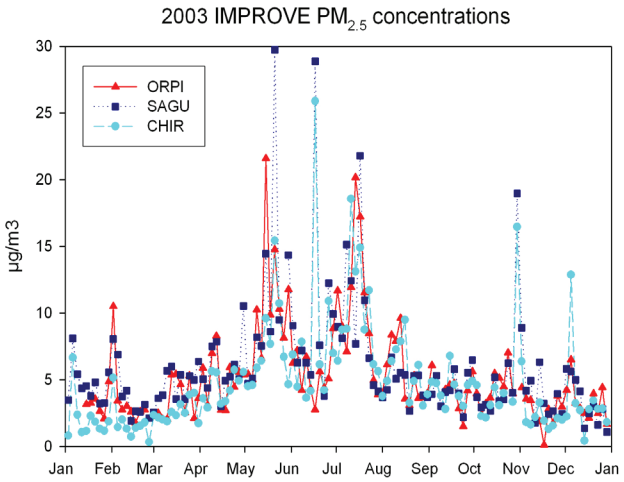

Figure 12-13. 2003 $PM_{2.5}$ concentrations for Organ Pipe Cactus National Monument, Saguaro National Park and Chiricahua National Monument. Data from IMPROVE particulate sampler.

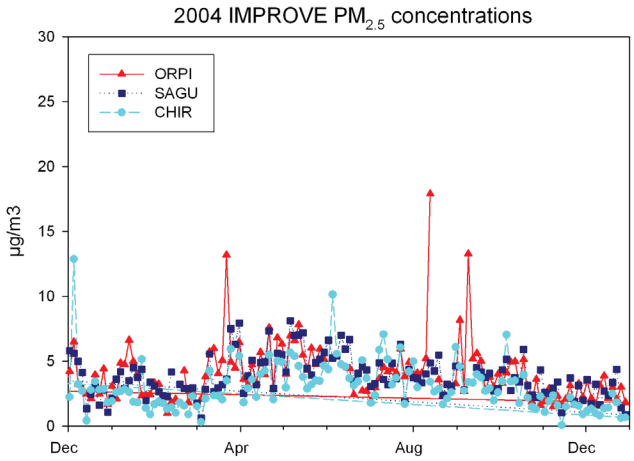

Figure 12-14. 2004 $PM_{2.5}$ concentrations for Organ Pipe Cactus National Monument, Saguaro National Park and Chiricahua National Monument. Data from IMPROVE particulate sampler.

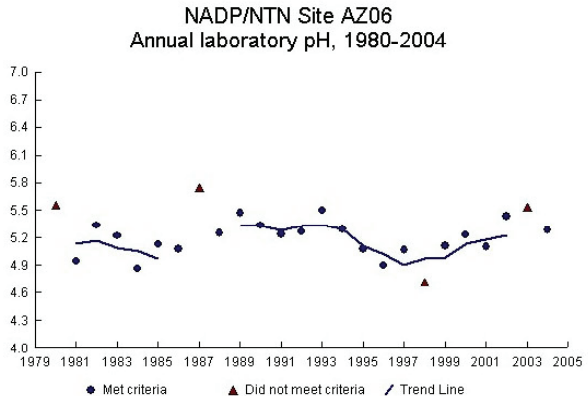

Figure 12-15. Trend plot for annual laboratory pH, 1980-2004, Organ Pipe Cactus N.M. wet deposition site, National Atmospheric Deposition Program.

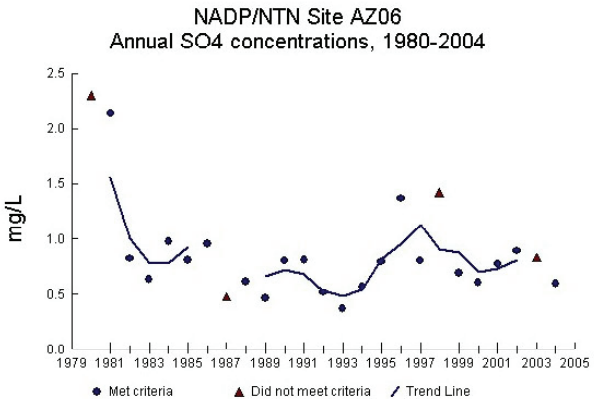

Figure 12-16. Trend plot for annual SO4 concentrations, 1980-2004, Organ Pipe Cactus N.M. wet deposition site, National Atmospheric Deposition Program.

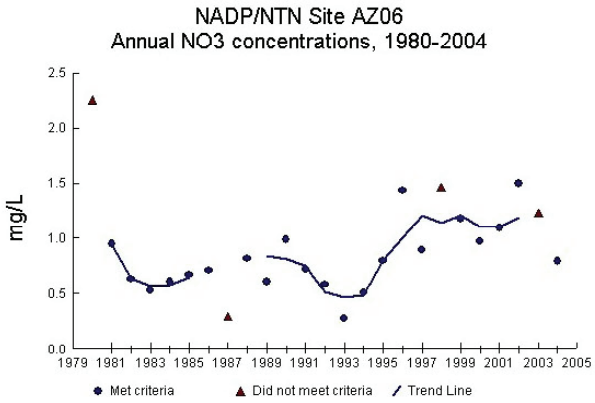

Figure 12-17. Trend plot for annual NO_3 concentrations, 1980-2004, Organ Pipe Cactus National Monument wet deposition site, National Atmospheric Deposition Program.

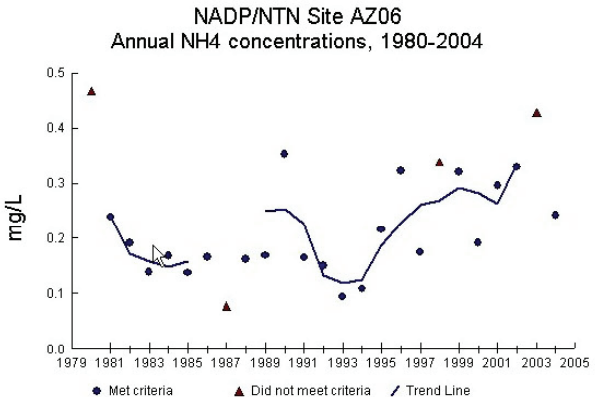

Figure 12-18. Trend plot for annual NH_4 concentrations, 1980-2004, Organ Pipe Cactus National Monument wet deposition site, National Atmospheric Deposition Program.

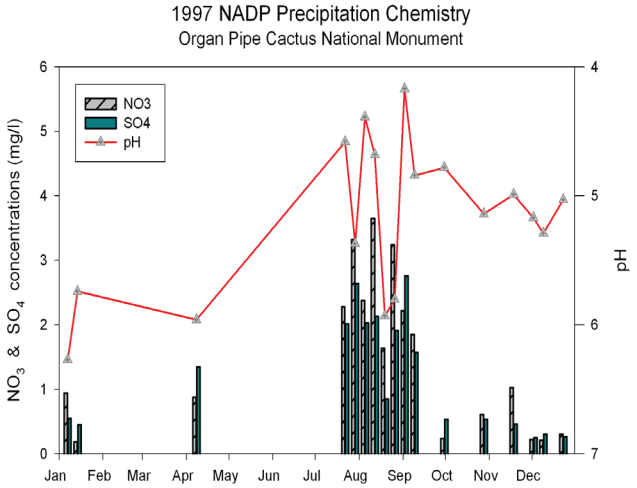

Figure 12-19. 1997 pH and NO_3 and SO_4 concentrations, Organ Pipe Cactus National Monument wet deposition site, National Atmospheric Deposition Program.

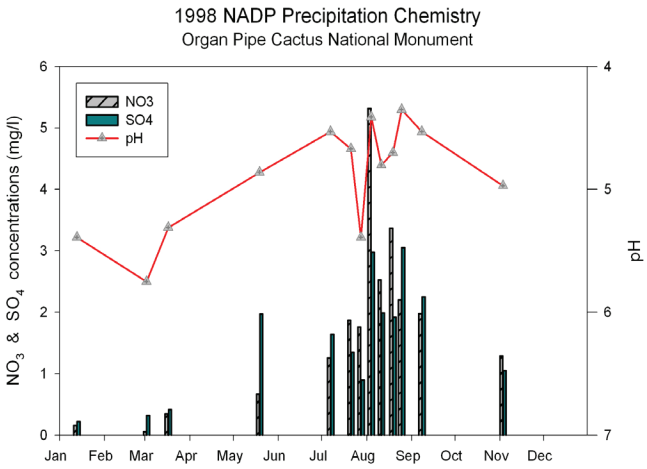

Figure 12-20. 1998 pH and NO_3 and SO_4 concentrations, Organ Pipe Cactus National Monument wet deposition site, National Atmospheric Deposition Program.

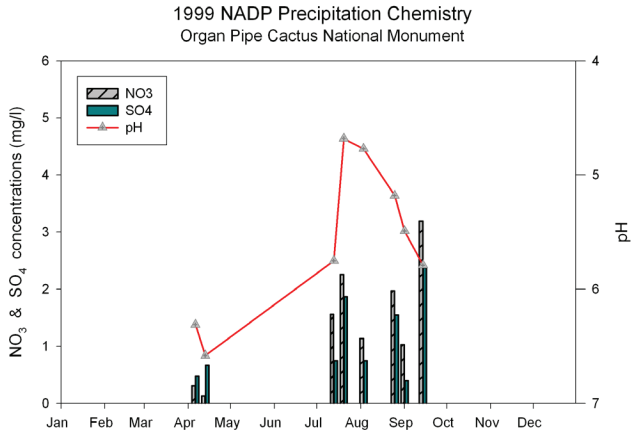

Figure 12-21. 1999 pH and NO_3 and SO_4 concentrations, Organ Pipe Cactus National Monument wet deposition site, National Atmospheric Deposition Program.

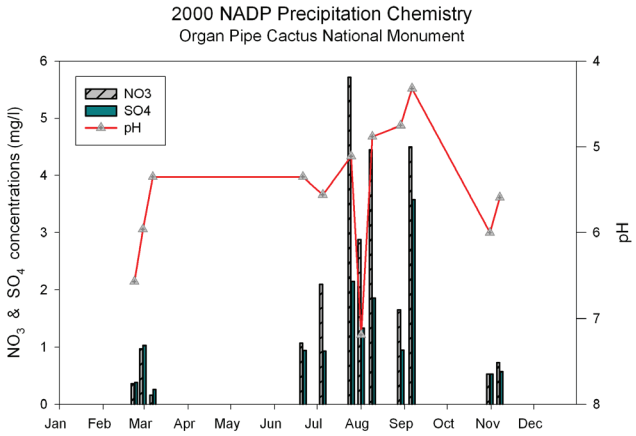

Figure 12-22. 2000 pH and NO_3 and SO_4 concentrations, Organ Pipe Cactus National Monument wet deposition site, National Atmospheric Deposition Program.

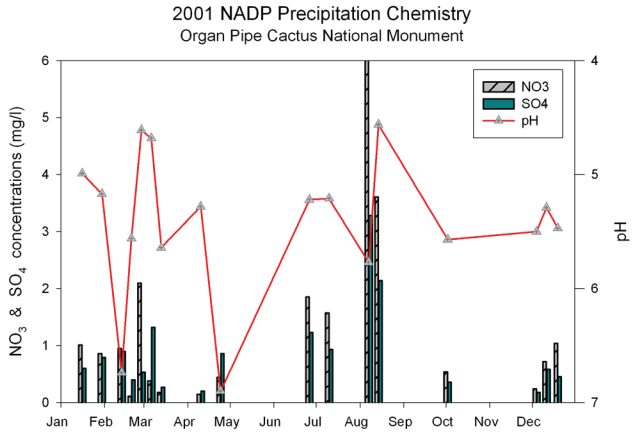

Figure 12-23. 2001 pH and NO_3 and SO_4 concentrations, Organ Pipe Cactus National Monument wet deposition site, National Atmospheric Deposition Program. (Value out of range = 8.28.)

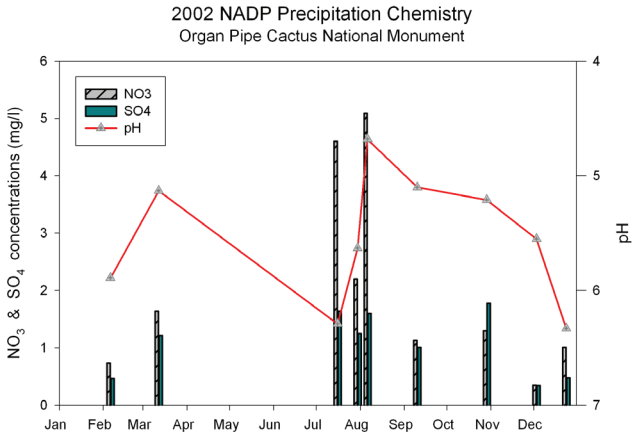

Figure 12-24. 2002 pH and NO_3 and SO_4 concentrations, Organ Pipe Cactus National Monument wet deposition site, National Atmospheric Deposition Program.

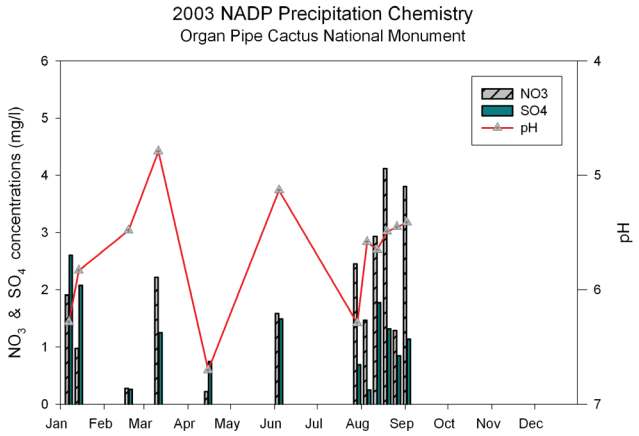

Figure 12-25. 2003 pH and NO_3 and SO_4 concentrations, Organ Pipe Cactus National Monument wet deposition site, National Atmospheric Deposition Program.

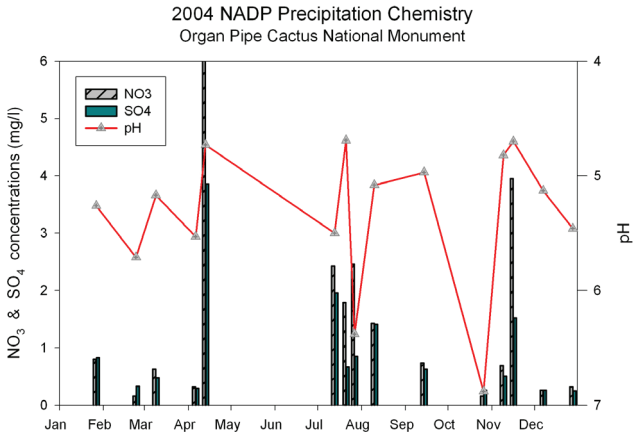

Figure 12-26. 2004 pH and NO_3 and SO_4 concentrations, Organ Pipe Cactus National Monument wet deposition site, National Atmospheric Deposition Program. (Value out of range = 8.36.)

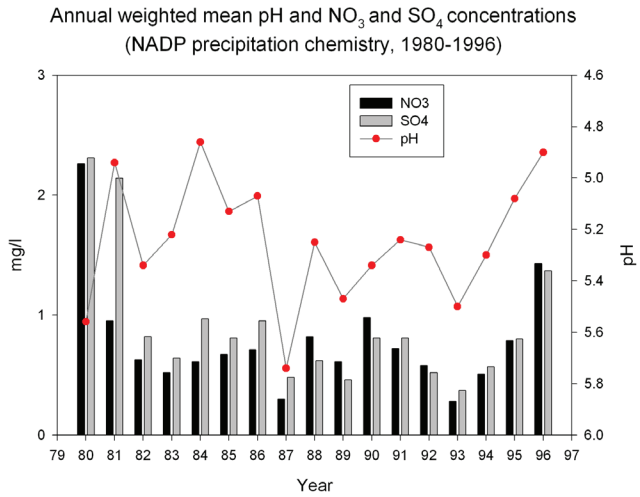

Figure 12-27. Annual weighted mean pH and NO_3 and SO_4 concentrations, 1980-1996, Organ Pipe Cactus National Monument wet deposition site, National Atmospheric Deposition Program.

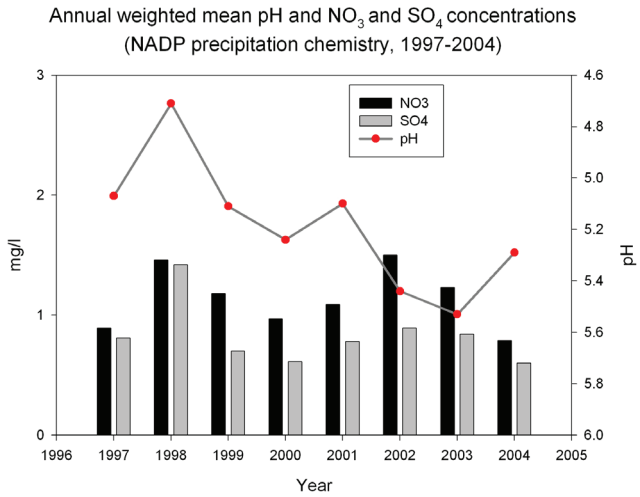

Figure 12-28. Annual weighted mean pH and NO_3 and SO_4 concentrations, 1997-2004, Organ Pipe Cactus National Monument wet deposition site, National Atmospheric Deposition Program.

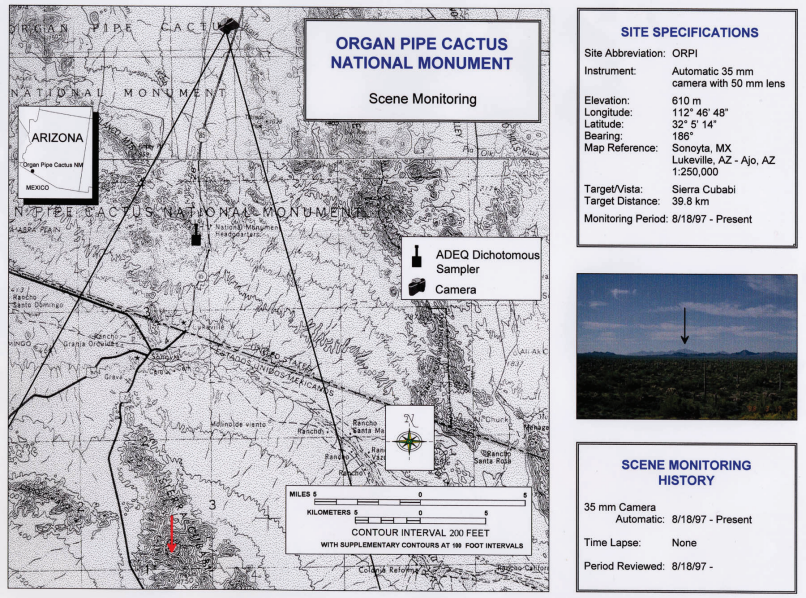

Figure 12-29. Site map of Organ Pipe Cactus National Monument visibility camera.

Organ Pipe Cactus National Monument
Representative Visibility Condition: **Good**

Organ Pipe Cactus National Monument
Representative Visibility Condition: **Medium**

Organ Pipe Cactus National Monument
Representative Visibility Condition: **Poor**

Organ Pipe Cactus National Monument
Representative Visibility Condition: **Bad**

Revised October 2005

Figure 12-30. Representative visibility conditions, 1997-2004, from Organ Pipe Cactus National Monument visibility camera.

Figure 12-31. Regional haze event on June 7, 2002, from Organ Pipe Cactus National Monument visibility camera.

Figure 12-32. Layered haze event on December 27, 2002, from Pinacate Biosphere Reserve visibility camera.

Groundwater

Colleen Filippone, Charles Conner, Ami Pate

Objectives

Quantifying and documenting groundwater resources, understanding effects of human activities on groundwater resources, understanding seasonal characteristics of groundwater flow regimes within the monument, understanding the response of groundwater storage to climate changes, providing data required for identifying long-term trends in groundwater availability and threats to surface waters.

Introduction

Groundwater is a prized resource at Organ Pipe Cactus National Monument (OPCNM). In addition to supporting plant life and supplying park facilities with potable water, groundwater is the source for important perennial surface water bodies including the Quitobaquito Springs and Pond complex, Williams Spring, Dripping Springs and Spring Arroyo Tinaja #2.

A total of ten wells are monitored quarterly by park staff for depth-to-water. Occasional monitoring occurs at park water supply wells. In the case of Pozo Salado well and Dowling Ranch well, measurement of depth to water is no longer possible due to obstruction or collapse within the well casing. Other wells, including Pozo Nuevo well and Hocker well, are of limited use at this time because water levels have declined below the bottom of the wells at these locations. Table 13-1 summarizes pertinent data for the wells discussed in this report. Locations of the wells included in the following discussion are indicated on Figure 13-1. Figure 13-2 illustrates the well locations relative to bedrock outcrop and alluvial surface geologic material.

Groundwater levels reflect water stored in void spaces between rock grains and in fractures. Volume of groundwater stored in the subsurface depends on porosity (void space) of the geologic host media, which may vary from near zero for dense igneous rocks to as high as 60% for very fine-grained sediments. Geologic conditions at OPCNM are typical of the Basin and Range geologic province, characterized by higher permeability, higher porosity alluvial deposits thickest in basin centers and thinning to the edges. The basins are bounded by mountainous uplands generally consisting of dense rock with lower porosity and permeability than the alluvium. The discussion of water levels that follows is based on this geologic paradigm.

In recent decades, research related to groundwater recharge in the arid desert regions of the Basin and Range province has greatly advanced our understanding of hydrologic processes in arid locations like OPCNM. (Hogan et al., 2004). The importance of mountain-front recharge as a predominant source of groundwater recharge to desert basins has been reinforced by determinations that where desert vegetation is present, virtually no deep percolation (recharge) occurs in basin areas away from ephemeral channels (Walvoord and Scanlon, 2004). Within basins, recharge is now understood to occur almost exclusively beneath ephemeral channels during flow events.

The following sections report monitoring results and provide brief overview interpretations of the data. The interpretations are of a general nature and are primarily based on the location of wells within the geologic setting at OPCNM. Detailed review of local geology, well geologic logs, and other pertinent data for each well where available is beyond the scope of this report. Along with graphs of depth to water at the wells, monthly total precipitation and cumulative precipitation derived from hourly data collected at the nearest climate station are plotted where available. Using

Figure 13-1. Location of monitoring wells, rain gauges and weather stations at Organ Pipe Cactus N.M.

regression analysis, trend lines were fitted to water level and monthly total precipitation data for the purpose of assessing long-term trends in the data.

When reviewing the plotted water level data and trend lines, it should be kept in mind that increasing depth to water, as plotted, indicates decreasing water level elevation. Trend lines, reported as regression coefficients, are reported in the figures and in Table 13-2 as feet per day for depth to water and as inches per month per day for monthly total precipitation. In the text discussion, regression coefficient values are reported as feet/year and inches/month/year for convenience.

Results

Alamo Wash Well

Alamo Wash Well (Alamo) is a 17-foot deep well located in a steep drainage on the west side of the rugged Ajo Mountain Range (Figures 1 and 2). Bedrock in the immediate area is volcanic in origin. Water levels as depth to water measured at Alamo Wash well are shown in Figure 13-3. The Alamo Canyon (ALAM) rain gauge is located nearby. Surface waters in Alamo Wash flow northwesterly toward Cherioni Wash. There are no known sources of anthropogenic groundwater extraction currently occurring in the vicinity of this well.

The period of record for Alamo extends from January 1987 to July 2005. As Figure 13-3 illustrates, depth to water at this well has varied between 12.7 feet and 1.7 feet over the period of record, a range of 11.0 feet. Also shown in Figure 13-3 are monthly total precipitation recorded at the nearby rain gauge (ALAM) and cumulative precipitation at that station over the precipitation monitoring period. Variability in water levels at this location is attributed to episodic down-gradient flow of precipitation infiltrated above the well within the substantial Alamo Wash watershed. The highest water levels in the well occur consistently in winter or spring, although some years do show water level increases of a lesser magnitude following the monsoon season. While an in-depth analysis is beyond the scope of this report, the availability of extended climatic, vegetation and water level data at this location is potentially useful for the analysis of mountain-front recharge at this location. Relationships between the duration and intensity of precipitation events and the effects of evapotranspirative demand on recharge are not well established for arid regions. Such an analysis would be of significant value in improving estimates of recharge to basins in arid regions. Results would have potentially wide applicability to the development of water balance components for arid region mountain-basin systems.

Regression coefficients for depth to water and monthly total precipitation at Alamo Wash well and Alamo Canyon rain gauge are shown on the lower graph in Figure 13-3. Regression coefficients for water levels at all wells and monthly precipitation data discussed here are summarized in Table 13-2. The coefficients shown on Figure 13-3 indicate that over the period of record, water levels have decreased at a rate of about 0.01 feet per year. Monthly total precipitation at the nearby rain gauge has decreased at a rate of 0.01 inch per month per year over the period shown in Figure 13-3.

Bates Well

Bates Well is a 67-foot deep well located in the alluvium of Growler Wash, west of Growler Pass on the former Bates ranch property (Figure 13-1). Bedrock in the area consists of intrusive and extrusive igneous rock types, with the Growler Mountains to the north and the Bates Mountains to the south and east. The primary source of groundwater in this area is most likely recharge originating as precipitation in the Growler Mountains. Subflow beneath Cherioni and Cuerda de Leña washes may contribute to groundwater at this location via Growler Wash. There are no known sources of anthropogenic groundwater extraction in the vicinity of this well.

Depth to water at Bates Well and monthly total

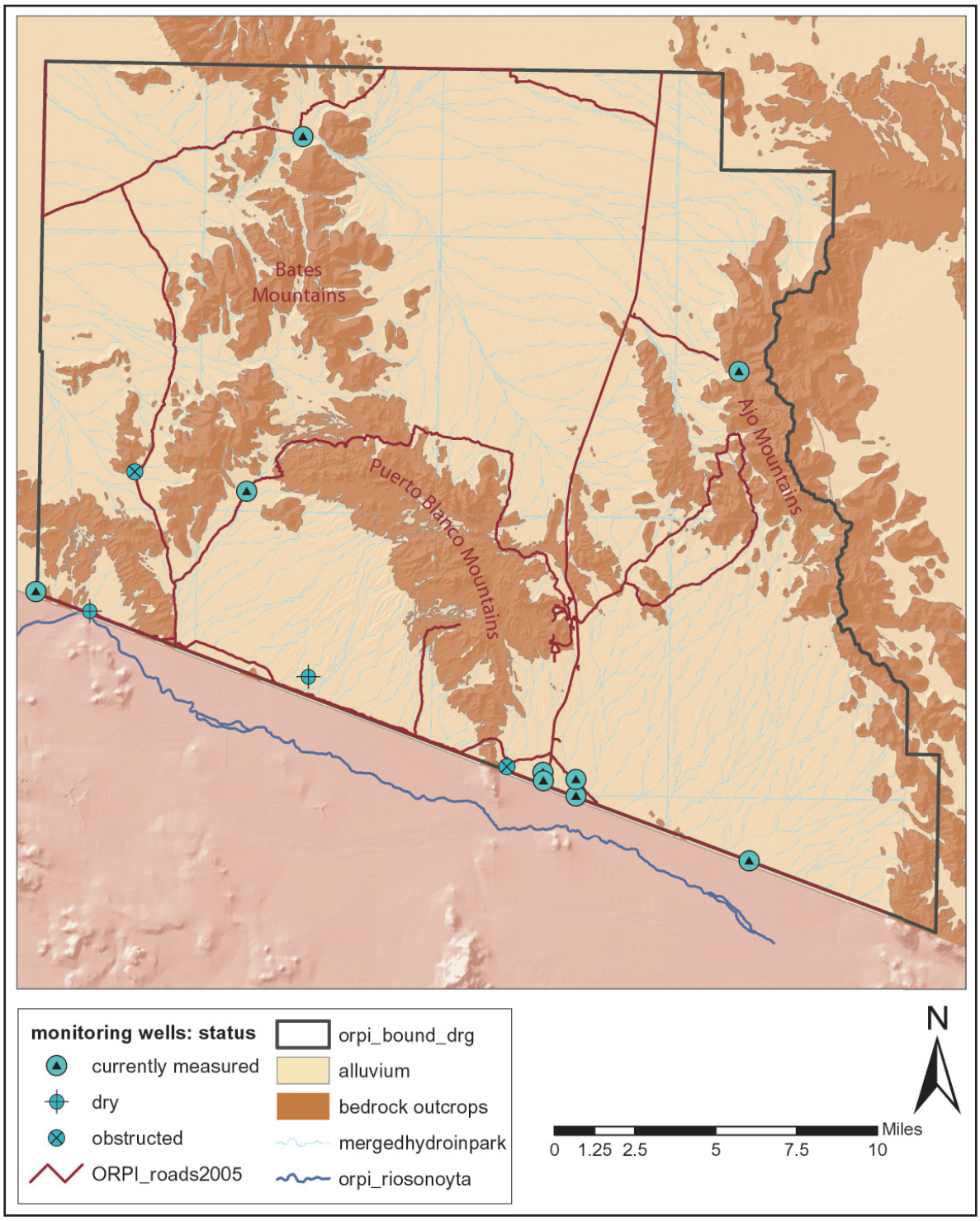

Figure 13-2. Monitoring well locations and geologic context, Organ Pipe Cactus N.M.

Table 13-1. Summary of well names and selected data, Organ Pipe Cactus N.M. (*the ADWR Wells 55 registry lists multiple wells with the same name. Unsure which is correct for this well at this time; *Groundwater drainage basins from NPS (1992), Figure 5.)

Well Name	Surface Elevation (ft)	Total Depth Well/Hole (ft)	Well Identifier (USGS and ADWR systems)	Well Location Hydrologic Unit Code (HUC)/ Groundwater Drainage Basin*
Alamo Canyon	~2,430(est)	17/21	ADWR 629154/ ADWR 632184*	San Cristobal Wash 15070203/ Valley of the Ajo
Bates	~1,350(est)	67/80	ADWR 629121/ ADWR 629122/ ADWR 632186*	San Cristobal Wash 15070203/ West of Bates Mountain
Pozo Nuevo	~1,260(est)	134/170	ADWR 629152/ ADWR 632185*	San Cristobal Wash 15070203/ West of Bates Mountain
Bonita	1,355	37/40	USGS 320115112573001 C-16-07 27BAD UNSURV ADWR 629153	Rio Sonoyta 15080102/West of Sonoyta Valley
Corner	1,000	97/101	USGS 315743113050201 C-17-08 09ADD UNSURV	Rio Sonoyta 15080102/West of Sonoyta Valley
Dowling	1,432		USGS 315315112501002 C-18-06 01DBB2	Rio Sonoyta 15080102/Sonoyta Valley
Hocker	981	18/18.7	USGS 315712113032101 C-17-08 11DCD UNSURV	Rio Sonoyta 15080102/West of Sonoyta Valley
Kalil	1,390	187	USGS 315254112490201 C-18-05 06DCD	Rio Sonoyta 15080102/Sonoyta Valley
Stack	1,405	206 (?)	USGS 315313112490701 C-18-05 06DBB	Rio Sonoyta 15080102/Sonoyta Valley
USGS #1 Camino Dos Republicas	1,400	250	USGS 315257112475301 C-18-05 05DDC	Rio Sonoyta 15080102/Sonoyta Valley
USGS #2 Lukeville	1,390	238/250	USGS 315232112475501 C-18-05 08ACA	Rio Sonoyta 15080102/Sonoyta Valley
USGS #3 Salsola	1,460	278/300	USGS 315056112424301 C-18-04 19AAC UNSURV	Rio Sonoyta 15080102/Sonoyta Valley
Headquarters #4 (South Well)	1,665	400/430	USGS 315655112480301 C-17-05 17ACB UNSURV ADWR 629089/ ADWR 632188	Rio Sonoyta 15080102/Sonoyta Valley
Headquarters #5 (North Well)	1,660	420	USGS 315702112480401 C-17-05 17ABC2 UNSURV ADWR 629090/ ADWR 632182*	Rio Sonoyta 15080102/Sonoyta Valley

precipitation recorded at the nearby Growler Valley rain gauge (1982-1987) and climate station (1987-2004) are shown in Figure 13-4. The period of record at Bates Well extends from January 1987 to July 2005. Over the monitoring period water levels have fluctuated over a range of 16.2 feet, with depth to water at Bates Well varying between 42.9 ft and 26.7 ft below the measuring point. Water levels at Bates well are generally higher (smaller depth to water) following the monsoon season and extending through the winter months, declining during the summer.

Groundwater levels here are sustained by subflow from recharge in the nearby watershed. Localized groundwater flow between the Valley of the Ajo and the west side of the Bates Mountains may occur beneath the wash that flows through Growler Canyon but is unlikely on a larger scale. As shown in Figure 13-4, an extended water level decline at Bates well began in January of 1991 and has continued with minor reversals to the current time. The rate of water level decline at this location is 0.7 feet/year, while the decline in monthly total precipitation at the nearby station has been only 0.03 inches/month/year.

Water levels at Bates well are currently the lowest recorded since the start of monitoring (highest depth to water). This long-term trend of decreasing water levels should be of concern to resource managers due to the accelerated rate of decline compared to other similarly situated wells (such as Bonita and Pozo Nuevo wells) and the unexplained nature of the decline. One potential cause of decreased groundwater availability at this location that should be investigated is the impact of diversion of surface flows by entrenchment of the Bates Well Road on infiltration in the watershed, both east and west of Growler Pass.

Since this well is the only long-term groundwater monitoring point in the northwestern quadrant of the park, and taking into account the observed decline of water levels, monitoring data from Bates well is considered to be extremely important to understanding long-term ecological function of the area. In particular, where depth to water in the well vicinity during the late 1980's and early 1990's may have been sufficient to marginal for the support of riparian trees, current depths to water at Bates well most likely exceed the ability of many woody species to survive.

Regression coefficients for depth to water at Bates well and monthly total precipitation at Growler Valley rain gauge/climate station are shown in the lower plot of Figure 13-4. These will be discussed in a later section.

Bonita Well

Bonita well is a 37-foot deep well located in the alluvium of Aguajita Wash east of the Cipriano Hills and west of the Puerto Blanco Mountains (Figure 13-1). Local bedrock is of volcanic origin. This well is the northwestern control point for understanding groundwater flow beneath La Abra Plain, the source waters for a very key natural resource, the Quitobaquito Spring and Pond complex. As such, water level data from this location are of especially great importance.

Depth to water at Bonita well and precipitation data from the Pozo Nuevo rain gauge and climate station are shown in Figure 13-5. The period of record at Bonita well extends from January 1987 to July 2005. During this time period, maximum depth to water was 33.7 feet and minimum depth to water was 25.0 feet, for a total range of 8.7 feet. Regression indicates that water levels at this location have declined about 0.2 feet/year during the period of record, while monthly total precipitation has declined 0.03 inches/month/year.

The quarterly monitoring indicates that the contribution of summer precipitation to groundwater at this location is substantial, with annual maximum water levels often occurring in October. This result highlights the importance of ephemeral channel and/or mountain front recharge during the summer monsoon period along Aguajita Wash to water levels at this

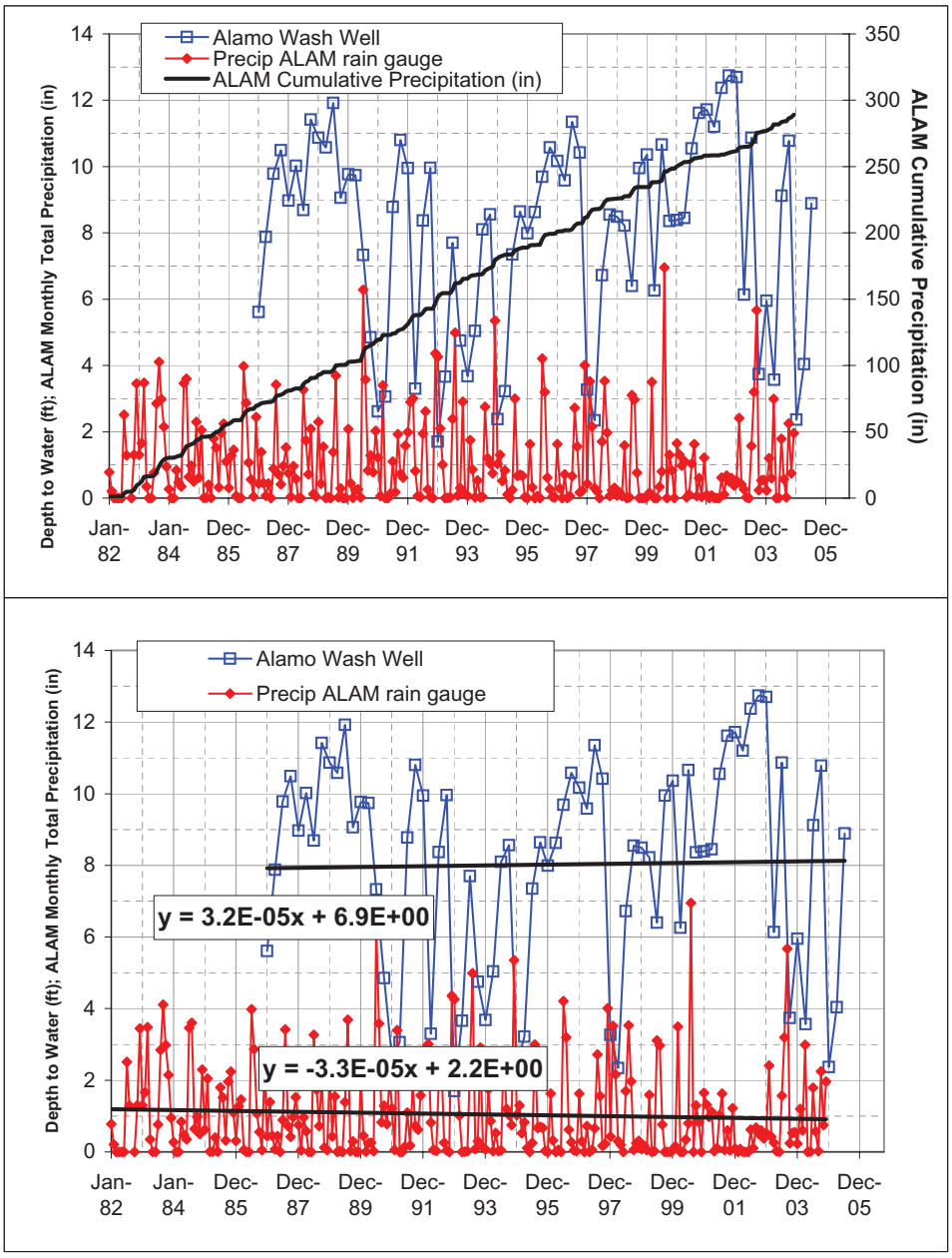

Figure 13-3. Alamo Wash well depth to water, Alamo Canyon rain gauge monthly total and cumulative precipitation data, and regression equations for each, Organ Pipe Cactus N.M.

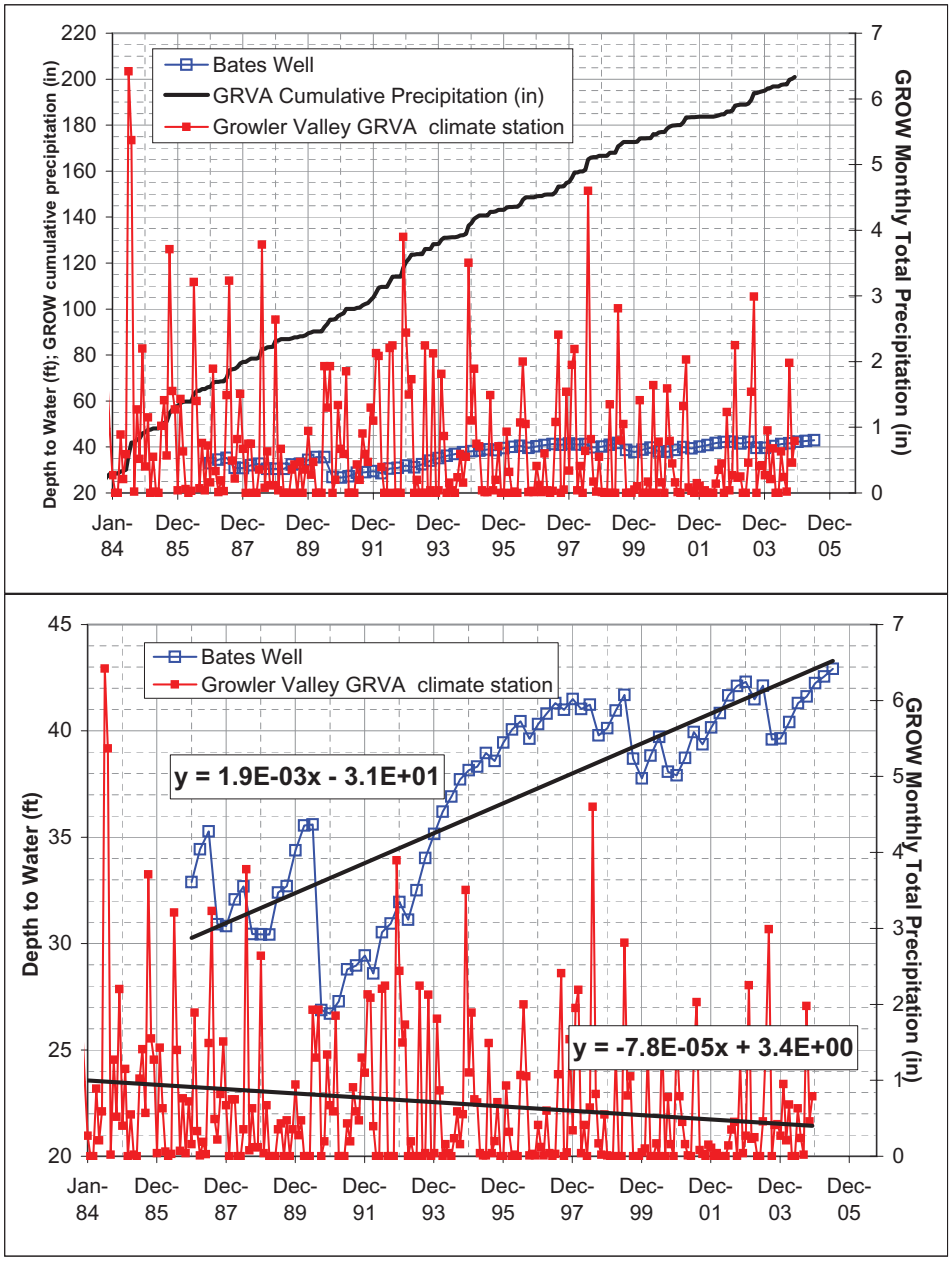

Figure 13-4. Bates well depth to water, Growler Valley rain gauge and climate station monthly total and cumulative precipitation, and regression equations, Organ Pipe Cactus N.M.

location.

Regression coefficients for depth to water at Bonita well and monthly total precipitation at the Pozo Nuevo rain gauge and climate station are shown in the lower plot of Figure 13-5. These will be discussed in a later section.

Pozo Nuevo Well
Pozo Nuevo well is a 134-foot deep well located in alluvium in the upper reaches of San Cristobal Wash, west of the Cipriano Hills (Figure 13-1). Bedrock in the area is of volcanic origin. Water level measurements were made at this well from January 1987 to October 2001, after which time the well was reported to be blocked and inaccessible for obtaining water level data. Over the period of record, depths to water at Pozo Nuevo well ranged 9 feet, between 48.2 feet and 39.2 feet below the measurement point, with an overall downward trend. Regression indicates a water level decline of 0.3 feet/year at Pozo Nuevo. Monthly total precipitation at this location was found to decline 0.03 inches/month/year.

Depth to water at Pozo Nuevo well and monthly total precipitation at Pozo Nuevo rain gauge and climate station are shown in Figure 13-6. Maximum annual water levels at the well occurred most often during the winter season, but sometimes occurred in October. Depth to water at Pozo Nuevo well fluctuates in a similar manner to Bonita well, where a combination of rapid response to channel infiltration during surface flow events and a dampened component derived from subflow and percolation of infiltrated waters from the upper drainage areas (mountain-front recharge) appears evident.

Figure 13-7 illustrates water levels for both Bonita and Pozo Nuevo wells. Water level fluctuations over time at both of these wells share many characteristics, not an entirely surprising result since they similarly situated geologically. The range of water levels at both wells is around nine feet, although the difference in the surface elevations of the wells themselves is nearly 100 feet. Neither of these wells is known to be impacted by groundwater pumping.

Regression coefficients for depth to water at Pozo Nuevo well and monthly total precipitation at the Pozo Nuevo rain gauge and climate station are shown in the lower plot of Figure 6 and are summarized in Table 13-2. These will be discussed in a later section.

Corner Well
Corner well is a 97-foot deep well located in the southwest corner of Organ Pipe Cactus National Monument (Figure 13-1). Corner well is situated in alluvium nearer the basin center than any of the wells dicussed above. Bedrock outcropping at the nearby Quitobaquito Hills is granitic. Depth to water at Corner well and monthly total and cumulative precipitation at the nearby Quitobaquito rain gauge are shown in Figure 13-8. Groundwater pumping south of the U.S. border with Mexico is an unknown and unquantified potential impact at this location.

Water levels at this well show the smallest range of the monitoring wells at 3.9 feet. The greatest depth to water measured at this location during monitoring to date is 62.58 feet, while the smallest depth to water (highest water level) during the same period was 58.65 feet. In most years, the highest water levels occur in April. Relatively stable water levels here likely result from the lack of substantial mountains that could contribute mountain-front recharge and the fact that the well is not located near a major wash. There is a wash nearby, but that channel drains a relatively minor area of the low-relief Quitobaquito Hills compared with the substantial relief and drainage area contributing to washes at which Alamo, Bonita, Pozo Nuevo and Bates well are located. In addition, surface geology at this location does not suggest a confluence of groundwater flow passing through this area as is the case for those wells.

As the lower plot in Figure 13-8 illustrates, water levels are declining very consistently over the

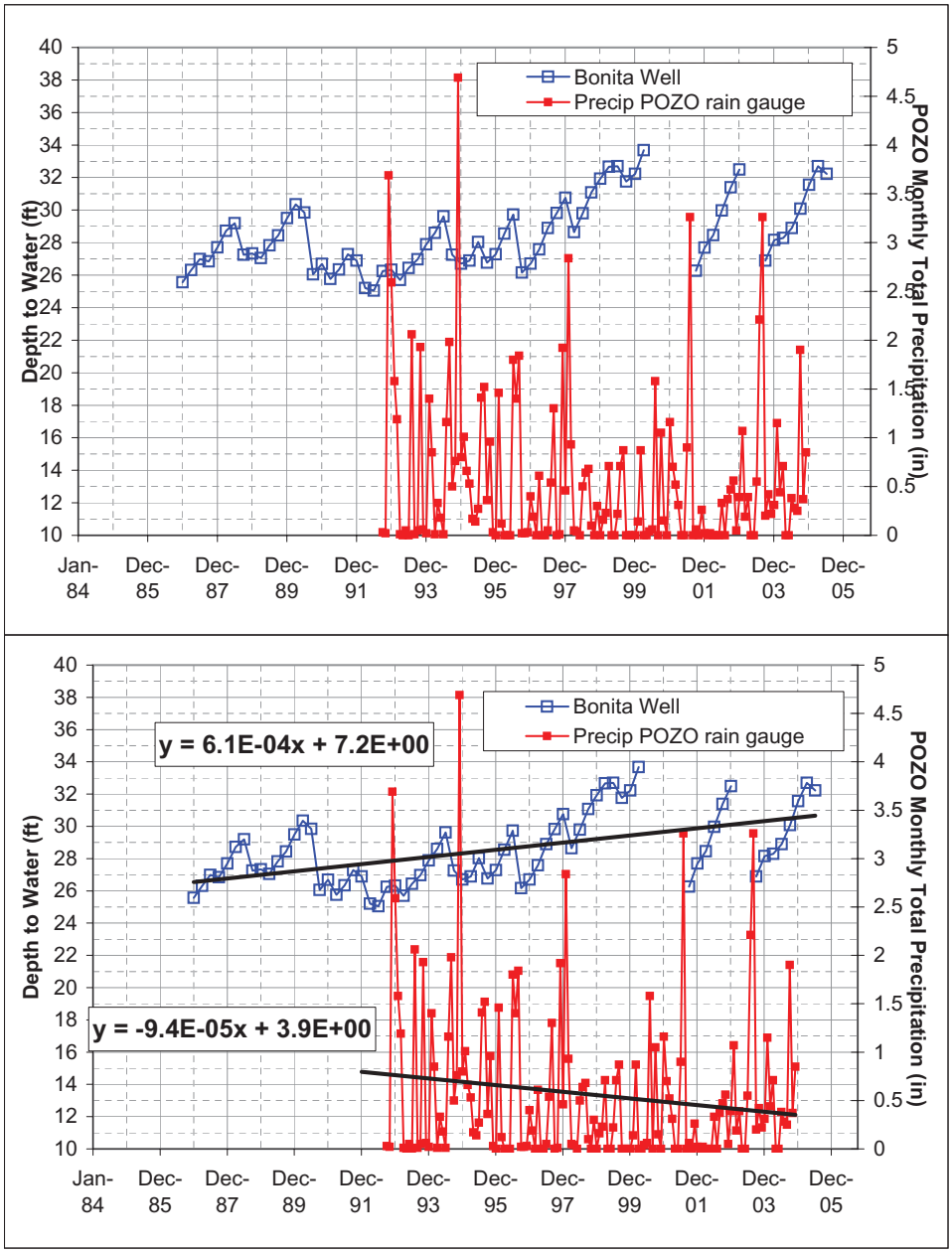

Figure 13-5. Bonita well depth to water, Pozo Nuevo rain gauge and climate station monthly total precipitation, and regression equations, Organ Pipe Cactus N.M.

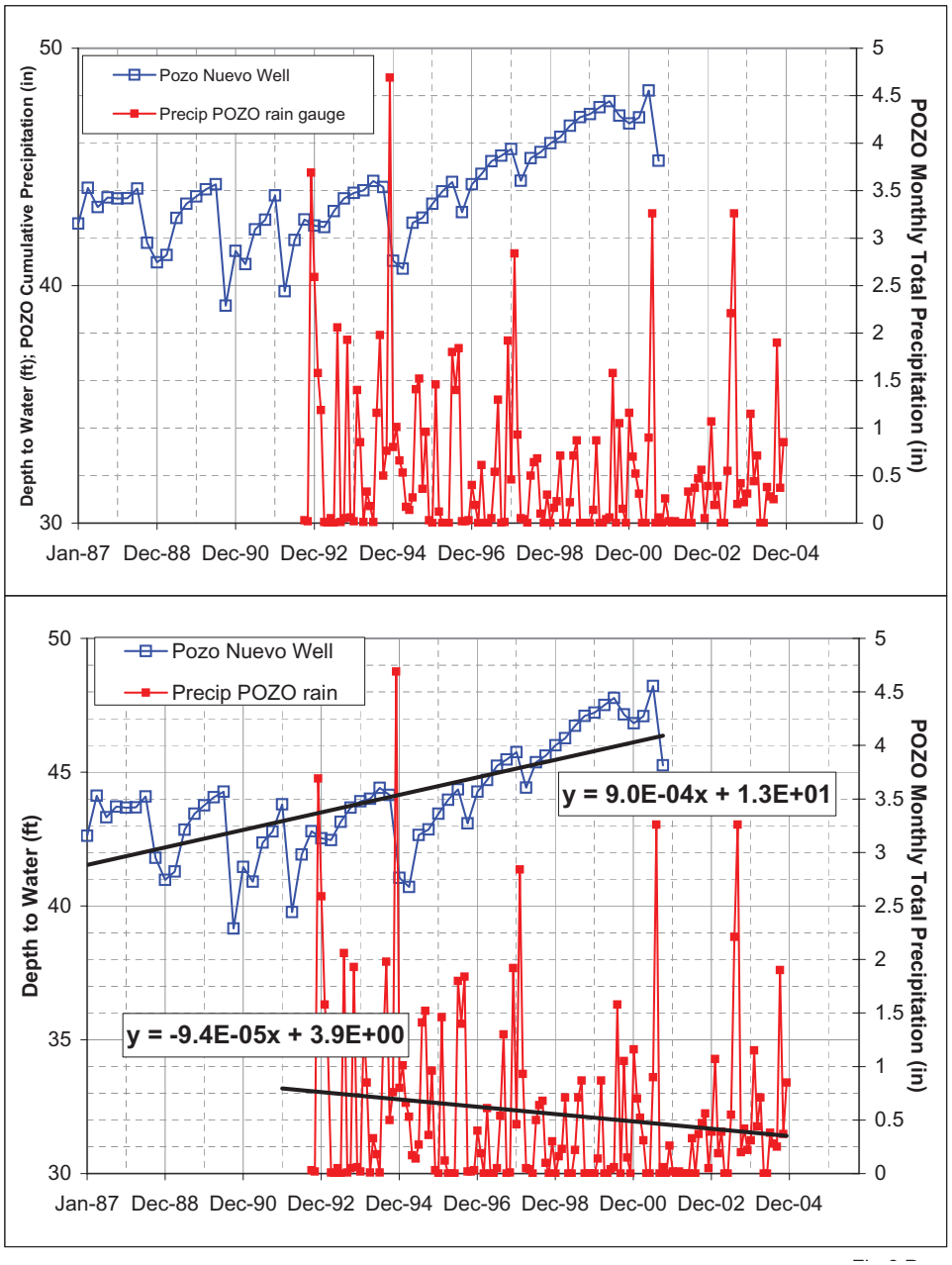

Figure 13-6. Pozo Nuevo well depth to water, Pozo Nuevo rain gauge and climate station monthly total precipitation, and regression equations, Organ Pipe Cactus N.M.

monitoring period. The declines are persisting at a rate of 0.2 feet/year. Monthly total precipitation decreases over the monitoring period at a rate of about 0.03 inches/month/year. Regression coefficients for depth to water at Corner well and monthly total precipitation at Quitobaquito rain gauge are summarized in Figure 8 and in Table 2. These will be discussed further in a later section.

Lukeville area wells

As shown in Figure 13-9, four wells are located in the immediate vicinity of the border city of Lukeville. Unlike Alamo, Bates, Bonita and Pozo Nuevo wells, the Lukeville area wells are located away from bedrock outcrops toward the interior of the Sonoyta Valley basin. Depths to water for these four wells are plotted in Figure 13-10. As Figure 13-10 illustrates, all of these wells show cyclic decreases in water levels (increases in depth to water) during the summer months, followed by partial recovery in the winter months. Minimum annual water levels (maximum depths to water) at these wells are typically recorded during the July monitoring cycle. Since water table recovery due to recharge at these wells is not sufficient to return water levels to former elevations from year to year, long-term water table declines at all of the Lukeville area wells are pronounced as shown in Figure 13-10. Long-term declines indicate a net loss of storage in the groundwater system, attributable to an imbalance between recharge and losses from the groundwater system. Groundwater pumping in the immediate area north and south of the U.S. –Mexico border is believed to be the major cause of summertime water table declines in this area.

The Lukeville area wells will be discussed in conjunction with the Dowling Ranch rain gauge. Dowling rain gauge is located at the Dowling Ranch area, west of Lukeville and east of the Sonoyta Mountains. Monthly total and cumulative precipitation for this rain gage are plotted in Figure 13-11. Regression analysis for the Dowling monthly total precipitation record indicates a long-term decline in monthly total precipitation of 0.016 inch/month/year (-4.4×10^{-5} inch/month/day).

Stack Well

Stack well is an approximately 200-foot deep well located in alluvium west of State Highway 85 near Lukeville. The monitoring record at Stack well spans the time period from January 1987 to the present. Depth to water at Stack is greatest of the four area wells, varying between 98.2 and 115.3 feet, for a total range of 17.1 feet over the period of record. The data record indicates a consistent annual water table rise in the winter months and fall in the summer months. As noted above, winter water table recoveries in the Lukeville area are not sufficient to attain the previous year's water levels. This annual deficit results in sustained long-term decline in water levels at this location of 0.9 feet/year.

Kalil Well

Kalil well is a 187-foot deep well located near Lukeville, south of Stack well and just east of State Highway 85 as shown on Figure 13-9. The monitoring record at Kalil well begins in January 1977 and continues to the present, providing the longest data record for the Lukeville area wells. Depth to water at Kalil well has varied from 66.0 to 96.3 feet, ranging over a total of 30.3 feet during the period of record. Regression analysis indicates that long-term water table elevation decline at Kalil well is 0.8 feet/year.

USGS #1 Camino Dos Republicas Well

The 250-foot deep USGS #1 Camino Dos Republicas well is located one-half mile north of the international boundary and one mile east of Lukeville along the Camino de Dos Republicas road (Figure 13-9). The NPS monitoring record at USGS #1 spans the time period from January 1993 to the present. The USGS-designated wells were continuously monitored in 1989 by U.S. Geological Survey (USGS) staff (NPS, 1992), but those data are not currently in hand for including in this report. Depths to water at this location have varied from 85.7 to 103.0 feet, a total range of 17.3 feet. Regression analysis of data from this well indicate a long-term water table decline of

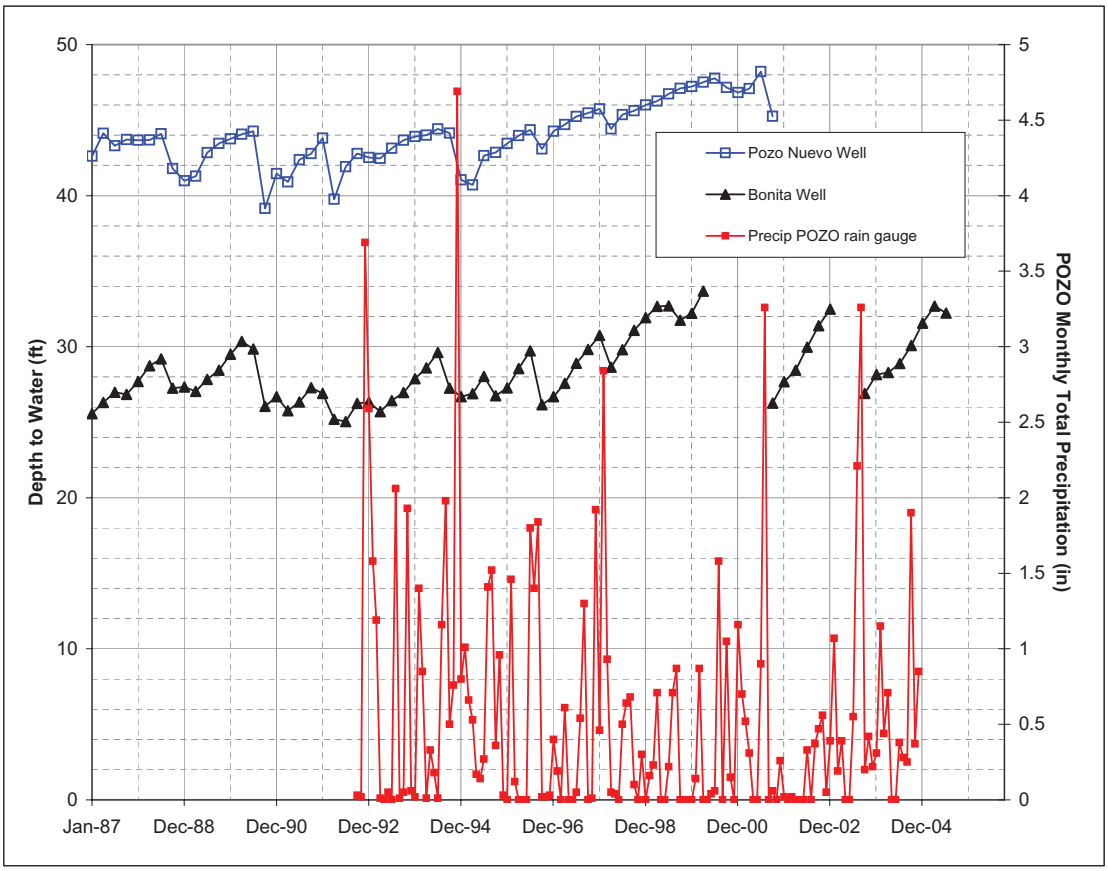

Figure 13-7. Pozo Nuevo and Bonita wells depth to water and Pozo Nuevo rain gauge and climate station monthly total precipitaion.

1.0 foot/year at Camino Dos Republicas.

USGS #2 Lukeville Well

The 238-foot deep USGS #2 Lukeville well is located along the international boundary one mile east of Lukeville (Figure 13-9). The well is reported to be about 238 feet in depth. Monitoring records at this well are similar to those at USGS #1, discussed above. Organ Pipe Cactus National Monument staff monitor this location on a quarterly basis since 1993. Depth to water at USGS #2 Lukeville well over this period have ranged between 72.2 and 91.5 feet, a range of 19.3 feet. Continuous monitoring data from this well for 1989 were reported in NPS (1992) but are not available for inclusion here. Regression analysis for data from this well indicate a long-term water table decline of 1.0 foot/year at USGS #2 Lukeville well.

USGS #3 Salsola

The 278-foot deep USGS #3 Salsola well is located 6.5 miles southeast of Lukeville along the international border. As shown in Figure 2, this well is more central to a basin interior than any other well discussed here. Monitoring history of USGS #3 Salsola is similar to that of the previous two USGS-designated wells. Depth to water at this location, shown in Figure 13-12, has ranged from 94.6 to 99.5 feet over the period of NPS monitoring beginning in 1993. The USGS continuous monitoring record in 1989 indicates a depth to water of 102 feet below ground surface in December 1988 (NPS 1992). The nearest precipitation record to this well is available at the Salsola climate station, shown in Figure 13-9.

Depths to water at the USGS #3 Salsola well show a long-term water level increase, the only location

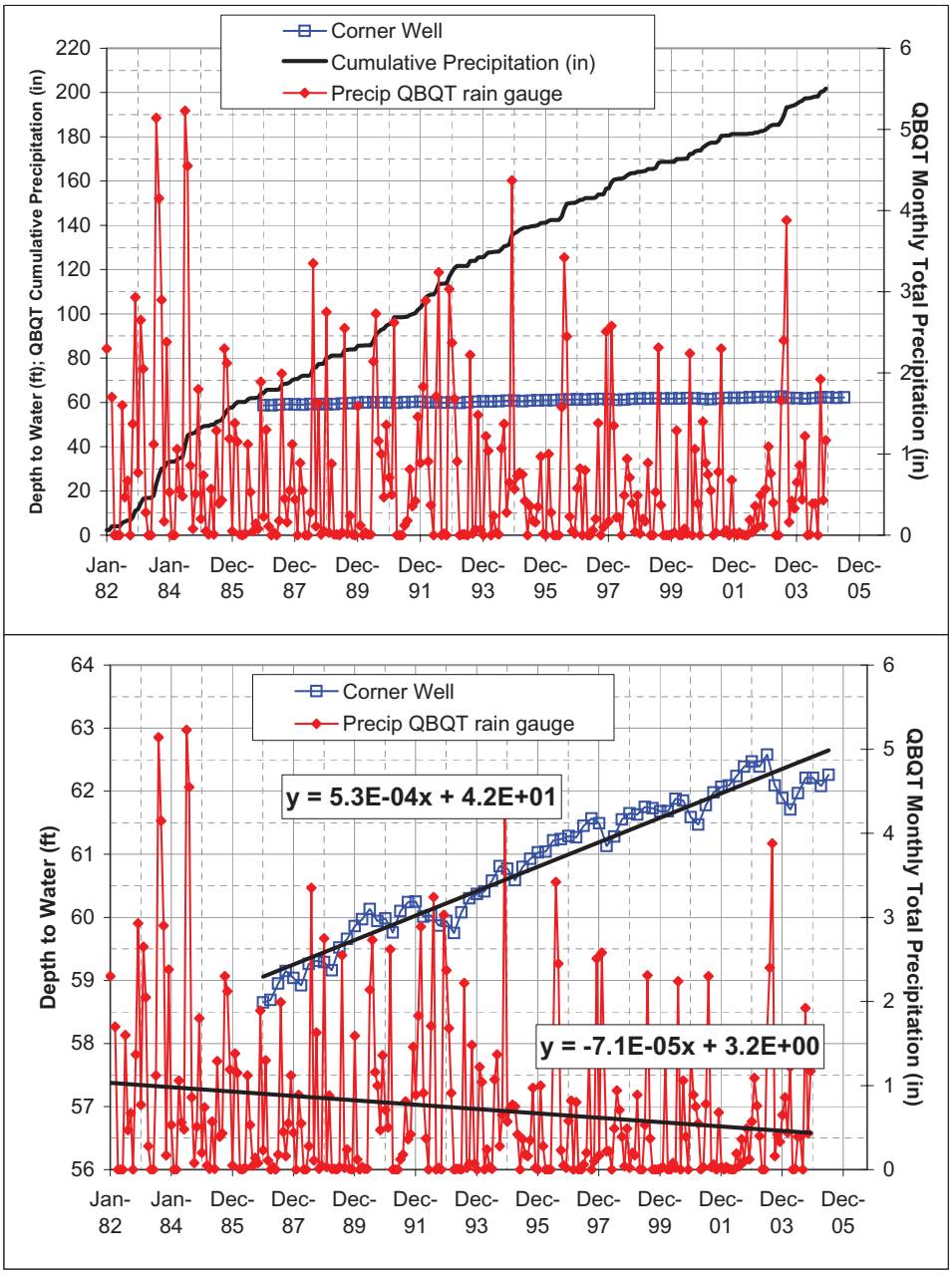

Figure 13-8. Corner well depth to water, Quitobaquito climate station monthly total and cumulative precipitation, and regression equations, Organ Pipe Cactus N.M.

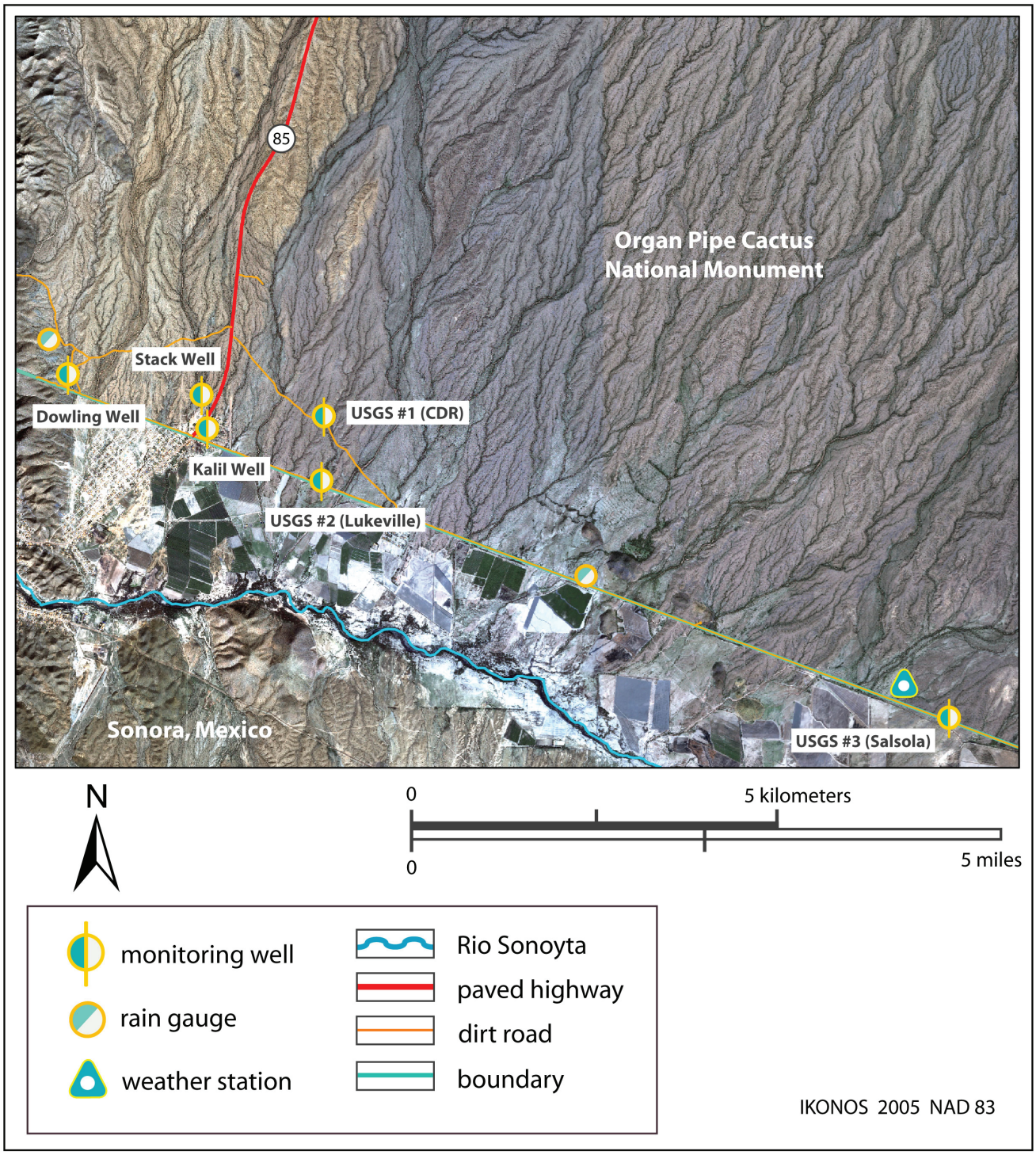

Figure 13-9. Lukeville area wells, Organ Pipe Cactus N.M.

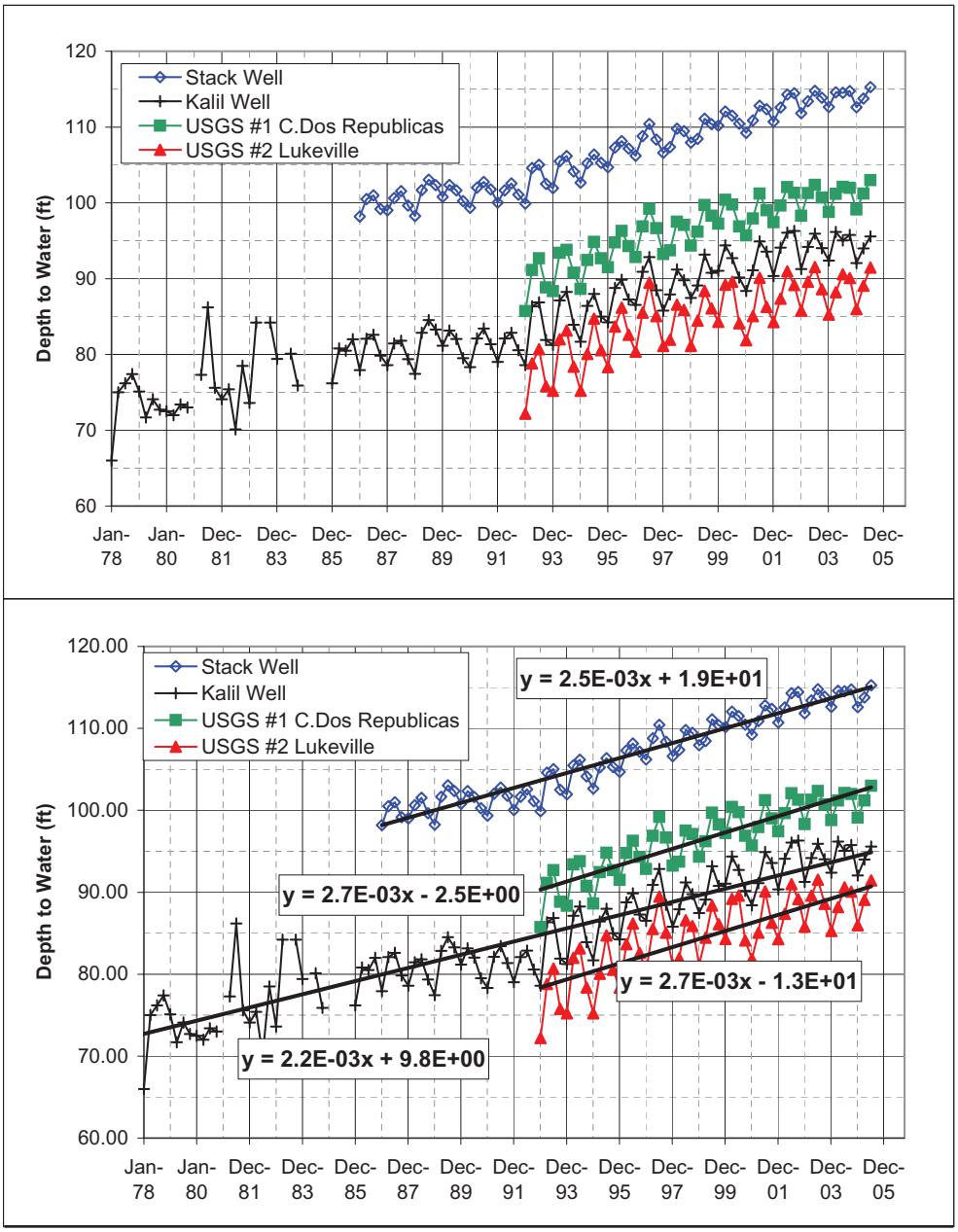

Figure 13-10. Lukeville area wells: Stack, Kalil, USGS #1 and USGS #2 wells depth to water and regression equations, Organ Pipe Cactus N.M.

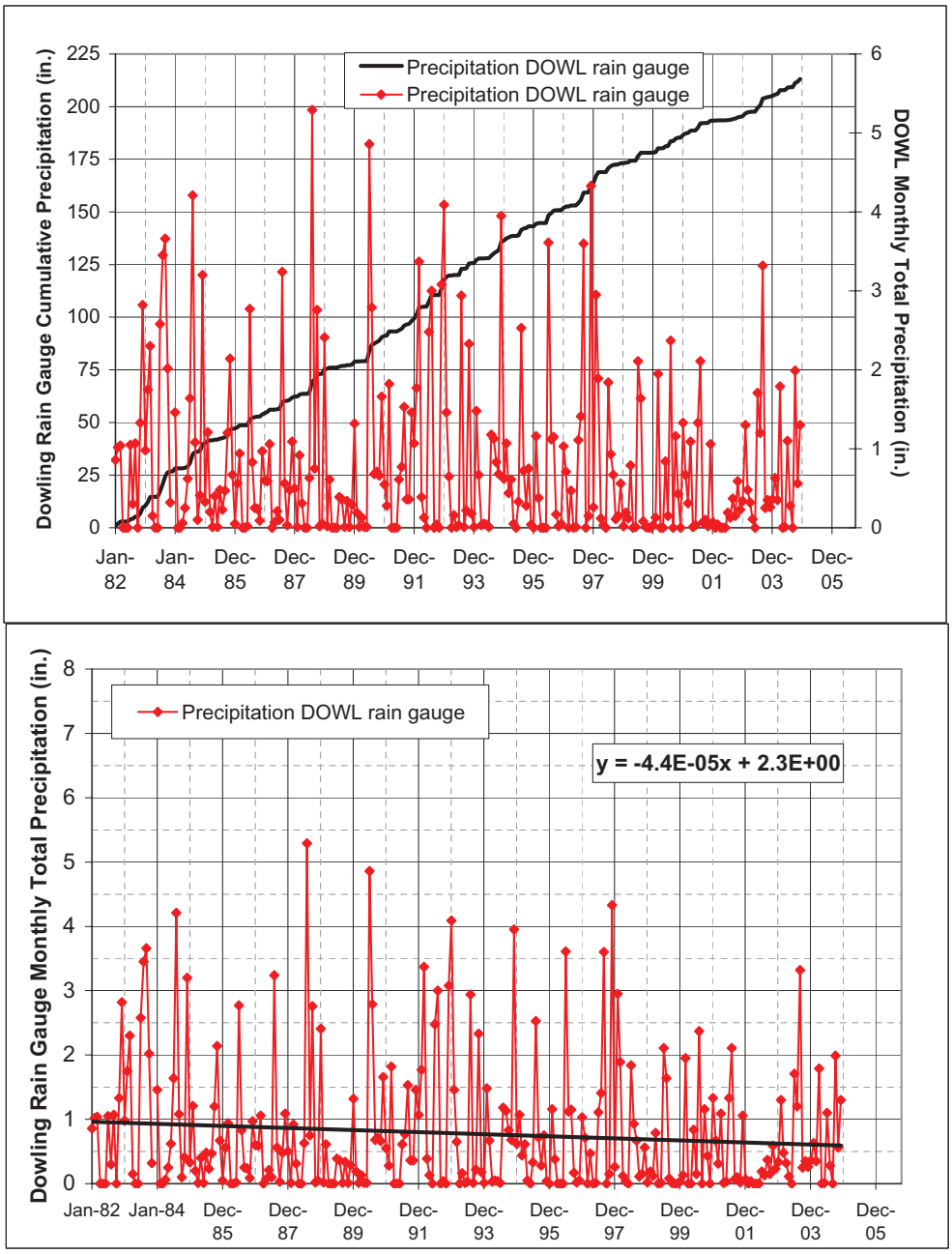

Figure 13-11. Dowling rain gauge monthly total and cumulative precipitation and regression equation, Organ Pipe Cactus N.M.

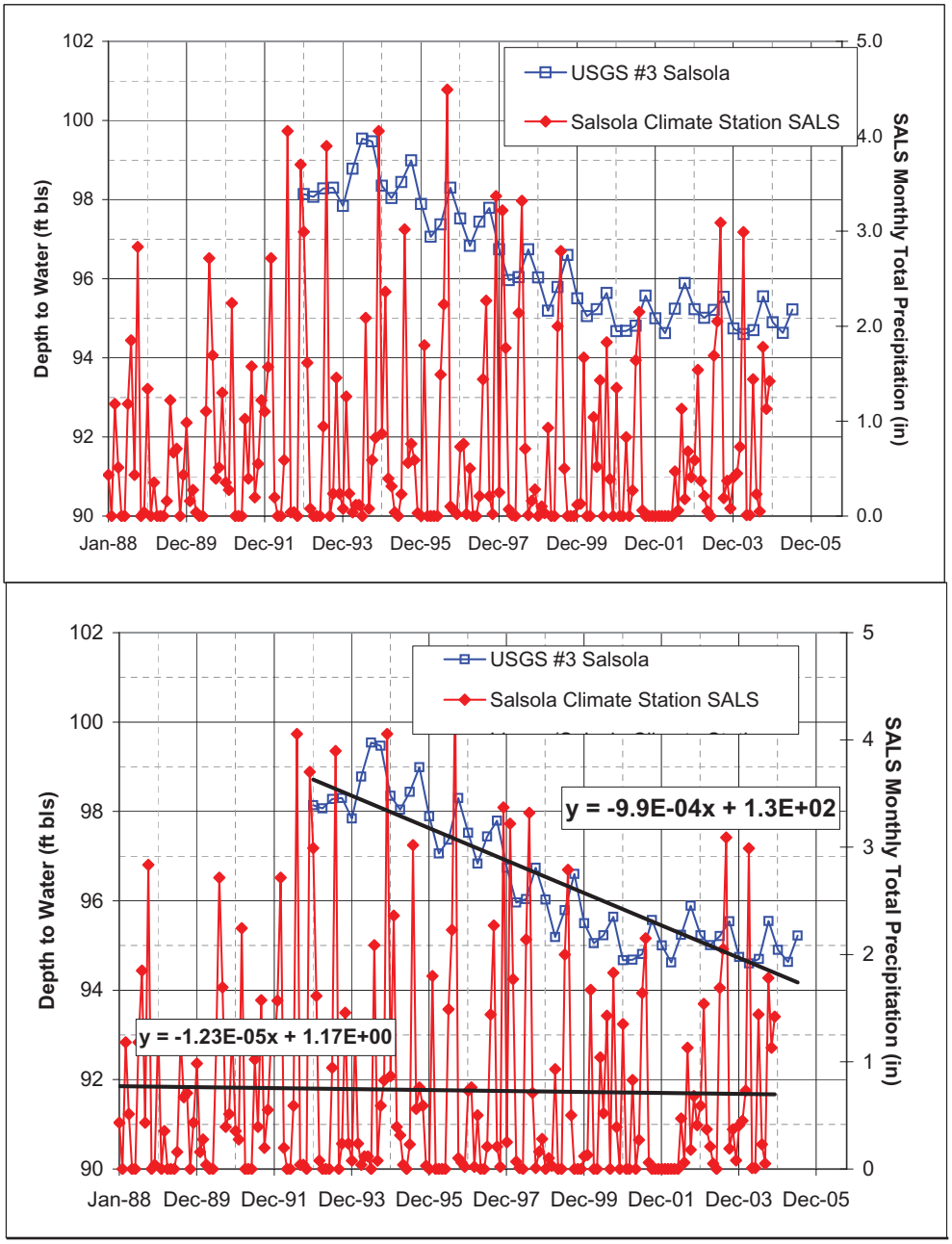

Figure 13-12. USGS #3 Salsola well depth to water, Salsola climate station monthly total precipitation and regression equations, Organ Pipe Cactus N.M.

of all the monitoring wells to do so. Minimum annual water level (maximum depth to water) at this well is typically recorded during the October monitoring cycle. Regression for the data shown in Figure 13-12 indicates a rate of increase of 0.4 feet/year since 1993. This increase indicates a net gain in storage within the groundwater system at this location. This gain could indicate increased recharge, decreased losses, or a combination of these.

Park Headquarters Wells

The park headquarters wells supply the park housing and administrative areas. These wells are located in alluvium adjacent to the maintenance complex southeast of Twin Peaks at the east end of the Puerto Blanco Mountains. Exposed rock types in the nearby mountains are of volcanic origin. At the current time, it is believed that depth to water at these wells is not regularly monitored, although it is recommended that at least one of these should be included in the monitoring program.

Headquarters #4 (South Well)

Headquarters well #4 (South well) is the primary water supply well for the park administrative area. The well was constructed in 1957 to a depth of 430 feet and was serviced in 2004 for the purpose of restoring production and removing sediment that had accumulated in the well bottom. Depth to water at this well in 1957 is reported as 310 feet below ground surface. Depth to water in 2003 was reported to be about 337 feet. It is not known at this time what other records of water levels at the South well, if any, are available in park files.

Headquarters #5 (North Well)

Headquarters #5 (North well) was drilled in 1974. Depth to water at that time was reported to be 308 feet at this well. The existence of more current depth to water data at this well is unclear, but it is recommended that this be investigated and this well be included in the regular monitoring program.

Review of regression coefficients for water level and monthly total precipitation

As discussed in the preceding section and shown on the accompanying figures, regression analyses of the depth to water and monthly total precipitation data were conducted using the regression function in Microsoft Excel software. This function applies a least-squares best-fit line to the data. The purpose of this analysis was to aid in assessing whether or not trends were present. Results of the regression analyses are summarized in Table 13-2 as water level regression coefficients (negative of depth to water regression coefficients) and monthly total precipitation regression coefficients. These coefficients represent the slopes of the lines fit to the data record using a least-squares approach, providing a measure of rate of change of the data over time.

In addition, the ratio of the water level regression coefficient to the monthly total precipitation regression coefficient is shown in Table 13-2 as a means of comparing rate of change of water levels to rate of change of precipitation at each location. An underlying assumption associated with making this comparison is that changes in precipitation will have an impact on groundwater storage as reflected by water levels in wells. While it is understood that the magnitude of groundwater level response to changes in precipitation is complex and will vary from place to place due to variation in local conditions, the set of data taken together allow preliminary comparison of this response for wells in relatively similar settings.

A nonzero regression coefficient for long-term data is indicative of a state of nonequilibrium. Values of the regression coefficient nearer to zero indicate that the data record is derived from a system nearer to equilibrium than one with values deviating more from zero, either positive or negative. Examination of the values presented in Table 2 indicates the following:

- Water levels declined over time at all monitoring wells except for the USGS

Table 13-2. Summary of regression coefficients for water level and monthly total precipitation with depth to water/precipitation ratio, Organ Pipe Cactus N.M. (*Water table elevation regression coefficient is equal to the negative of the depth to water regression coefficient.)

	Water Level (WL) Regression Coefficient* (ft/day)	Monthly Total Precipitation (MTP) Regression Coefficient* (inch/month/day)	Regression Coefficient Ratio WL/MTP (ft/inch/month)
Alamo Wash/Alamo Canyon precipitation	-3.2E-05	-3.3E-05	1.0
Bates Well/Growler Valley precipitation	-1.9E-03	-7.8E-05	24.4
Bonita Well/Pozo Nuevo precipitation	-6.1E-04	-9.4E-05	6.5
Pozo Nuevo Well/Pozo Nuevo precipitation	-9.0E-04	-9.4E-05	9.6
Corner Well/Quitobaquito precipitaton	-5.3E-04	-7.1E-05	7.5
Dowling precipitation		-4.4E-05	
Kalil Well	-2.2E-03	-4.4E-05	50.0
Stack Well	-2.5E-03	-4.4E-05	56.8
USGS #1 C. Dos Republicas	-2.7E-03	-4.4E-05	61.4
USGS #2 Lukeville	-2.7E-03	-4.4E-05	61.4
USGS #3 Salsola/Salsola precipitation	9.9E-04	-1.2E-05	-80.5

#3 Salsola location, where water levels showed an increasing trend

- Monthly total precipitation rates declined at all stations. Variability is attributed primarily to orographic effects and differences in length of station records.
- The ratios of rate of change in water levels to rate of change in monthly total precipitation (WL/MTP) range from -80.5 ft/inch/month (at Salsola) to 61.4 ft/inch/month at the USGS wells near Lukeville
- WL/MTP ratios with high absolute values suggest anthropogenic impacts on groundwater reserves as observed at the Lukeville area wells and at Salsola

The rate of water level decline is greatest at the Lukeville area wells, where declines at the four wells range from 0.8 ft/year (-2.2 x 10^{-3} ft/day) to 1.0 ft/year (-2.7 x 10^{-3} ft/day). Due to the known presence of groundwater extraction for potable and irrigation water supply on both sides of the border, these declines are attributed to groundwater mining at this location. Monthly total precipitation in the Lukeville area has declined also, but at a medium rate (-0.016 inch/month/year) compared to precipitation declines at the other stations. WL/MTP ratios for these four wells are the highest of the monitoring areas.

Water level declines at Alamo Wash well are about

0.012 feet/year (-3.2 x 10^{-5} feet/day). Monthly total precipitation rates declined at 0.012 inch/month/year (-3.3 x 10^{-5} inch/month/day). This well is relatively high in its watershed and is not impacted by human groundwater withdrawals.

Bonita well, Pozo Nuevo well and Corner well show very similar water level declines over the monitoring period, ranging from 0.19 ft/year (-5.3 x 10^{-4} ft/day) to 0.33 ft/year (-9.0 x 10^{-4} ft/day). Declines in monthly total precipitation rates were also similar in the area of these wells, at 0.026 inch/month/year (-7.1 x 10^{-5} in/month/day) to 0.034 inch/month/year (-9.1 x 10^{-5} inch/month/day). WL/MTP ratios for these three wells were all between 5 and 10 ft/inch/month.

Rate of water level decline at Bates well is nearly as great as that observed in the Lukeville area at 0.7 feet/year (-1.9 x 10^{-3} feet/day). This is an unexpected result due to the absence of sustained groundwater extraction by humans in that area. Monthly total precipitation in the area declined at a rate of 0.028 inch/month/year (-7.8 x 10^{-5} inch/month/day). WL/MTP ratio for Bates well and the Growler Valley precipitation record is significantly higher than that for the three wells discussed in the preceding paragraph at 24.4 feet/inch/month. It would be expected that Bates well data would show greater similarity to those wells than was shown by this analysis.

Table 13-2 indicates that the USGS #3 Salsola well exhibits a positive rate of change of water levels over the period of record, increasing at 0.36 feet/year (+9.9 x 10^{-4} feet/day). Monthly total precipitation at the Salsola climate station shows the smallest rate of decline for all of the stations reported here, at 0.004 inch/month/year (- 1.9 x 10^{5} inch/month/day). The WL/MTP ratio for this site is negative due to the differences in the slopes of the water level and monthly total precipitation trend lines. Increasing water levels at Salsola since at least 1988 indicate that a decrease in groundwater extraction or an increase in recharge, or both, in the vicinity of the monitoring well has occurred. Water level rise since that time reflects an extended adjustment of the water table in the area. It should be noted that long-term changes in groundwater levels can result from very distant impacts over extended periods of time, from years to decades. The rate of water level adjustment at Salsola is retarded by annual cycles of net deficit in the summer months.

Discussion

Quarterly depth to water monitoring at OPCNM provides a valuable data record needed to understand subsurface groundwater dynamics at regional and local scales within and adjacent to park boundaries. The data set, when analyzed in combination with long-term precipitation records, makes it possible to assess changes in groundwater levels relative to seasonal, annual and long-term climatic trends.

As discussed in the preceding sections, the availability of the data set as a whole allows estimation of what may be natural water level response to declining precipitation rates over the monitoring period. The analysis of data from these sites provides an order-of-magnitude estimate of what may be occurring to groundwater levels within similar unmonitored settings that are also experiencing declining precipitation rates. Factors that influence rate of water level decline in any specific area include:

- Area of contributing watershed (ft^2)
- Recharge deficit rate ($gal/day/ft^2$)
- Aquifer storage as a function of water level elevation (gal/ft)
- Other physical and biological factors – possibly nonlinear – that potentially reduce infiltration – increased evaporation, increased plant water capture, decreased permeability to infiltration, increased runoff

Significantly higher rates of water level decline in wells in the Lukeville area and to a lesser extent at Bates well, suggest the possible presence of impacts to groundwater resources over

and above what is occurring naturally due to reduced precipitation. A more in-depth analysis is recommended to better understand how differences in local conditions may be impacting the discrepancies in water level trends between these wells.

The widespread decline of water level elevations at wells in and near OPCNM should be of concern to resource managers for several reasons. The concept of sustainability rests fundamentally on a system in equilibrium. Decline in water level elevations on the widespread scale presented here clearly reflects a system out of equilibrium. This condition is the result of, and in turn has the potential to impact, nonequilibrium in conditions above and below the ground surface.

Due to a lack of long-term data records, for the arid southwest it is unknown how water level elevation trends can be expected to fluctuate over very-long time scales under the influence of climatic variability at scales of decades to centuries. Groundwater levels are influenced by surface conditions including climate, flora and fauna, soils and geology. The relationships between climate, flora, fauna, surface water and groundwater interact in complex ways. The groundwater monitoring program at OPCNM provides an invaluable opportunity to increase our understanding of these relationships so vital to the fundamental mission of the park.

Acknowledgements
Field work conducted by Charles Conner

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Water Quality

Ami Pate, Colleen Filippone

Objectives: Long term trends in water quality vital signs at tinajas and perennial springs, long term trends in flow rate at Quitobaquito springs system.

Introduction

Perennial water bodies are scarce in arid to semi-arid central and southern Arizona. The presence of water and riparian habitats around surface waters create biological focal points for the surrounding region. The chemical and biological integrity of these waters is critical to the vitality and continued existence of aquatic and upland ecosystems. Ensuring the integrity of park water quality, due to its importance in sustaining natural, aquatic park ecosystems is a fundamental component of the NPS's mission.The goal of the water quality monitoring program at Organ Pipe Cactus National Monument (OPCNM) is to provide data on water quality and quantity to better understand the natural variation in surface water systems.

Water quality management objectives will meet all state (ADEQ 2003) and federal (EPA) requirements. Director's Order #83 and outlines additional water quality standards for National Parks (1999). Park specific natural resource management goals are outlined in the Draft General Management Plan – Development Concept Plan – Environmental Impact Statement (OPCNM 1995 draft). These include:

1. Protection of the natural and cultural resources of Quitobaquito Springs area, while accommodating visitor use.
2. Establish and maintain baseline data on the condition of Sonoran Desert ecosystems.
3. Achieve sufficient understanding of Sonoran Desert ecosystems for effective protection.
4. Restore and preserve intact a significant and representative portion of Sonoran Desert ecosystems.
5. Protection of critical habitat at Quitobaquito Springs for the Quitobaquito desert pupfish.

The monument exhibits topography typical of the basin and range province, consisting of valleys filled with alluvium eroded from the surrounded mountain ranges. Elevation in the monument ranges from 300m to 1465m. Average annual rainfall at OPCNM was 9.5 in/yr at an elevation of 512m (Western Regional Climate Center, 2004). Sources of surface water are very limited. No perennial rivers or streams exist within the monument; ephemeral flow occurs for brief periods as a result of locally heavy summer raimstorms or rare regional storms. Brown et al (1983) inventoried surface water resources at the monument and provided information for three springs, 68 tinajas (rainfall recharged ephemeral and intermittent bedrock catchments), three stock tanks, seven watering troughs, and three sewage disposal ponds. The watering troughs and stock tanks were eliminated as water sources by the monument in 1982. The perennial springs provide the only reliable year-round water source and are extremely important to biota and wildlife.

Springs

Quitobaquito is an aquifer-fed wetland located in the southwest corner of the monument on the U.S./Mexico border. The permanent waters in this area have been a focal point of human migration and occupation for thousands of years, and the complicated cultural/natural interactions persist to this day. The NPS acquired the wetland from the last Hia'ced O'odham inhabitant in 1958, and since then has faced the difficulty of managing a human-manipulated landscape as a natural preserve, which is the principal remaining habitat for the Desert Pupfish (*Cyprinodon eremus*). The springs, channel, seeps and pond form a system that dates to the 1800s, and are designated critical habitat for the Desert

Pupfish. The Quitobaquito system also supports the endemic Quitobaquito tryonia snail (*Tryonia quitobaquitae*), an isolated population of Sonoran mud turtle (*Kinosternon sonoriensis*) (candidate for federal listing), a diverse resident and migrant avian fauna, foraging free-tailed bat species, and medicinal wetland plants.

Dripping Springs is another important perennial spring within the park, especially for wildlife water. In the driest periods, it may be the only source of water in 270 square miles (700km^2.) It is formed by a fracture seep in a small cave. The flow is contained within the cave and a small catchment basin (Brown et al 1983). The water levels have been declining for the last three years, possibly from the continuing drought. Dripping Springs is along a major illegal trafficking route and water quality is being impacted by trash and fecal material from these activities.

Tinajas

Tinajas (or rock pools) are important ecological systems due to their relative scarcity and critical functions for terrestrial wildlife and unique plant communities. Rock pools in arid systems have received scant attention in the scientific literature, yet they may be the most susceptible of all aquatic habitats to human influences (Dodson 1988). There are approximately 68 major tinajas in the monument. Most are in the Ajo (35), Bates (15), and Puerto Blanco (8) Mountains (Brown et al 1983). The longevity of the water is affected by the size and runoff characteristics of the watershed draining into the tinaja, volume of the catchments, amount of shade received, and permeability of the bedrock. Water quality of tinajas is highly variable, and is susceptible to contamination from human activities and atmospheric deposition of chemicals.

Water quality

The National Park Service (NPS) Water Resources Division (WRD) have identified three water-quality parameters and two physical parameters as "core" freshwater indicators for long-term aquatic monitoring projects (NPS 2002). These measures were selected as the most fundamental parameters required for characterization of water-quality of aquatic ecosystems, and are known to be related to both biological and physicochemical processes. The required measures include:

- Specific conductance
- Dissolved oxygen
- pH
- Temperature
- Flow rate or water level

Surface water chemistry measurements and Quitobaquito temperature monitoring were started in 1998 after funding from the U.S. Air Force Quitobaquito Wetlands Project allowed purchase of water monitoring equipment. Instrumentation and protocol were modeled after a pilot study at Joshua Tree National Park.

Water quantity

The two primary springs in the Quitobaquito system have been historically managed to provide water to the pond. In 1974 a V-notch weir flow was installed to facilitate spring monitoring at Quitobaquito (NPS 1992). U.S. Geological Survey (USGS) personnel began analog recording of discharge stage at the weir in 1981. In 1990 a 2-inch Parshall flume and a dry datalogger bunker were installed as part of the Quitobaquito Habitat Project. This flume continues to be the primary monitoring point for spring discharge at the site. Digital monitoring using a pressure transducer and datalogger was conducted by USGS 1990-1992. Flow rates reported by Carruth (1996) indicate a range between 15 and 40 gallons per minute (gpm) (57 and 151 liters per minute) with an average of 28 gpm (106 liters per minute) between 1981 and 1992. Spring flow and pond level at Quitobaquito have declined in recent years. In 2005, NPS hydrologist Colleen Filippone assisted OPCNM staff with the installation of a new continuous flow monitor at the springs, as well as continuous digital temperature, dissolved oxygen and conductivity monitors.

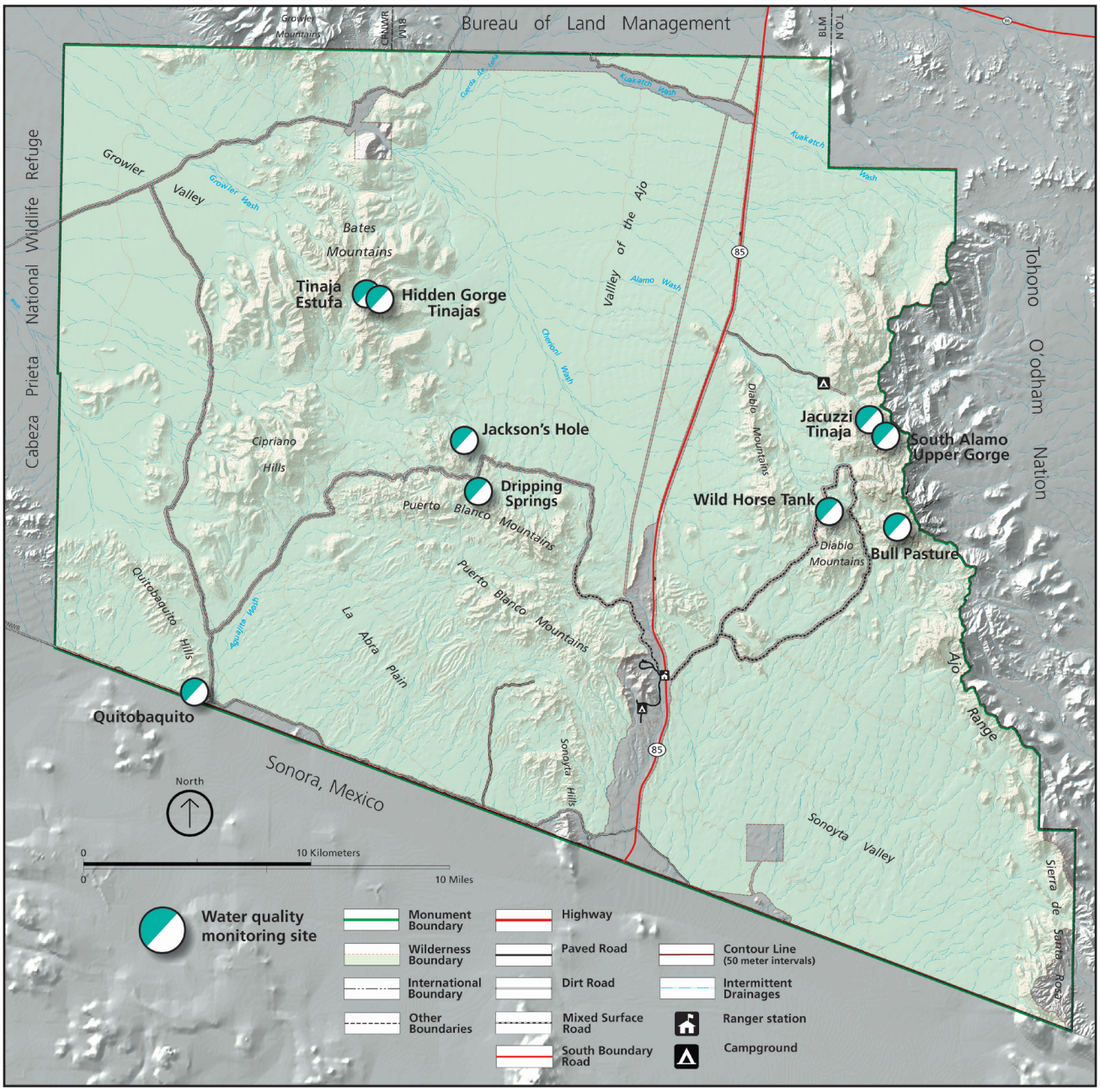

Figure 14-1. Water quality monitoring sites, Organ Pipe Cactus N.M.

Methods

Water chemistry

Selected tinaja sites and Quitobaquito springs, channel and pond were sampled seasonally from 1998 to 2005 (Figure 14-1). The following parameters were measured: specific conductance, dissolved oxygen, pH, and temperature. Air temperature and approximate water level were also recorded most of the time. From 1998 to 2001, alkalinity was also measured.
The same testing equipment was used consistently throughout the project: Orion 115 conductivity meter and cell, Orion 250A pH meter and low maintenance triode pH probe, YSI 95 dissolved oxygen meter and Hach alkalinity titration test kit (Figure 14-2). Temperature was usually taken from the conductivity and pH meters' automatic temperature compensation probes. Various thermometer models were used for air temperature.

The pH meter was calibrated in the office or in the field for each monitoring session, using pH 7 and pH 10 standard buffer solutions. The conductivity meter was calibrated by measuring a 75, 447, or 1413 µs standard solution, depending on the expected value of the sample. This measurement was used to calculate a correction factor for the water sample measurement. The YSI dissolved oxygen meter was calibrated in the field by entering altitude and salinity values. Measurements for pH and conductivity were taken by submerging the probes approximately 8 cm into the surface water site, and letting the probes equilibrate to water temperature for approximately 1-2 minutes. Values recorded were usually the second or third stable reading, or an average of 3 readings. The YSI dissolved oxygen probe was allowed to equilibrate in the atmosphere for at least 15 minutes. The probe was then submerged 8-10 cm and agitated in the surface water site at the rate of 1 foot per second. After readings stabilized, a measurement was recorded.

Water temperature

Hobo Stowaway temperature sensors were deployed at Quitobaquito intermittently from 1997-2004 at the southwest spring, in mid-channel pools, and in the pond. In November 2005, these sensors were replaced by new Hobo H8 temperature sensors in the channel, moat and pond.

Stowaway temperature sensors were programmed to record hourly temperatures, and placed in

Figure 14-2. Water quality testing equipment in the OPCNM laboratory.

Table 1. Physical characteristics of selected water chemistry monitoring sites, Organ Pipe Cactus N.M. (Description of geologic substrate from Geological Reconnaisance map of Organ Pipe Cactus National Monument.)

Site	Elevation (m)	Estimated volume (g), from Brown 1983	Description of geologic substrate
South Alamo Canyon	820	376	Rhyolite, rhyodacite and minor dacite flows
Jackson's Hole	520	2059	Childs latite flows and flow breccias
Dripping Springs	630	2510	Augite andesite
Tinaja Estufa	580	4996	Childs latite flows and flow breccias
Wild Horse Tank	725	64,241	Rhyolite, rhyodacite and minor dacite flows
Quitobaquito Springs	335	--	Biotite granite of Aguajita Spring

Table 2. Summary of water chemistry results at selected sites, 1998-2005, Organ Pipe Cactus N.M.

Site	pH mean	pH range	conductivity mean (µs)	conductivity range (µs)	dissolved oxygen range (mg/l)
Dripping Springs (excluding July 2001)	7.2	7.03 – 7.40	351	289 – 399	0.2 – 7.7
Dripping Springs, July 15,2001	6.58	--	849	--	0.9
Quitobaquito-southwest spring	7.5	7.43 – 7.67	1164	1112 – 1191	4.83 – 8.3
Quitobaquito-midchannel pool	8.0	7.87 – 8.14	1173	1115 – 1374	5.86 – 9.83
Quitobaquito pond (W shore)	9.3	8.46 – 9.88	1312	1149 – 1552	1.49 – 15.3
South Alamo Canyon (Jacuzzi)	8.5	6.98 – 10.68	287	221 – 344	1.71 – 14.5
Tinaja Estufa	9.5	8.33 – 10.64	273	117 – 451	5.43 – 16.7
Wild Horse Tank	8.9	8.04 – 9.99	282	175 – 401	5.93 – 15.49

submersible cases. They were brought back to the office for data download.

Quitobaquito southwest spring monitoring
In 2005, NPS Intermountain Region hydrologist Filippone and OPCNM staff installed continuous flow monitoring and water chemistry monitoring system consisting of a Campbell Scientific CR21x datalogger, a 0-1 psi pressure transducer, a Campbell Scientific CS547A-L30 water conductivity/temperature probe, and a Oxyguard dissolved oxygen probe. Manual discharge measurements are also made just below the southwest spring; this is accomplished by blocking the channel with towels and diverting water into a 3-inch diameter plastic pipe for collecting time versus discharge measurements. Two observers with stopwatch and measuring

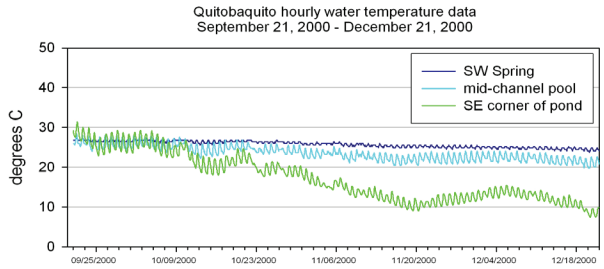

Figure 14-3. Quitobaquito water temperature, September 21-December 21, 2000.

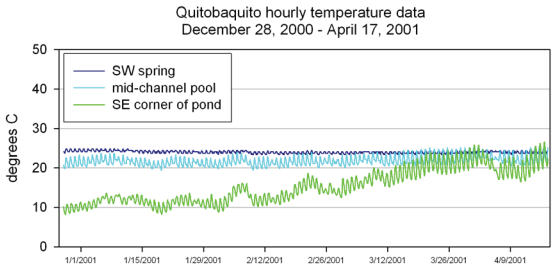

Figure 14-4. Quitobaquito water temperature, December 28-April 17, 2001.

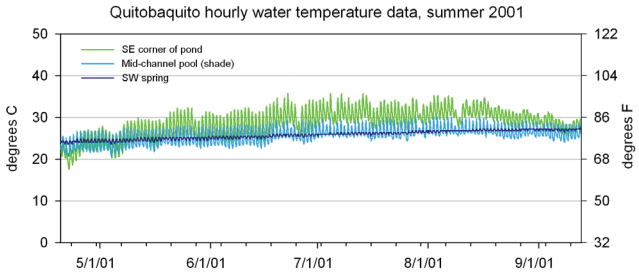

Figure 14-5. Quitobaquito water temperature, April – September, 2001.

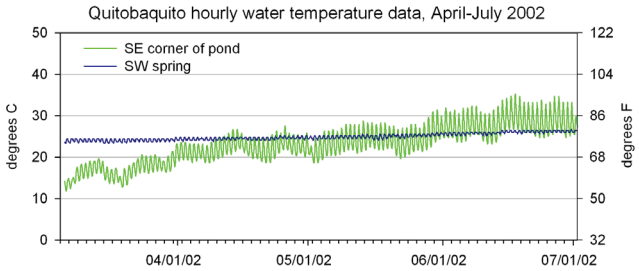

Figure 14-6. Quitobaquito water temperature, April - July 2002.

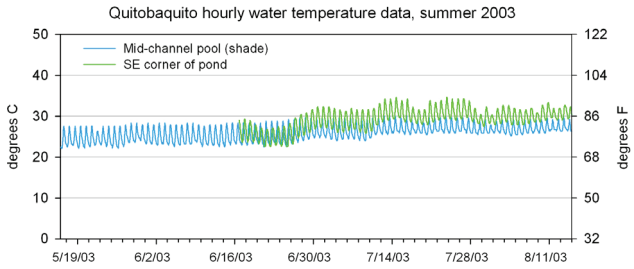

Figure 14-7. Quitobaquito water temperature, May – August 2003.

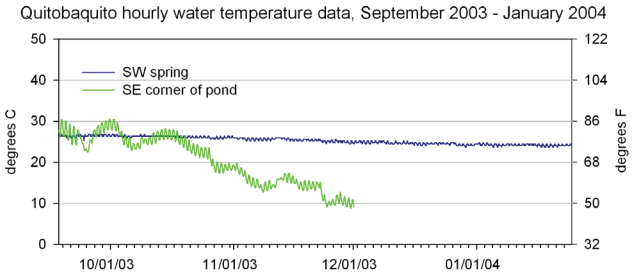

Figure 14-8. Quitobaquito water temperature, September 2003 - January 2004.

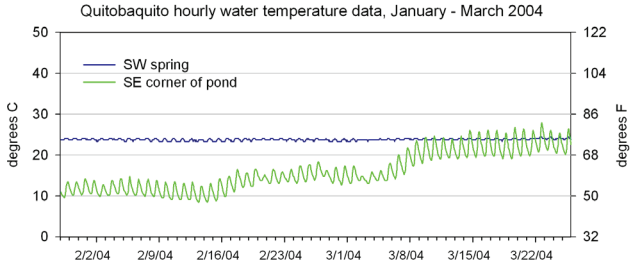

Figure 14-9. Quitobaquito water temperature, January - March 2004, Organ Pipe Cactus N.M.

bucket are required for this process.

Miscellaneous Quitobaquito water quantity observations
In addition to water quantity data monitoring from instrumentation, monument staff have recorded information on flume stage and pond level during routine Quitobaquito inspections since 1991. Pond level is a standardized measurement from the bottom lip of the overflow pipe.

Results

Water chemistry
In initial protocol development, three seasons were identified as important for tinaja sampling: after winter rains, late spring after many tinajas have dried up and water is concentrated at a few important wildlife sites, and after summer monsoon rains. Since monument wet deposition monitoring has shown a clear difference between summer and winter precipitation chemistry, the objective was to see if tinaja chemistry was effected by rainfall events. However, the variability of pH and conductivity over time did not appear to correlate with specific seasons; the geologic substrate (Table 14-1) of the tinajas likely buffers precipitation deposition. Also, tinaja waters are subject to constant changes in recharge rates, temperature and plant growth, all which affect water chemistry.

Quitobaquito demonstrated the least variability in water chemistry results, 1998-2005 (Table 14-2, Tables 14-9 through 14-11). Conductivity and pH measurements were very consistent in the southwest spring pool, the channel and the pond; while dissolved oxygen measurements were fairly consistent in the southwest spring and channel only.

Dripping Springs water chemistry (Table 14-3) changed significantly after an extreme event in summer 2001. Staff found the water level at an all-time low (60 cm below lip of dam), and the water fouled with decaying bees and birds, and illegal migrant trash. Water chemistry was measured before a clean-up effort (15 July 2001) and after the clean-up effort (22 July 2001). A detailed report on Dripping Springs' physical conditions in 2001 and management actions is available in Appendix E.

Water temperature
Water temperature data from 1998-2004 show a consistent diurnal pattern (Figures 14-3 - 14-9), with the southeast pond site fluctuating the most with seasonal temperature change. The southwest spring mean temperature range was 23.9 – 27.1 degrees C, September 2000-February. During that time frame, the southeast pond maximum temperature was 35.8 degrees C on June 22, 2001, and minimum temperature was 6.6 degrees C on December 17, 2001.

Quitobaquito springs
Stage-flow rate measurements to date illustrate typical diurnal cycling attributable to evapotranspiration effects. Perturbations to stage in the data record are attributed to water level impacts at the spring from wildlife and human visitation.

Discussion

Surface water quality
The 1998-2005 surface water chemistry measurements should be considered a pilot study of NPS Water Resource Division core parameter monitoring in the monument. Tinaja water chemistry results from 1998 – 2005 can be used to determine future sampling frequency and instrumentation needs.

Quitobaquito springs
Flow rates at Quitobaquito southwest spring flume in 2005 averaged approximately 16 gallons per minute. Compared to rates reported by previous monitoring efforts of 28 gallons per minute between 1981 and 1992, current flow from the southwest spring is reduced to only 57% of historical rates. Quitobaquito pond water levels have declined significantly and outflow from the pond, formerly a perennial discharge, has not been documented since 1998. Pond levels

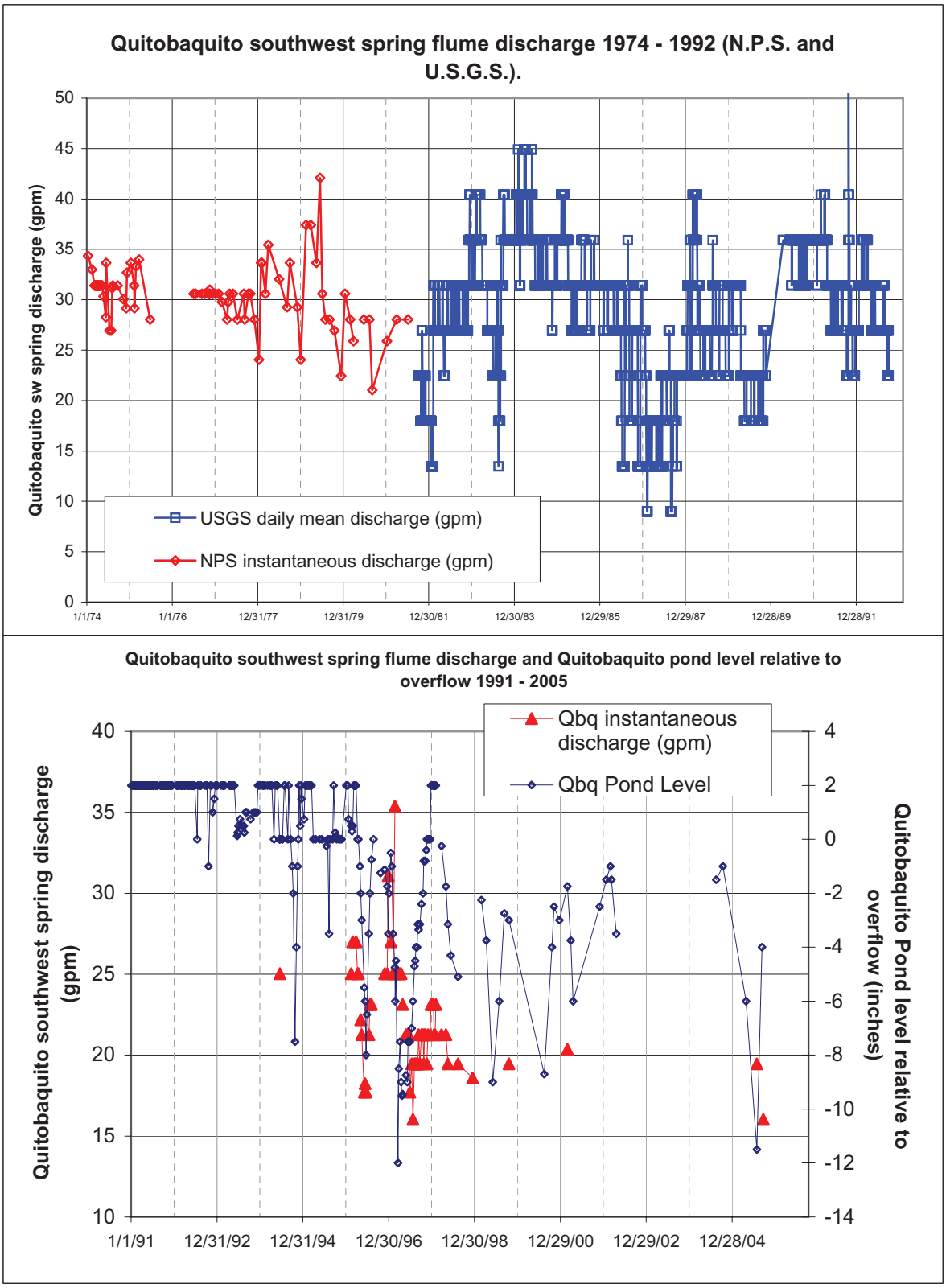

Figure 10. Quitobaquito southwest spring discharge 1974-2005 and Quitobaquito pond level, 1991-2005, Organ Pipe Cactus N.M. United States Geological Survey and National Park Service data.

in 2005 reached the lowest levels recorded since monitoring began in 1991 (Figure 14-10).

Nearby Burro Spring (formerly intermittent) and Williams Spring (formerly perennial) have ceased flowing completely in the last few years. These springs are located on the same high-angle fault along the southwest side of the Quitobaquito Hills discussed by Carruth (1996). Drying up of these springs in combination with decreasing flow rates at Quitobaquito Spring are probably related and indicate that there should be significant concern for the future viability of spring flows supporting Quitobaquito pupfish habitat. Also, vegetation growth in the springs area has become dense and may be contributing to the observed decline in discharge rate at the flume via evapotranspiration and/or clogging of the collection drains by roots. Groundwater pumping south of the border is an unquantified potential threat to the groundwater supply to Quitobaquito Springs. The likely existence of a hydraulic connection between groundwater in Aguajita wash and irrigation wells in Mexico is discussed by Carruth (1996).

Recommendations

- Results, methodology, site selection and monitoring frequency for surface water quality measurements should be reviewed by NPS hydrologists. Consultation and integration with the Sonoran Desert Inventory & Monitoring Network will assist in further analysis of past results, and developing future protocols for nutrient loading, biological conditions (with aquatic macroinvertebrates and algae indicators), and EPA priority metals.

- A groundwater monitoring system in the immediate source area of the springs should be planned and implemented, including a monitoring well installed in or near Aguajita Wash northeast of the Quitobaquito Hills.

- In cooperation with the Pinacate Biosphere Reserve staff, efforts to obtain groundwater level and pumping data from south of the border should be continued.

- In keeping with historical and ecological resource values associated with Quitobaquito spring and impoundment, it is recommended that a plan be made and funds sought for the purpose of submitting an application to Arizona Department of Environmental Quality for classification of the Quitobaquito spring and pond complex as a designated Unique Water in the State of Arizona. This designation constitutes formal recognition of the classified waters as outstanding state resource waters and provides greater protections than are afforded to undesignated waters.

Acknowledgements

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Table 14-1. Water quality results at Dripping Springs, 1998-2004, Organ Pipe Cactus N.M.

Date	Time	pH	Conductivity (µ/s)	DO-mg/L	Alk--total	TDS (mg/L)	Water temp (C)	Air temp	Pool volume	Notes
27-May-98	1345-1445	7.2	365	1.79	92		16	25 C		
5-Sep-98	1500-1600	7.4	399	0.20	140	192	23	32 C		
4-Mar-99	1220-1320	7.18	340	0.48	97.6	164	14.5	21 C		
7-Oct-99	1330	7.28	371	1.32	84		19			
14-Apr-00	1345-1500	7.18	360	1.75	84-88	172	15.6	approx 89 F	pool overflowing	
16-Apr-01	1210-1250	7.24	289	4.90	52.8		13.2	mid 80s F	2” below damn lip	many bees, doves; migrant trash. Flies and dove feathers
15-Jul-01	1140	6.58	849	0.91	370		21.7		60 cm below dam lip	part of clean-up effort.
22-Jul-02		7.26	359	3.77			21.5		depth = .43 m at deepest point	
6-Dec-04	1117	7.03	327	7.70			11.6		pool full, some overflow	

Table 14-4. Water quality results at Jackson's Hole, 1998-2001, Organ Pipe Cactus N.M.

Date	Time	pH	Conductivity (µ/s)	DO-mg/L	Alk--total	TDS (mg/L)	Water temp (C)	Air temp	Pool volume	Notes
27-May-98	1100-1200	7.45	547	0.45-.056	178.4		21			
5-Sep-98	1200-1330	7.4	468	3.60	142		25	27-32 C		
9-Apr-99	1150	6.86	912	3.89	42		11	15 C		
7-Oct-99	1100	7.83	551	5.43	61		20	80's F		
13-Apr-01	1250-1350	7.65	539	7.00	66		15.6	mid 70s F	10-12" deep	water clear

Table 14-5. Water quality results at miscellaneous sites in the Ajo Mountains, 1998-2004, Organ Pipe Cactus N.M.

Site	Date	Time	pH	Conductivity (µ/s)	DO-mg/L	Alk--total	TDS (mg/L)	Water temp (C)	Air temp	Pool volume	Notes
Alamo near cistern	21-May-98	1630	7.5	266	7.93	n/a		25-27	30 C		
Bull Pasture "Deer Drop" tinaja	25-May-04	1920	8.06	256	8.68			16.7		approx 11x12 ft.	clear water
Bull Pasture "Juniper" tinaja	12-Oct-03		8.1		7.70		156	21.8	33.6 C		clear flowing water

Table 14-6. Water quality results at Tinaja Estufa and Hidden Gorge Tinaja, 2000-2004, Organ Pipe Cactus N.M.

Site	Date	Time	pH	Conductivity (m/s)	DO-mg/L	Alk--total	TDS (mg/L)	Water temp (C)	Air temp	Pool volume	Notes
Tinaja Estufa, above dam	25-Aug-03	1640	10.64	308	16.70			34.1	41.2 C		
Tinaja Estufa, above dam	23-Sep-03	730	8.33	311			167	24.1			
Tinaja Estufa, below dam	4-May-00	900	8.63	451	5.43	125		20.5			
Tinaja Estufa, below dam	25-Aug-03	1550	10.48	220	15.70			34.7	41.2 C		
Tinaja Estufa, below dam	23-Sep-03	730	9.98	117	7.50		62	24.3	26.8		
Tinaja Estufa, below dam	24-Oct-04		8.89	233	12.00			20			
Hidden Gorge Tinaja	4-May-00	1000	7.68	501	0.49	145		20		approx. 2' deep, 4.5' x 30"	

Table 14-7. Water quality results at South Alamo Canyon, 1998-2004, Organ Pipe Cactus N.M.

Site	Date	Time	pH	Conductivity (m/s)	DO-mg/L	Alk--total	TDS (mg/L)	Water temp (C)	Air temp	Pool volume	Notes
Jacuzzi tinajas	3-Sep-98	1015	8.06	278	4.78		130	26	29 C		
Jacuzzi tinajas	12-Apr-99	1100-1300	10.68	312	10.50	41	147	12.8	18.5 C		
Jacuzzi tinajas	1-Oct-99	1200-1330	9.02	221	3.09	28-67	105	23.9-27.4			
Jacuzzi tinajas	5-Apr-00	1330	6.98	297	11.60	74		18.3-22	89 F		
Jacuzzi tinajas	12-Apr-01	1545-1700	7.09	305	9.60	73.6		19.4	70-74 F	full, inflow and outflow	water clear, no algae
Jacuzzi tinajas	29-Aug-01										
Jacuzzi tinajas	16-Jul-02	900	7.23	313	1.71			25.5		pool level approx. 4" below top	
Jacuzzi tinajas	11-Sep-03	1540	9.96	226	14.50			29.9	36.7 C		
Jacuzzi tinajas	24-May-04	1852	8.87	344	11.14			23.2		approx: 7' x 4' x 3' depth	tinajas full & flowing, tinajas below Jacuzzi full, clear water, many tadpoles
pool below jacuzzi tinajas	3-Sep-98	0815-0945	8.2	250	2.36	116	166	24	27 C		
pool below jacuzzi tinajas	12-Apr-99	1300	7.25	255	7.78	40	120	13	20.7 C		
S. Alamo--upper gorge	16-Jul-02	1020	7.31	318	1.25			25		approx. 12' x 6' pool	tinaja covered with thick layer of algae

Table 14-8. Water quality results at Wild Horse Tank, 1998-2004, Organ Pipe Cactus N.M.

Date	Time	pH	Conductivity (m/s)	DO-mg/L	Alk--total	TDS (mg/L)	Water temp (C)	Air temp	Pool volume	Notes
12-Feb-98		9.99	187.4	15.49				23.4 C		
20-May-98	1600	8.63	278	--			18.5	31.5 C		
7-Sep-98	1530-1620	8.76	175	13.26	73-82	79	30	34 C		
10-Mar-99	1600-1730	8.73	401	13.51	174		17.6	19.7 C		
12-Oct-99	1030	8.04	370	5.93	131		20			
11-Apr-00	1255	9.73	237	16.60	93		18.1-22.7	90 F		
12-Oct-03	1040	9.16	276	11.70		144	23.5	30 C		
31-Jan-05	1145	8.35	321	10.10		159	12.7	66 F	approx. 12 x 12 m	upper pools also have water; tank cloudy w/algae,
late May 04		8.26	289	8.55						

Table 14-9. Water quality results at Quitobaquito southwest spring pool, 1998-2005, Organ Pipe Cactus N.M

Date	Time	pH	Conductivity (m/s)	DO-mg/L	Alk--total	TDS (mg/L)	Water temp (C)	Air temp
11-Feb-98		7.54	1112	6.03	254		24.9	
24-Jun-98	1700	7.54	1355	4.83	240		25.1	
25-Jun-98	45			5.29			25.4	
25-Jun-98	831			5.13			25.5	
25-Sep-98	1030	7.59	1132	5.68	176		27	
17-Feb-99	1420-1545	7.52	1148	5.60	222		24.4	
24-Jun-99	1825	7.48	1160	5.92			26	
24-Sep-99	1345-	7.51	1120	5.93	209		28	
10-May-00	1240	7.36	1136	5.58	152		26.1	
25-Apr-02	1350	7.67	1179	5.70			25.7	37.2 C
10-Dec-02	--	7.5	1114	6.40			25.4	19 C
5-Sep-03	1028	7.58	1159	5.78	224		27.2	32.3 C
26-Mar-04	1111	7.44	1165	5.80			24.7	30.1 C
27-Jan-05	1225	7.43	1191	8.31		603	24	

Table 14-10. Water quality results from Quitobaquito mid-channel pool, 1998-2005, Organ Pipe Cactus N.M.

Date	Time	pH	Conductivity (m/s)	DO-mg/L	Alk--total	TDS (mg/L)	Water temp (C)	Air temp
11-Feb-98		8.01	1178	7.50	256		24	
24-Jun-98	1745	7.88	1374	5.86			25.5	35 C
25-Jun-98	50			6.57			24.1	
25-Jun-98	835			6.84			24.9	
25-Sep-98	1050	8.06	1127	7.17			27	
17-Feb-99	1430	8.05	1143	7.48			23.8	
24-Jun-99	1815	7.88	1158	6.95			26.4	
24-Sep-99	1405	8.06	1138	8.16			28	
10-May-00	1220	8.14	1137	9.83			27	
25-Apr-02	1330		1191	8.30			27	35.8 C
10-Dec-02	--	7.94	1115	6.70			24	19 C
5-Sep-03	1045	7.98	1160	7.34			27.8	33.9 C
26-Mar-04	1120	7.87	1169	7.87			24.5	
27-Jan-05	1200	7.89	1183	6.07		598	24	20.7 C

Table 14-11. Water quality results at Quitobaquito Pond, 1998-2005, Organ Pipe Cactus N.M.

Site	Date	Time	pH	Conductivity (m/s)	DO-mg/L	Alk--total	Water temp (C)	Air temp
QBQ-pond, boat launch	11-Feb-98		8.81	1170	10.83		17.5	
QBQ-pond, boat launch	24-Jun-98	1900	9.56	1591	15.30	252		
QBQ-pond, boat launch	25-Jun-98	930	9.53	1328	6.72		26.7	
QBQ-pond, boat launch	24-Sep-98	1000	9.6	1365	1.49		26	
QBQ-pond, boat launch	25-Sep-98	1000				206		
QBQ-pond, boat launch	17-Feb-99	1530	8.99	1159	14.30	203	15	25.8 C
QBQ-pond, boat launch	24-Jun-99	1740	9.79	1552	11.60		33.26	
QBQ-pond, boat launch	24-Sep-99	1430	9.88	1299	13.44	181	34.5	
QBQ-pond, boat launch	10-May-00	1130	9.74	1352	6.15	157	28	
QBQ-pond, boat launch	25-Apr-02	1420	9.8	1382	12.50		31.7	
QBQ-pond, boat launch	10-Dec-02	--	8.87	1184	6.10		13.8	19 C
QBQ-pond, boat launch	5-Sep-03	1100	9.28	1322	8.10	186	32.6	34.4 C
QBQ-pond, boat launch	26-Mar-04	1130	9.11	1209	9.10		23.7	
QBQ-pond, boat launch	27-Jan-05	1245	8.46	1149	8.70		18	
QBQ-pond, middle	24-Jun-98	1830	9.56	1591	15.30	n/a	32	28 C
QBQ-pond, middle	24-Sep-98	1000-1055	9.45	1363	7.51/9.5-10.5	n/a	26	30 C
QBQ-pond, middle	17-Feb-99	1600	8.95	1175	15.43		18	
QBQ-pond, middle	24-Jun-99	1840	9.71	1333	15.90		33.6	
QBQ-pond, middle	24-Sep-99	1305	9.44	1301	15.21		32.9	
QBQ-pond, middle	10-May-00	1150	9.79	1328	9.20		27	
QBQ-pond, middle (no veg)	25-Jun-98	111			9.76		27.6	
QBQ-pond, middle (no veg)	25-Jun-98	812			7.73		25.8	
QBQ-pond, middle (w/aquatic veg)	25-Jun-98	107			9.95		26.6	
QBQ-pond, middle (w/aquatic veg)	25-Jun-98	808			7.56		24.8	
QBQ-pond, cottonwood	24-Sep-98	1000-1055	9.58	1382	11.40		26	
QBQ-pond, deepest area	24-Jun-98	1845	9.52	1624	13.90	n/a	31.5	
QBQ-pond, deepest area	10-May-00	1205	9.83	1352	7.77		28	
QBQ-pond, deepest area (no veg)	25-Jun-98	821			5.39		25.7	
QBQ-pond, deepest area (open)	24-Sep-98	1000-1055	9.44	1394	8.71	n/a	26	
QBQ-pond, deepest area (shade)	24-Sep-98	1000-1055	9.39	1415	4.25	n/a	25	
QBQ-pond, deepest area (veg)	25-Jun-98	114			9.22		27.6	
QBQ-pond, deepest area (veg)	25-Jun-98	817			6.40		26.2	

Land Use Trends

Charles Conner

Objectives

Determine status and trends of land use activities adjacent to Organ Pipe Cactus National Monument, and assess threats to monument ecosystems and wilderness values.

Introduction

Changes in land uses adjacent to protected lands can contribute to habitat fragmentation and loss of wildlife corridors. Disturbed lands are also more susceptible to invasive species, which can spread to natural landscapes. Organ Pipe Cactus National Monument shares its Arizona boundaries with lands managed by the Tohono O'odham Nation (TON), the Bureau of Land Management (BLM) and the Cabeza Prieta National Wildlife Refuge (CPNWR). While livestock trespass has sometimes been a problem in the past on the TON and BLM boundaries, most of the land on these three sides of OPCNM is relatively pristine and not subject to significant development. The monument's 48 kilometer southern boundary intersects the U.S./Mexico international border in a semi-rural area of Sonora, Mexico that has been steadily developing in recent decades. Agricultural development and associated groundwater depletion, along with the effects of other agricultural practices (pesticide drift, soil contamination, etc.), were early concerns of resource managers, and in recent years an increase in population and urban development has increased impacts adjacent to monument lands.

In the *Land Use Trends Surrounding Organ Pipe Cactus National Monument* (Bruce Brown, Great Western Research, 1988) project, conducted in 1987 and 1988, researchers examined agricultural development in the Sonoyta Valley adjacent to the monument in Sonora, Mexico. Agricultural and urban development in this area has the potential to negatively impact the natural resources of the monument through depletion of the aquifer in the Rio Sonoyta watershed that is shared by the monument and Mexico. In addition, other aspects of agricultural and urban development are of concern. The aerial application of agricultural pesticides is a threat due to wind drift. Increased human habitation causes impact from pollution and wind blown trash, habitat degradation and land clearing, woodcutting, livestock trespass, non-native plants and animals, and altered wildfire frequency.

The Mexican portion of the Sonoyta Valley is a prime site for agricultural development. At the conclusion of the research phase of the project in 1988, over 12,140 hectares had been developed for irrigated agriculture. Total water withdrawal from the approximately 165 agricultural wells in 1987–88 was estimated to be 83,152 acre-feet (1.026×10^8 m^3), more than 2.5 times the average annual groundwater recharge rate of 28,135 acre-feet (3.472×10^7 m^3). Although moratoriums have been in effect to (1) prohibit development of new wells for irrigation and (2) limit the land developed for irrigated agriculture to the present 12,950 ha, this is of little reassurance when one realizes that the total current annual pumping capacity in the Sonoyta Valley is estimated to be 191,000 acre-feet (2.357×10^8 m^3), or more than 6 times the estimated annual groundwater recharge rate.

Four different methods were recommended in the monitoring protocol to track agricultural development in the Sonoyta Valley:

1. Biannual photo-point photography of the entire border area to detect changes through time;
2. Periodic aerial photography of the same area;
3. Collection of data from Mexican agricultural officials on crops, acreage, and chemical use;
4. Estimation of the amount of water being

pumped for agriculture based on computations using well depths and electrical consumption of the pumps.

Monument resource management staff have conducted the agricultural photo-point monitoring protocol since 1988. These photo-points are located adjacent to the international border, both in Mexico and the United States, and offer long-term visual information on changes in land use.

As recommended in the Land Use Trends final report, a good working relationship has been maintained with Mexican agricultural officials from the Secretaría de Agricultura, Ganadería, Desarollo Rural, Pesca y Alimentación (SAGARPA), formerly the Secretaría de Agricultura, Ganadería y Desarollo Rural (SAGAR), formerly the Secretaría de Agricultura y Recursos Hidráulicos (SARH), located in Sonoyta, Sonora. Resource management personnel have regularly provided depth-to-water data from monument wells and agricultural photo-point photos to these officials. In return, the monument has received data on depth-to-water and electricity use at Mexican agricultural wells, and information on crops and pesticide use. As will be mentioned elsewhere, there have been problems with data availability. The depth-to-water data became unavailable after 1993, due to budget restrictions that eliminated the annual well depth measurements. Electrical data for the pumps became unavailable, or at least prohibitively difficult to obtain, after 1997 due to its centralization in Caborca, Sonora, some 100 miles to the south. Crop and pesticide use data have been intermittently available.

Methods

Agricultural Photo-points

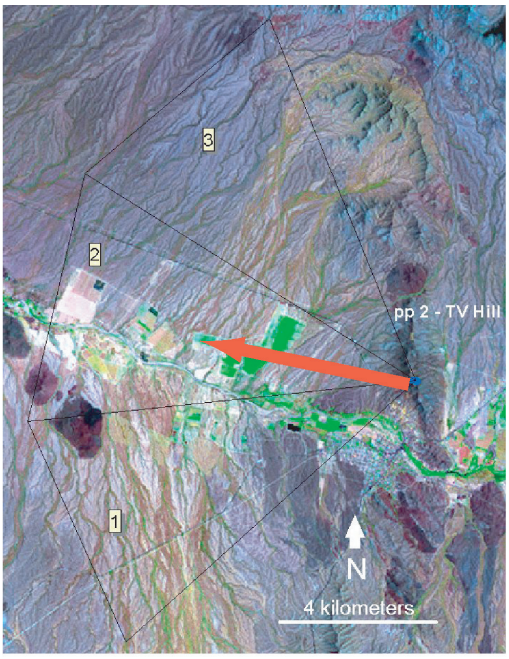
Twice each year, in April and November, a sequence of photos was taken from each of the 8 established photo points along the border. Four of these points are on the Mexican side of the border, while 4 are on the U.S. side. Each photo-point consists of a tagged rebar and 3 painted spots indicating the placement of the tripod. The head of the tripod was leveled by shortening two of the legs, and thus the photos were taken from exactly repeatable locations. Each individual photo in each panoramic sequence was located by means of comparison to existing black and white photos that are contained in the monitoring field book. These photos each had a vertical mark in the center to correspond with the cross-hairs focusing screen used in the camera. Elevation was also similarly set by using the top of a distant feature such as a mountain top. Each photo sequence was shot using both color slide and black and white print film. Once processed, the slides, prints, and negatives were labeled and archived. One duplicate set of black and white prints was provided to SAGAR.

Mexican Agricultural Data

Soon after the beginning of each year, from 1987 through 1997, electrical and well-depth data have been retrieved from Mexican agriculture and utility officials. These data were entered into a Lotus spreadsheet which calculated, using assumed pump efficiencies, the amount of water being drawn from each well. A copy of this spreadsheet, when completed, was provided to SAGAR. Information from SAGAR on well depths has not been available since 1993 due to the lack of money to conduct the survey. It is hoped that the wells will be sounded again sometime in the foreseeable future. Consequently, the calculations used in the estimates for water pumping for the years 1994 - 1997 were based on well depths from 1993. These estimates were considered reasonable in that the consumption of electricity by the pumps is much more highly variable than the well depths.

Results

All 8 boundary photo points have been visited and photos taken without incident. Slides and prints showing Mexican agricultural development on the monument boundary (Figure 15-1 - 15-3) were processed and archived in the monument museum vault. Copies of the black-and-white photos were provided to agency officials in



ORPI Ecological Monitoring Program
Land Use Trends
Photopoint #2-2 -- TV Hill

November 9, 1988

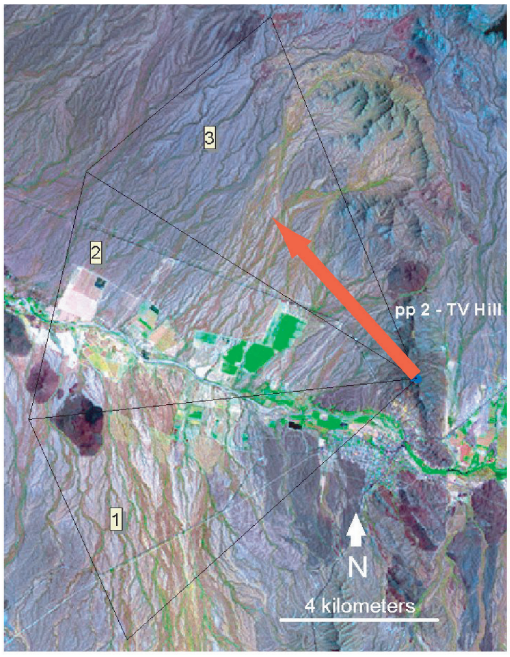
November 13, 1992

May 27, 1996

November 13, 2000

November 9, 2004

Figure 15-1. Land use trends photopoint #2-2 (TV Hill), 1988-2004.



ORPI Ecological Monitoring Program
Land Use Trends
Photopoint #2-3 -- TV Hill

November 9, 1988

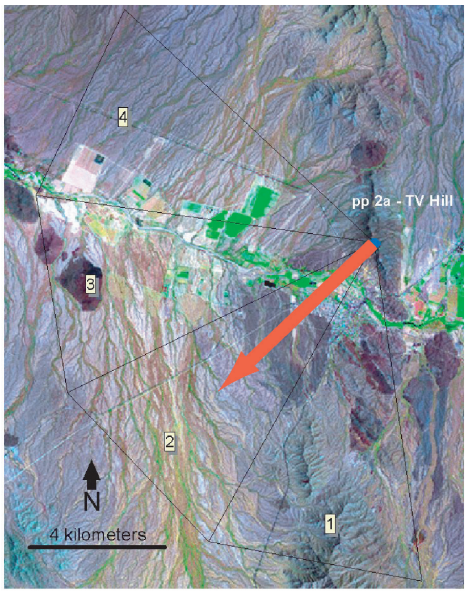
November 13, 1992

May 27, 1996

November 13, 2000

November 9, 2004

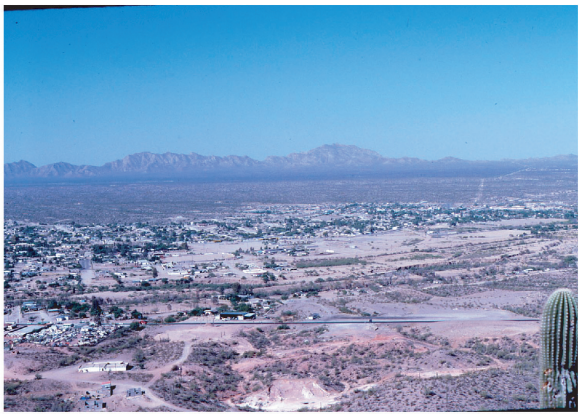
Figure 15-2. Land use trends photopoint #2-3 (TV Hill), 1988-2004.



ORPI Ecological Monitoring Program
Land Use Trends
Photopoint #2a-2 -- TV Hill

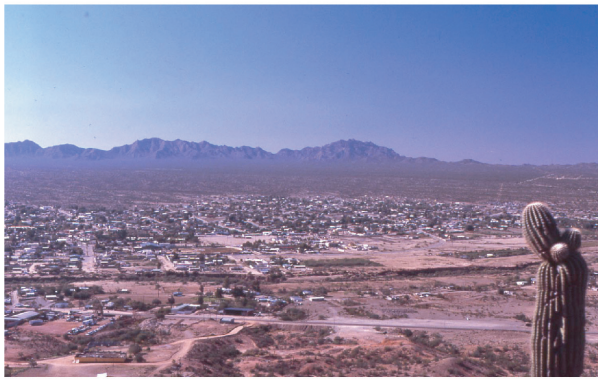
November 9, 1988

November 13, 1992



May 27, 1996

November 13, 2000



November 9, 2004

Figure 15-3. Land use trends photopoint #2a-2 (TV Hill), 1988-2004.

Sonoyta.

Electrical data for the agricultural wells in Mexico has not been available since 1997. As mentioned before, well depths have not been taken since 1993, so depths from that year were used through 1997 for pumping estimates. These figures were processed and entered into the appropriate Lotus spreadsheets. No water pumping calculations have been done since 1997.

Discussion

Up to 1997, the last year for which data were available, agriculture in the Sonoyta Valley seemed to be somewhat on the rebound, with water usage nearly equal to 1991 levels. Cotton prices have dropped and energy is still expensive. More data on crop acreage and chemical use would be useful, as would data on municipal water use by the growing town of Sonoyta. Mexican officials are trying to revive the program of checking well depths, although the standard procedure has been to get a reliable *static* level by shutting down the pumps for a few days and then getting a stable reading. This is useful for monitoring groundwater depletion, but *dynamic* levels (when the pumps are operating) are much more relevant to the calculation of the volume of water being extracted. It is not clear when or if these measurements will be made. Overall, many factors relating to agriculture besides well establishment and water use, such as seed, fertilizer, and pesticide use, are tracked by SAGARPA and related agencies, and it might be well worth the effort to try to utilize this valuable information in our attempt to monitor this significant activity on our southern boundary.

The most notable result seen from the photo points has been the recent rapid increase in urbanization along the border. Whole settlements have sprung up, as well as facilities for travelers, communication towers, etc. Large patches of land have been cleared in preparation for further development, and much of this is along Mexican Route 2 adjacent to the boundary with OPCNM. Development along this highway corridor has the very real potential to impede wildlife movement.

Anecdotal reports from monument staff indicate a large increase in trespass by domestic and/or feral dogs near the south boundary, and sometimes several miles north of the boundary. Wind blown trash from border settlements is also increasing. Historic structures on the border have experienced degradation from vandalism and wood theft. As the Sonoyta population grows, these impacts to wilderness values and natural and cultural resources will likely increase.

Recommendations

- Seek funding for SAGARPA to measure the well depths.
- Attempt to acquire data now stored in Caborca, Sonora.
- Request more data, as before, on crop acreage and pesticide and fertilizer use.
- Generally reestablish and solidify relations with resource agency personnel in Mexico, both in Sonoyta and elsewhere.
- Develop educational programs for Sonoyta schools on cross-boundary conservation issues in conjunction with the Pinacate Biosphere Reserve staff.
- Continue the border photo-point photos at a reduced frequency (once per year), due to budget constraints.
- Acquire or produce better maps of the developed zone along the border, including ejido boundaries and well locations; quantify and map land use boundaries using satellite imagery.

Acknowledgements

We thank the (former) staff of SAGAR and SARH in Sonoyta, including most importantly Jesús Castro and Ricardo Vásquez, who were invaluable in facilitating the field work in Mexico, as well

as providing valuable crop data for the Sonoyta Valley. Roy Irving (NPS) set up the initial photo points and data spreadsheets, and Ami Pate (NPS-ORPI) did a significant amount of the field work.

Literature cited

Land Use Trends Surrounding Organ Pipe Cactus National Monument (Bruce Brown, Great Western Research, 1988

Appendix A: Lizards

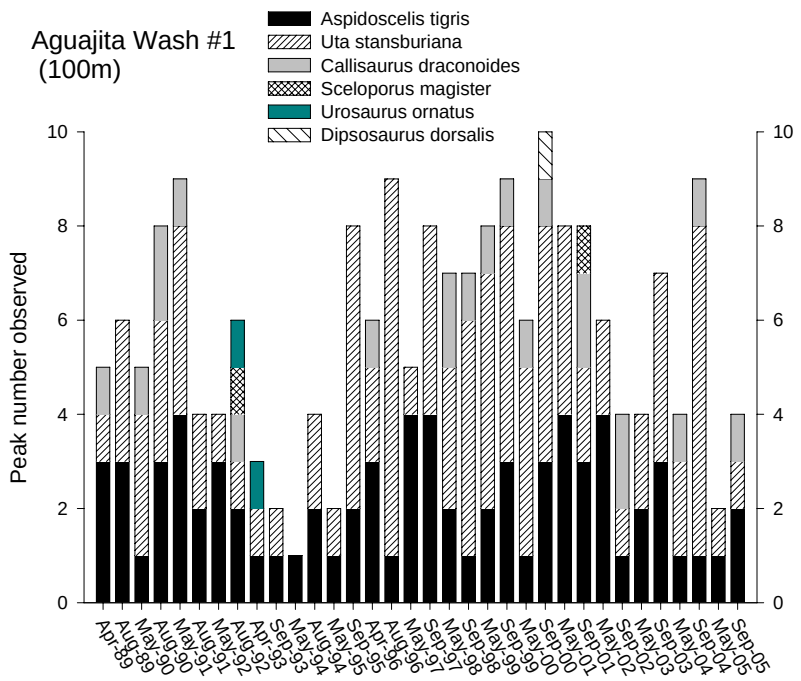


Figure A-1. Peak counts of lizard species, among multiple walks, on Aguajita Wash transect 1 (saltbush), 1989 – 2005, Organ Pipe Cactus N.M.

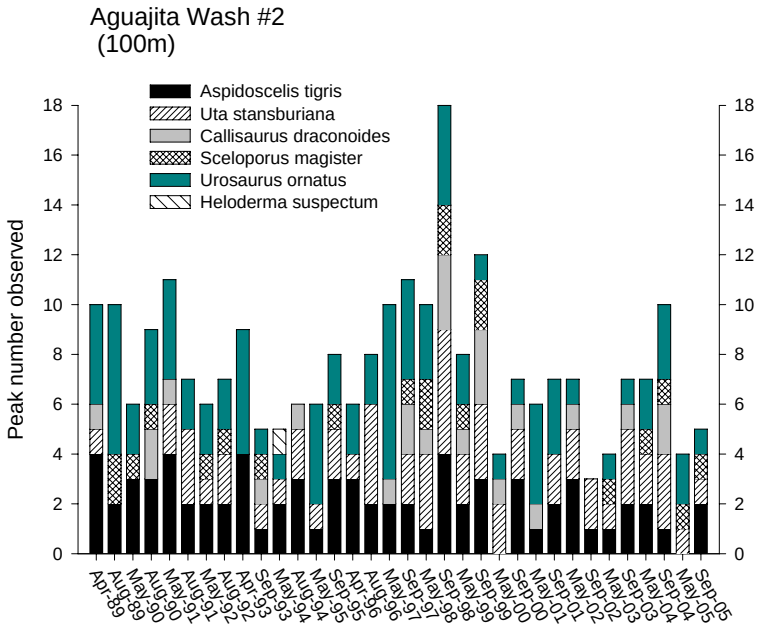


Figure A-2. Peak counts of lizard species, among multiple walks, on Aguajita transect 2 (bosque), 1989 – 2005, Organ Pipe Cactus N.M.

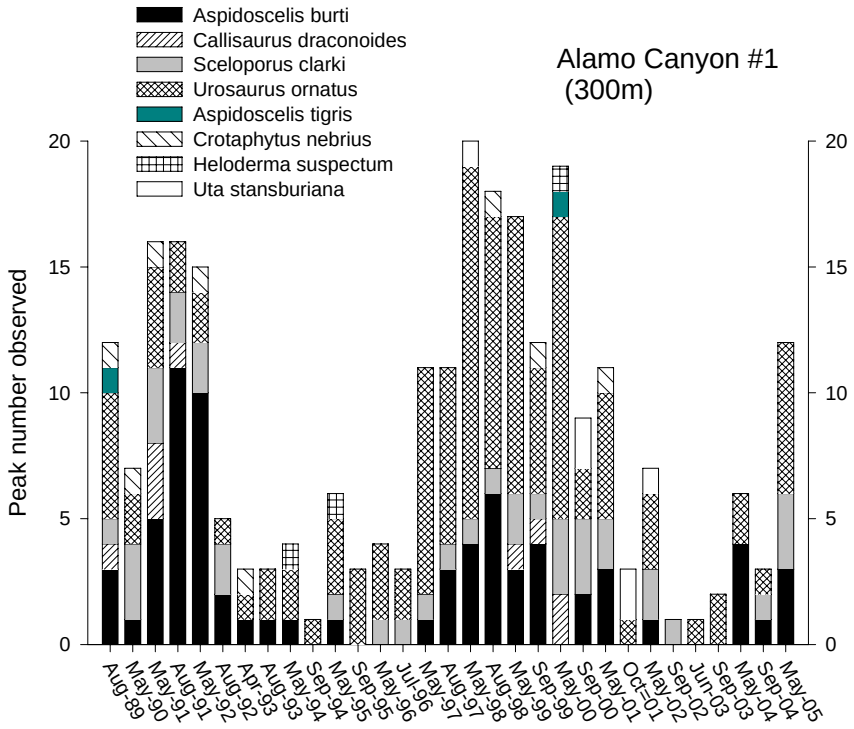


Figure A-3. Peak counts of lizard species, among multiple walks, on Alamo Canyon transect 1 (canyon bottom), 1989 – 2005, Organ Pipe Cactus N.M.

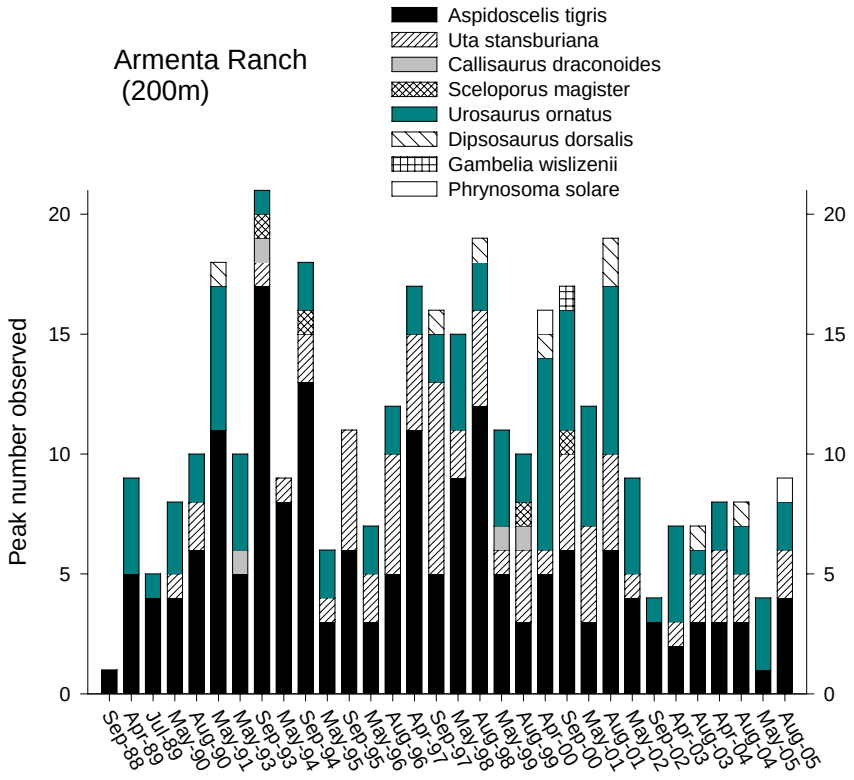


Figure A-4. Peak counts of lizard species, among multiple walks, on Armenta Ranch transect 1, 1988 – 2005, Organ Pipe Cactus N.M.

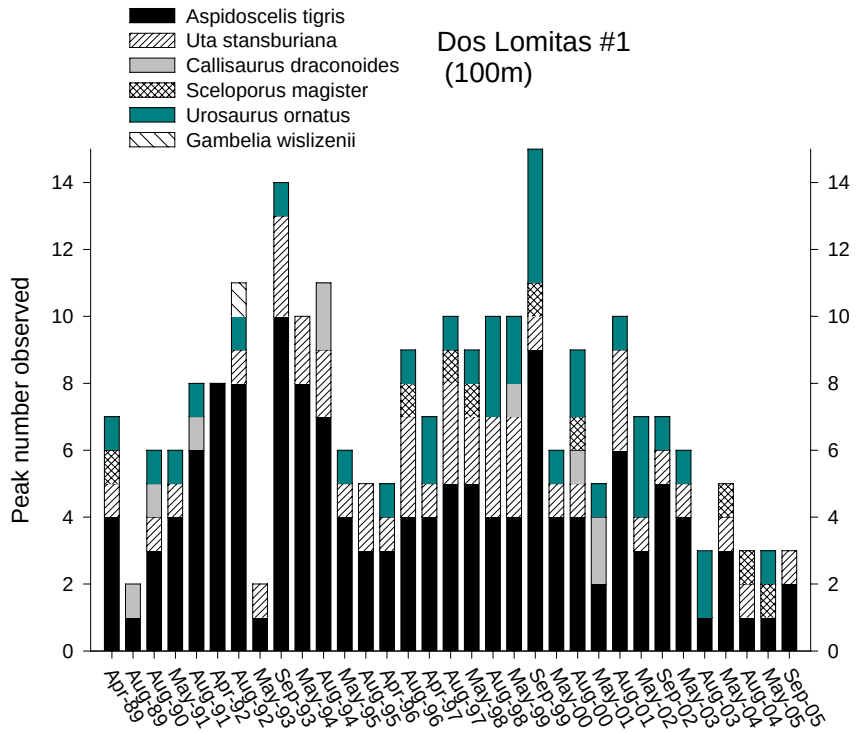


Figure A-5. Peak counts of lizard species, among multiple walks, on Burn Site transect, 1989 – 2005, Organ Pipe Cactus N.M.

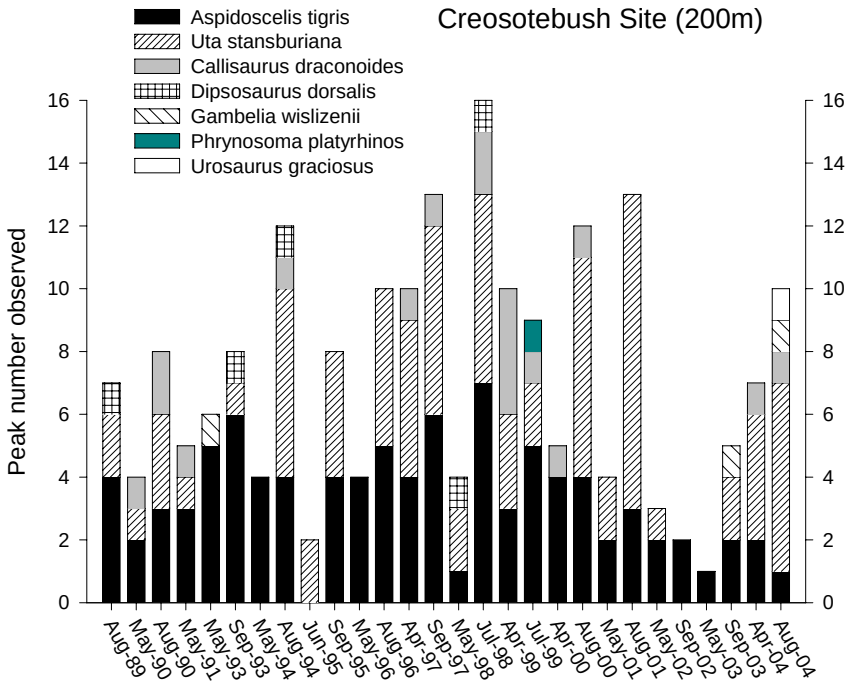


Figure A-6. Peak counts of lizard species, among multiple walks, on Creosotebush Site transect, 1989 – 2005, Organ Pipe Cactus N.M.

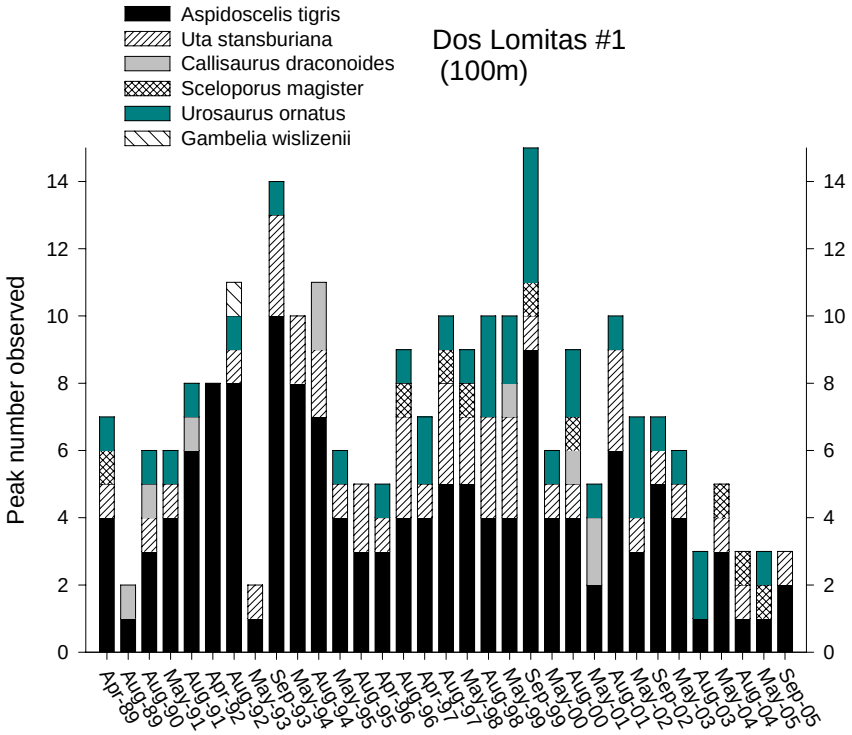


Figure A-7. Peak counts of lizard species, among multiple walks, on Dos Lomitas transect 1 (inside exclosure), 1989 – 2005, Organ Pipe Cactus N.M.

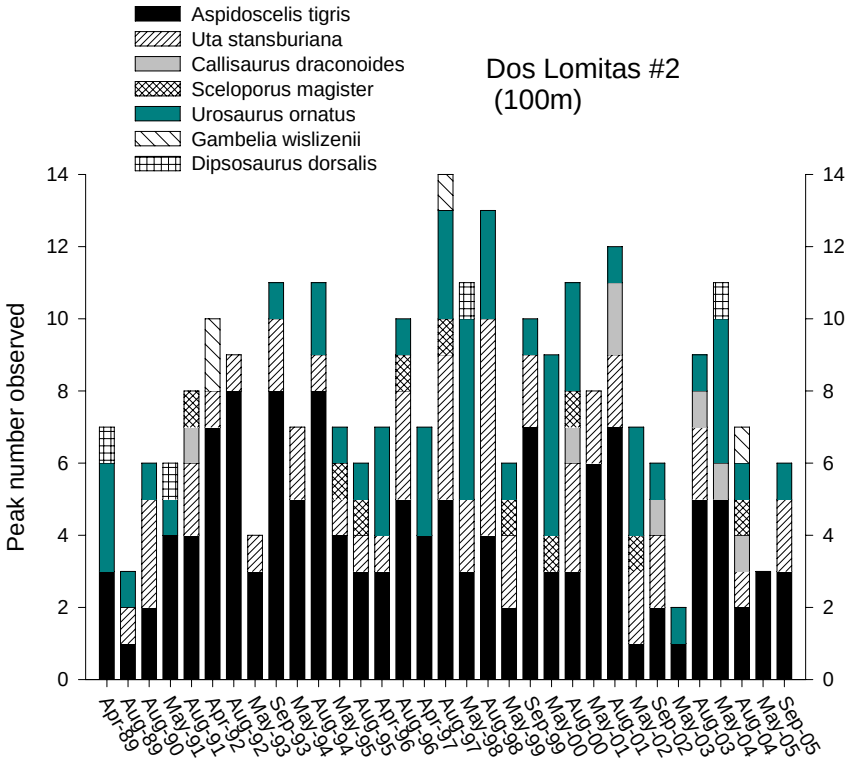


Figure A-8. Peak counts of lizard species, among multiple walks, on Dos Lomitas transect 2 (outside exclosure), 1989 – 2005, Organ Pipe Cactus N.M.

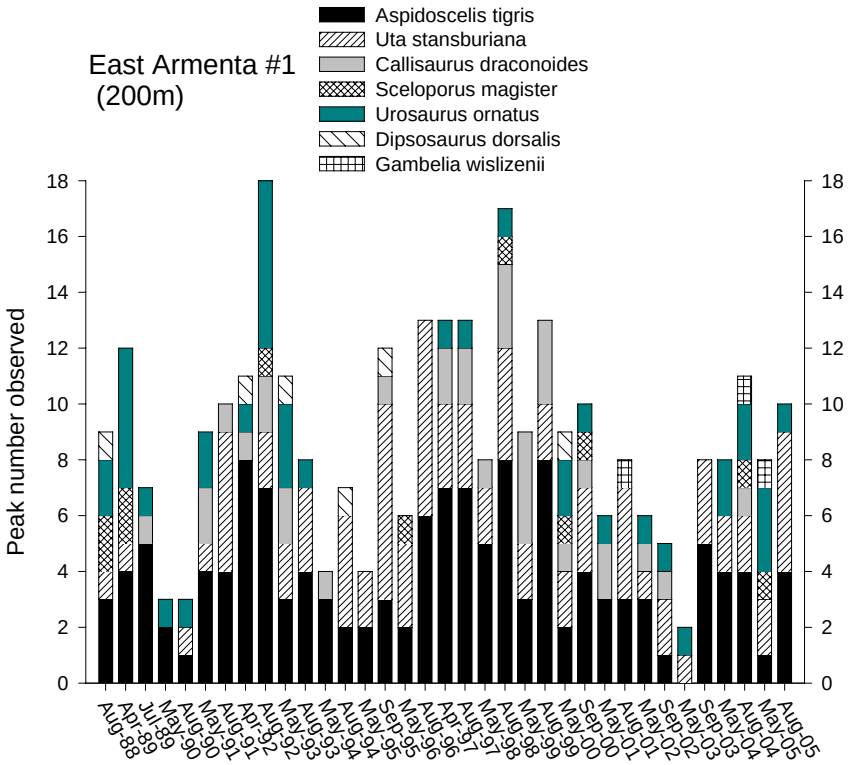


Figure A-9. Peak counts of lizard species, among multiple walks, on East Armenta transect 1 (desertscrub), 1988 – 2005, Organ Pipe Cactus N.M.

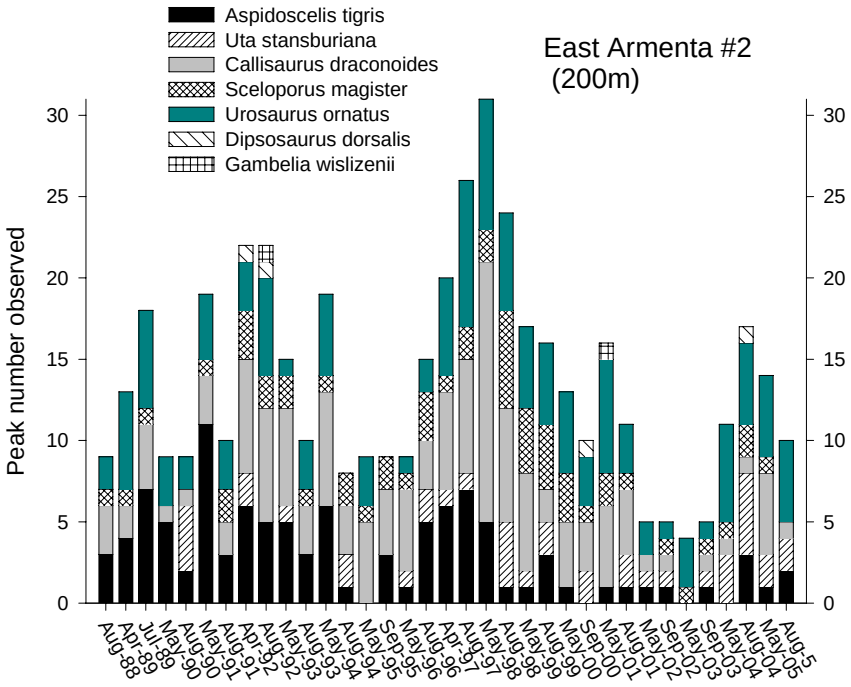


Figure A-10. Peak counts of lizard species, among multiple walks, on East Armenta transect 2 (Kuakatch Wash), 1988 – 2005, Organ Pipe Cactus N.M.

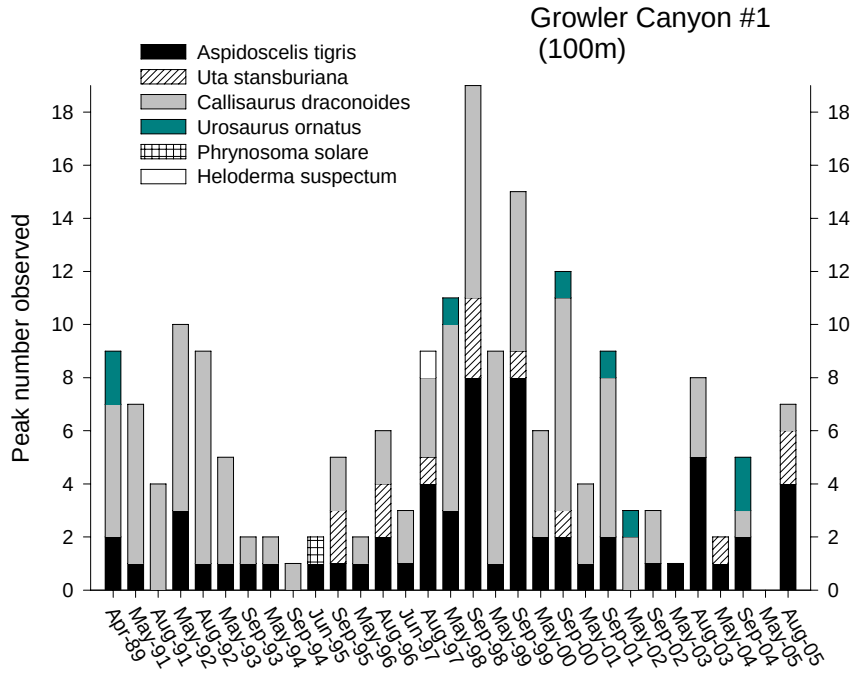


Figure A-11. Peak counts of lizard species, among multiple walks, on Growler Canyon transect 1 (wash bed), 1989 – 2005, Organ Pipe Cactus N.M.

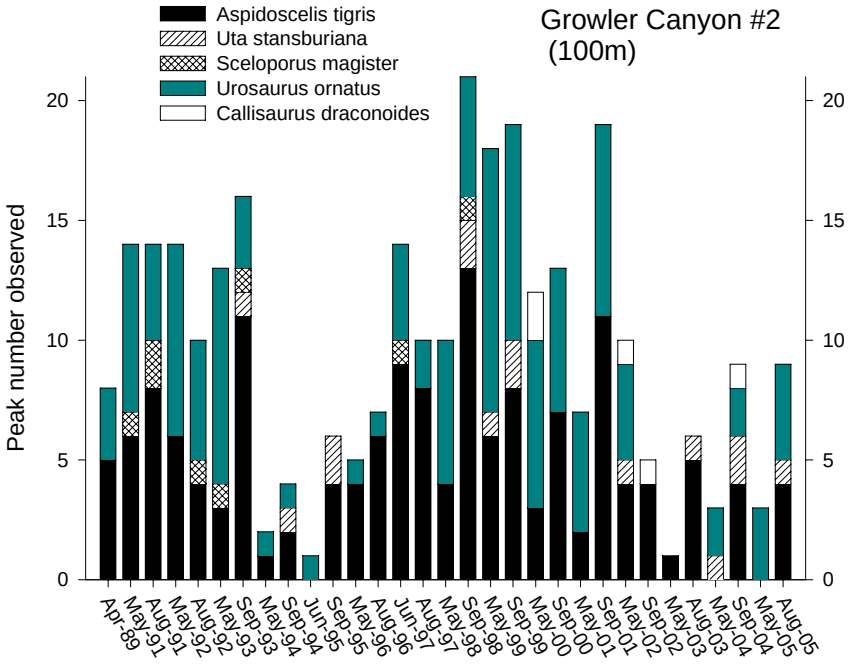


Figure A-12. Peak counts of lizard species, among multiple walks, on Growler Canyon transect 2 (bosque), 1989 – 2005, Organ Pipe Cactus N.M.

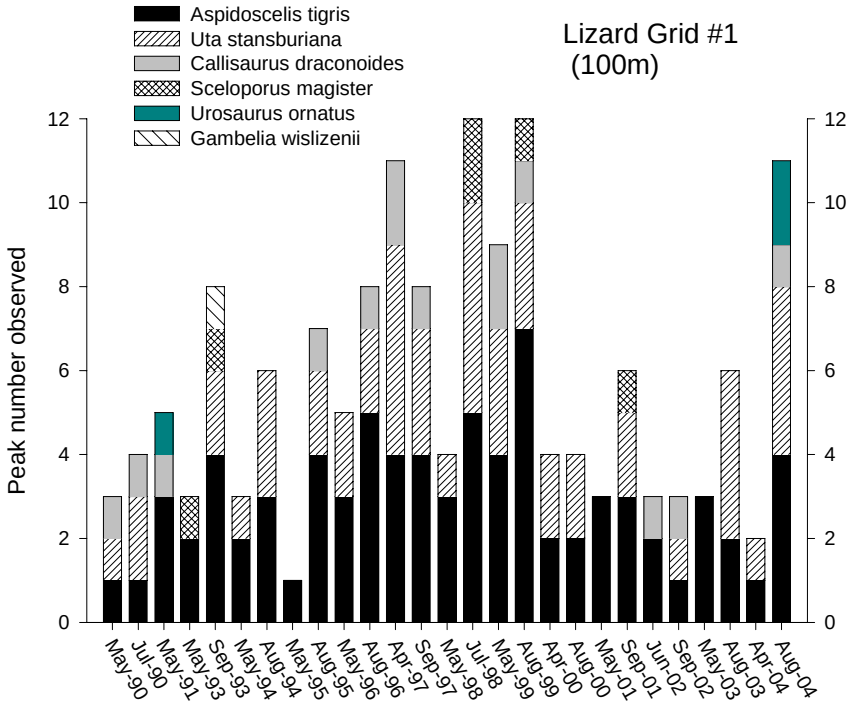


Figure A-13. Peak counts of lizard species, among multiple walks, on Lizard Grid transect 1 (north), 1990 – 2004, Organ Pipe Cactus N.M.

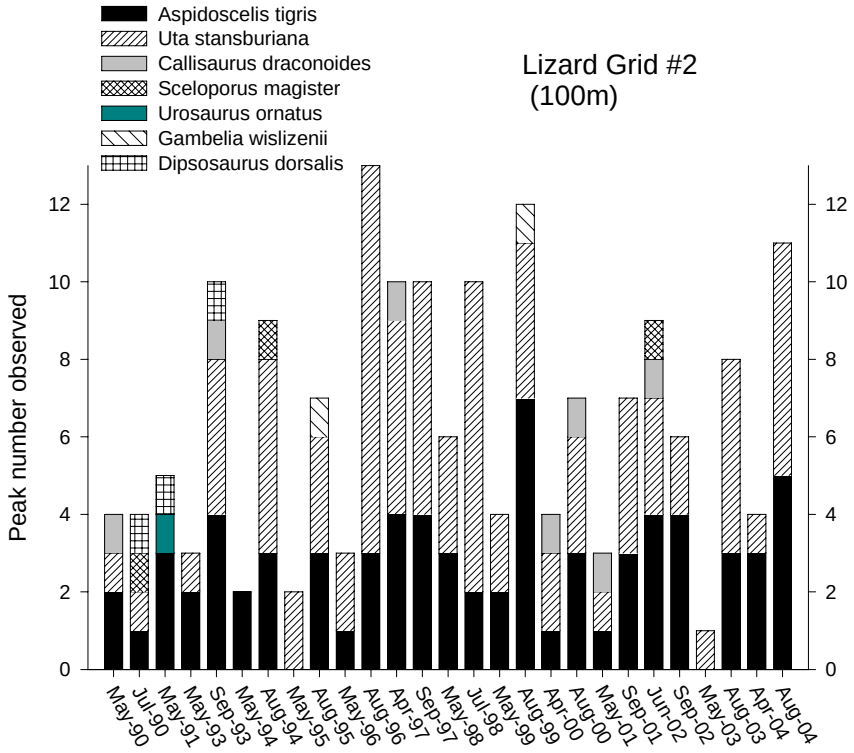


Figure A-14. Peak counts of lizard species, among multiple walks, on Lizard Grid transect 2 (south), 1990 – 2004, Organ Pipe Cactus N.M.

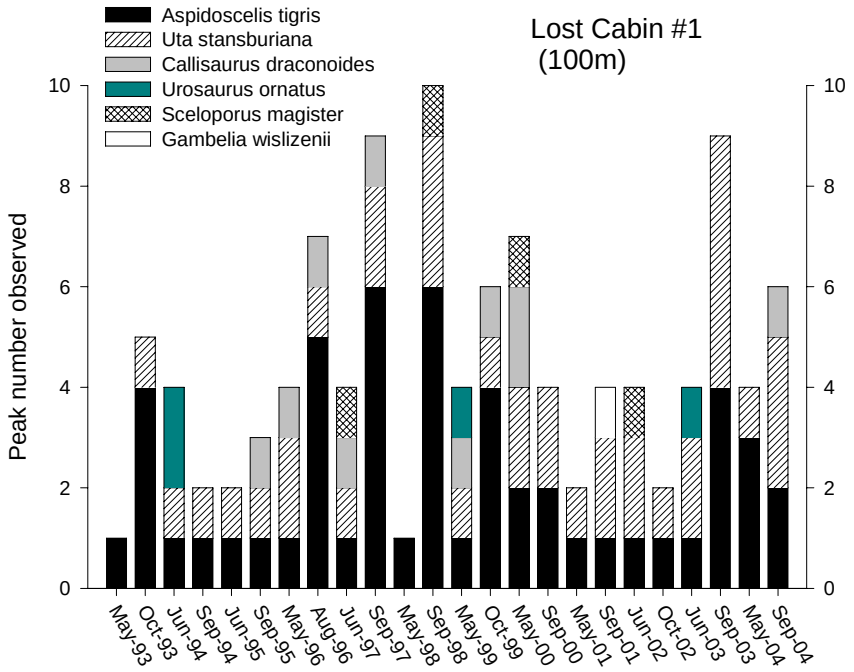


Figure A-15. Peak counts of lizard species, among multiple walks, on Lost Cabin transect #1 (wash flats), 1993 – 2005, Organ Pipe Cactus N.M.

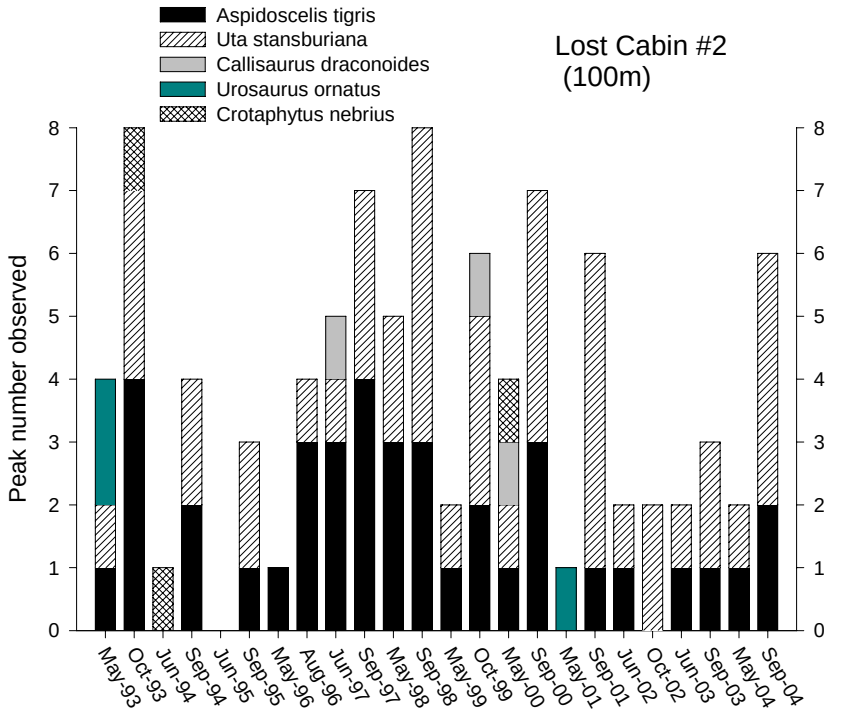


Figure A-16. Peak counts of lizard species, among multiple walks, on Lost Cabin transect 2 (rocky draw), 1993 – 2005, Organ Pipe Cactus N.M.

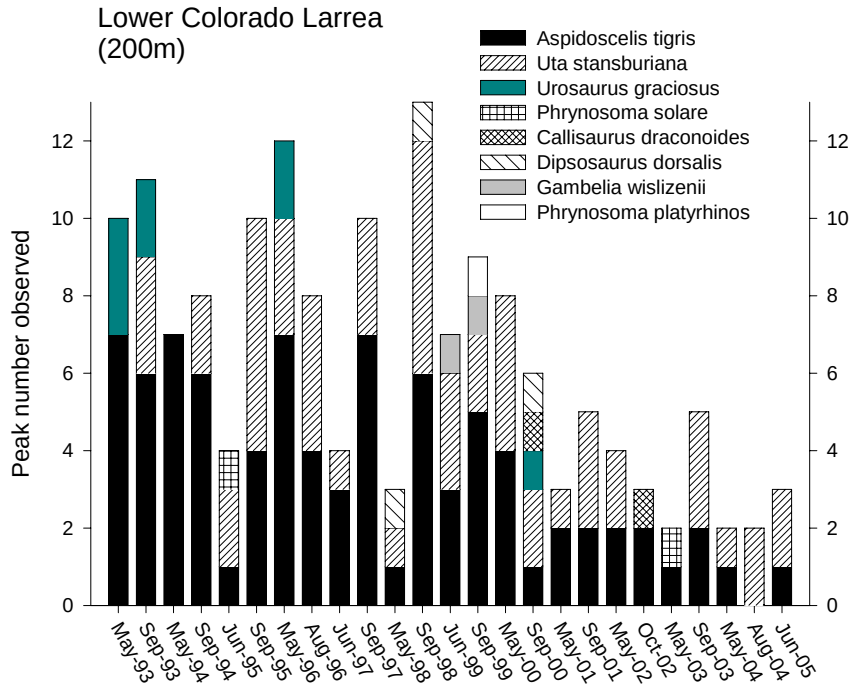


Figure A-17. Peak counts of lizard species, among multiple walks, on Lower Colorado Larrea transect, 1993–2005, Organ Pipe Cactus N.M.

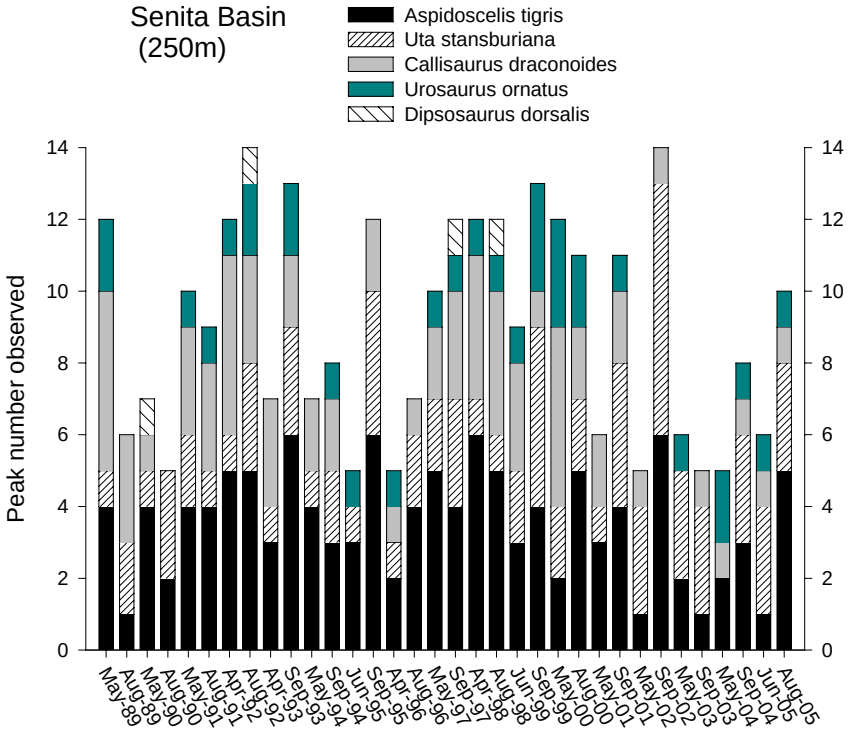


Figure A-18. Peak counts of lizard species, among multiple walks, on Senita Basin transect, 1989 – 2005, Organ Pipe Cactus N.M.

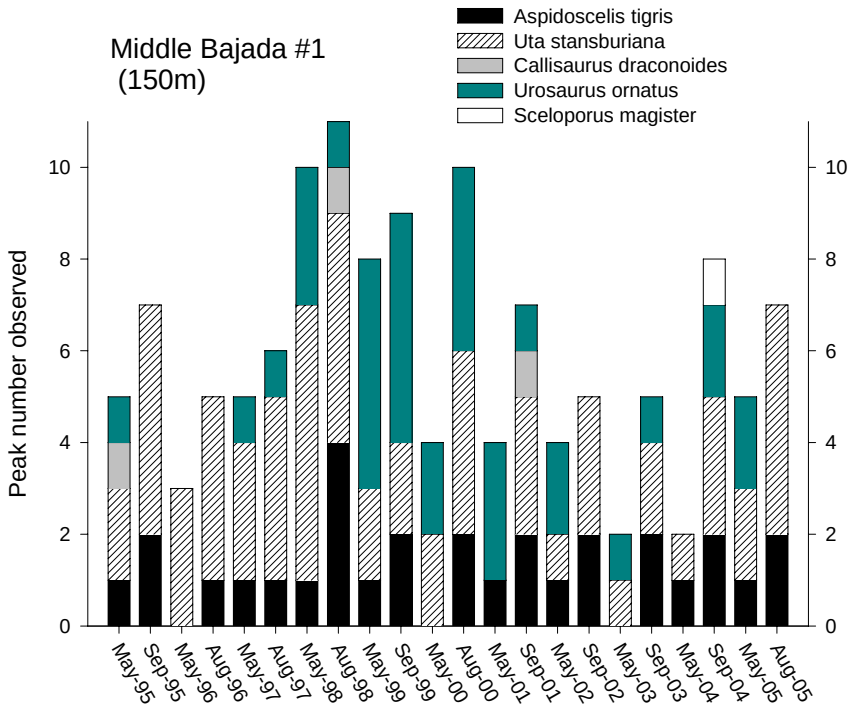


Figure A-19. Peak counts of lizard species, among multiple walks, on Middle Bajada transect 1 (wash), 1995 – 2005, Organ Pipe Cactus N.M.

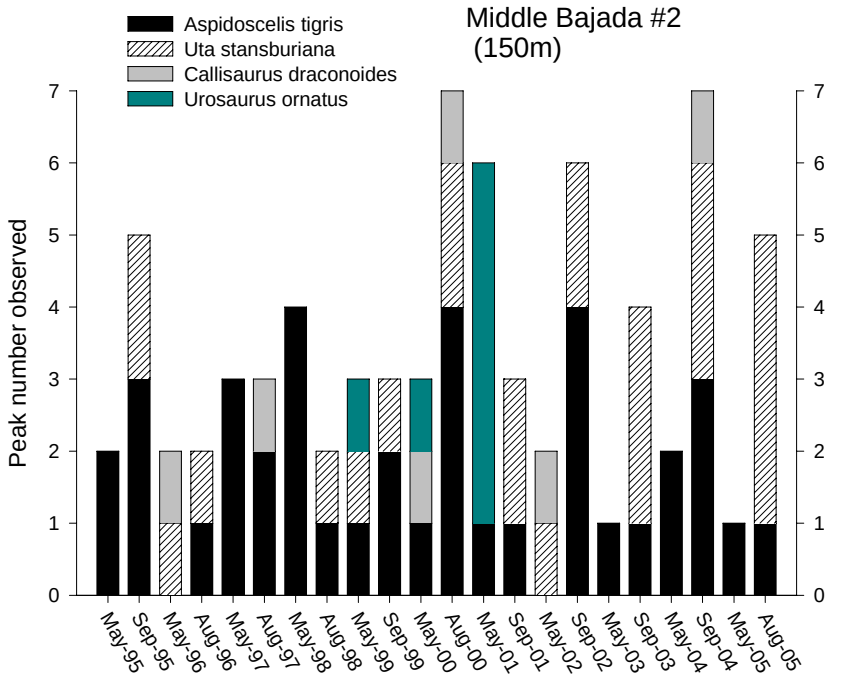


Figure A-20. Peak counts of lizard species, among multiple walks, on Middle Bajada transect 2 (flats), 1995 – 2005, Organ Pipe Cactus N.M.

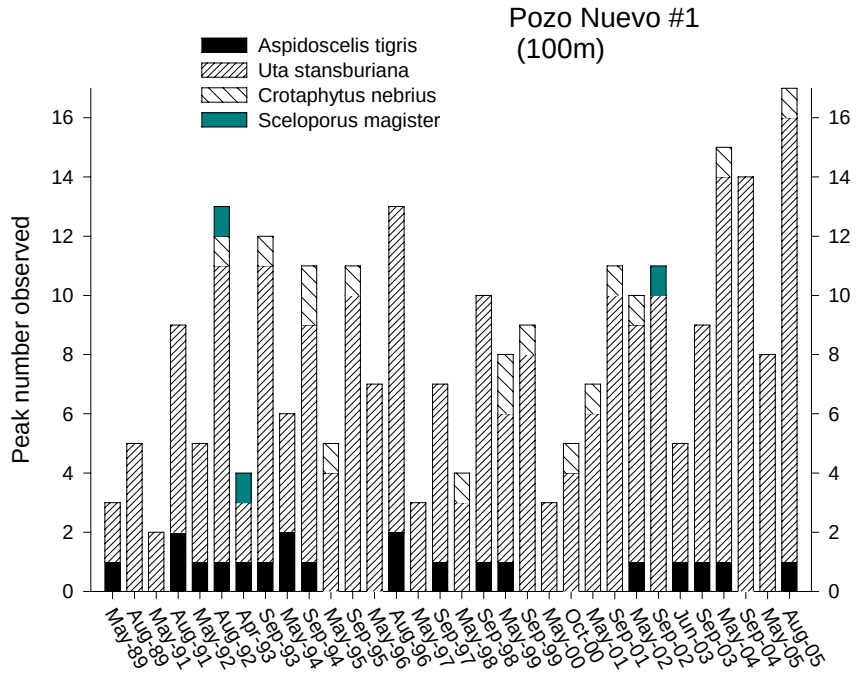


Figure A-21. Peak counts of lizard species, among multiple walks, on Pozo Nuevo transect 1 (hill base), 1989 – 2005, Organ Pipe Cactus N.M.

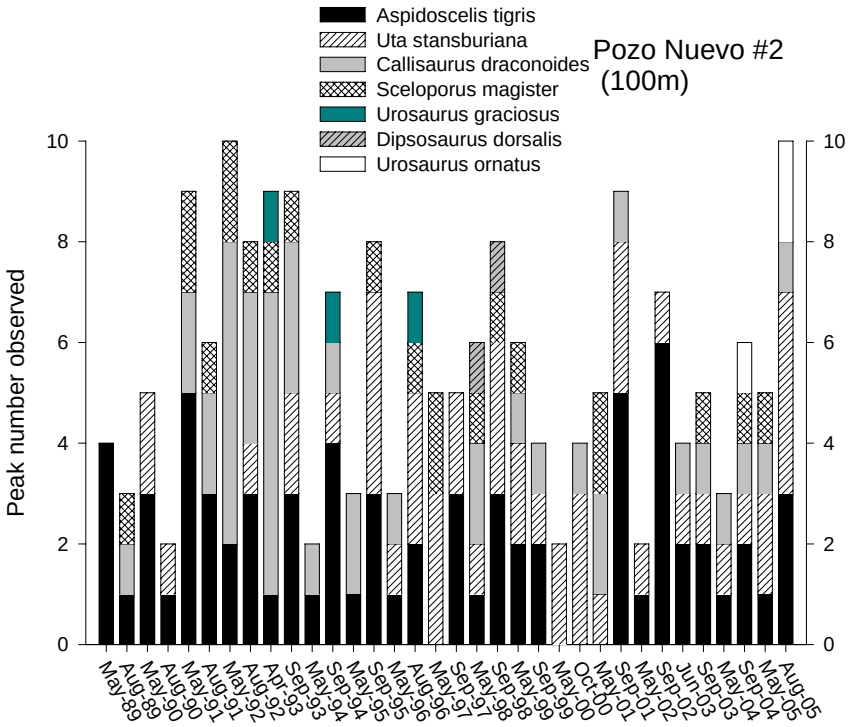


Figure A-22. Peak counts of lizard species, among multiple walks, on Pozo Nuevo transect 2 (wash), 1989 – 2005, Organ Pipe Cactus N.M.

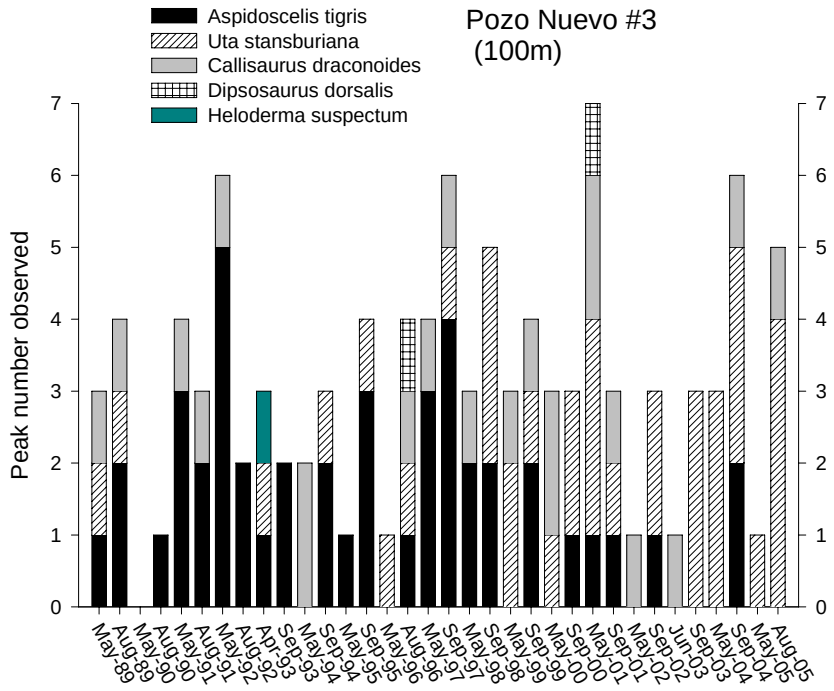


Figure A-23. Peak counts of lizard species, among multiple walks, on Pozo Nuevo transect 3 (dumosa bursage), 1989 – 2005, Organ Pipe Cactus N.M.

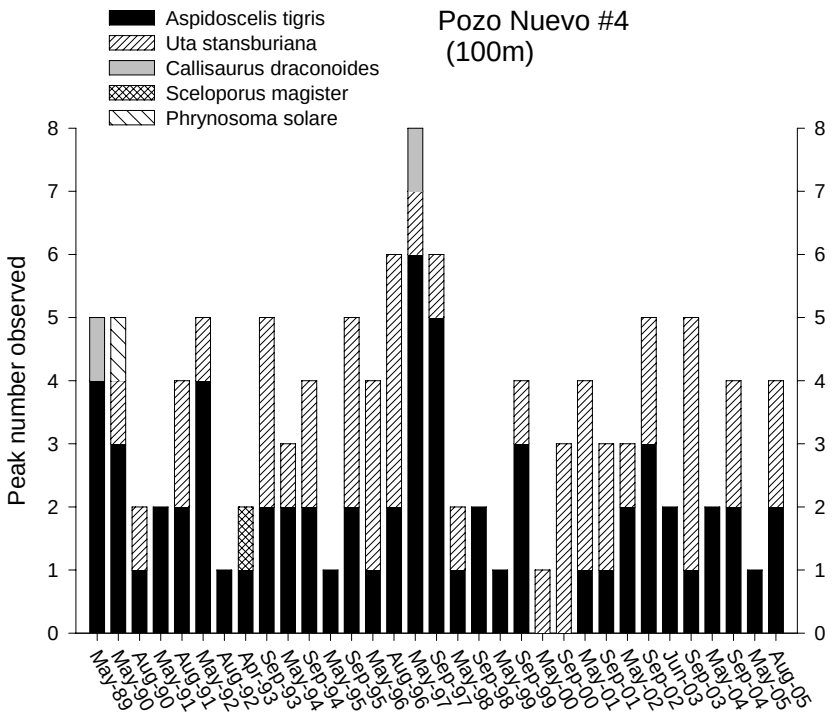


Figure A-24. Peak counts of lizard species, among multiple walks, on Pozo Nuevo transect 4 (deltoidea bursage), 1989 – 2005, Organ Pipe Cactus N.M.

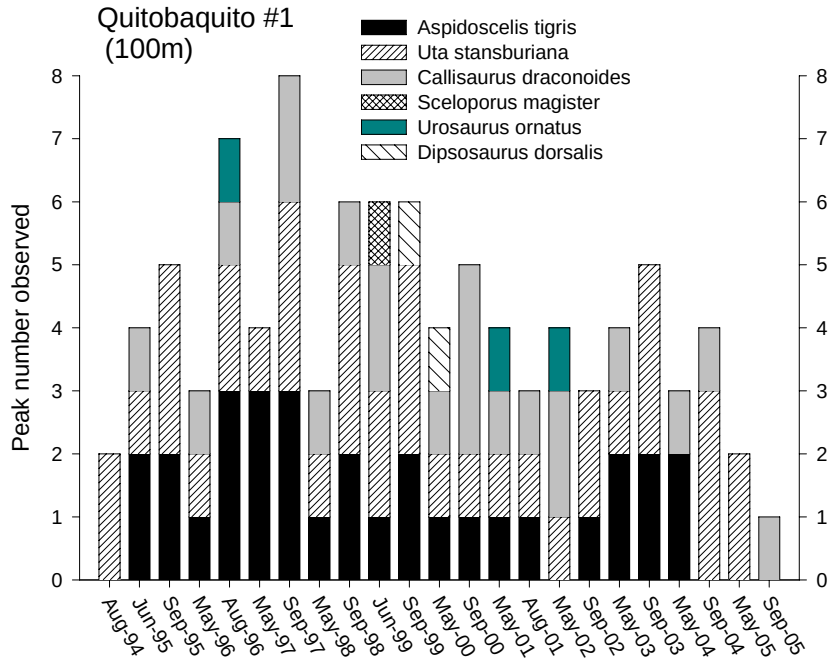


Figure A-25. Peak counts of lizard species, among multiple walks, on Quitobaquito transect 1 (hill), 1994 – 2005, Organ Pipe Cactus N.M.

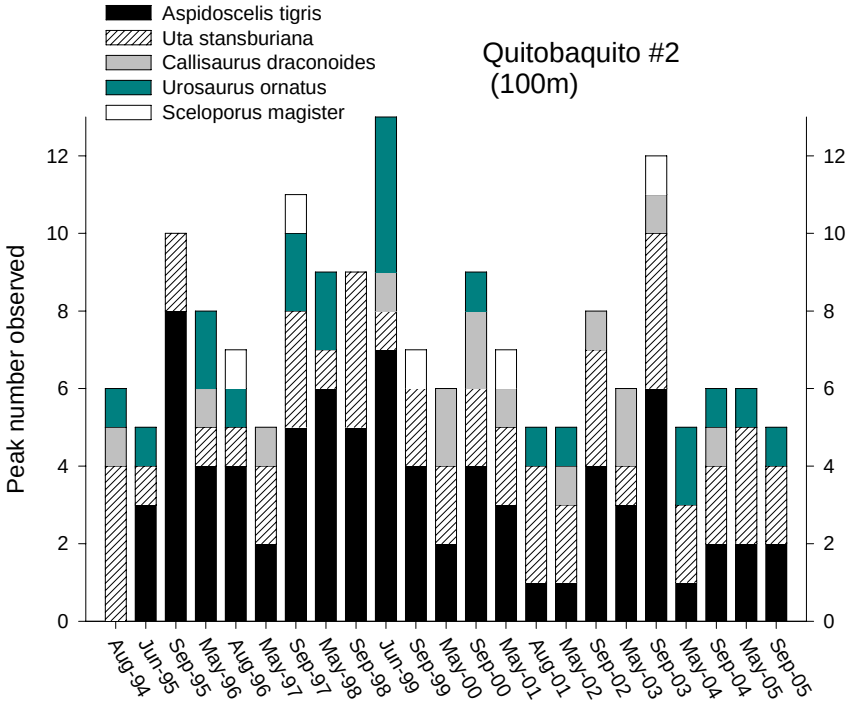


Figure A-26. Peak counts of lizard species, among multiple walks, on Quitobaquito transect 2 (bosque), 1994 – 2005, Organ Pipe Cactus N.M.

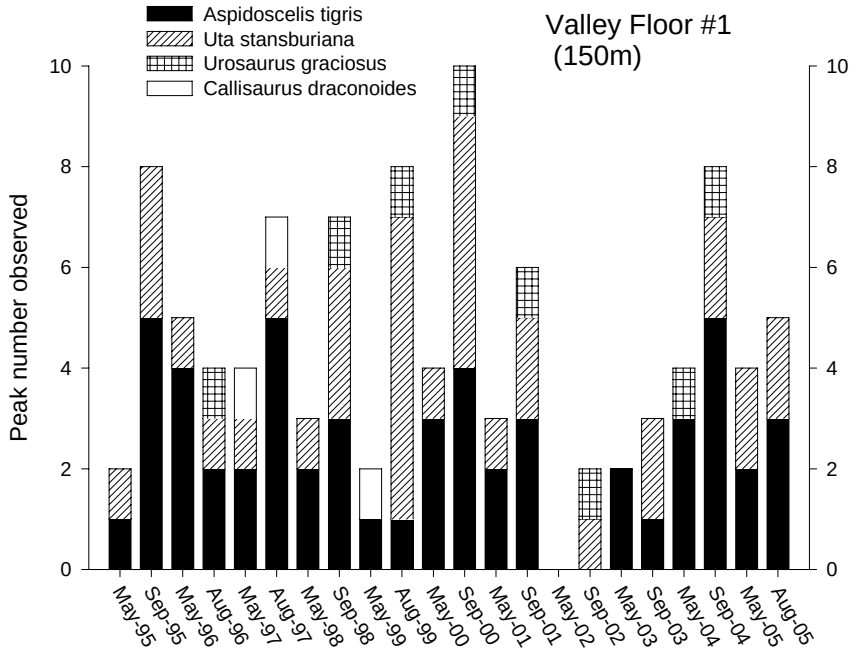


Figure A-27. Peak counts of lizard species, among multiple walks, on Valley Floor transect 1 (flats), 1995 – 2005, Organ Pipe Cactus N.M.

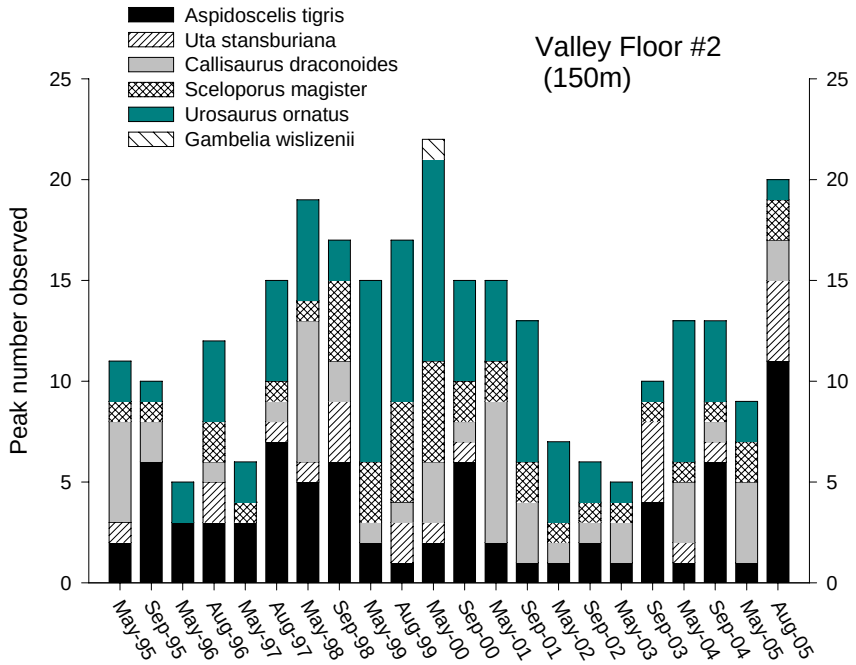


Figure A-28. Peak counts of lizard species, among multiple walks, on Valley Floor transect 2, 1995 – 2005, Organ Pipe Cactus N.M.

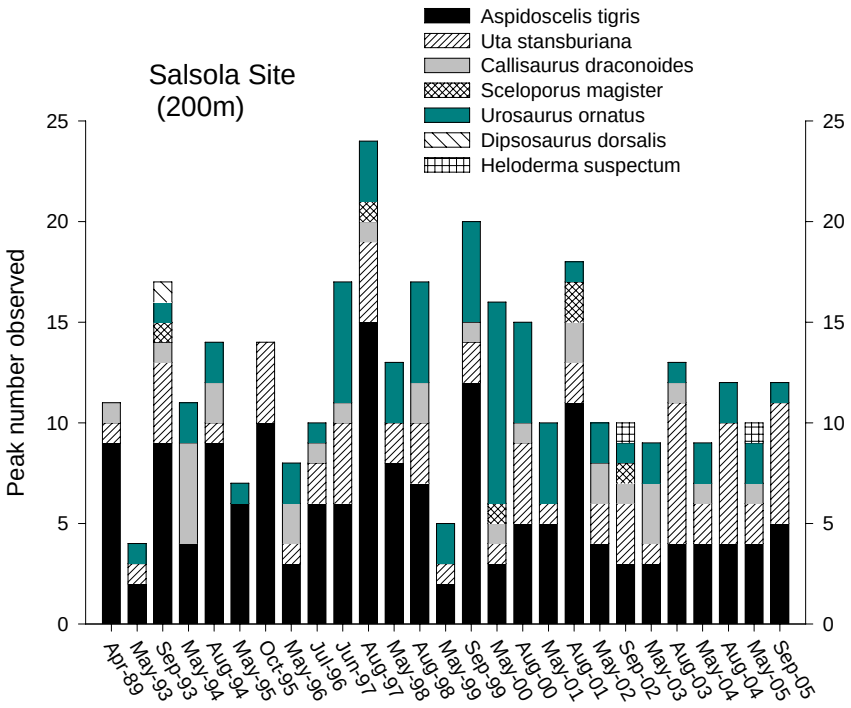


Figure A-29. Peak counts of lizard species, among multiple walks, on Salsola Site transect, 1989 – 2005, Organ Pipe Cactus N.M.

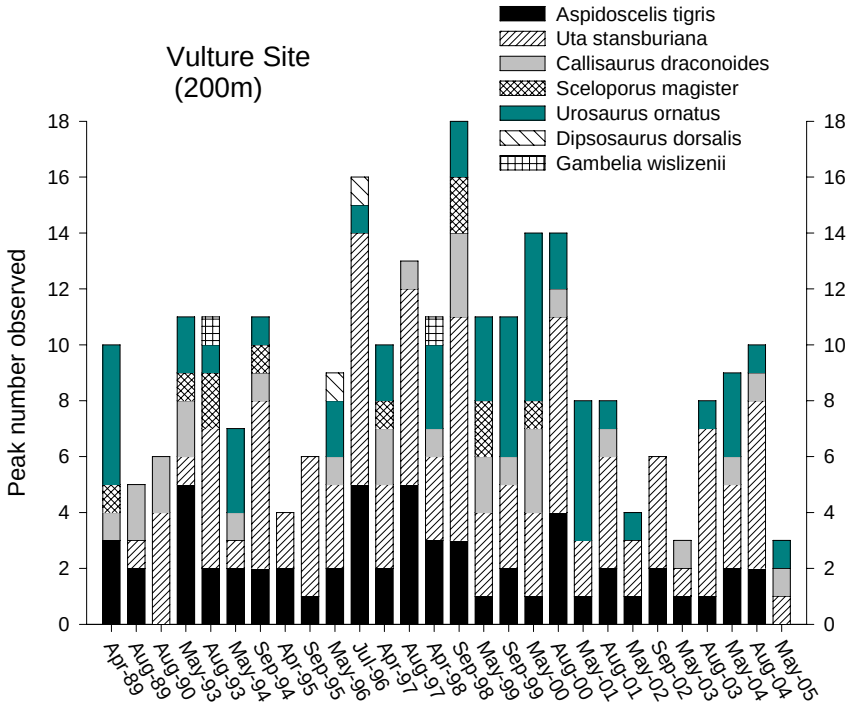


Figure A-30. Peak counts of lizard species, among multiple walks, on Vulture Site transect, 1989 – 2005, Organ Pipe Cactus N.M.

Appendix B: Nocturnal Rodents

Table B-1. Summary statistics for nocturnal rodents at Aguajita Wash quadrat 1, 1997 – 2005, Organ Pipe Cactus N.M.

	1997	1998	1999	2000	2001	2002	2003	2004	2005
Murid total abundance	3	7	1	6	9	1	1	1	1
Murid total biomass (g)	138	920	133	756	1302	117	20	111	32
Heteromyid total abundance	37	25	35	37	37	34	29	42	46
Heteromyid total biomass (g)	688	450	645	629	605	625	450	838	892
Species richness	5	4	4	4	3	4	4	4	5
Diversity (H')	.907	0.902	0.647	0.709	0.663	0.474	0.865	1.037	0.965
Capture success, night 1	49%	37%	41%	51%	59%	45%	41%	53%	51%
Capture success, night 2	47%	53%	55%	57%	53%	41%	27%	63%	67%
Recaptures	30%	46%	41%	36%	35%	35%	23%	45%	33%

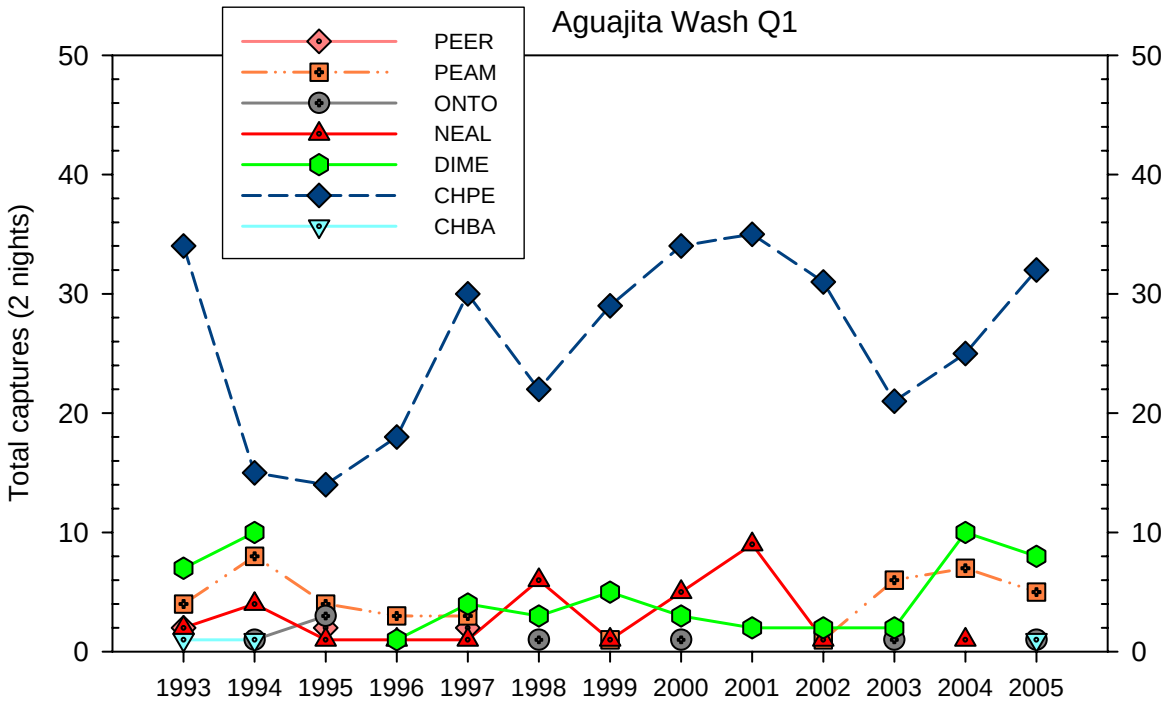


Figure B-1. Relative abundance of nocturnal rodent species at Aguajita Wash quadrat 1, 1993 – 2005, Organ Pipe Cactus N.M. (CHBA = *Chaetodipus baileyi*, CHPE = *Chaetodipus penicillatus*, DIME = *Dipodomys merriami*, NEAL = *Neotoma albigula*, ONTO = *Onychomys torridus*, PEAM = *Perognathus amplus*, PEER = *Peromyscus eremicus*)

Table B-2. Summary statistics for nocturnal rodents at Aguajita Wash quadrat 2, 1997 – 2005, Organ Pipe Cactus N.M.

	1997	1998	1999	2000	2001	2002	2003	2004	2005
Murid total abundance	0	5	3	3	7	1	1	2	3
Murid total biomass (g)	0	504	257	152	762	147	18	51	364
Heteromyid total abundance	34	23	35	26	32	28	24	47	39
Heteromyid total biomass (g)	734	515	712	533	554	582	445	976	894
Species richness	3	5	5	5	5	4	4	4	4
Diversity (H')	0.907	1.329	1.096	1.338	1.300	1.177	1.097	1.208	1.244
Capture success, night 1	47%	31%	47%	27%	55%	31%	43%	69%	55%
Capture success, night 2	55%	49%	55%	43%	45%	41%	16%	69%	61%
Recaptures	59%	46%	44%	24%	45%	30%	50%	56%	50%

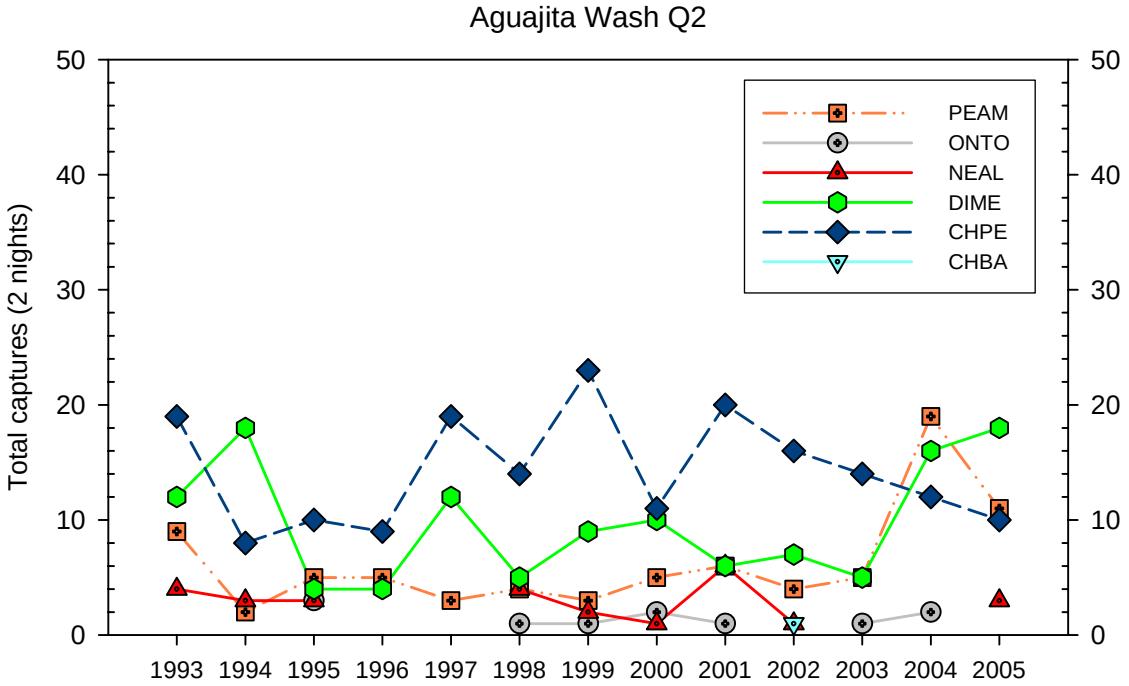


Figure B-2. Relative abundance of nocturnal rodent species at Aguajita Wash quadrat 2, 1993 – 2005, Organ Pipe Cactus N.M. (CHBA = *Chaetodipus baileyi*, CHPE = *Chaetodipus penicillatus*, DIME = *Dipodomys merriami*, NEAL = *Neotoma albigula*, ONTO = *Onychomys torridus*, PEAM = *Perognathus amplus*).

Table B-3. Summary statistics for nocturnal rodents at Alamo Canyon quadrat 1, 1997 – 2005, Organ Pipe Cactus N.M. (1998 = expanded grid)

	1997	1998	1999	2000	2001	2002	2003	2004	2005
Murid total abundance	12		10	4	7	3	6	18	21
Murid total biomass (g)	966		611	431	753	437	474	886	1580
Heteromyid total abundance	21		46	30	36	32	14	41	39
Heteromyid total biomass (g)	277		819	402	682	610	217	499	855
Species richness	5		5	5	5	3	5	5	5
Diversity (H')	1.359		1.379	1.321	1.348	0.924	1.443	1.214	1.417
Capture success, night 1	45%		65%	49%	53%	49%	18%	80%	76%
Capture success, night 2	53%		73%	45%	51%	41%	33%	69%	69%
Recaptures	58%		33%	55%	32%	45%	31%	41%	32%

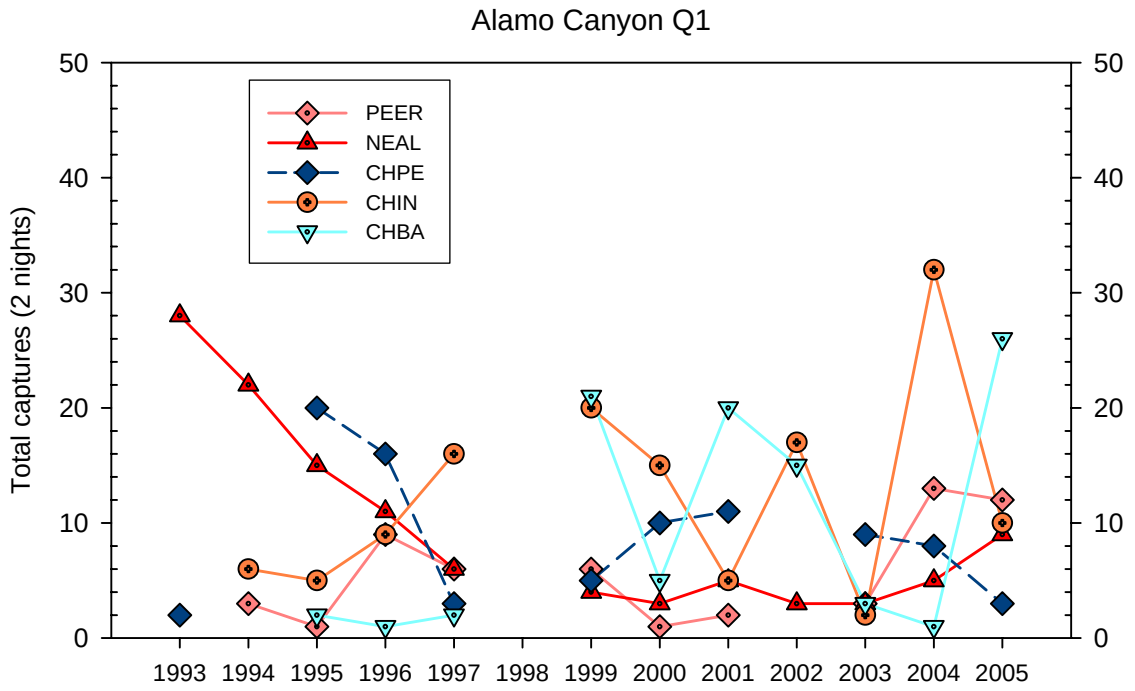


Figure B-3. Relative abundance of nocturnal rodent species at Alamo Canyon quadrat 1, 1993 – 2005, Organ Pipe Cactus N.M. (CHBA = *Chaetodipus baileyi*, CHIN = *Chaetodipus intermedius*, CHPE = *Chaetodipus penicillatus*, NEAL = *Neotoma albigula*, PEER = *Peromyscus eremicus*).

Table B-4. Summary statistics for nocturnal rodents at Alamo Canyon quadrat 2, 1997 – 2005, Organ Pipe Cactus N.M.

	1997	1998	1999	2000	2001	2002	2003	2004	2005
Murid total abundance	15	9	7	2	8	6	6	11	16
Murid total biomass (g)	1063	602	457	346	1429	782	869	398	1351
Heteromyid total abundance	11	6	44	26	30	30	6	40	35
Heteromyid total biomass (g)	177	118	919	450	629	713	162	536	1001
Species richness	5	5	5	4	4	5	4	5	5
Diversity (H')	1.508	1.490	1.076	1.188	0.959	0.971	1.144	1.253	1.017
Capture success, night 1	31%	12%	51%	35%	39%	43%	12%	51%	49%
Capture success, night 2	35%	24%	63%	31%	45%	45%	14%	67%	57%
Recaptures	35%	25%	16%	27%	14%	32%	14%	21%	4%

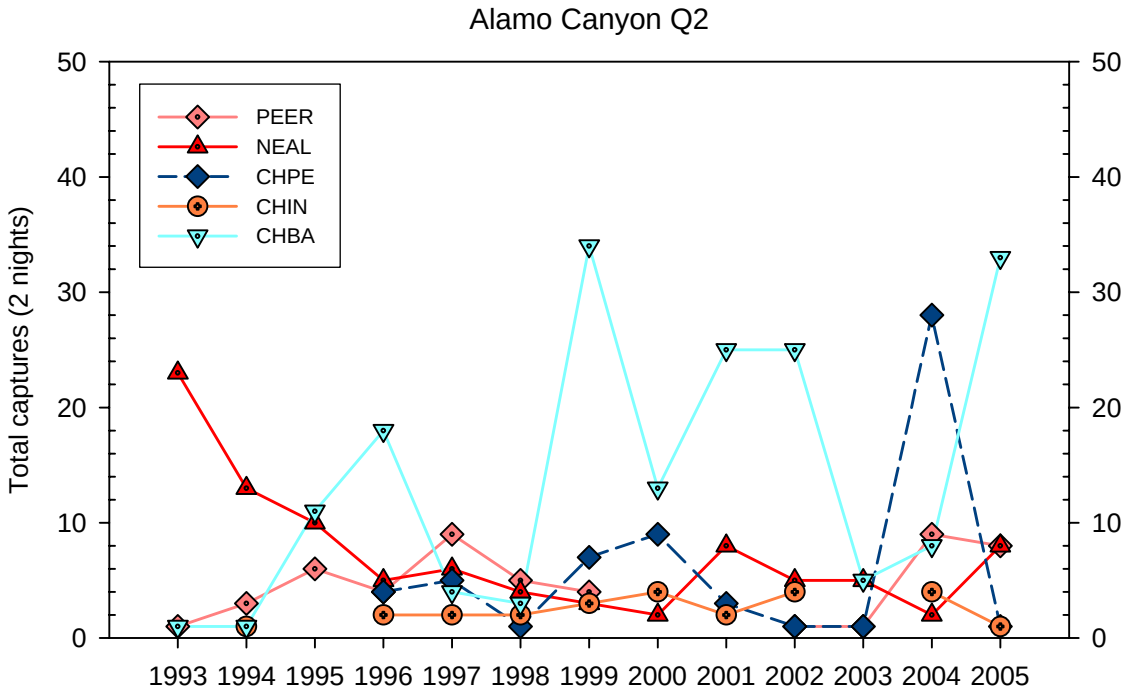


Figure B-4. Relative abundance of nocturnal rodent species at Alamo Canyon quadrat 2, 1993 – 2005, Organ Pipe Cactus N.M. (CHBA = *Chaetodipus baileyi*, CHIN = *Chaetodipus intermedius*, CHPE = *Chaetodipus penicillatus*, NEAL = *Neotoma albigula*, PEER = *Peromyscus eremicus*).

Table B-5. Summary statistics for nocturnal rodents at Armenta Ranch quadrat 1, 2001 – 2005, Organ Pipe Cactus N.M.

	2001	2002	2003	2004	2005
Murid total abundance	0	1	1	0	4
Murid total biomass	0	19	12	0	390
Heteromyid total abundance	41	48	28	24	14
Heteromyid total biomass	1084	1062	770	773	307
Species richness	4	5	4	3	5
Diversity (H')	1.096	1.295	1.017	0.544	1.349
Capture success, night 1	55%	57%	43%	33%	18%
Capture success, night 2	53%	63%	41%	41%	27%
Recaptures	46%	32%	60%	60%	31%

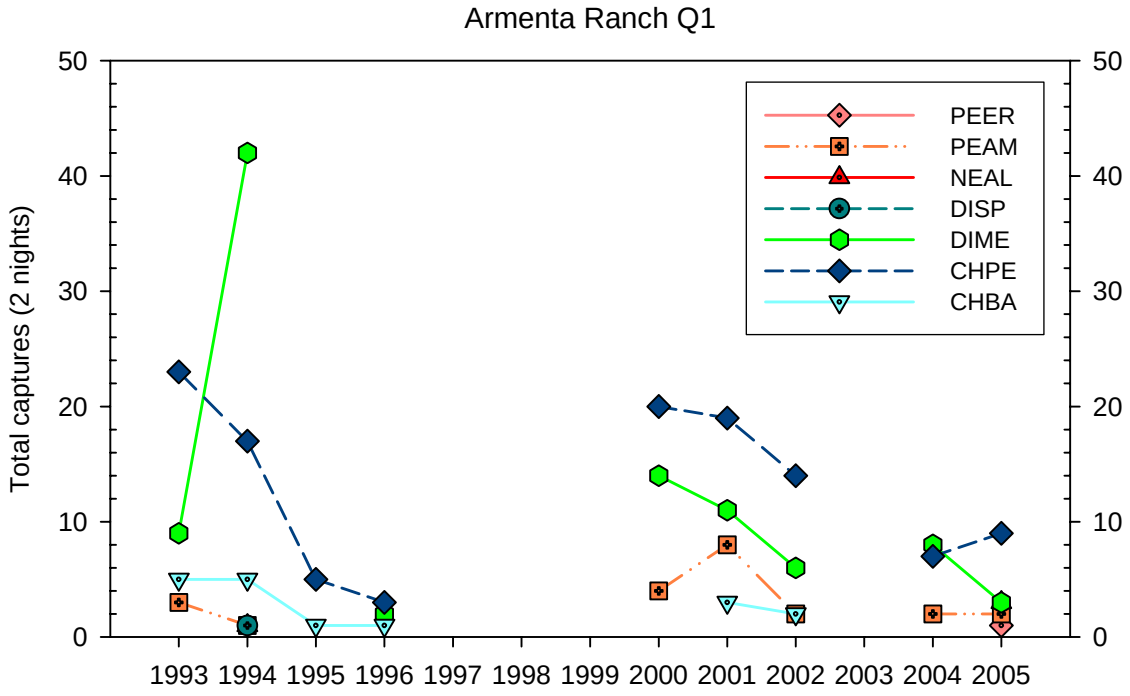


Figure B-5. Relative abundance of nocturnal rodent species at Armenta Ranch quadrat 1, 1993 – 2005, Organ Pipe Cactus N.M. (CHBA = *Chaetodipus baileyi*, CHPE = *Chaetodipus penicillatus*, DIME = *Dipodomys merriami*, DISP = *Dipodomys spectabilis*, NEAL = *Neotoma albigula*, PEAM = *Perognathus amplus*, PEER = *Peromyscus eremicus*).

Table B-6. Summary statistics for nocturnal rodents at Armenta Ranch quadrat 2, 2001 – 2005, Organ Pipe Cactus N.M.

	2000	2001	2002	2004	2005
Murid total abundance	0	1	1	0	2
Murid total biomass (g)	0	19	12	0	176
Heteromyid total abundance	41	48	28	24	20
Heteromyid total biomass (g)	1084	1062	770	773	531
Species richness	4	5	4	3	4
Diversity (H')	1.096	1.295	1.017	0.544	1.084
Capture success, night 1	55%	57%	43%	33%	31%
Capture success, night 2	53%	63%	41%	41%	33%
Recaptures	46%	32%	60%	60%	56%

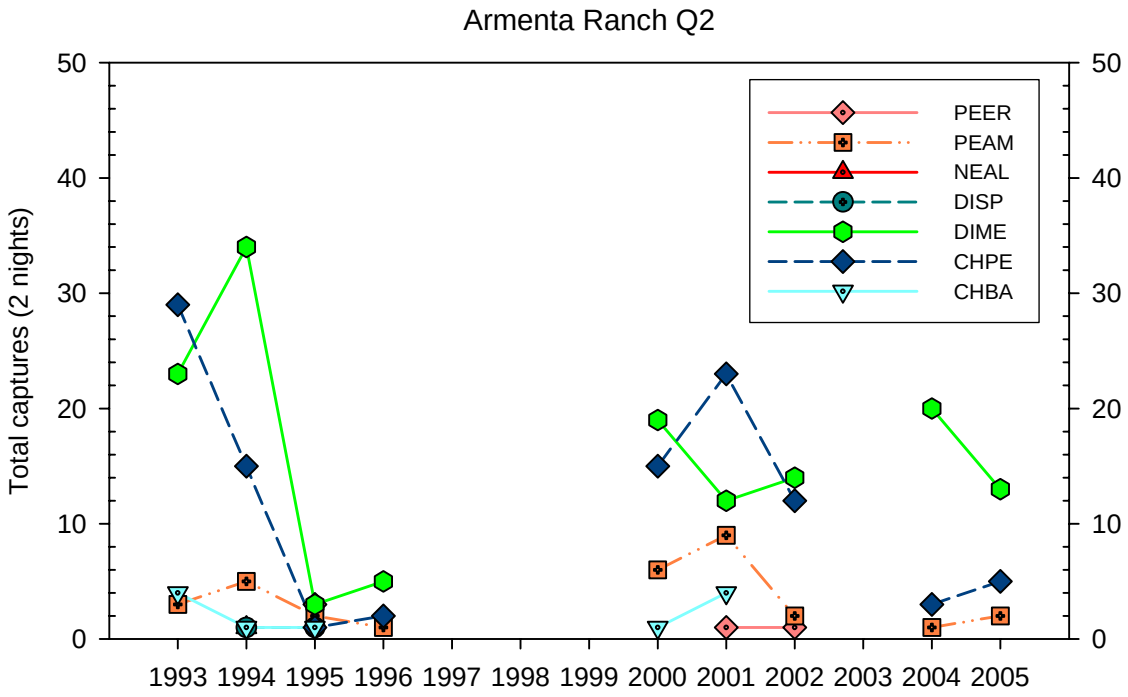


Figure B-6. Relative abundance of nocturnal rodent species at Armenta Ranch quadrat 2, 1993 – 2005, Organ Pipe Cactus N.M. (CHBA = *Chaetodipus baileyi*, CHPE = *Chaetodipus penicillatus*, DIME = *Dipodomys merriami*, DISP = *Dipodomys spectabilis*, NEAL = *Neotoma albigula*, PEAM = *Perognathus amplus*, PEER = *Peromyscus eremicus*).

Table B-7. Summary statistics for nocturnal rodents at Bull Pasture quadrat 1, 1997 – 2005, Organ Pipe Cactus N.M.

	1997	1998	1999	2000	2001	2002	2003	2004	2005
Murid total abundance	7	5	12	4	6	7	3	13	13
Murid total biomass (g)	519	541	632	347	420	218	330	899	790
Heteromyid total abundance	5	7	23	13	36	30	21	39	45
Heteromyid total biomass (g)	105	208	517	286	869	628	439	674	1058
Species richness	5	4	5	5	5	5	5	5	5
Diversity (H')	1.474	1.199	1.185	1.344	1.045	1.186	1.212	1.465	1.122
Capture success, night 1	14%	14%	39%	16%	49%	59%	29%	65%	73%
Capture success, night 2	18%	18%	53%	20%	51%	41%	31%	63%	69%
Recaptures	44%	44%	38%	10%	28%	60%	33%	35%	35%

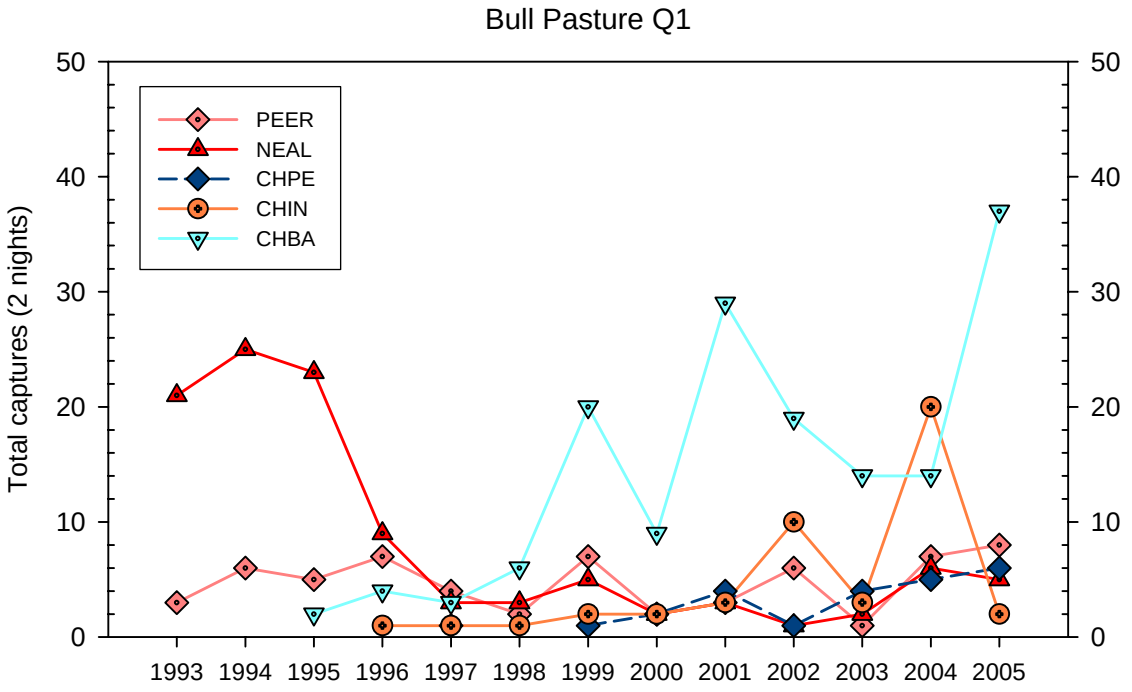


Figure B-7. Relative abundance of nocturnal rodent species at Bull Pasture quadrat 1, 1993 – 2005, Organ Pipe Cactus N.M. (CHBA = *Chaetodipus baileyi*, CHIN = *Chaetodipus intermedius*, CHPE = *Chaetodipus penicillatus*, NEAL = *Neotoma albigula*, PEER = *Peromyscus eremicus*).

Table B-8. Summary statistics for nocturnal rodents at Dos Lomitas quadrat 1, 1997 – 2005, Organ Pipe Cactus N.M.

	1997	1998	1999	2000	2001	2002	2003	2004	2005
Murid total abundance	3	3	0	1	3	2	2	3	7
Murid total biomass (g)	67	260	0	28	63	172	44	136	486
Heteromyid total abundance	39	13	46	54	31	30	28	41	34
Heteromyid total biomass (g)	1282	330	1061	1427	938	764	689	1007	732
Species richness	4	4	2	4	4	5	4	5	6
Diversity (H')	0.720	1.180	0.646	0.845	1.066	1.206	1.012	1.285	1.598
Capture success, night 1	45%	18%	61%	80%	47%	47%	41%	55%	43%
Capture success, night 2	63%	22%	61%	71%	47%	49%	43%	59%	67%
Recaptures	35%	36%	47%	54%	52%	63%	52%	41%	39%

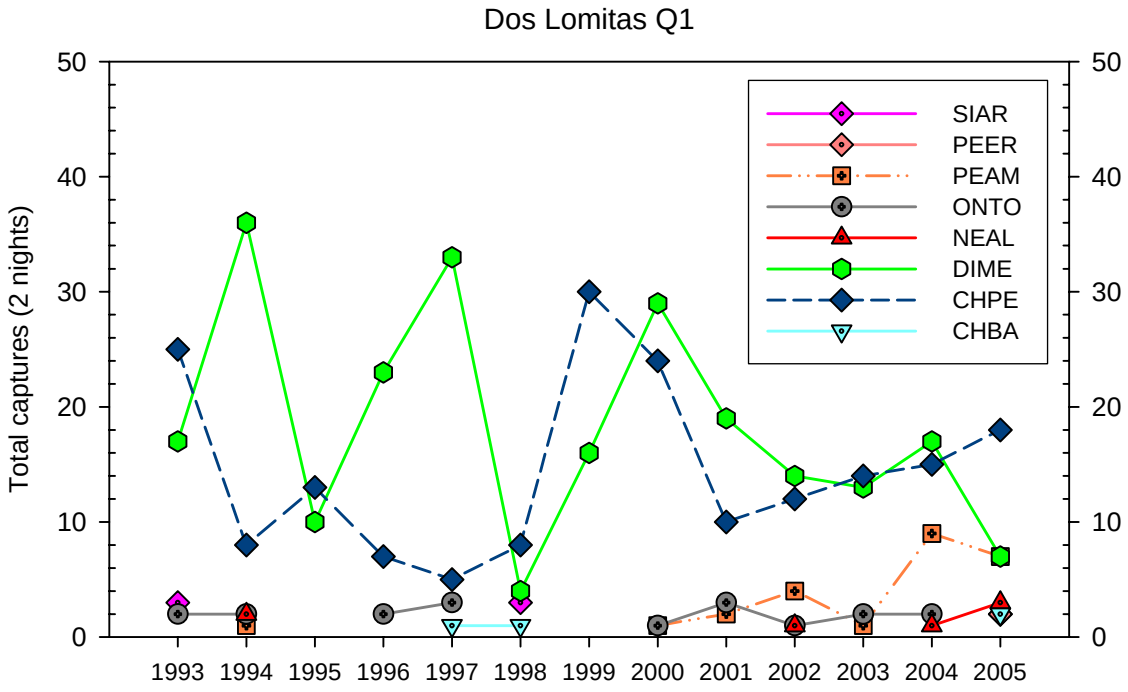


Figure B-8. Relative abundance of nocturnal rodent species at Dos Lomitas quadrat 1, 1993 – 2005, Organ Pipe Cactus N.M. (CHBA = *Chaetodipus baileyi*, CHPE = *Chaetodipus penicillatus*, DIME = *Dipodomys merriami*, NEAL = *Neotoma albigula*, ONTO = *Onychomys torridus*, PEAM = *Perognathus amplus*, PEER = *Peromyscus eremicus*, SIAR = *Sigmodon arizonae*).

Table B-9. Summary statistics for nocturnal rodents at Dos Lomitas quadrat 2, 1997 – 2005, Organ Pipe Cactus N.M.

	1997	1998	1999	2000	2001	2002	2003	2004	2005
Murid total abundance	1	3	0	0	1	0	0	4	4
Murid total biomass (g)	--	197	0	0	142	0	0	365	481
Heteromyid total abundance	38	28	49	47	34	44	33	51	47
Heteromyid total biomass (g)	919	687	1193	1221	886	915	695	1183	770
Species richness	4	4	2	2	3	3	5	5	5
Diversity (H')	0.878	0.920	0.616	0.687	0.796	0.816	1.153	1.077	0.875
Capture success, night 1	35%	33%	61%	78%	57%	59%	45%	69%	57%
Capture success, night 2	55%	43%	71%	76%	47%	61%	51%	82%	76%
Recaptures	19%	29%	46%	76%	70%	50%	56%	48%	38%

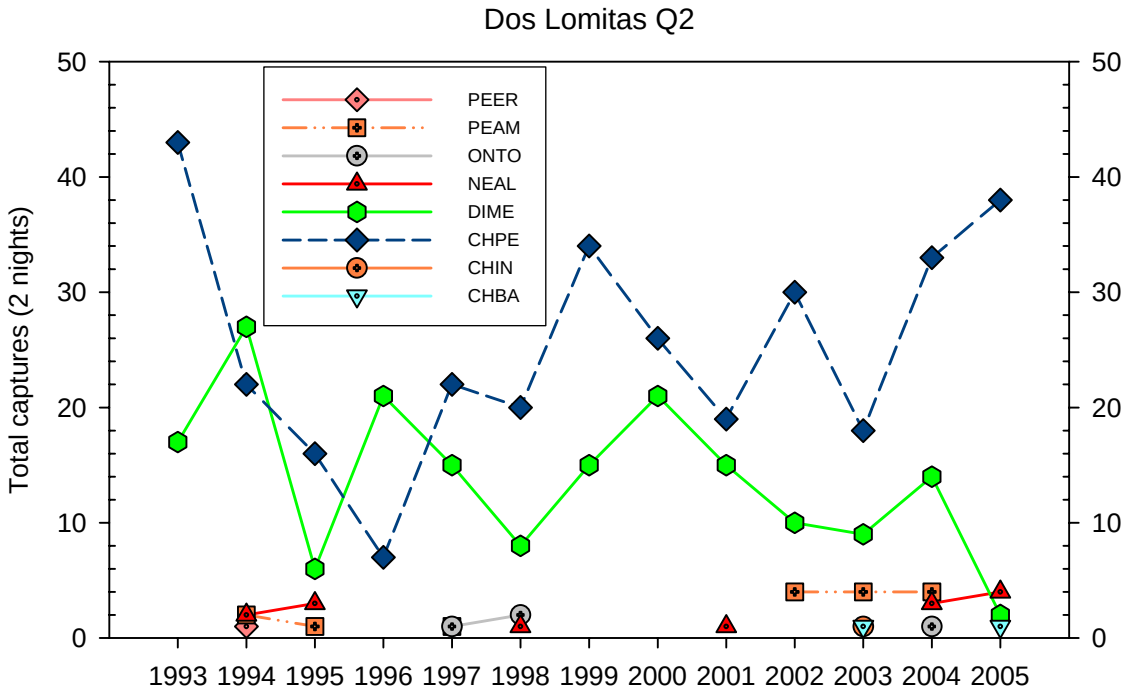


Figure B-9. Relative abundance of nocturnal rodent species at Dos Lomitas quadrat 2, 1993 – 2005, Organ Pipe Cactus N.M. (CHBA = *Chaetodipus baileyi*, CHIN = *Chaetodipus intermedius*, CHPE = *Chaetodipus penicillatus*, DIME = *Dipodomys merriami*, NEAL = *Neotoma albigula*, ONTO = *Onychomys torridus*, PEAM = *Perognathus amplus*, PEER = *Peromyscus eremicus*).

Table B-10. Summary statistics for nocturnal rodents at Dripping Springs quadrat 2, 1997 – 2005, Organ Pipe Cactus N.M.

	1997	2000	2001	2002	2003	2004	2005
Murid total abundance	4	6	9	5	15	18	17
Murid total biomass (g)	278	503	1098	523	2013	2147	2303
Heteromyid total abundance	30	46	27	33	25	50	34
Heteromyid total biomass (g)	543	780	466	587	436	988	755
Species richness	4	4	5	4	4	5	5
Diversity (H')	1.005	1.041	1.406	1.057	1.174	1.342	1.106
Capture success, night 1	49%	61%	53%	43%	51%	88%	67%
Capture success, night 2	39%	67%	37%	55%	55%	76%	57%
Recaptures	47%	33%	44%	37%	44%	32%	36%

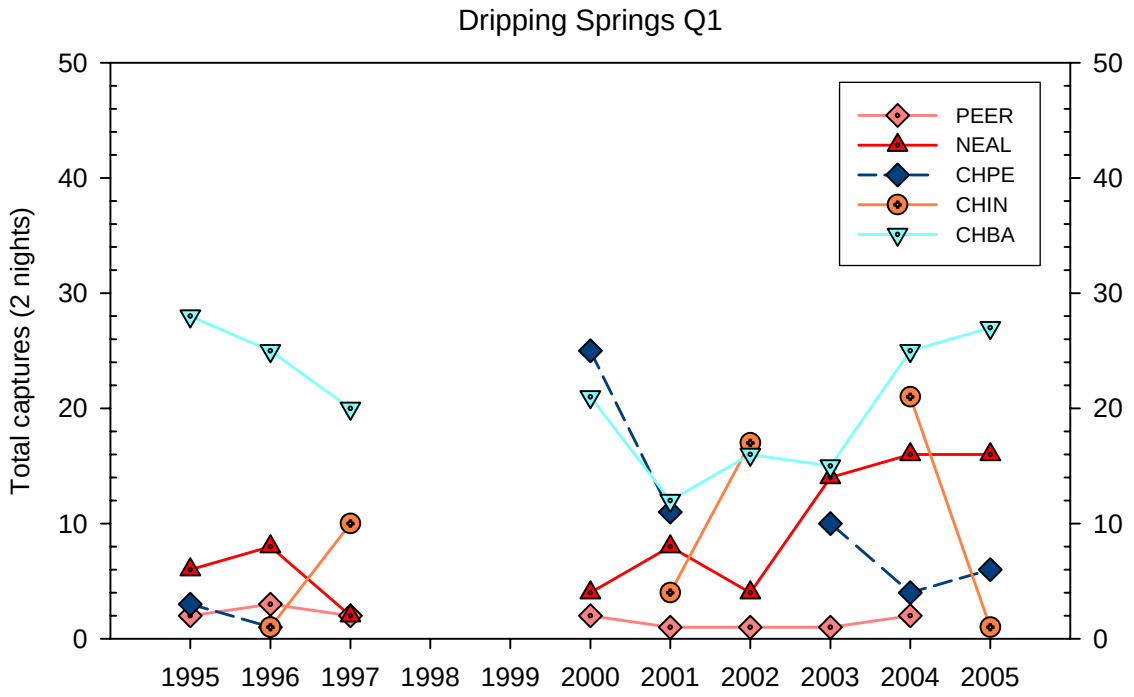


Figure B-10. Relative abundance of nocturnal rodent species at Dripping Springs quadrat 1, 1995 – 2005, Organ Pipe Cactus N.M. (CHBA = *Chaetodipus baileyi*, CHIN = *Chaetodipus intermedius*, CHPE = *Chaetodipus penicillatus*, NEAL = *Neotoma albigula*, PEER = *Peromyscus eremicus*).

Table B-11. Summary statistics for nocturnal rodents at East Armenta quadrat 1, 1997 – 2005, Organ Pipe Cactus N.M.

	1997	2000	2001	2002	2003	2004	2005
Murid total abundance	0	7	3	2	2	7	11
Murid total biomass (g)	0	888	549	243	305	1048	1495
Heteromyid total abundance	36	41	42	36	30	40	46
Heteromyid total biomass (g)	742	1104	936	632	500.8	950	834
Species richness	3	4	4	4	4	4	5
Diversity (H')	1.040	1.463	1.316	1.211	1.076	1.186	1.433
Capture success, night 1	45%	65%	55%	45%	31%	67%	65%
Capture success, night 2	49%	63%	65%	45%	71%	69%	76%
Recaptures	42%	48%	44%	27%	51%	59%	30%

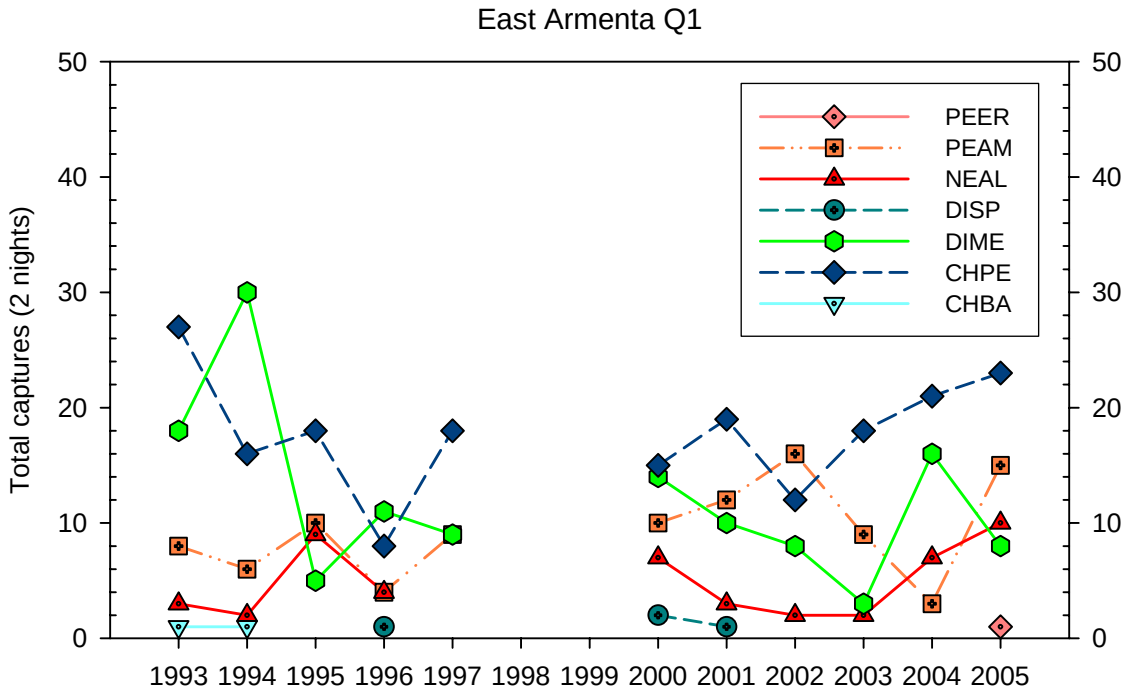


Figure B-11. Relative abundance of nocturnal rodent species at East Armenta quadrat 1, 1993 – 2005, Organ Pipe Cactus N.M. (CHBA = *Chaetodipus baileyi*, CHPE = *Chaetodipus penicillatus*, DIME = *Dipodomys merriami*, DISP = *Dipodomys spectabilis*, NEAL = *Neotoma albigula*, PEAM = *Perognathus amplus*, PEER = *Peromyscus eremicus*).

Table B-12. Summary statistics for nocturnal rodents at East Armenta quadrat 2, 1997 – 2005, Organ Pipe Cactus N.M.

	1997	1998	1999	2000	2001	2002	2003	2004	2005
Murid total abundance	4	2	2	4	8	2	3	6	15
Murid total biomass (g)	601	237	93	426	980	261	350	784	1871
Heteromyid total abundance	20	16	74	39	46	36	32	43	29
Heteromyid total biomass (g)	592	365	1412	846	998	732	511	1205	596
Species richness	5	4	5	4	4	4	4	5	4
Diversity (H')	1.423	1.149	1.144	1.277	1.311	1.190	1.173	1.343	1.355
Capture success, night 1	29%	14%	94%	53%	53%	51%	16%	59%	49%
Capture success, night 2	41%	31%	86%	61%	78%	55%	88%	67%	73%
Recaptures	50%	27%	29%	43%	26%	52%	37%	39%	42%

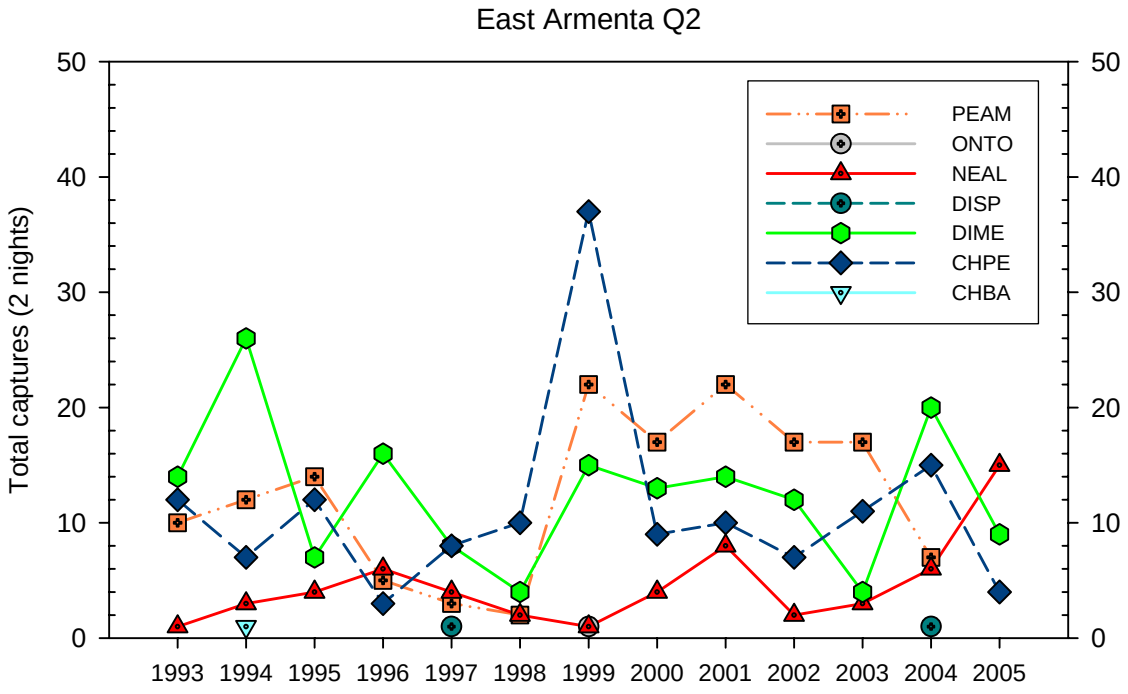


Figure B-12. Relative abundance of nocturnal rodent species at East Armenta quadrat 2, 1993 – 2005, Organ Pipe Cactus N.M. (CHBA = *Chaetodipus baileyi*, CHPE = *Chaetodipus penicillatus*, DIME = *Dipodomys merriami*, DISP = *Dipodomys spectabilis*, NEAL = *Neotoma albigula*, ONTO = *Onychomys torridus*, PEAM = *Perognathus amplus*).

Table B-13. Summary statistics for nocturnal rodents at Growler Canyon quadrat 1, 1997 – 2005, Organ Pipe Cactus N.M.

	1997	1998	1999	2000	2001	2002	2003	2004	2005
Murid total abundance	0	2	0	0	1	2	0	0	2
Murid total biomass (g)	0	265	0	0	17	262	0	0	285
Heteromyid total abundance	29	33	62	52	73	52	41	61	26
Heteromyid total biomass (g)	708	726	1632	1085	1289	1075	626	1369	504
Species richness	2	3	3	2	5	3	2	4	5
Diversity (H')	0.688	0.741	0.764	0.540	0.523	0.719	0.115	0.991	1.213
Capture success, night 1	45%	33%	71%	65%	86%	69%	53%	73%	27%
Capture success, night 2	45%	55%	71%	55%	88%	67%	57%	84%	45%
Recaptures	68%	30%	23%	26%	26%	39%	46%	39%	32%

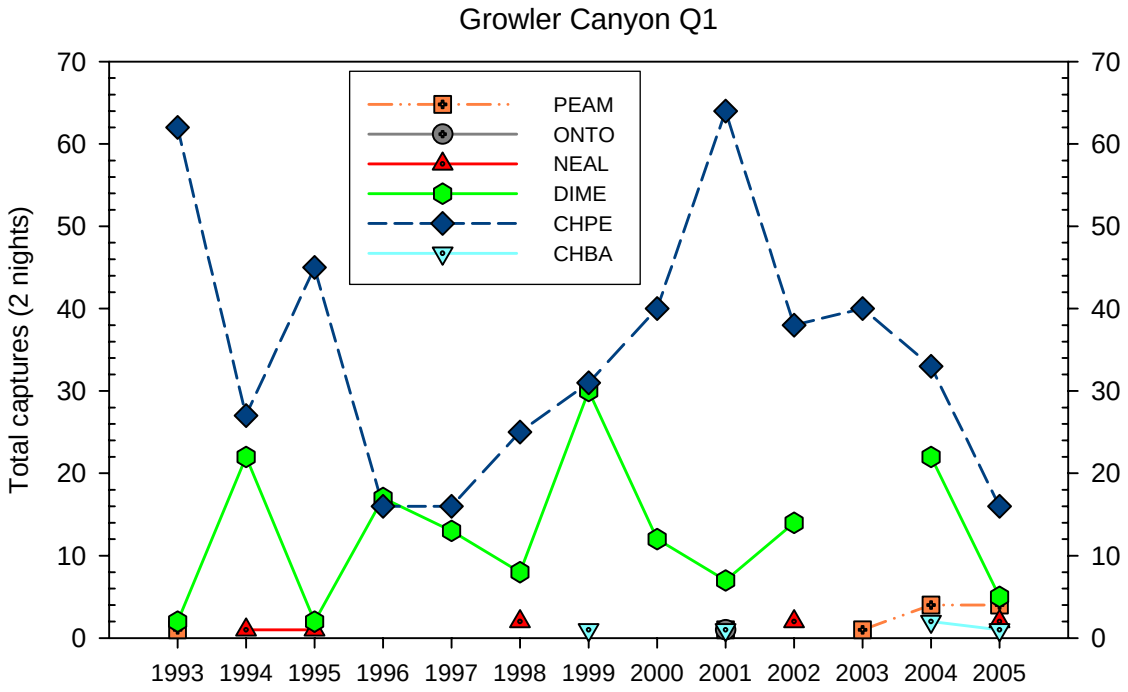


Figure B-13. Relative abundance of nocturnal rodent species at Growler Canyon quadrat 1, 1993 – 2005, Organ Pipe Cactus N.M. (CHBA = *Chaetodipus baileyi*, CHPE = *Chaetodipus penicillatus*, DIME = *Dipodomys merriami*, NEAL = *Neotoma albigula*, ONTO = *Onychomys torridus*, PEAM = *Perognathus amplus*).

Table B-14. Summary statistics for nocturnal rodents at Growler Canyon quadrat 2, 1997 – 2005, Organ Pipe Cactus N.M.

	1997	1998	1999	2000	2001	2002	2003	2004	2005
Murid total abundance	0	1	1	0	1	0	4	0	0
Murid total biomass (g)	0	156	13	0	142	0	612	0	0
Heteromyid total abundance	32	40	58	58	74	53	44	69	31
Heteromyid total biomass (g)	723	1062	1365	1175	1243	997	729	1229	631
Species richness	3	4	5	2	5	4	5	4	3
Diversity (H')	0.798	0.843	0.962	0.486	0.436	0.689	0.721	0.823	0.790
Capture success, night 1	35%	41%	61%	71%	90%	69%	51%	73%	31%
Capture success, night 2	49%	57%	76%	69%	86%	57%	61%	88%	41%
Recaptures	38%	25%	22%	32%	26%	32%	23%	23%	20%

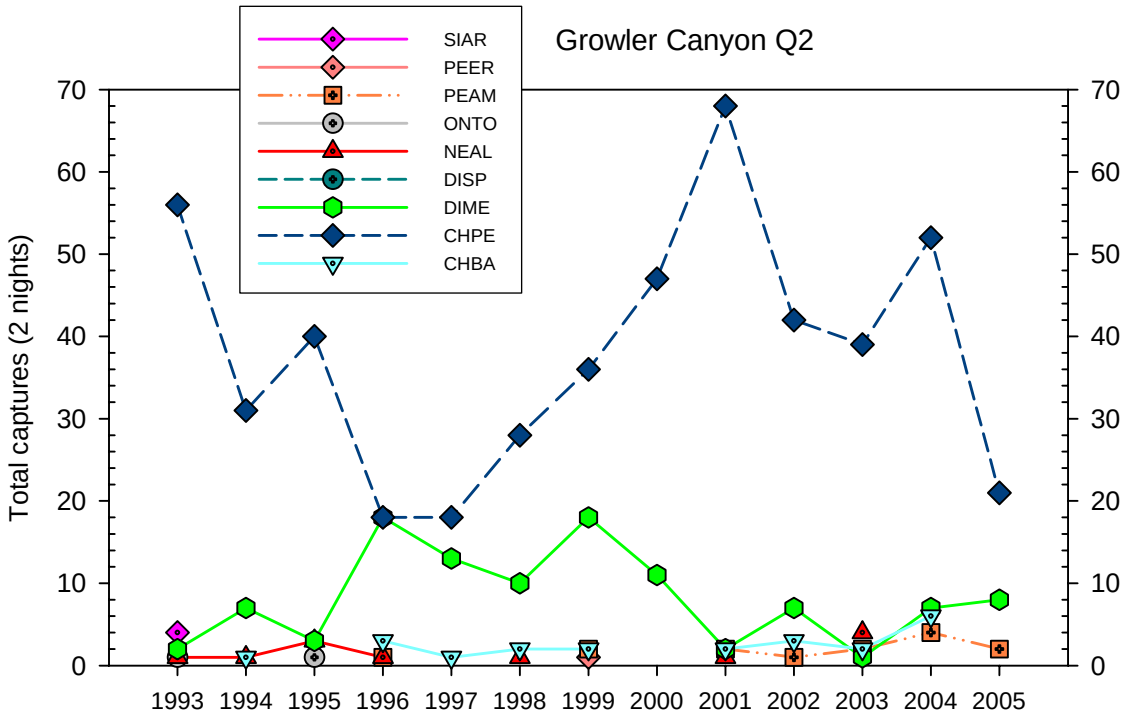


Figure B-14. Relative abundance of nocturnal rodent species at Growler Canyon quadrat 2, 1993 – 2005, Organ Pipe Cactus N.M. (CHBA = *Chaetodipus baileyi*, CHPE = *Chaetodipus penicillatus*, DIME = *Dipodomys merriami*, DISP = *Dipodomys spectabilis*, NEAL = *Neotoma albigula*, ONTO = *Onychomys torridus*, PEAM = *Perognathus amplus*, PEER = *Peromyscus eremicus*, SIAR = *Sigmodon arizonae*).

Table B-15. Summary statistics for nocturnal rodents at Lower Colorado Larrea quadrat 1, 1997 – 2005, Organ Pipe Cactus N.M.

	1997	2000	2001	2003	2004	2005
Murid total abundance	0	0	0	0	0	0
Murid total biomass (g)	0	0	0	0	0	0
Heteromyid total abundance	24	22	10	32	31	27
Heteromyid total biomass (g)	735	434	163	759	758	589
Species richness	2	3	3	3	2	2
Diversity (H')	0.287	0.837	0.943	1.013	0.811	0.659
Capture success, night 1	29%	33%	10%	29%	45%	27%
Capture success, night 2	31%	35%	16%	49%	43%	39%
Recaptures	33%	65%	38%	25%	57%	26%

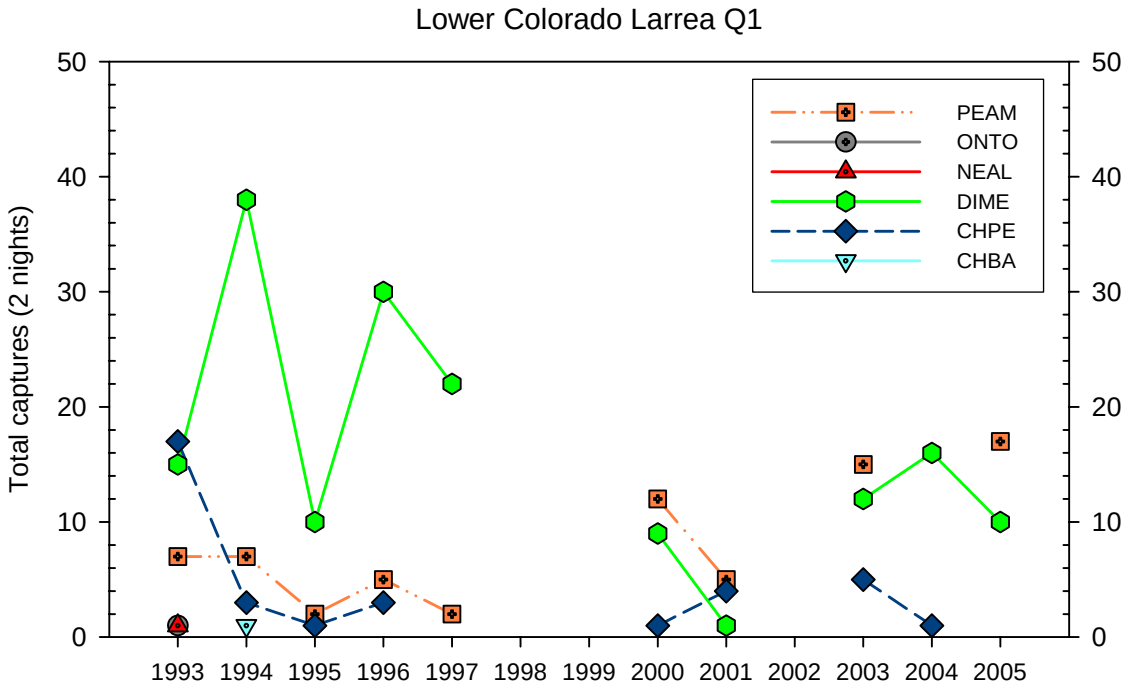


Figure B-15. Relative abundance of nocturnal rodent species at Lower Colorado Larrea quadrat 1, 1993 – 2005, Organ Pipe Cactus N.M. (CHBA = *Chaetodipus baileyi*, CHPE = *Chaetodipus penicillatus*, DIME = *Dipodomys merriami*, NEAL = *Neotoma albigula*, ONTO = *Onychomys torridus*, PEAM = *Perognathus amplus*).

Table B-16. Summary statistics for nocturnal rodents at Lower Colorado Larrea quadrat 2, 1997 – 2005, Organ Pipe Cactus N.M.

	1997	1998	1999	2000	2001	2003	2004	2005
Murid total abundance	0	0	0	0	1	0	0	1
Murid total biomass (g)	0	0	0	0	33	0	0	13
Heteromyid total abundance	24	8	53	26	8	36	37	37
Heteromyid total biomass (g)	676	191	1322	444	176	1151	896	737
Species richness	2	2	4	3	3	4	2	4
Diversity (H')	0.512	0.662	0.854	0.828	0.937	1.214	0.693	0.959
Capture success, night 1	41%	6%	82%	33%	8%	20%	63%	27%
Capture success, night 2	33%	12%	49%	39%	14%	57%	47%	65%
Recaptures	75%	17%	46%	47%	29%	7%	74%	19%

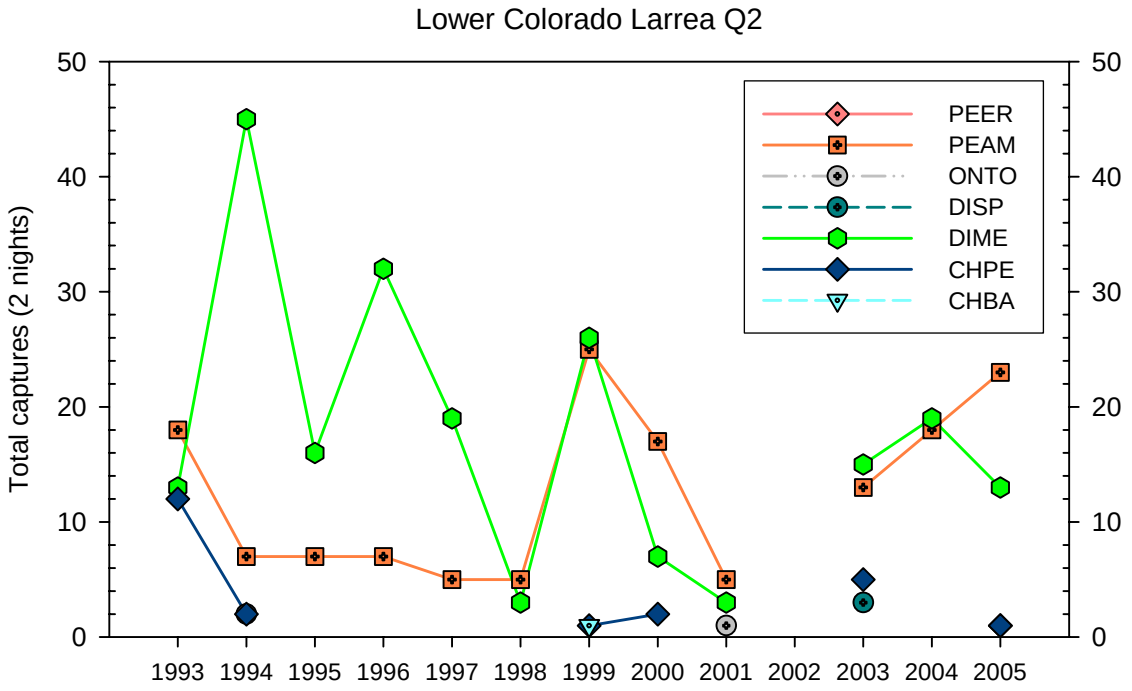


Figure B-16. Relative abundance of nocturnal rodent species at Lower Colorado Larrea quadrat 2, 1993 – 2005, Organ Pipe Cactus N.M. (CHBA = *Chaetodipus baileyi*, CHPE = *Chaetodipus penicillatus*, DIME = *Dipodomys merriami*, DISP = *Dipodomys spectabilis*, ONTO = *Onychomys torridus*, PEAM = *Perognathus amplus*, PEER = *Peromyscus eremicus*).

Table B-17. Summary statistics for nocturnal rodents at Middle Bajada quadrat 1, 1997 – 2005, Organ Pipe Cactus N.M.

	1997	1998	1999	2000	2001	2002	2003	2004	2005
Murid total abundance	1	1	2	3	1	0	3	5	3
Murid total biomass (g)	20	160	162	233	156	0	478	781	402
Heteromyid total abundance	20	10	30	40	41	21	14	60	40
Heteromyid total biomass (g)	342	218	701	801	877	433	241	1158	987
Species richness	5	4	5	6	5	5	5	6	6
Diversity (H')	1.073	1.241	0.716	1.213	0.854	1.354	1.564	1.288	1.060
Capture success, night 1	24%	14%	35%	53%	49%	29%	16%	82%	43%
Capture success, night 2	29%	8%	47%	67%	49%	18%	33%	84%	55%
Recaptures	36%	0	35%	48%	25%	22%	44%	39%	19%

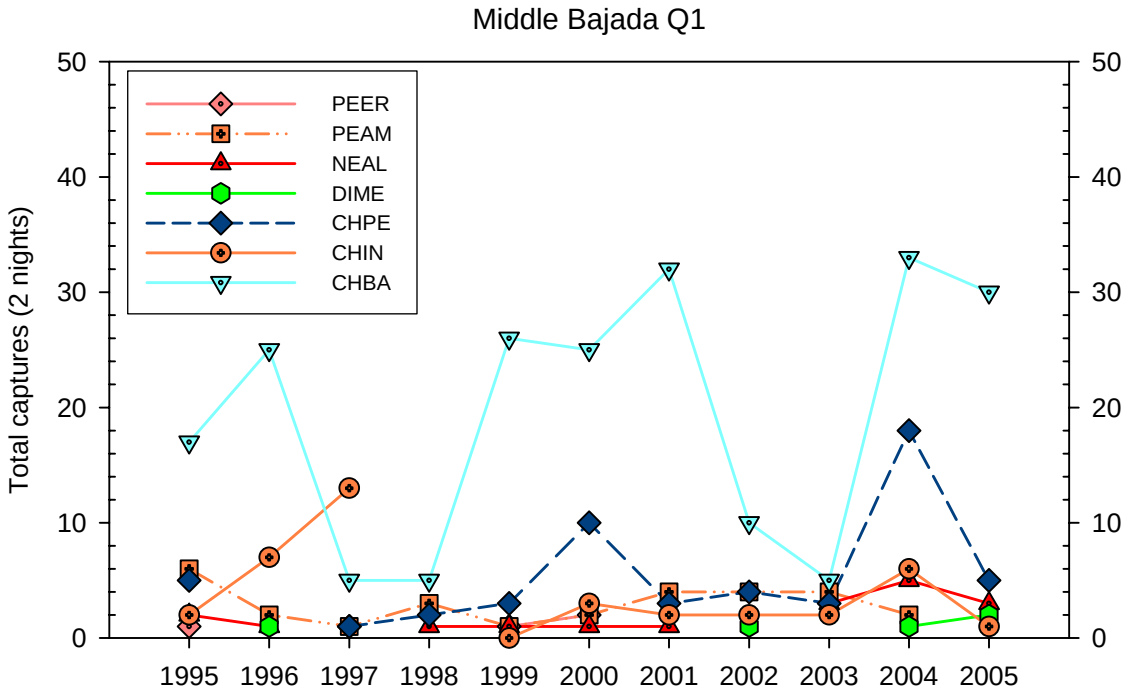


Figure B-17. Relative abundance of nocturnal rodent species at Middle Bajada quadrat 1, 1993 – 2005, Organ Pipe Cactus N.M. (CHBA = *Chaetodipus baileyi*, CHIN = *Chaetodipus intermedius*, CHPE = *Chaetodipus penicillatus*, DIME = *Dipodomys merriami*, NEAL = *Neotoma albigula*, PEAM = *Perognathus amplus*, PEER = *Peromyscus eremicus*).

Table B-18. Summary statistics for nocturnal rodents at Middle Bajada quadrat 2, 1997 – 2005, Organ Pipe Cactus N.M.

	1997	2000	2001	2002	2003	2004	2005
Murid total abundance	0	0	0	0	1	3	3
Murid total biomass (g)	0	0	0	0	155	318	446
Heteromyid total abundance	12	49	50	29	22	52	46
Heteromyid total biomass (g)	228	1201	1133	749	521	1262	1392
Species richness	3	4	4	3	4	5	4
Diversity (H')	0.918	0.849	0.746	0.964	1.068	1.293	0.933
Capture success, night 1	18%	63%	73%	41%	12%	71%	49%
Capture success, night 2	14%	76%	53%	35%	47%	78%	73%
Recaptures	57%	51%	46%	47%	30%	47%	31%

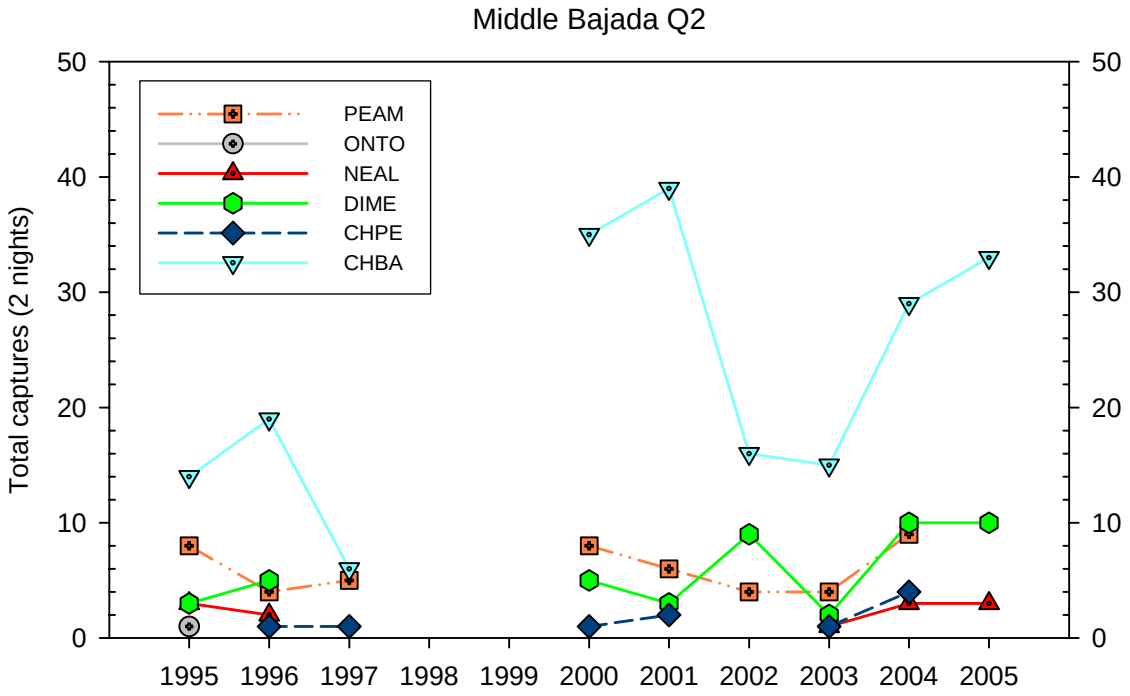


Figure B-18. Relative abundance of nocturnal rodent species at Middle Bajada quadrat 2, 1993 – 2005, Organ Pipe Cactus N.M. (CHBA = *Chaetodipus baileyi*, CHPE = *Chaetodipus penicillatus*, DIME = *Dipodomys merriami*, NEAL = *Neotoma albigula*, ONTO= *Onychomys torridus*, PEAM = *Perognathus amplus*).

Table B-19. Summary statistics for nocturnal rodents at Pozo Nuevo quadrat 1, 1997 – 2005, Organ Pipe Cactus N.M.

	1997	1998	1999	2000	2001	2002	2003	2004	2005
Murid total abundance	0	0	0	0	0	0	0	0	2
Murid total biomass (g)	0	0	0	0	0	0	0	0	103
Heteromyid total abundance	6	14	16	17	9	12	19	40	40
Heteromyid total biomass (g)	84	407	303	246	229	259	446	1082	1055
Species richness	4	3	3	3	4	2	3	4	4
Diversity (H')	1.242	0.992	0.865	0.959	1.149	0.693	0.857	1.009	1.001
Capture success, night 1	10%	18%	24%	20%	8%	20%	20%	59%	45%
Capture success, night 2	6%	16%	18%	27%	14%	8%	31%	47%	61%
Recaptures	67%	38%	56%	46%	29%	50%	40%	52%	27%

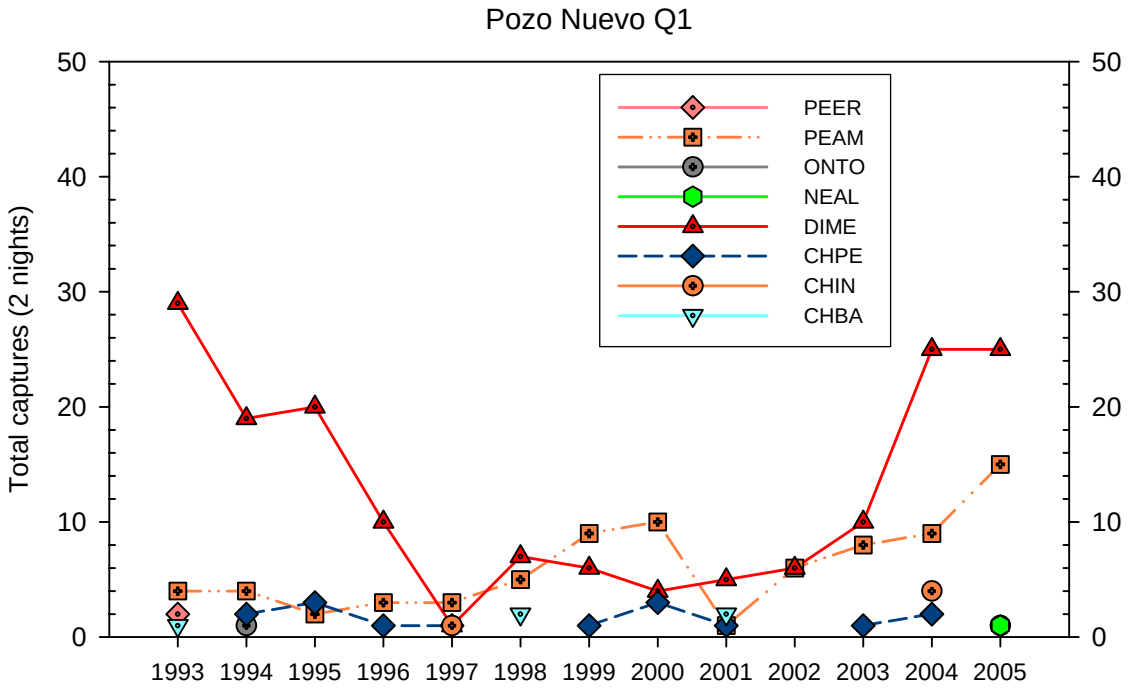


Figure B-19. Relative abundance of nocturnal rodent species at Pozo Nuevo quadrat 1, 1993 – 2005, Organ Pipe Cactus N.M. (CHBA = *Chaetodipus baileyi,* CHIN = *Chaetodipus intermedius*, CHPE = *Chaetodipus penicillatus*, DIME = *Dipodomys merriami*, NEAL = *Neotoma albigula*, ONTO = *Onychomys torridus*, PEAM = *Perognathus amplus*, PEER = *Peromyscus eremicus*).

Table B-20. Summary statistics for nocturnal rodents at Pozo Nuevo quadrat 2, 1997 – 2005, Organ Pipe Cactus N.M.

	1997	1998	1999	2000	2001	2002	2003	2004	2005
Murid total abundance	0	0	0	0	0	0	0	1	1
Murid total biomass (g)	0	0	0	0	0	0	0	93	115
Heteromyid total abundance	11	19	30	31	19	23	21	44	33
Heteromyid total biomass (g)	307	517	754	675	537	660	450	1161	1045
Species richness	3	4	3	3	3	3	3	4	3
Diversity (H')	0.760	1.297	1.010	0.973	0.766	0.822	0.999	1.002	1.023
Capture success, night 1	20%	22%	35%	51%	27%	35%	16%	57%	43%
Capture success, night 2	16%	24%	41%	43%	27%	16%	41%	49%	51%
Recaptures	88%	33%	35%	71%	54%	25%	35%	29%	36%

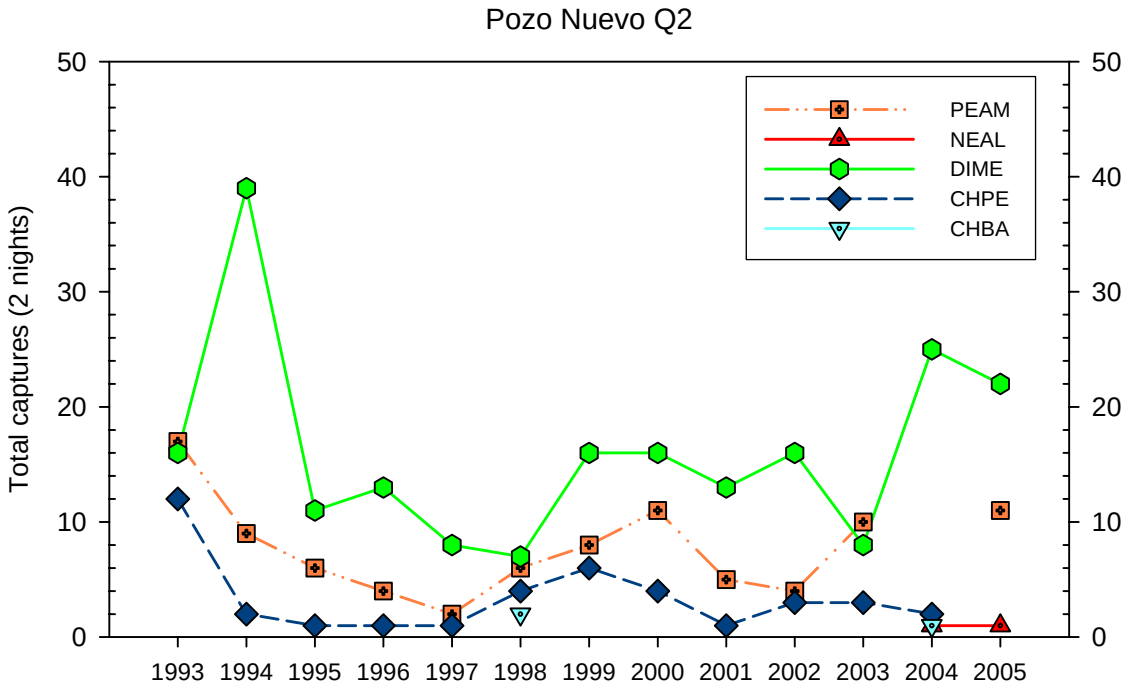


Figure B-20. Relative abundance of nocturnal rodent species at Pozo Nuevo quadrat 2, 1993 – 2005, Organ Pipe Cactus N.M. (CHBA = *Chaetodipus baileyi*, CHPE = *Chaetodipus penicillatus*, DIME = *Dipodomys merriami*, NEAL = *Neotoma albigula*, PEAM = *Perognathus amplus*).

Table B-21. Summary statistics for nocturnal rodents at Quitobaquito quadrat 1, 1997 – 2005, Organ Pipe Cactus N.M.

	1997	1998	1999	2000	2001	2002	2003	2004	2005
Murid total abundance	15	16	15	18	23	12	7	27	38
Murid total biomass (g)	1230	1575	430	2079	2373	1066	544	2422	2170
Heteromyid total abundance	30	16	45	22	32	17	28	30	13
Heteromyid total biomass (g)	366	196	559	269	363	235	303	381	204
Species richness	4	4	4	3	3	3	3	4	5
Diversity (H')	1.153	1.206	1.285	0.993	1.204	1.154	1.116	1.477	1.296
Capture success, night 1	55%	41%	78%	53%	76%	29%	41%	78%	61%
Capture success, night 2	65%	37%	63%	53%	63%	39%	53%	78%	71%
Recaptures	44%	33%	29%	46%	42%	21%	42%	50%	40%

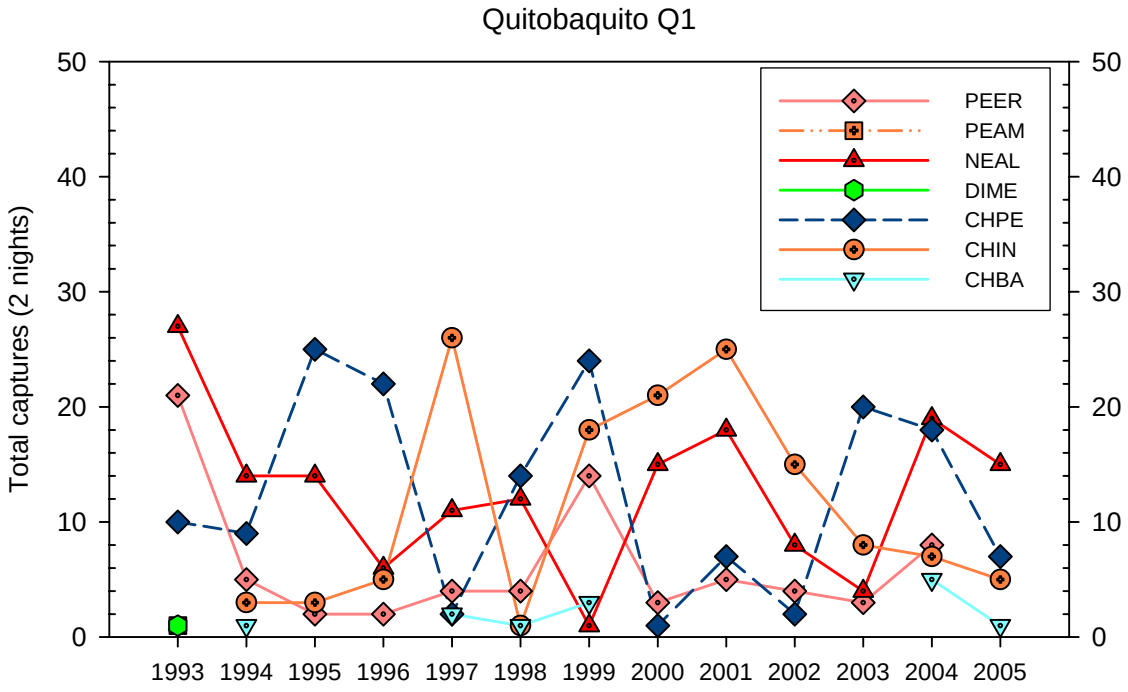


Figure B-21. Relative abundance of nocturnal rodent species at Quitobaquito quadrat 1, 1993 – 2005, Organ Pipe Cactus N.M. (CHBA = *Chaetodipus baileyi*, CHIN = *Chaetodipus intermedius*, CHPE = *Chaetodipus penicillatus*, DIME = *Dipodomys merriami*, NEAL = *Neotoma albigula*, PEAM = *Perognathus amplus*, PEER = *Peromyscus eremicus*).

Table B-22. Summary statistics for nocturnal rodents at Quitobaquito quadrat 2, 1997 – 2005, Organ Pipe Cactus N.M.

	1997	1998	1999	2000	2001	2002	2003	2004	2005
Murid total abundance	0	10	6	11	15	6	5	10	14
Murid total biomass (g)	0	993	514	812	1372	378	335	741	1060
Heteromyid total abundance	39	20	22	20	19	14	15	33	22
Heteromyid total biomass (g)	671	391	460	404	390	301	324	593	598
Species richness	3	4	4	5	6	5	5	6	4
Diversity (H')	0.447	1.057	1.077	1.305	1.574	1.333	1.235	1.265	1.361
Capture success, night 1	63%	31%	41%	43%	45%	24%	27%	59%	39%
Capture success, night 2	51%	45%	35%	51%	55%	29%	31%	67%	59%
Recaptures	68%	32%	53%	60%	56%	43%	53%	58%	41%

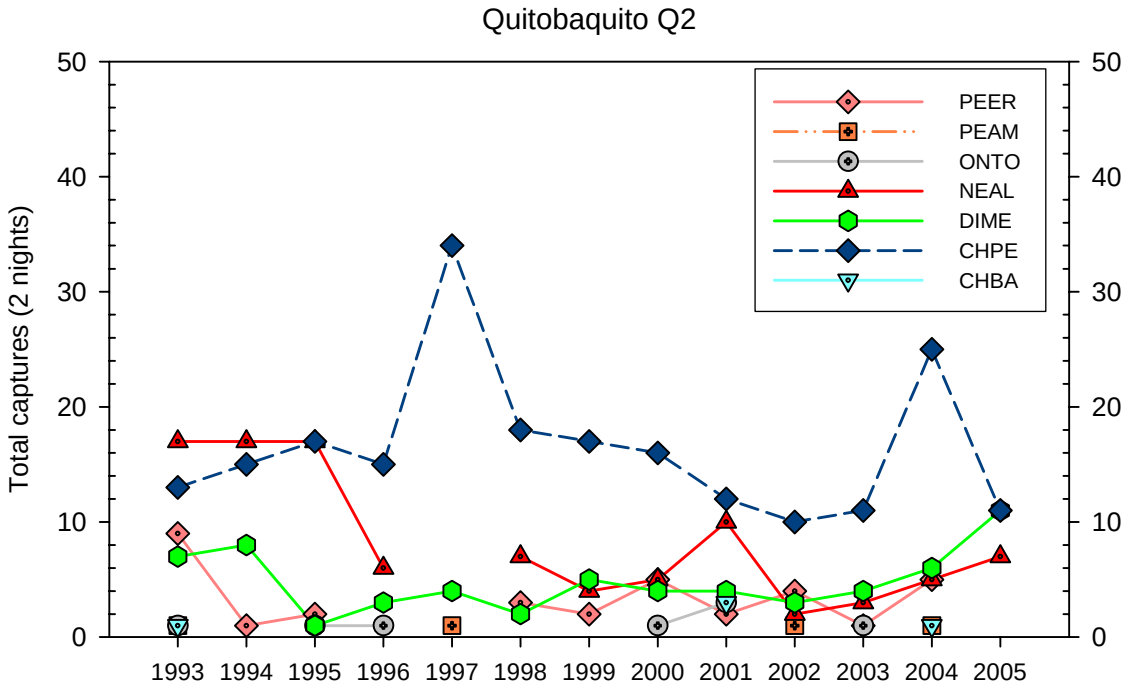


Figure B-22. Relative abundance of nocturnal rodent species at Quitobaquito quadrat 2, 1993 – 2005, Organ Pipe Cactus N.M. (CHBA = *Chaetodipus baileyi*, CHPE = *Chaetodipus penicillatus*, DIME = *Dipodomys merriami*, NEAL = *Neotoma albigula*, ONTO = *Onychomys torridus*, PEAM = *Perognathus amplus*, PEER = *Peromyscus eremicus*).

Table B-23. Summary statistics for nocturnal rodents at Salsola quadrat 1, 1997 – 2004, Organ Pipe Cactus N.M.

	1997	1998	1999	2000	2001	2002	2003	2004
Murid total abundance	0	1	1	0	2	0	1	3
Murid total biomass (g)	0	30	14	0	43	0	23	65
Heteromyid total abundance	65	33	38	58	44	43	38	55
Heteromyid total biomass (g)	1661.5	612	891	1409	949	906	706	1058
Species richness	4	4	3	2	5	3	4	4
Diversity (H')	0.887	0.485	0.727	0.632	1.0438	0.849	0.853	0.906
Capture success, night 1	80	37	80	82	57	49	43	65
Capture success, night 2	88	51	0	71	61	63	53	88
Recaptures	40	36	0	49	40	39	31	40

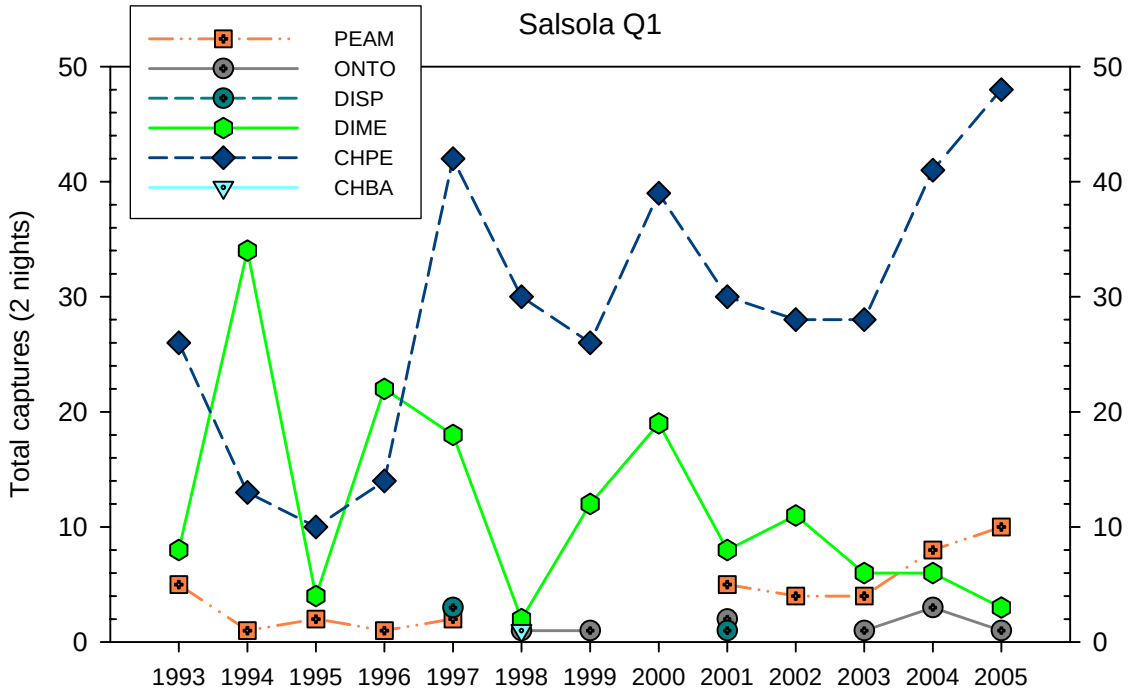


Figure B-23. Relative abundance of nocturnal rodent species at Salsola quadrat 1, 1993 – 2005, Organ Pipe Cactus N.M. (CHBA = *Chaetodipus baileyi*, CHPE = *Chaetodipus penicillatus*, DIME = *Dipodomys merriami*, DISP = *Dipodomys spectabilis*, ONTO = *Onychomys torridus*, PEAM = *Perognathus amplus*).

Table B-24. Summary statistics for nocturnal rodents at Salsola quadrat 2, 1997 – 2004, Organ Pipe Cactus N.M.

	1997	1998	1999	2000	2001	2002	2003	2004
Murid total abundance	2	0	1	2	4	1	1	1
Murid total biomass (g)	179.3	0	79	278	559	168	145	31
Heteromyid total abundance	66	46	36	65	43	51	50	73
Heteromyid total biomass (g)	1159	830	714	1555	974	1133	946	1617
Species richness	4	2	3	3	3	3	4	4
Diversity (H')	0.413	--	0.403	0.720	0.661	0.552	0.707	0.609
Capture success, night 1	73	47	76	82	53	53	61	82
Capture success, night 2	84	61	0	80	65	73	67	90
Recaptures	22	23	0	31	34	28	36	23

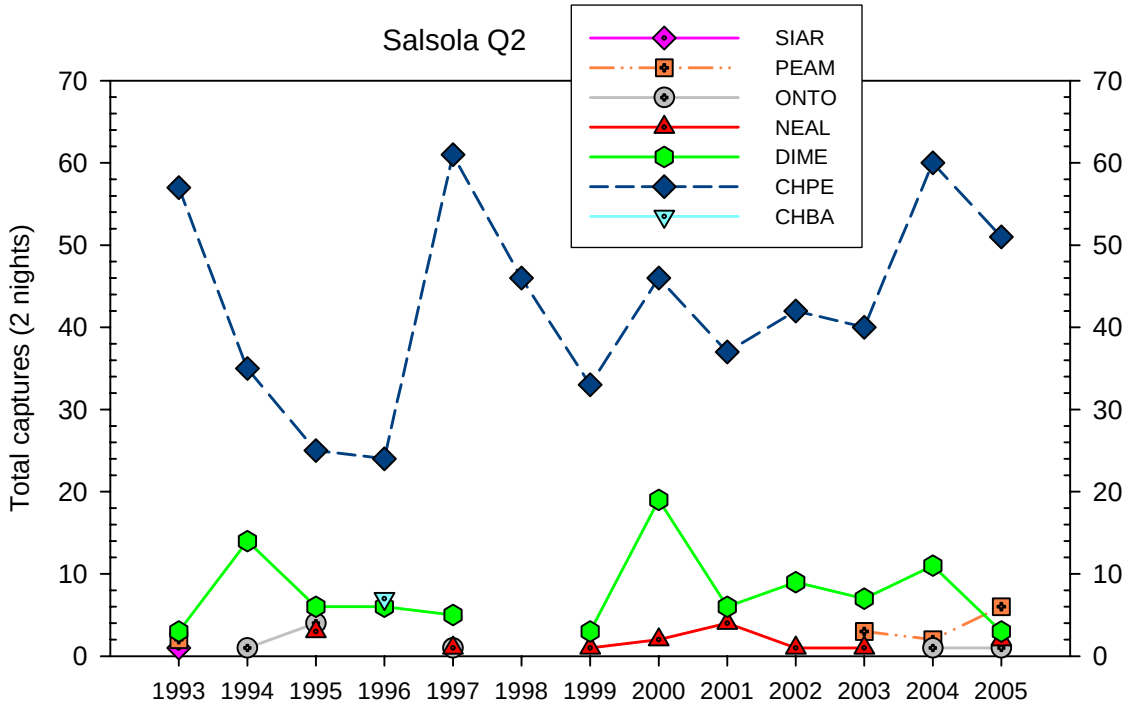


Figure B-24. Relative abundance of nocturnal rodent species at Salsola quadrat 2, 1993 – 2005, Organ Pipe Cactus N.M. (CHBA = *Chaetodipus baileyi*, CHPE = *Chaetodipus penicillatus*, DIME = *Dipodomys merriami*, NEAL = *Neotoma albigula*, ONTO = *Onychomys torridus*, PEAM = *Perognathus amplus*, SIAR = *Sigmodon arizonae*).

Table B-25. Summary statistics for nocturnal rodents at Senita Basin quadrat 1, 1997 – 2005, Organ Pipe Cactus N.M.

	1997	1998	1999	2000	2001	2002	2003	2004	2005
Murid total abundance	0	0	2	1	3	0	0	5	5
Murid total biomass (g)	0	0	213	119	479	0	0	475	622
Heteromyid total abundance	13	6	33	25	14	29	8	42	24
Heteromyid total biomass (g)	204	107	730	573	317	699	188	1019	559
Species richness	5	2	4	5	4	5	4	6	5
Diversity (H')	1.413	0.693	0.646	1.229	1.006	1.190	1.213	1.358	1.152
Capture success, night 1	14%	4%	43%	29%	16%	33%	4%	67%	31%
Capture success, night 2	22%	10%	33%	33%	24%	35%	20%	63%	33%
Recaptures	45%	20%	13%	25%	25%	24%	40%	55%	13%

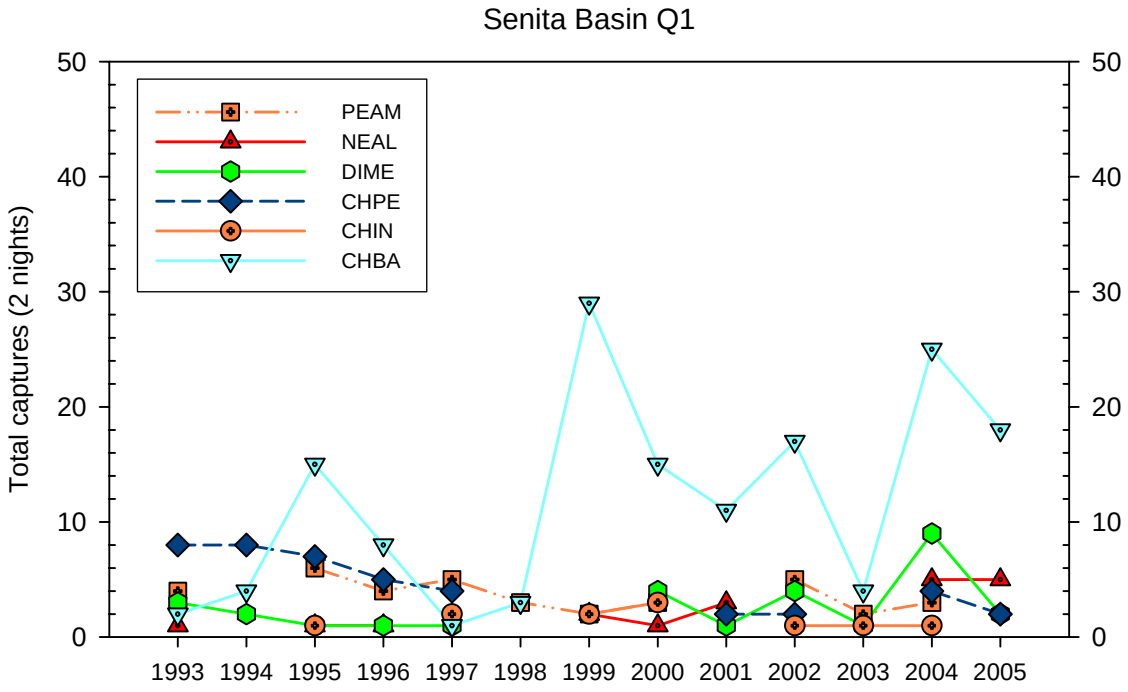


Figure B-25. Relative abundance of nocturnal rodent species at Senita Basin quadrat 1, 1993 – 2005, Organ Pipe Cactus N.M. (CHBA = *Chaetodipus baileyi*, CHIN = *Chaetodipus intermedius*, CHPE = *Chaetodipus penicillatus*, DIME = *Dipodomys merriami*, NEAL = *Neotoma albigula*, PEAM = *Perognathus amplus*).

Table B-26. Summary statistics for nocturnal rodents at Senita Basin quadrat 2, 1997 – 2005, Organ Pipe Cactus N.M.

	1997	1998	1999	2000	2001	2002	2003	2004	2005
Murid total abundance	0	1	1	0	1	1	0	0	9
Murid total biomass (g)	0	149	137	0	127	128	0	0	1083
Heteromyid total abundance	32	15	19	28	16	19	14	38	21
Heteromyid total biomass (g)	512	273	381	623	341	511	402	769	426
Species richness	4	4	4	5	6	4	3	6	6
Diversity (H')	1.119	1.228	1.094	1.253	1.344	0.708	0.759	1.695	1.446
Capture success, night 1	37%	12%	29%	27%	14%	22%	10%	57%	37%
Capture success, night 2	55%	24%	14%	35%	22%	29%	22%	73%	43%
Recaptures	48%	17%	14%	12%	9%	36%	18%	56%	38%

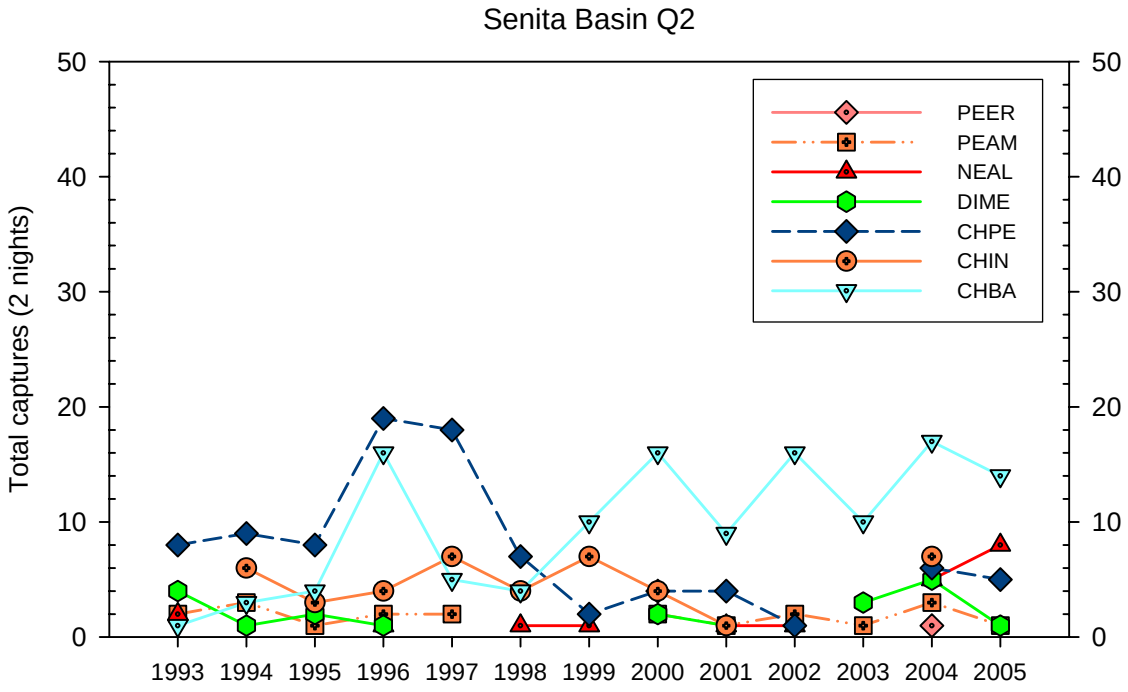


Figure B-26. Relative abundance of nocturnal rodent species at Senita Basin quadrat 2, 1993 – 2005, Organ Pipe Cactus N.M. (CHBA = *Chaetodipus baileyi*, CHIN = *Chaetodipus intermedius*, CHPE = *Chaetodipus penicillatus*, DIME = *Dipodomys merriami*, NEAL = *Neotoma albigula*, PEAM = *Perognathus amplus*, PEER = *Peromyscus eremicus*).

Table B-27. Summary statistics for nocturnal rodents at Valley Floor quadrat 1, 1997 – 2005, Organ Pipe Cactus N.M.

	1997	1998	1999	2000	2001	2002	2003	2004	2005
Murid total abundance	0	0	0	0	0	0	0	0	0
Murid total biomass (g)	0	0	0	0	0	0	0	0	0
Heteromyid total abundance	8	3	39	43	38	37	6	41	29
Heteromyid total biomass (g)	176	48	771	1136	666	843	177	1152	778
Species richness	3	2	3	3	3	3	2	4	3
Diversity (H')	0.974	0.637	0.868	0.977	0.944	1.018	0.637	0.886	0.779
Capture success, night 1	102%	4%	41%	61%	37%	51%	4%	61%	29%
Capture success, night 2	10%	6%	45%	55%	59%	55%	14%	55%	41%
Recaptures	60%	67%	14%	52%	31%	56%	43%	59%	25%

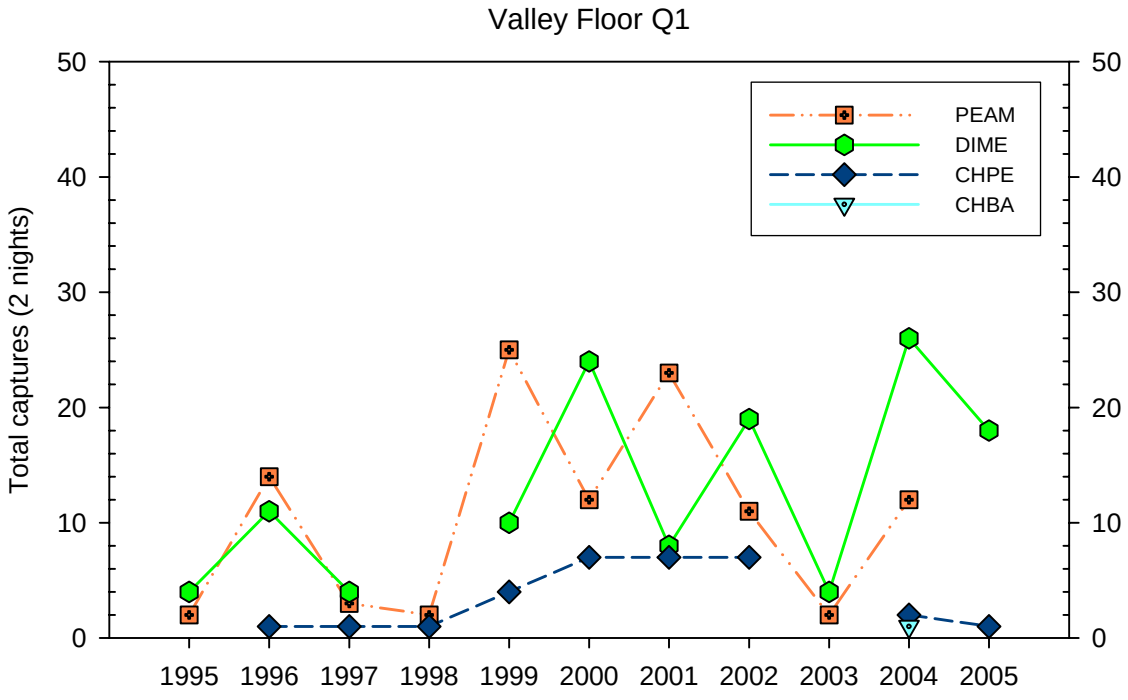


Figure B-27. Relative abundance of nocturnal rodent species at Valley Floor quadrat 1, 1993 – 2005, Organ Pipe Cactus N.M. (CHBA = *Chaetodipus baileyi*, CHPE = *Chaetodipus penicillatus*, DIME = *Dipodomys merriami*, PEAM = *Perognathus amplus*).

Table B-28. Summary statistics for nocturnal rodents at Valley Floor quadrat 2, 1997 – 2005, Organ Pipe Cactus N.M.

	1997	1998	1999	2000	2001	2002	2003	2004	2005
Murid total abundance	0	0	0	0	4	1	1	0	3
Murid total biomass (g)	0	0	0	0	612	139	160	0	292
Heteromyid total abundance	28	4	41	70	54	59	21	59	56
Heteromyid total biomass (g)	461	107	839	1460	966	1154	354	1441	1234
Species richness	3	2	4	4	4	4	4	4	5
Diversity (H')	0.833	0.562	1.250	0.903	1.008	0.825	0.663	0.951	1.007
Capture success, night 1	24%	6%	43%	82%	61%	71%	10%	65%	59%
Capture success, night 2	49%	2%	53%	98%	73%	84%	49%	76%	82%
Recaptures	33%	0	23%	38%	22%	39%	33%	27%	25%

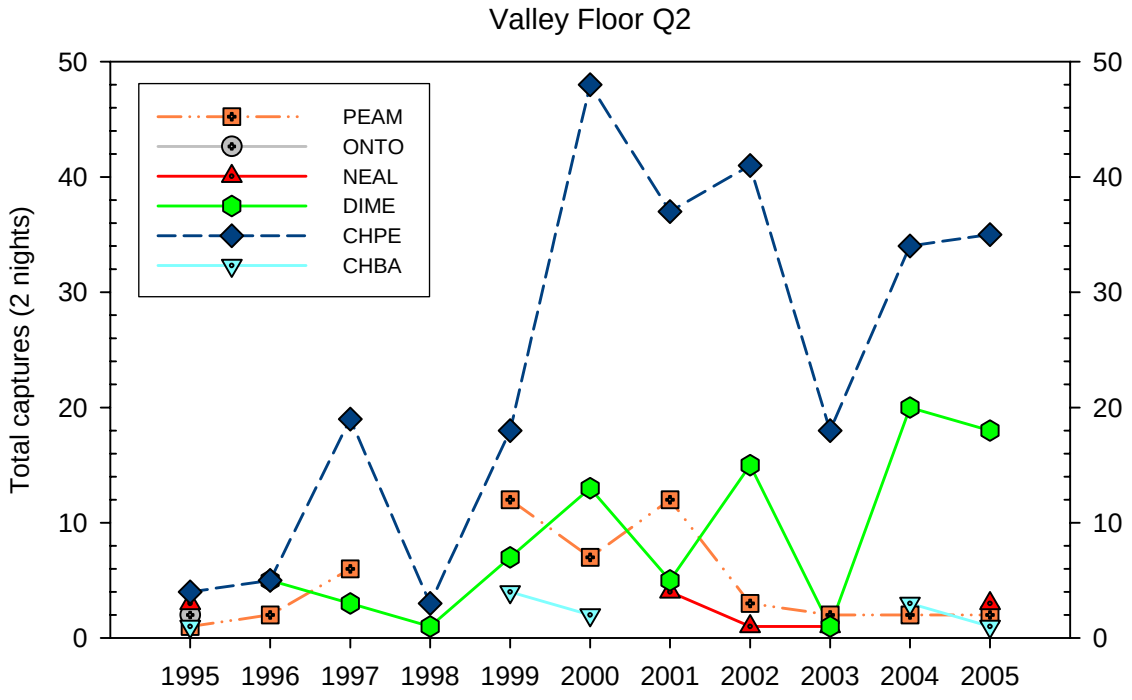


Figure B-28. Relative abundance of nocturnal rodent species at Valley Floor quadrat 2, 1993 – 2005, Organ Pipe Cactus N.M. (CHBA = *Chaetodipus baileyi*, CHPE = *Chaetodipus penicillatus*, DIME = *Dipodomys merriami*, NEAL = *Neotoma albigula*, ONTO = *Onychomys torridus*, PEAM = *Perognathus amplus*).

Table B-29. Summary statistics for nocturnal rodents at Vulture quadrat 1, 1997 – 2005, Organ Pipe Cactus N.M.

	1997	1998	1999	2000	2001	2002	2003	2004	2005
Murid total abundance	2	6	0	0	1	0	1	4	4
Murid total biomass (g)	296	689	0	0	126	0	95	549	521
Heteromyid total abundance	17	7	34	29	16	12	50	34	32
Heteromyid total biomass (g)	236	159	663	421	233	191	764	554	499
Species richness	4	4	4	3	4	3	4	4	4
Diversity (H')	1.192	1.231	0.803	0.497	1.053	0.918	0.820	1.216	1.221
Capture success, night 1	22%	12%	39%	43%	20%	8%	63%	49%	35%
Capture success, night 2	27%	18%	53%	33%	27%	18%	69%	47%	51%
Recaptures	38%	22%	42%	50%	46%	11%	41%	39%	24%

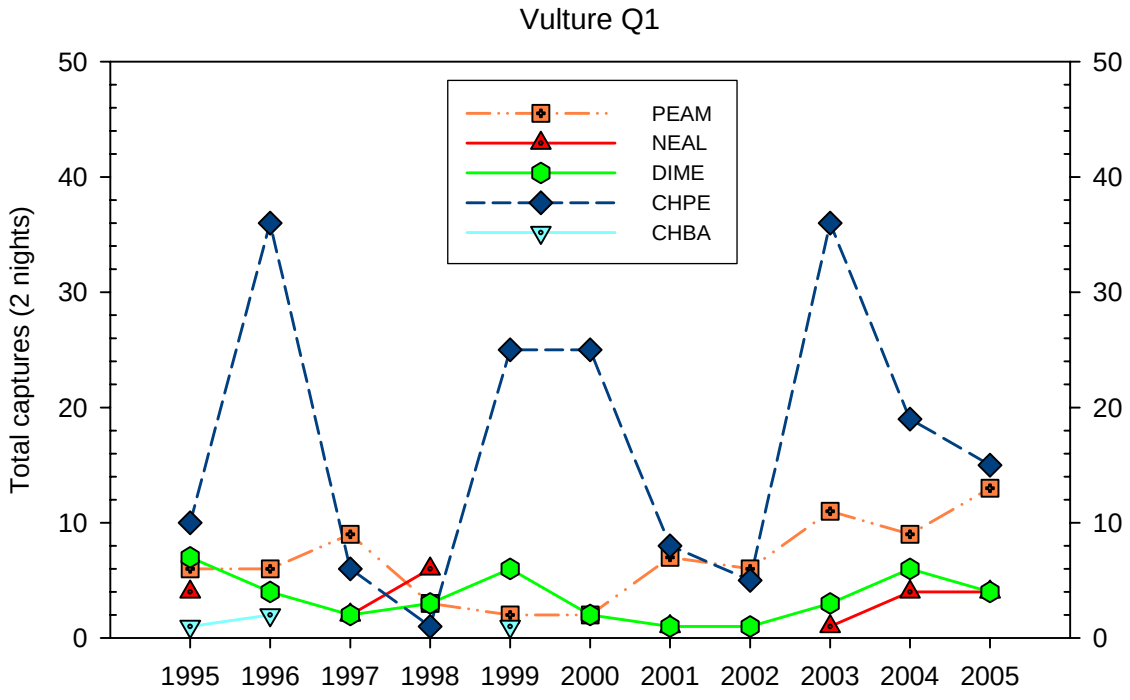


Figure B-29. Relative abundance of nocturnal rodent species at Vulture quadrat 1, 1993 – 2005, Organ Pipe Cactus N.M. (CHBA = *Chaetodipus baileyi*, CHPE = *Chaetodipus penicillatus*, DIME = *Dipodomys merriami*, NEAL = *Neotoma albigula*, PEAM = *Perognathus amplus*).

Table B-30. Summary statistics for nocturnal rodents at Vulture quadrat 2, 1997 – 2005, Organ Pipe Cactus N.M.

	1997	1998	1999	2000	2001	2002	2003	2004	2005
Murid total abundance	1	4	0	5	2	0	2	3	5
Murid total biomass (g)	85	512	0	372	298	0	265	434	595
Heteromyid total abundance	16	9	53	39	17	2	61	43	36
Heteromyid total biomass (g)	225	282	873	666	325	72	948	699	673
Species richness	4	3	3	5	4	1	4	4	4
Diversity (H')	1.005	1.058	0.444	1.093	1.234	0	0.718	1.145	1.306
Capture success, night 1	16%	14%	57%	41%	24%	4%	84%	63%	45%
Capture success, night 2	27%	24%	61%	59%	16%	2%	82%	57%	61%
Recaptures	31%	50%	17%	17%	13%	100%	45%	46%	37%

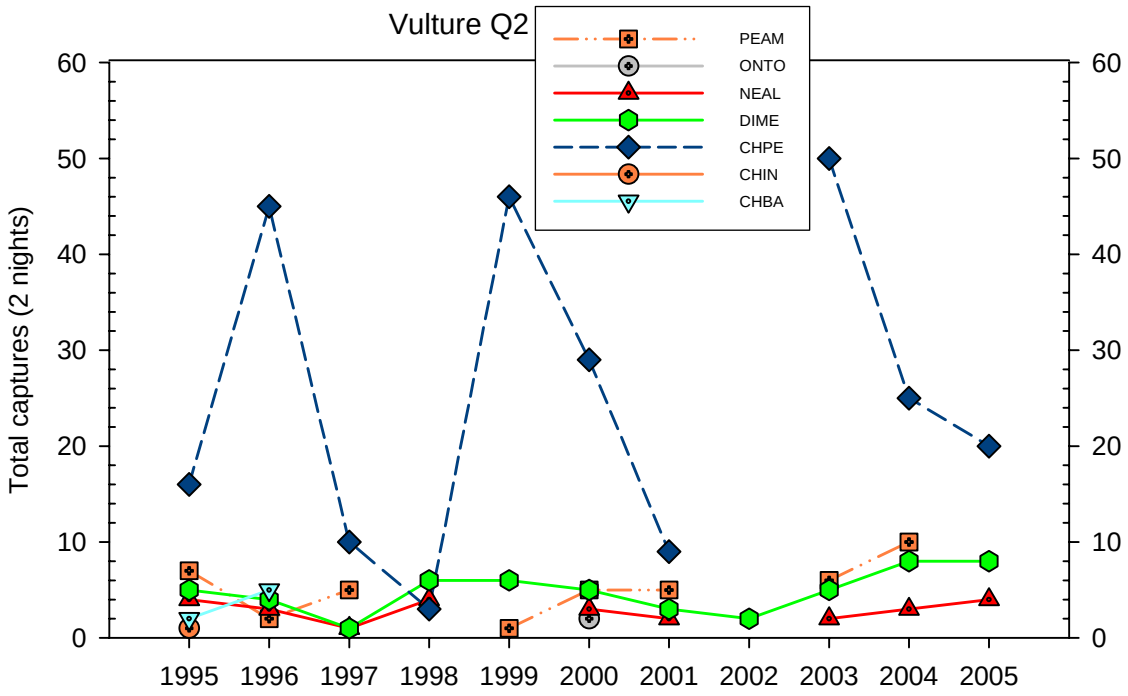


Figure B-30. Relative abundance of nocturnal rodent species at Vulture quadrat 2, 1993 – 2005, Organ Pipe Cactus N.M. (CHBA = *Chaetodipus baileyi*, CHIN = *Chaetodipus intermedius*, CHPE = *Chaetodipus penicillatus*, DIME = *Dipodomys merriami*, NEAL = *Neotoma albigula*, ONTO = *Onychomys torridus*, PEAM = *Perognathus amplus*).

Appendix C - Climate

Table C-1. Summary statistics for precipitation at Acuña Site weather station, 1988 to 2005, Organ Pipe Cactus N.M. Average annual total is 7.95 inches (201.9mm).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	0.81	0.94	0.87	0.30	0.05	0.02	0.85	1.95	0.65	0.37	0.30	0.85
S.D.	1.01	0.98	0.89	0.40	0.13	0.04	0.94	1.25	0.94	0.62	0.37	1.29
Skew	1.51	0.94	1.26	1.23	3.29	2.36	0.88	0.20	2.34	2.17	1.39	1.74
Max	3.27	3.11	3.07	1.26	0.51	0.13	2.60	4.13	3.73	2.17	1.30	4.21
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00
Years	17	17	17	17	18	18	17	18	18	18	18	18

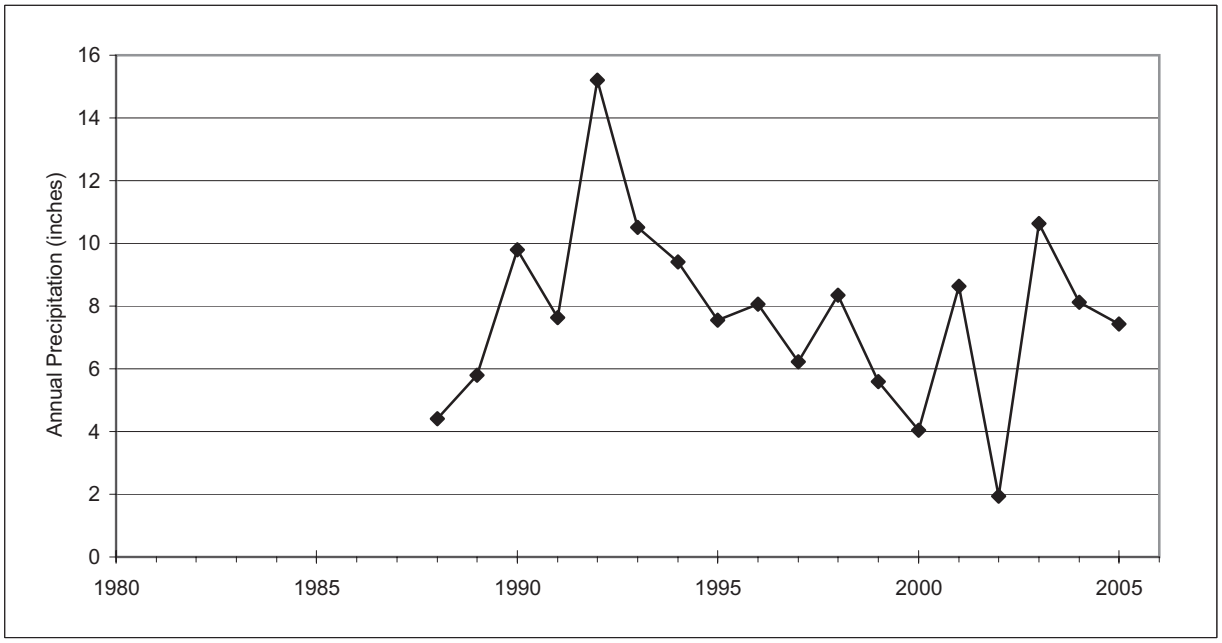


Figure C-1a. Annual precipitation at Acuña Site weather station, 1988 to 2005.

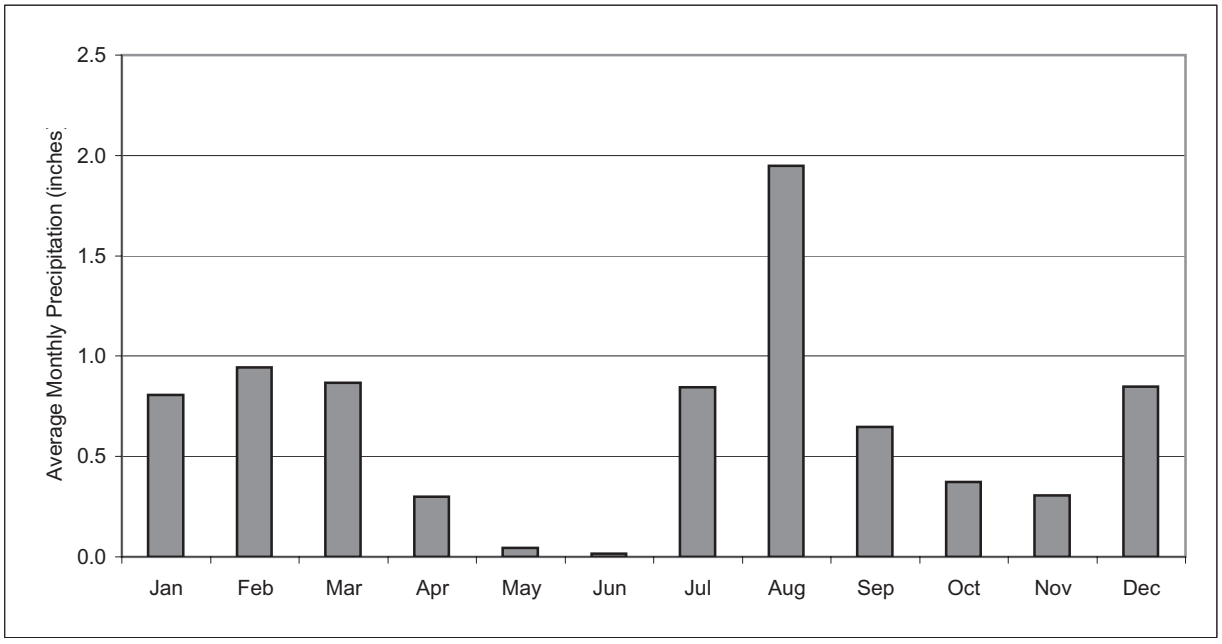


Figure C-1b. Average monthly precipitation at Acuña Site weather station, 1988 to 2005.

Table C-2. Summary statistics for precipitation at Aguajita Wash weather station, 1988 to 2005, Organ Pipe Cactus N.M. Average annual total is 7.39 inches (187.7mm).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	0.76	0.85	0.81	0.27	0.06	0.00	0.67	1.64	0.72	0.33	0.35	0.94
S.D.	0.73	0.73	0.78	0.34	0.12	0.00	0.75	1.82	1.01	0.45	0.40	1.25
Skew	1.32	0.47	1.36	1.55	1.88	NA	1.01	1.69	1.95	2.18	1.37	1.55
Max	2.40	2.23	2.56	1.16	0.35	0.00	2.32	6.34	3.54	1.57	1.34	4.17
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Years	14	14	13	14	14	14	14	12	14	15	14	15

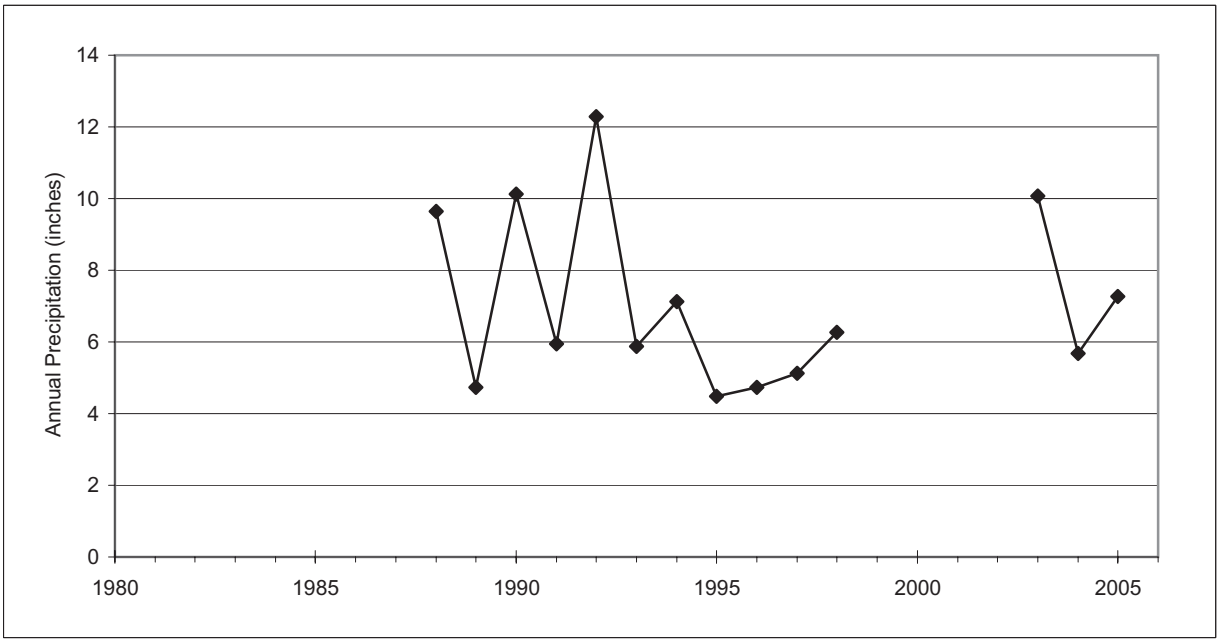


Figure C-2a. Annual precipitation at Aguajita Wash weather station, 1988 to 2005.

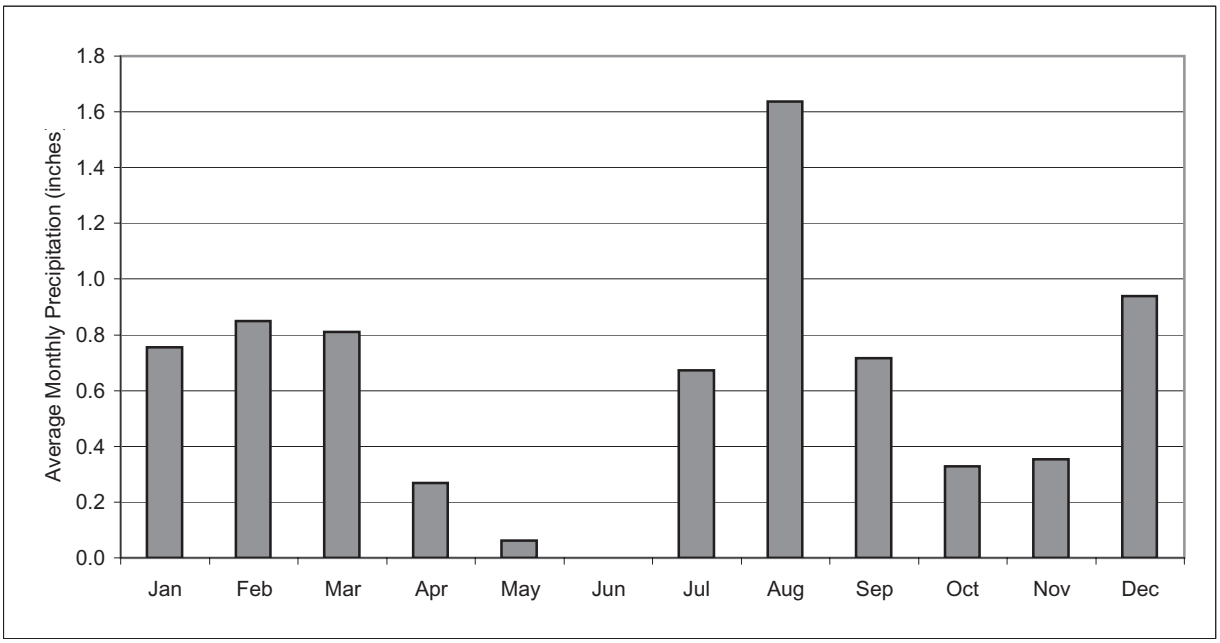


Figure C-2b. Average monthly precipitation at Aguajita Wash weather station, 1988 to 2005.

Table C-3. Summary statistics for precipitation at Alamo Canyon weather station (in canyon), 1996 to 2005, Organ Pipe Cactus N.M. Average annual total is 10.95 inches (278.1mm).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	0.90	1.30	0.89	0.62	0.02	0.05	1.42	2.64	1.25	0.65	0.33	0.88
S.D.	1.16	1.25	1.26	0.91	0.05	0.11	1.06	1.67	1.98	0.71	0.31	1.38
Skew	1.77	0.64	1.59	1.68	2.98	2.30	1.77	-0.17	2.74	1.49	0.22	2.09
Max	3.55	3.50	3.47	2.60	0.16	0.31	3.92	5.36	6.69	2.21	0.72	4.35
Min	0.06	0.00	0.02	0.00	0.00	0.00	0.20	0.05	0.00	0.00	0.00	0.00
Years	9	9	8	9	9	9	9	9	10	10	10	10

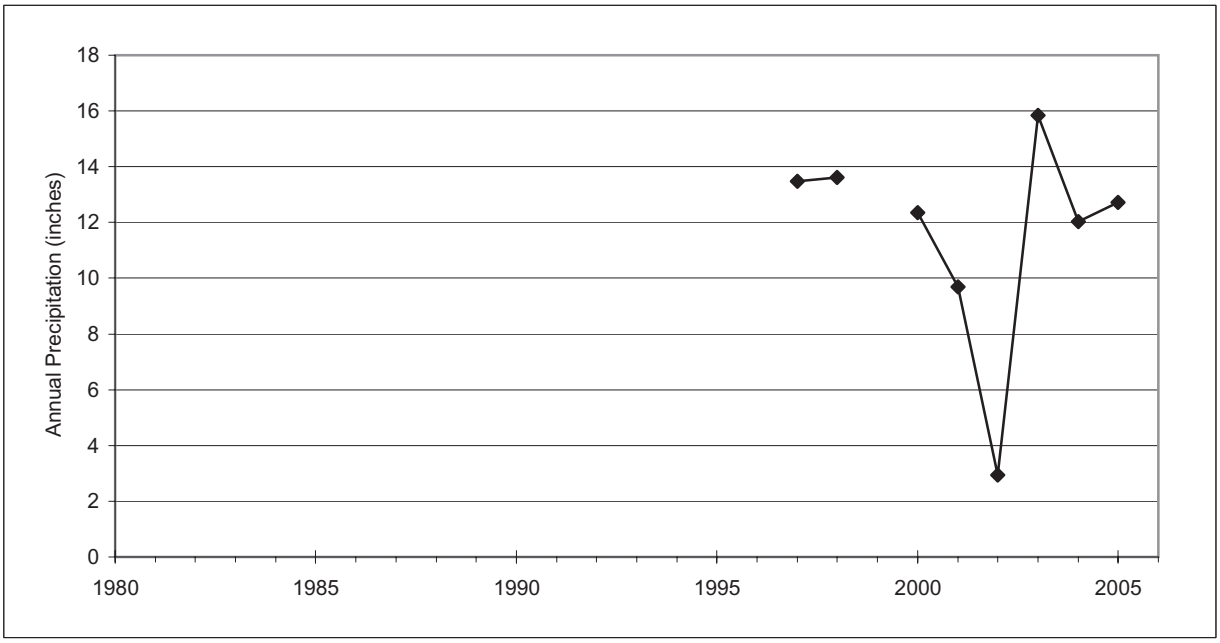


Figure C-3a. Annual precipitation at Alamo Canyon weather station (in canyon), 1996 to 2005.

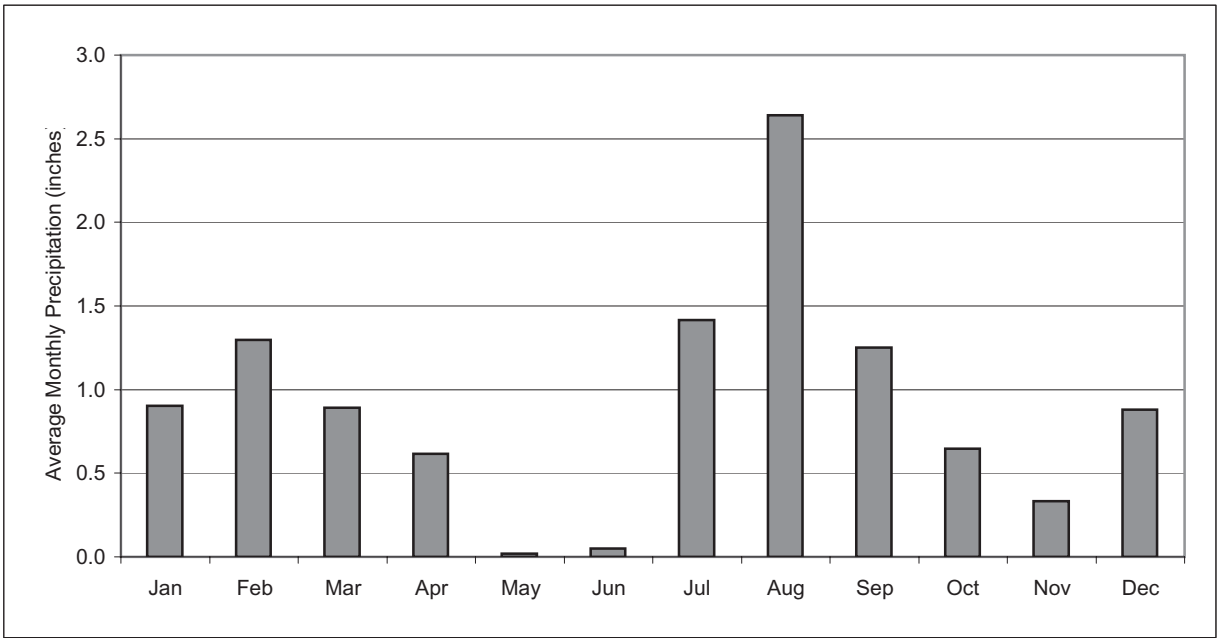


Figure C-3b. Average monthly precipitation at Alamo Canyon weather station (in canyon), 1996 to 200

Table C-4. Summary statistics for precipitation at Bull Pasture weather station, 1988 to 2005, Organ Pipe Cactus N.M. Average annual total is 11.93 inches (303.0mm).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	1.41	1.25	1.03	0.50	0.08	0.04	1.69	2.44	0.87	0.68	0.51	1.41
S.D.	1.94	1.17	1.10	0.66	0.15	0.15	1.39	1.56	1.21	0.78	0.73	1.93
Skew	2.55	1.08	1.16	1.78	2.15	4.13	1.28	1.07	2.58	1.68	2.57	1.42
Max	7.99	4.35	2.99	2.48	0.51	0.66	5.20	6.85	5.03	2.83	3.03	5.67
Min	0.03	0.00	0.02	0.00	0.00	0.00	0.12	0.27	0.00	0.00	0.00	0.00
Years	18	17	18	18	17	18	18	18	18	18	18	18

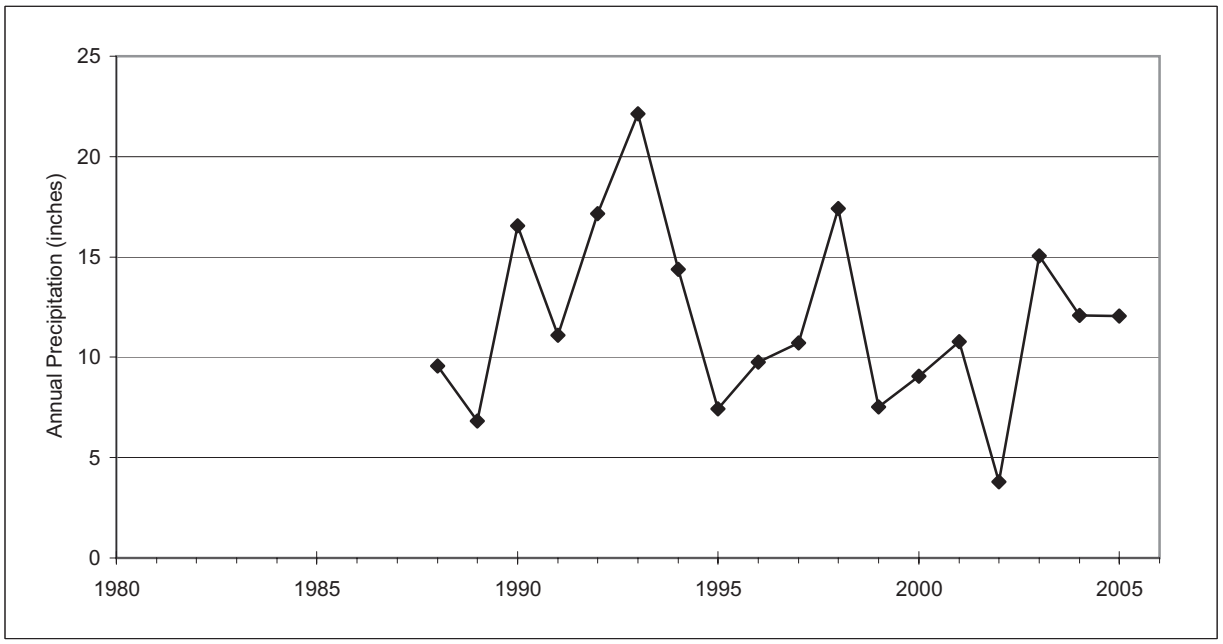


Figure C-4a. Annual precipitation at Bull Pasture weather station, 1988 to 2005.

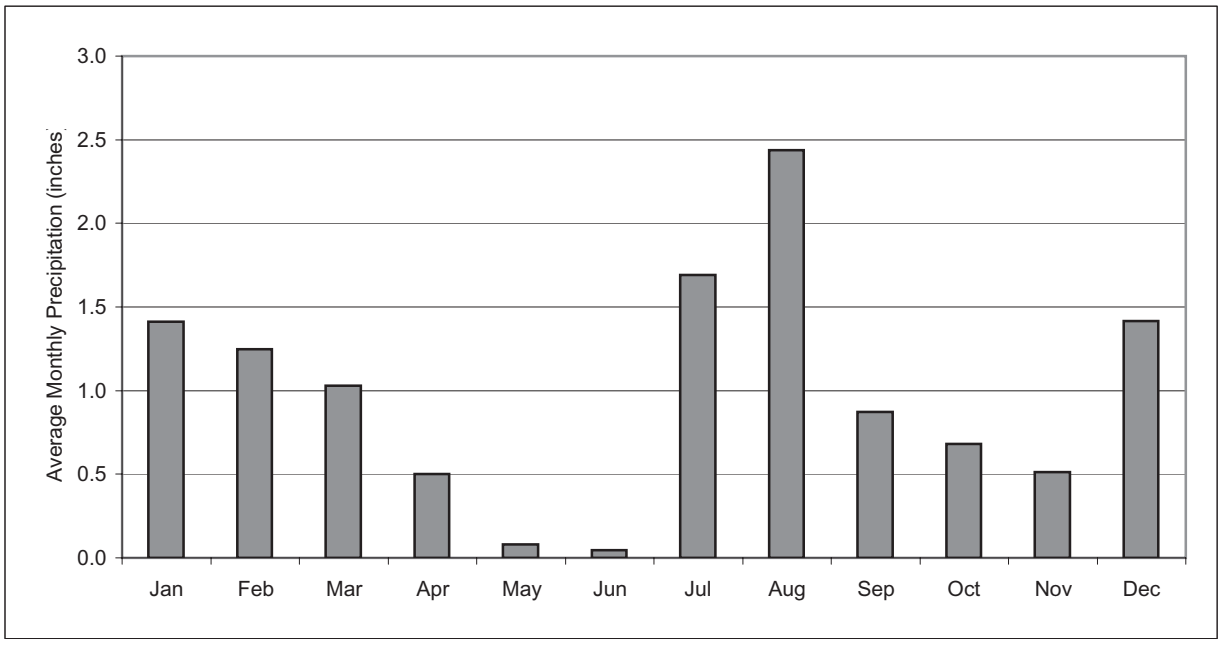


Figure C-4b. Average monthly precipitation at Bull Pasture weather station, 1988 to 2005.

Table C-5. Summary statistics for precipitation at East Armenta weather station, 1988 to 2005, Organ Pipe Cactus N.M. Average annual total is 7.97 inches (202.4mm).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	0.73	0.92	0.80	0.32	0.06	0.03	1.43	1.62	0.47	0.42	0.33	0.84
S.D.	0.82	0.98	0.89	0.50	0.13	0.08	1.18	1.17	0.53	0.61	0.44	1.18
Skew	1.35	0.82	1.42	2.15	2.53	3.20	0.78	0.76	0.77	1.95	1.88	1.56
Max	2.91	3.13	3.11	1.91	0.47	0.32	4.02	3.94	1.55	1.97	1.69	3.70
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.07	0.00	0.00	0.00	0.00
Years	17	17	17	18	18	18	18	17	17	17	18	18

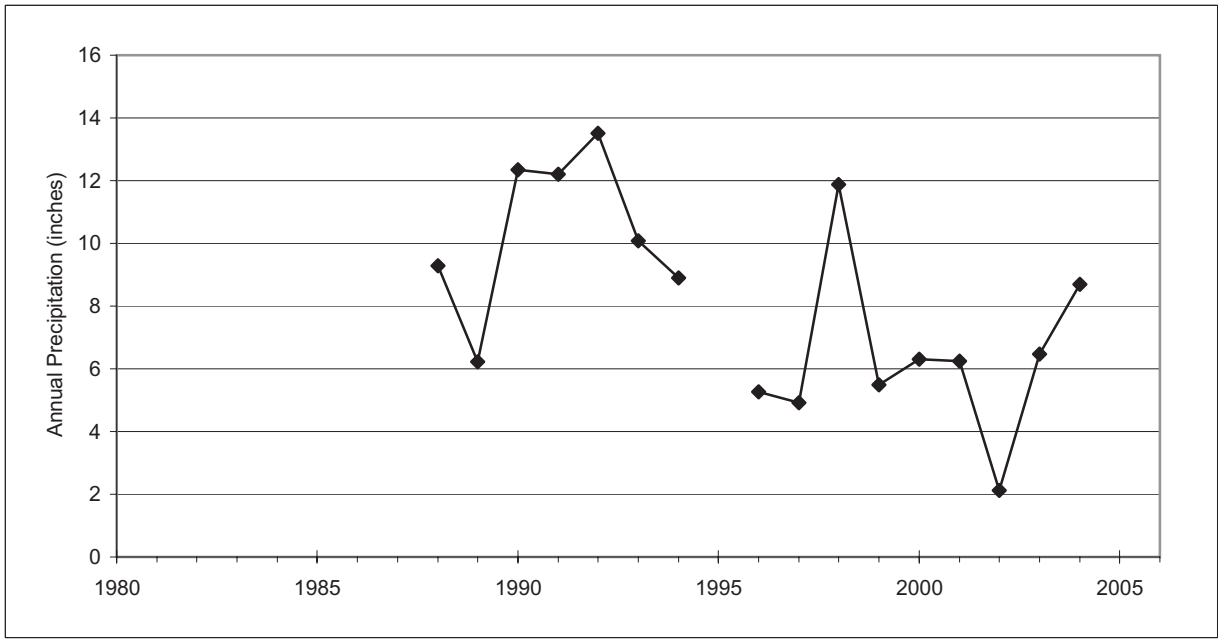


Figure C-5a. Annual precipitation at East Armenta weather station, 1988 to 2005.

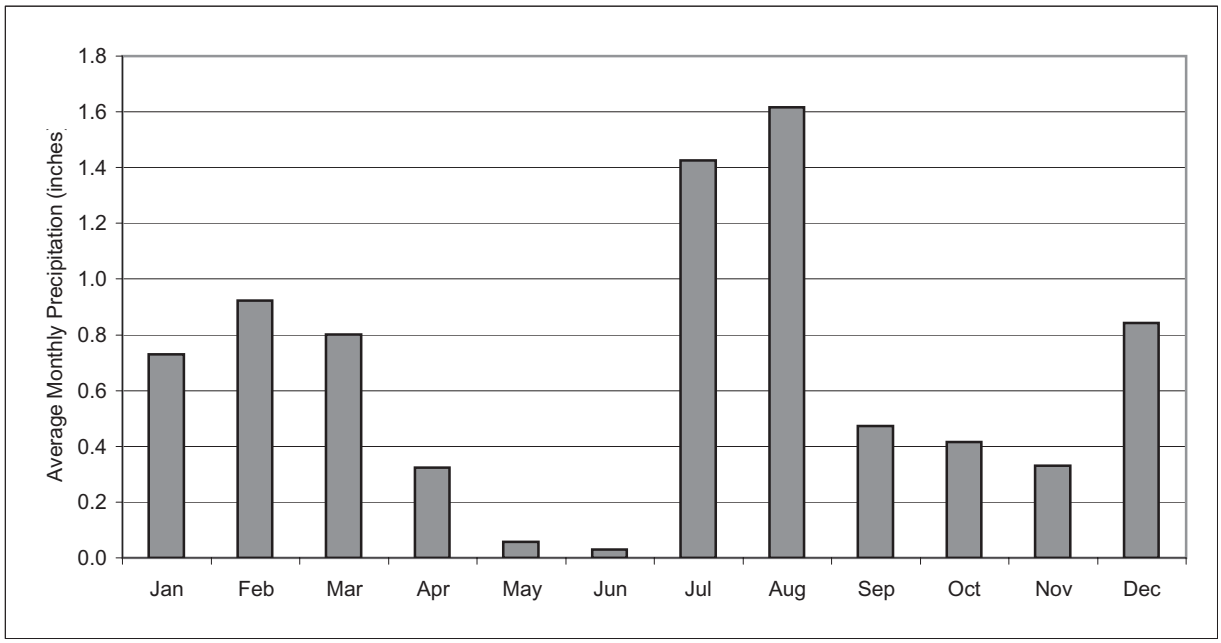


Figure C-5b. Average monthly precipitation at East Armenta weather station, 1988 to 2005.

Table C-6. Summary statistics for precipitation at Growler Valley weather station (and rain gauge), 1982 to 2005, Organ Pipe Cactus N.M. Average annual total is 8.72 inches (221.5mm).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	0.71	0.99	0.77	0.28	0.05	0.04	1.16	1.92	0.73	0.61	0.54	0.93
S.D.	0.75	0.84	0.77	0.38	0.10	0.12	1.47	1.46	0.89	0.96	0.65	1.08
Skew	1.35	0.22	0.93	1.38	2.28	4.35	2.23	1.02	1.22	2.18	1.24	1.49
Max	2.64	2.35	2.41	1.35	0.41	0.59	6.42	5.37	2.99	3.71	2.13	3.90
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00
Years	24	23	24	24	24	24	24	24	24	24	24	24

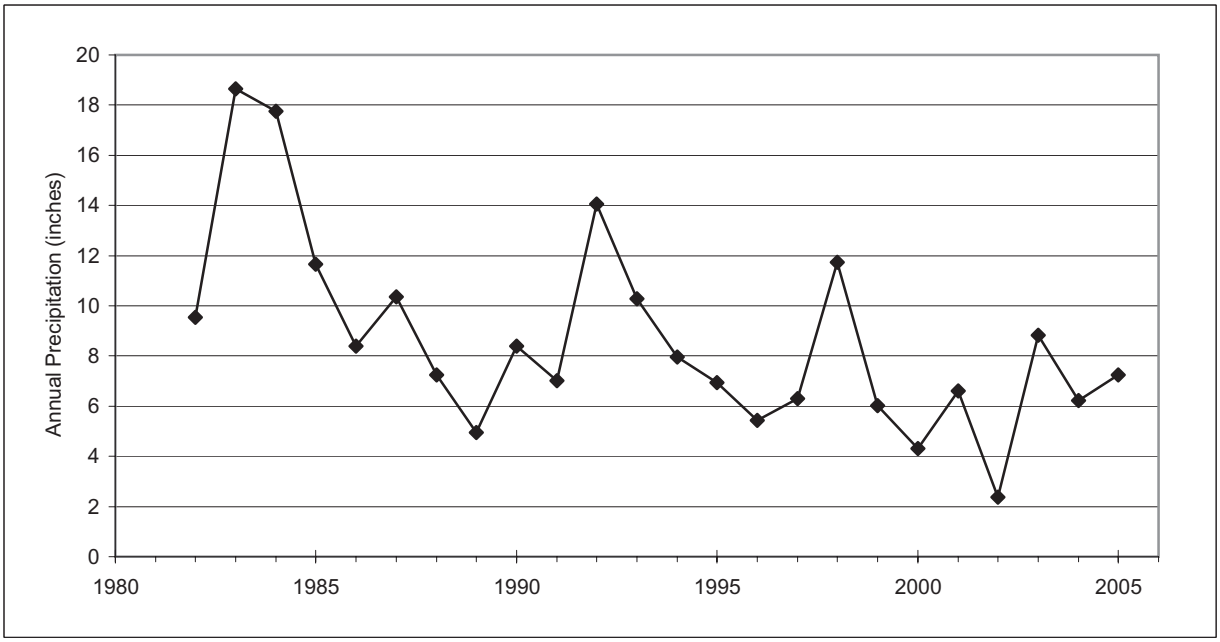


Figure C-6a. Annual precipitation at Growler Valley weather station (and rain gauge), 1982 to 2005.

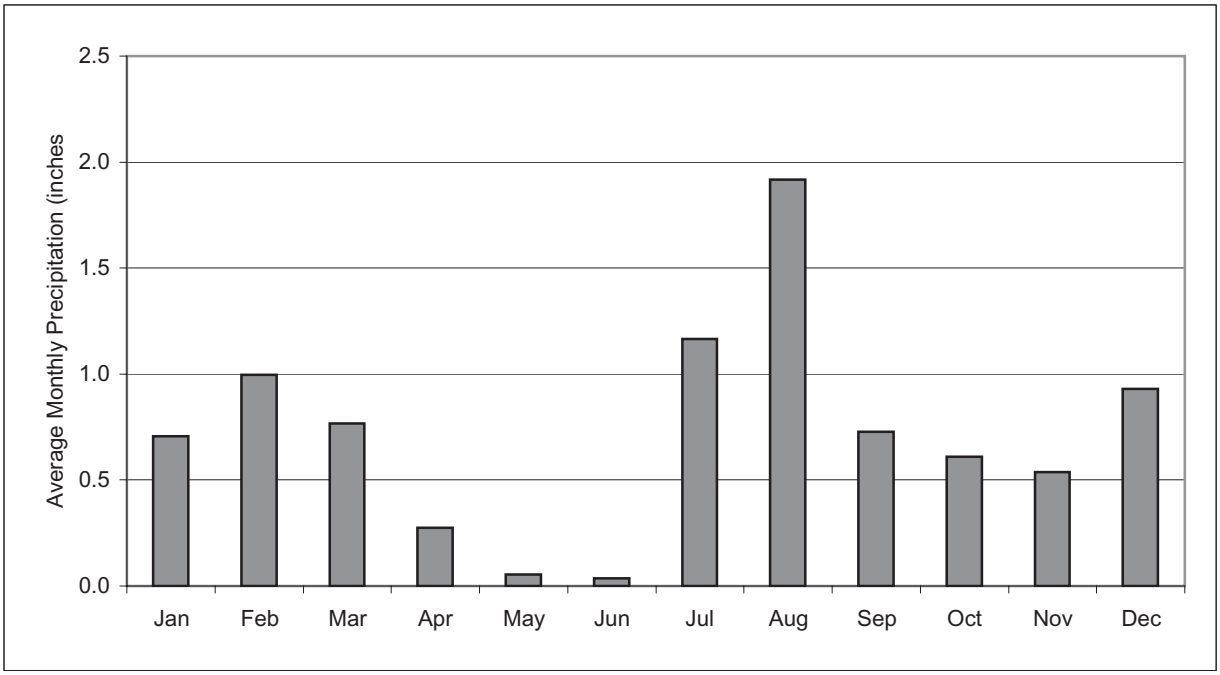


Figure C-6b. Average monthly precipitation at Growler Valley weather station (and rain gauge), 1982 t

Table C-7. Summary statistics for precipitation at Middle Bajada weather station, 1996 to 2005, Organ Pipe Cactus N.M. Average annual total is 8.51 inches (216.2mm).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	0.69	1.00	0.56	0.57	0.03	0.05	1.38	1.80	0.81	0.57	0.31	0.74
S.D.	0.99	1.05	0.82	0.78	0.08	0.11	1.12	0.96	1.05	0.69	0.32	1.13
Skew	1.98	0.83	1.66	1.94	3.15	3.00	1.08	-0.17	1.51	1.59	0.56	1.98
Max	3.04	2.89	2.43	2.50	0.24	0.37	3.76	3.38	3.23	1.92	0.84	3.54
Min	0.01	0.00	0.00	0.00	0.00	0.00	0.17	0.02	0.00	0.00	0.00	0.00
Years	9	9	10	10	10	10	10	10	10	10	10	10

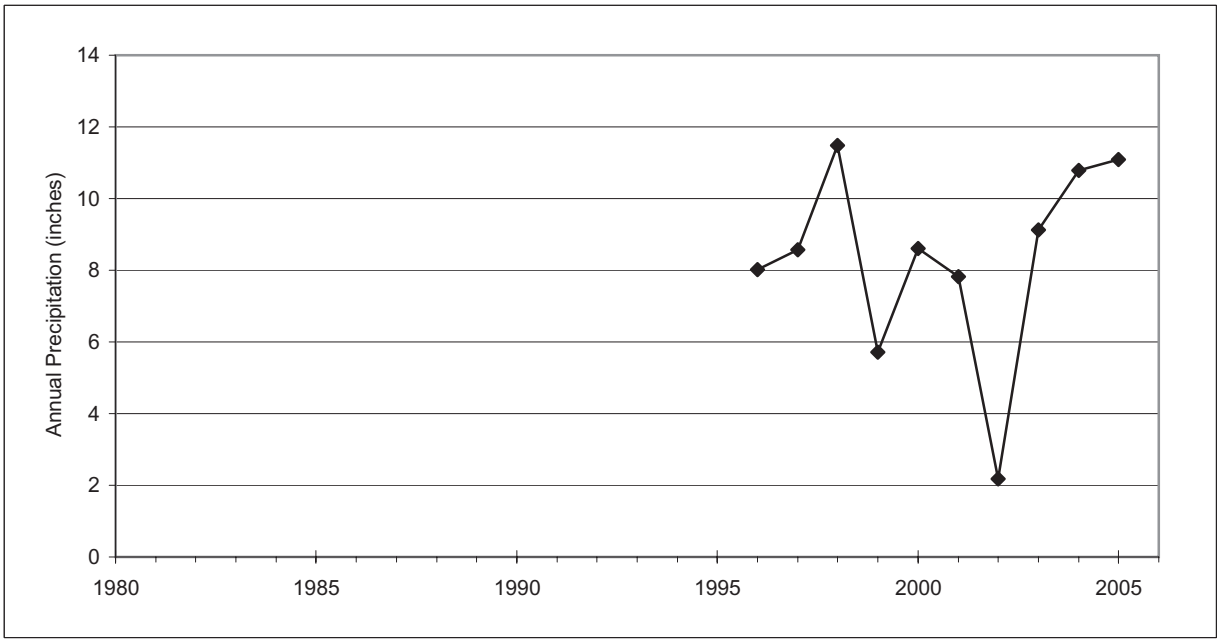


Figure C-7a. Annual precipitation at Middle Bajada weather station, 1996 to 2005.

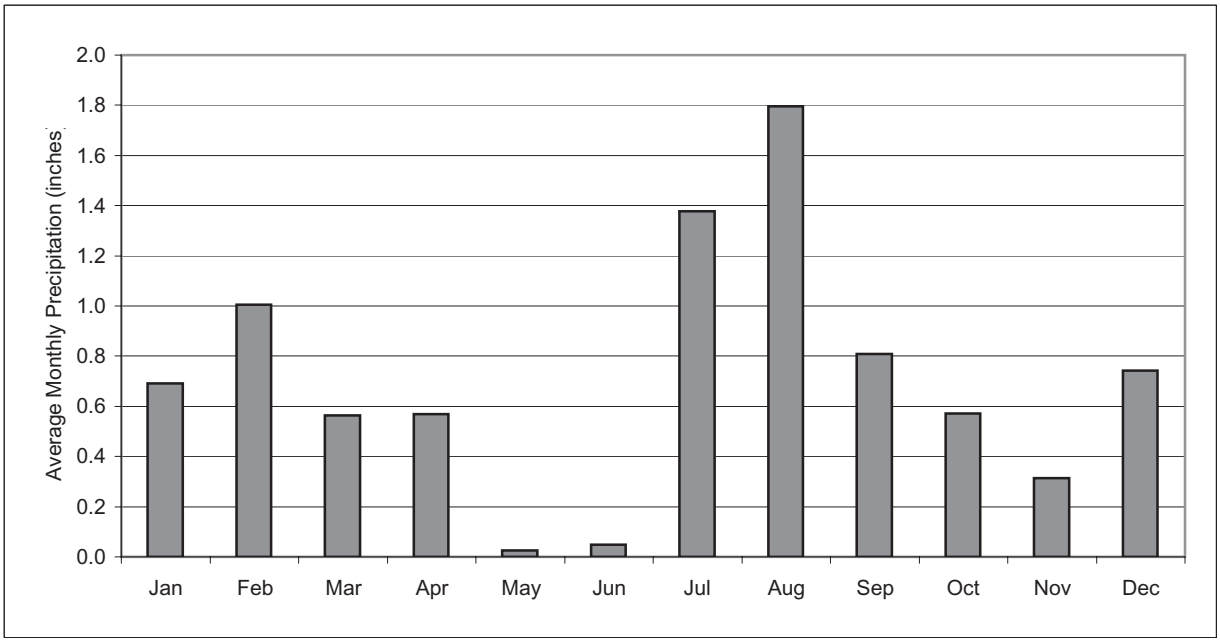


Figure C-7b. Average monthly precipitation at Middle Bajada weather station, 1996 to 2005.

Table C-8. Summary statistics for precipitation at Pozo Nuevo weather station (and raingauge), 1992 to 2005, Organ Pipe Cactus N.M. Average annual total is 6.71 inches (170.4mm).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	0.56	1.04	0.48	0.26	0.04	0.03	0.44	1.31	0.93	0.37	0.37	0.86
S.D.	0.74	0.81	0.39	0.29	0.10	0.06	0.49	0.90	1.00	0.53	0.55	1.51
Skew	1.93	0.63	0.43	0.55	2.60	1.95	1.90	0.59	1.09	2.16	1.99	1.94
Max	2.59	2.84	1.19	0.71	0.33	0.18	1.80	3.26	3.26	1.90	1.93	4.69
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Years	13	13	13	13	13	13	13	13	13	14	14	14

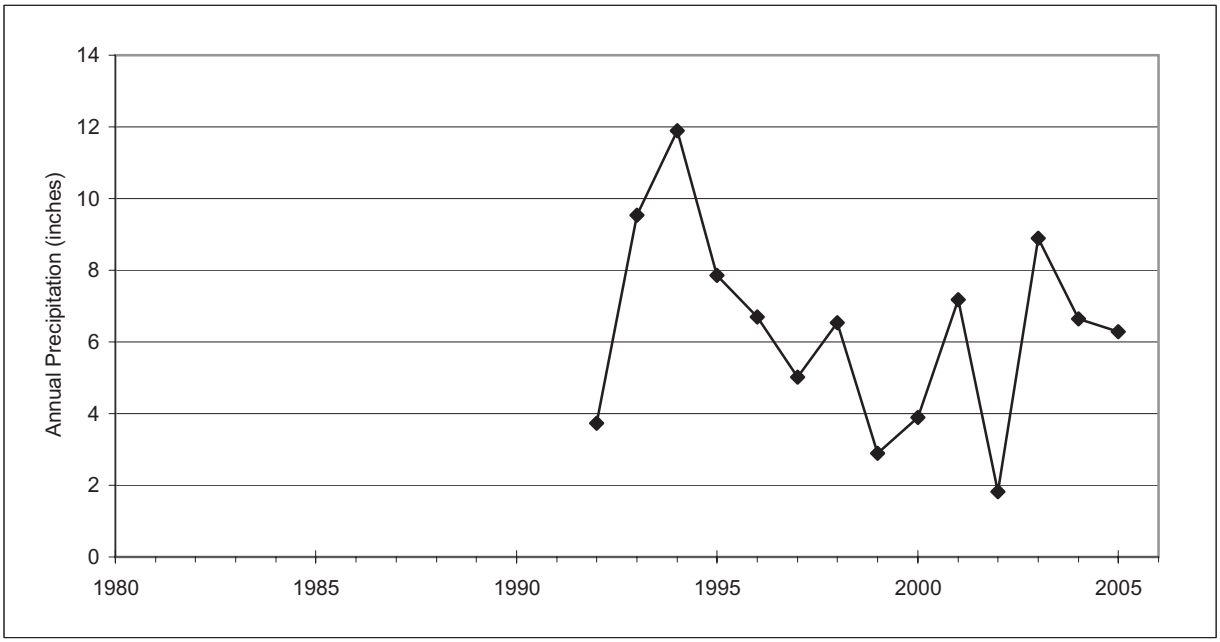


Figure C-8a. Annual precipitation at Pozo Nuevo weather station (and rain gauge), 1992 to 2005.

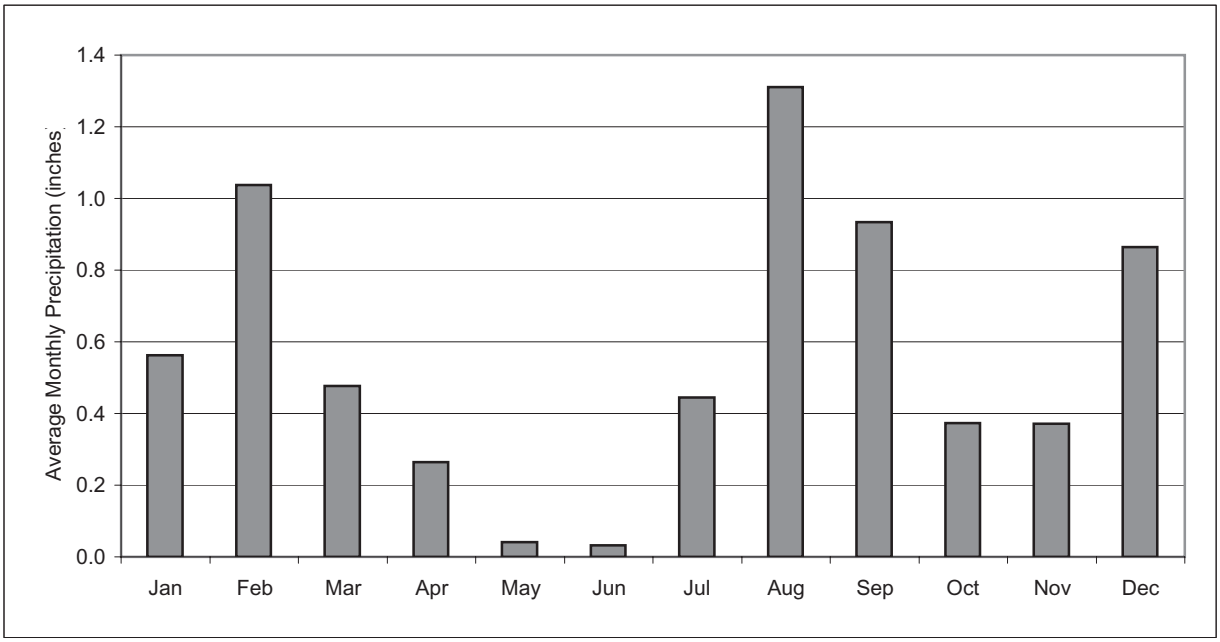


Figure C-8b. Average monthly precipitation at Pozo Nuevo weather station (and rain gauge), 1992 to 2

Table C-9. Summary statistics for precipitation at Salsola Site weather station, 1988 to 2005, Organ Pipe Cactus N.M. Average annual total is 8.67 inches (220.2mm).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	0.78	0.91	0.68	0.37	0.01	0.08	0.98	2.01	0.98	0.58	0.37	0.92
S.D.	0.84	0.96	0.86	0.72	0.03	0.25	0.66	1.17	1.23	0.78	0.44	1.37
Skew	1.51	0.92	1.31	3.20	2.97	3.79	0.22	0.04	1.74	1.93	1.14	1.56
Max	2.99	3.22	2.72	2.99	0.12	1.04	2.14	4.06	4.49	2.83	1.46	4.06
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00
Years	18	18	18	18	18	18	18	18	18	18	18	18

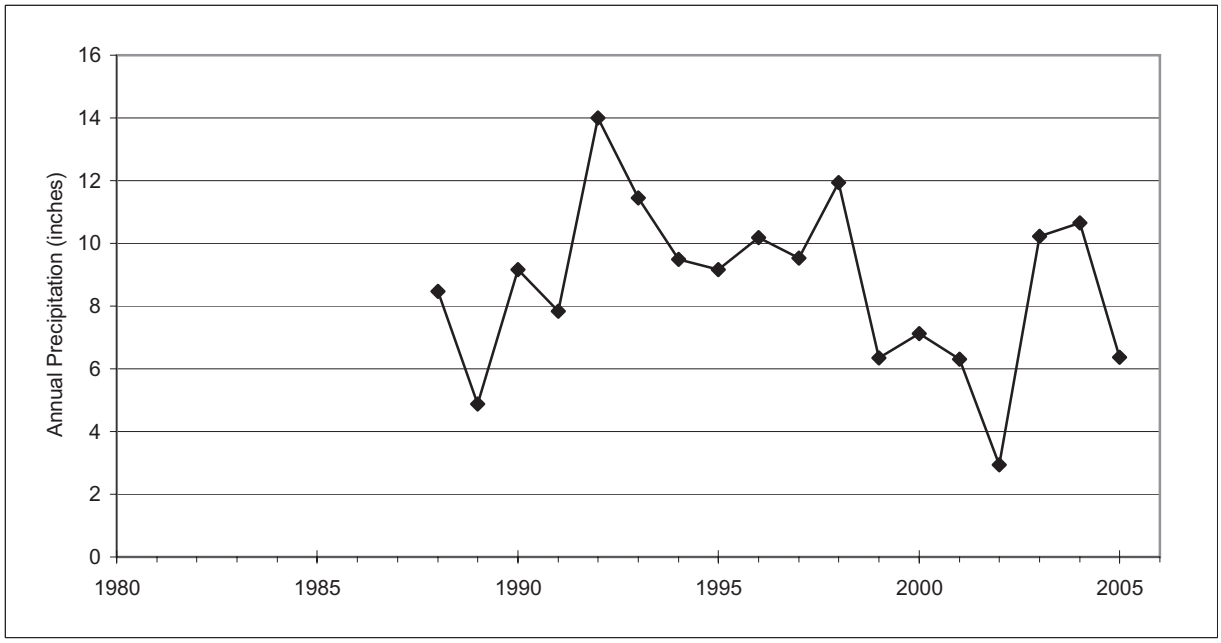


Figure C-9a. Annual precipitation at Salsola Site weather station, 1988 to 2005.

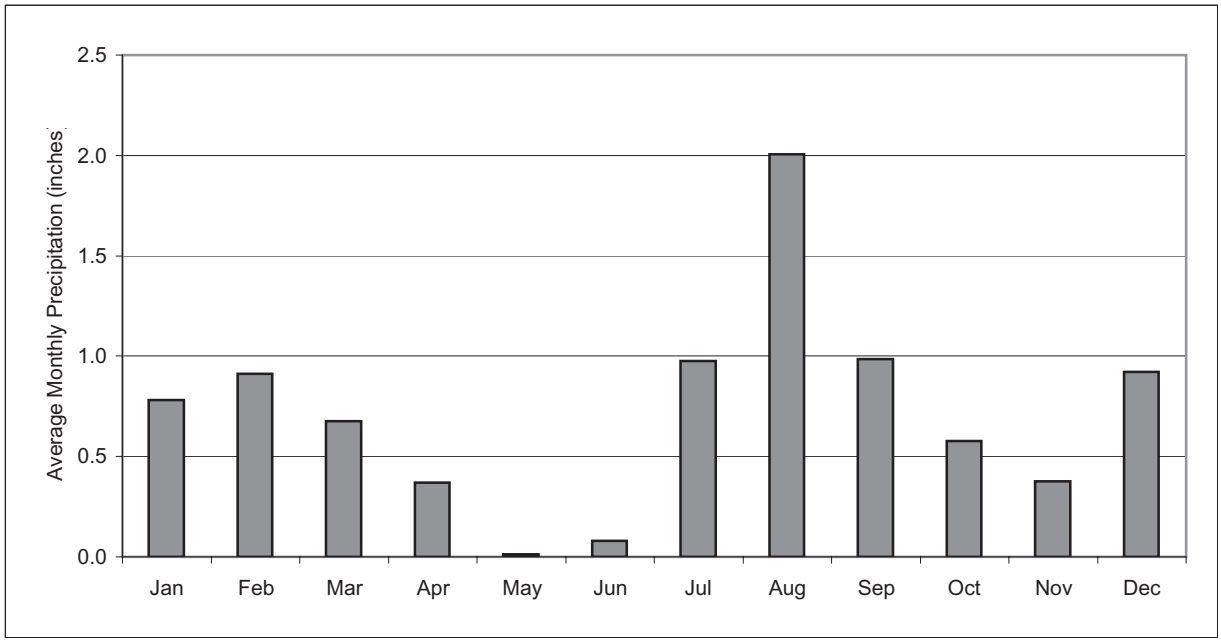


Figure C-9b. Average monthly precipitation at Salsola Site weather station, 1988 to 2005.

Table C-10. Summary statistics for precipitation at Senita Basin weather station, 1988 to 2005, Organ Pipe Cactus N.M. Average annual total is 9.02 inches (229.1mm).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	0.88	1.03	0.82	0.30	0.04	0.05	1.00	1.73	1.08	0.59	0.37	1.14
S.D.	0.92	0.95	0.86	0.46	0.10	0.15	1.26	1.07	1.42	0.72	0.56	1.42
Skew	1.16	0.69	1.73	2.05	2.81	3.99	2.17	0.61	1.86	1.58	2.79	1.23
Max	2.95	2.82	3.35	1.63	0.37	0.62	5.08	4.21	5.34	2.40	2.28	4.45
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Years	18	18	18	17	17	18	18	18	17	17	17	17

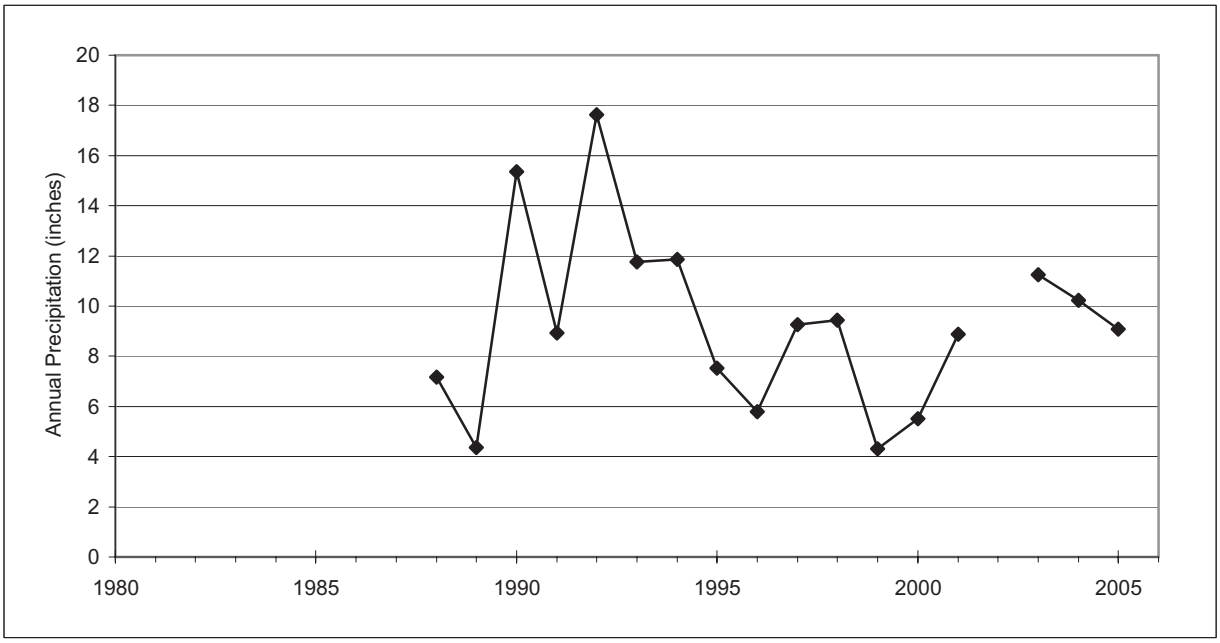


Figure C-10a. Annual precipitation at Senita Basin weather station, 1988 to 2005.

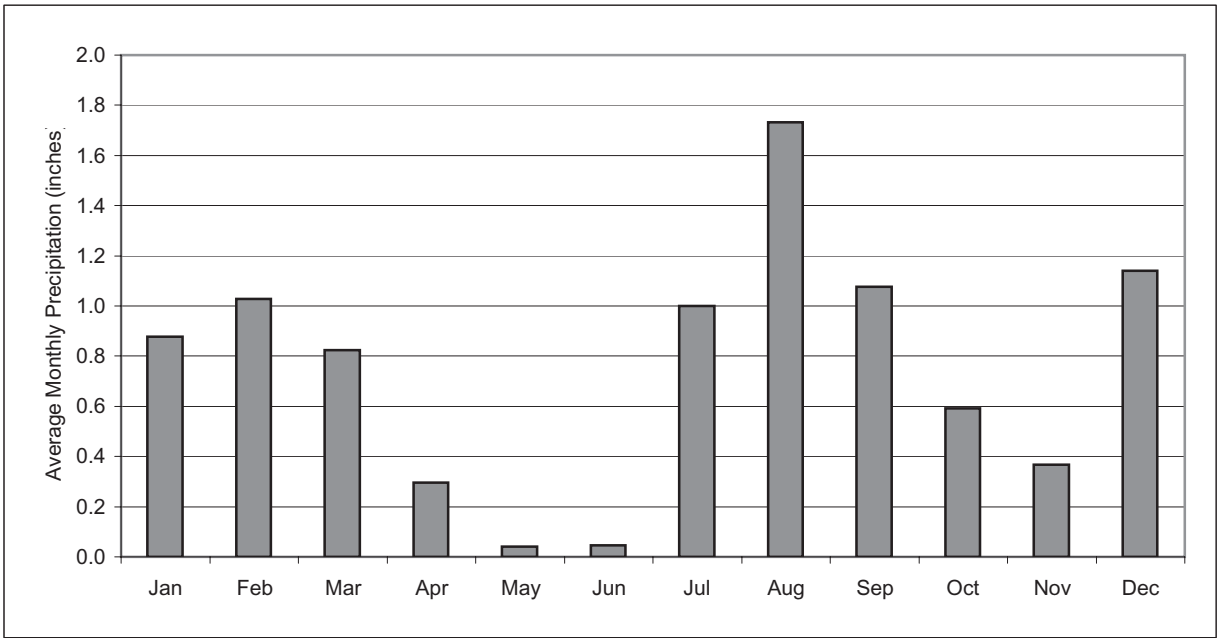


Figure C-10b. Average monthly precipitation at Senita Basin weather station, 1988 to 2005.

Table C-11. Summary statistics for precipitation at Valley Floor weather station, 1996 to 2005, Organ Pipe Cactus N.M. Average annual total is 6.99 inches (177.6mm).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	0.49	0.86	0.53	0.40	0.00	0.12	1.01	1.65	0.79	0.46	0.25	0.42
S.D.	0.57	0.94	0.67	0.53	0.01	0.23	0.75	1.42	1.02	0.75	0.34	0.58
Skew	1.30	0.93	1.15	1.56	3.16	2.12	0.28	0.84	1.94	1.64	1.40	1.81
Max	1.61	2.67	1.71	1.60	0.02	0.69	2.32	4.58	3.34	2.01	0.99	1.82
Min	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
Years	9	9	10	10	10	10	10	10	10	10	10	10

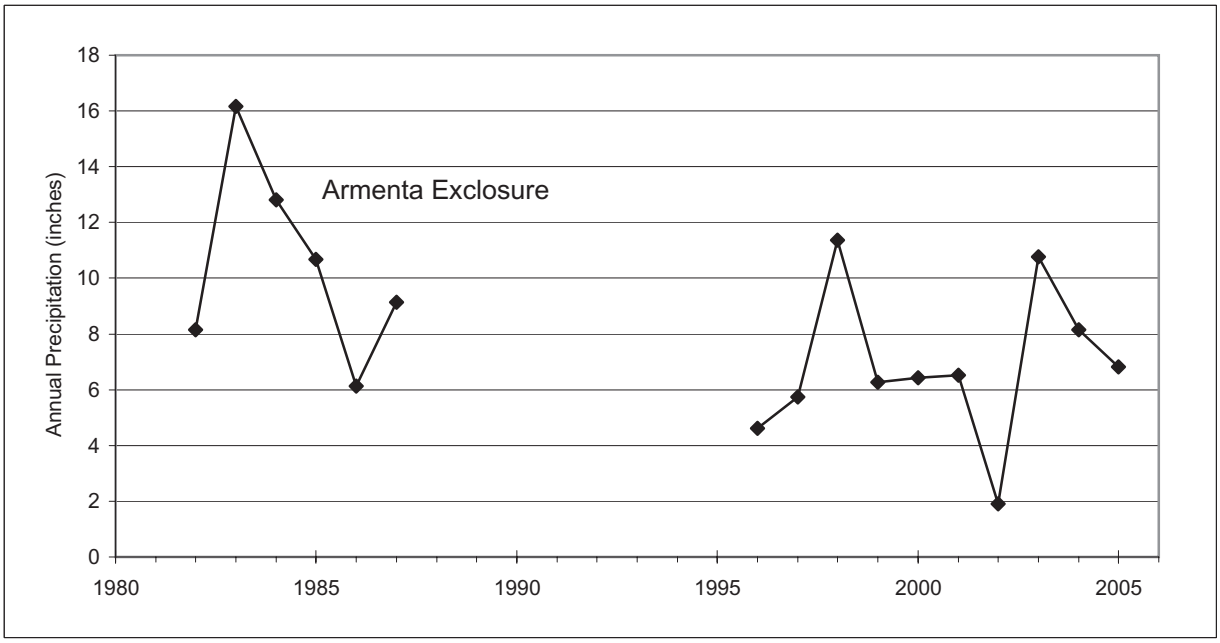


Figure C-11a. Annual precipitation at Valley Floor weather station, 1996 to 2005.

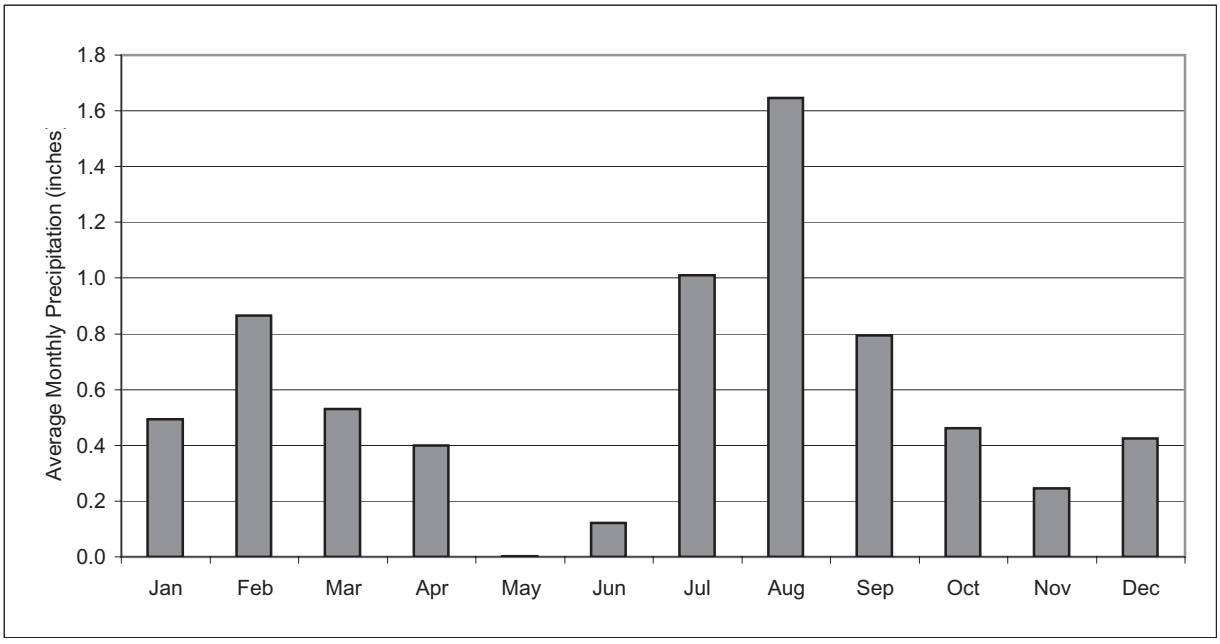


Figure C-11b. Average monthly precipitation at Valley Floor weather station, 1996 to 2005.

Table C-12. Summary statistics for precipitation at Alamo Canyon rain gauge (near campground), 1982 to 2005, Organ Pipe Cactus N.M. Average annual total is 12.62 inches (320.6mm).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	1.07	1.19	1.04	0.46	0.11	0.05	1.95	2.77	1.08	0.81	0.68	1.41
S.D.	1.12	1.02	1.20	0.69	0.17	0.10	1.48	1.49	1.35	0.80	0.78	1.57
Skew	1.48	0.51	1.18	2.46	1.52	2.61	1.26	0.46	2.41	1.31	1.61	1.13
Max	4.26	3.52	3.50	2.99	0.53	0.35	6.28	6.95	5.67	2.98	2.91	5.35
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.11	0.00	0.00	0.00	0.00
Years	24	24	24	24	24	24	24	24	23	24	24	24

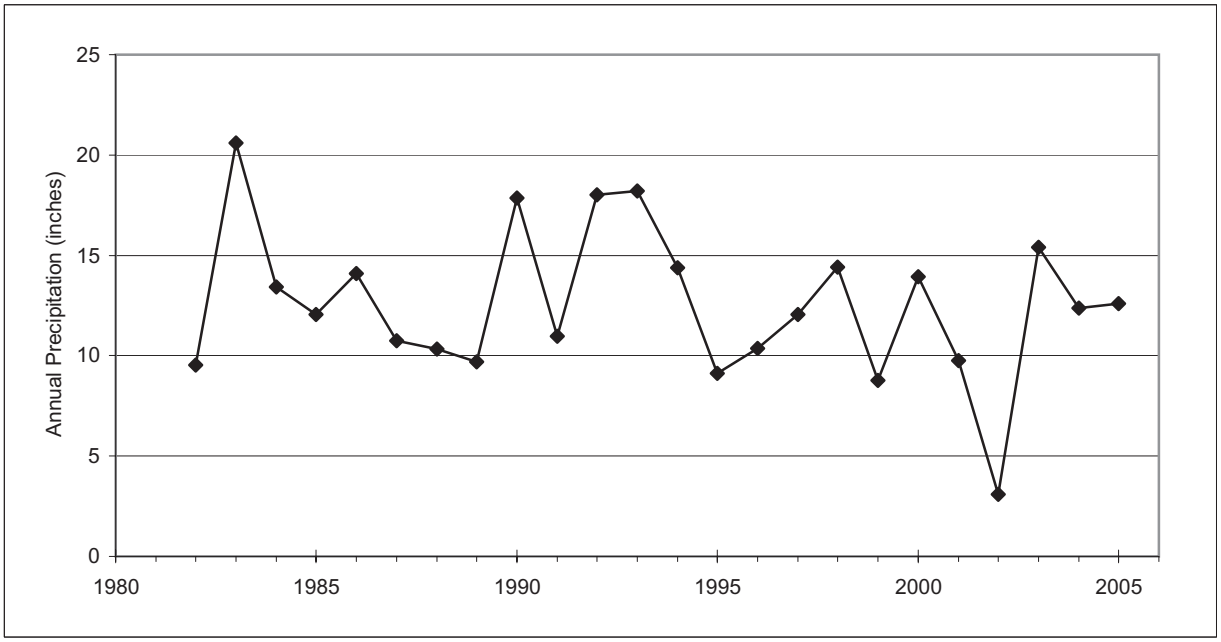


Figure C-12a. Annual precipitation at Alamo Canyon rain gauge (near campground), 1982 to 2005.

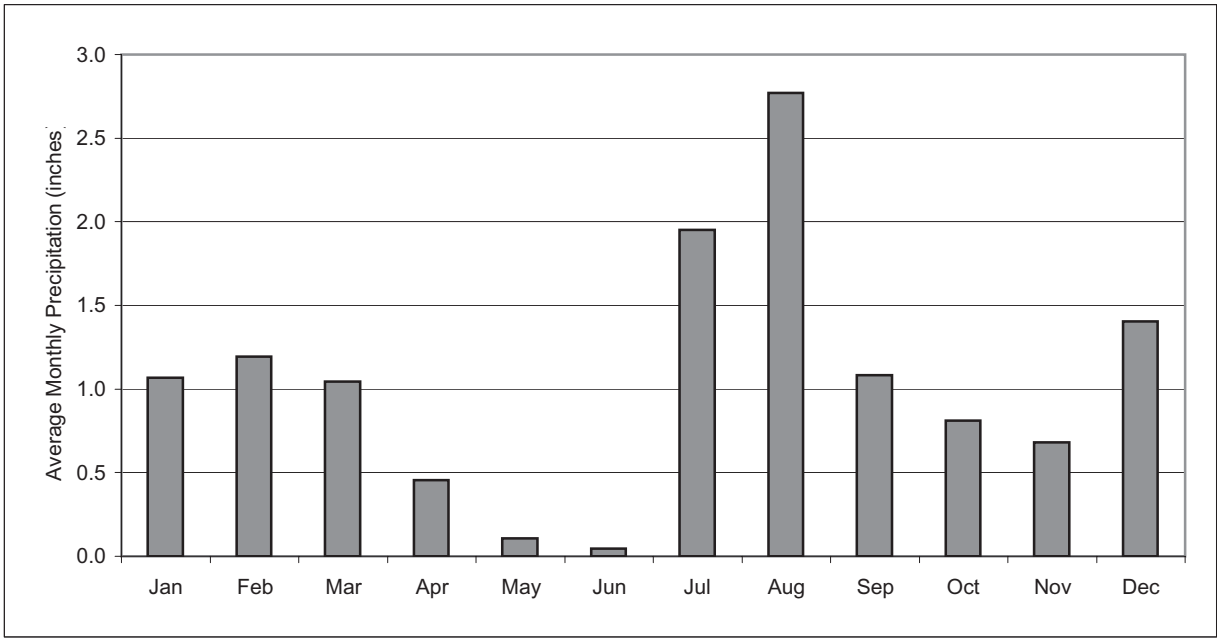


Figure C-12b. Average monthly precipitation at Alamo Canyon rain gauge (near campground), 1982 to

Table C-13. Summary statistics for precipitation at Arch Canyon rain gauge, 1982 to 2005, Organ Pipe Cactus N.M. Average annual total is 14.26 inches (362.2mm).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	1.22	1.33	1.31	0.50	0.15	0.05	2.02	3.05	1.40	0.93	0.78	1.52
S.D.	1.56	1.15	1.48	0.71	0.24	0.14	1.27	1.58	1.53	0.87	0.96	1.73
Skew	2.57	0.65	1.09	1.99	2.15	4.42	0.53	0.33	1.30	0.94	1.63	1.11
Max	7.01	4.00	4.49	2.89	0.99	0.68	5.11	7.04	5.63	2.85	3.20	5.58
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.11	0.00	0.00	0.00	0.00
Years	24	24	24	24	24	24	24	24	24	24	24	24

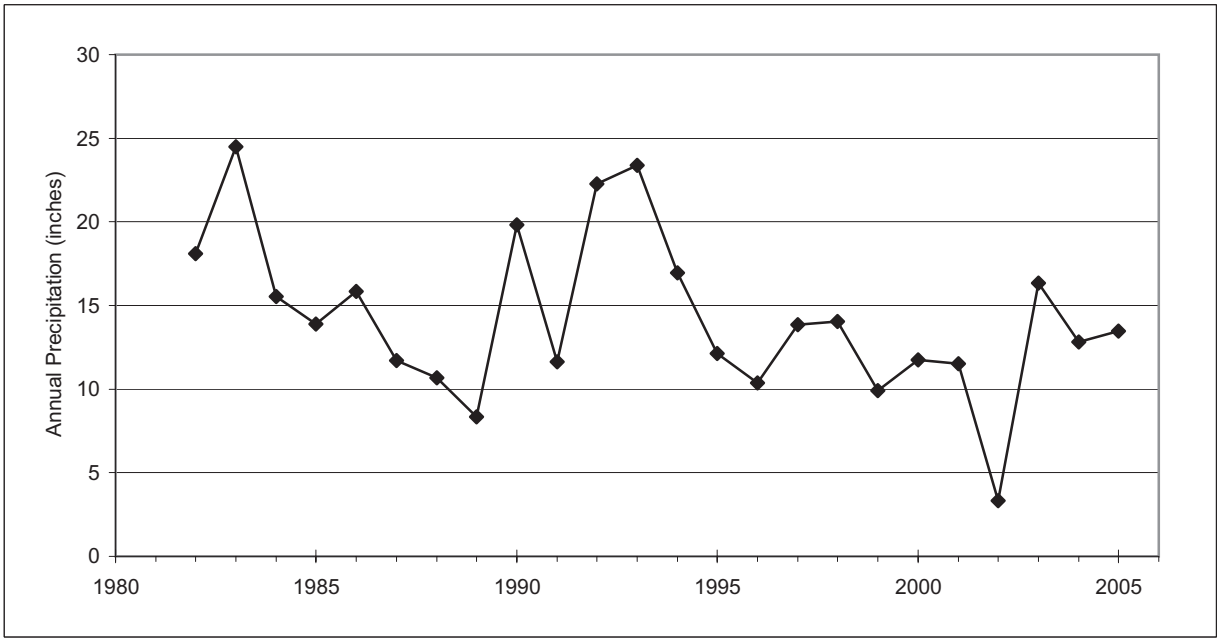


Table C-13a. Annual precipitation at Arch Canyon rain gauge, 1982 to 2005.

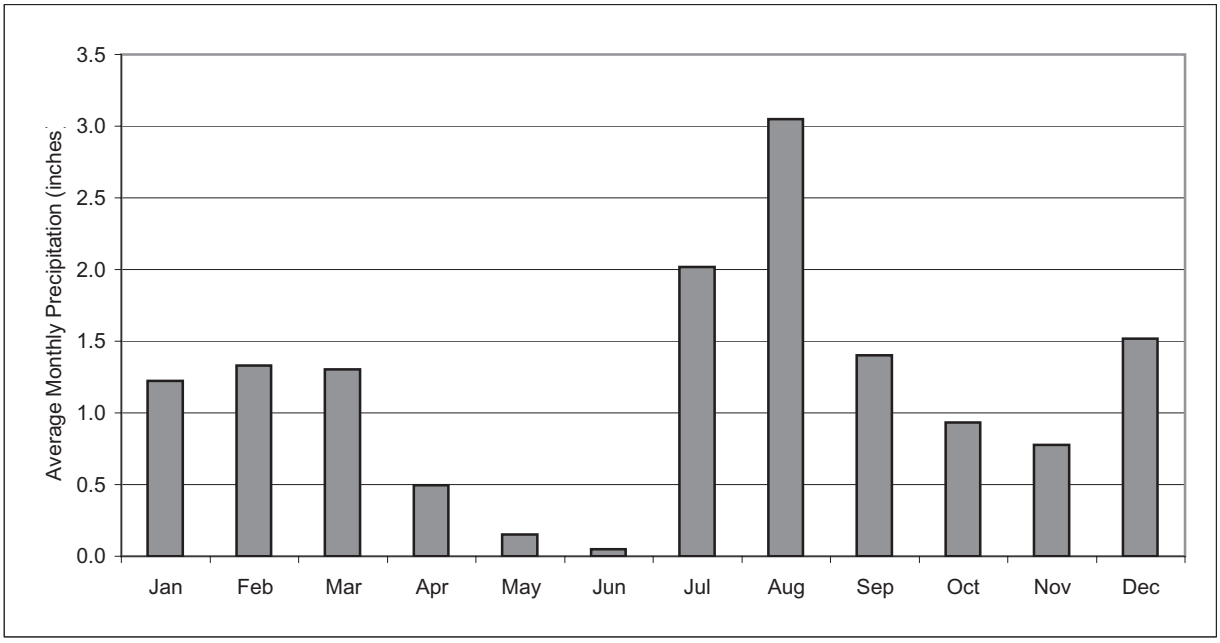


Table C-13b. Average monthly precipitation at Arch Canyon rain gauge, 1982 to 2005.

Table C-14. Summary statistics for precipitation at Bates Well rain gauge (two locations), 1982 to 2005, Organ Pipe Cactus N.M. Average annual total is 9.27 inches (235.5mm).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	0.59	1.20	0.62	0.38	0.16	0.02	1.63	1.85	0.67	0.67	0.63	0.85
S.D.	0.62	0.98	0.69	0.49	0.33	0.03	1.52	1.21	1.15	0.91	0.87	0.93
Skew	1.41	0.28	1.30	1.42	2.74	2.23	1.11	-0.34	2.80	1.02	2.31	1.12
Max	1.84	2.91	2.15	1.44	1.13	0.10	4.50	3.43	4.10	2.34	3.15	2.66
Min	0.02	0.00	0.00	0.00	0.00	0.00	0.04	0.04	0.00	0.00	0.00	0.00
Years	12	13	13	12	12	11	13	13	12	12	13	13

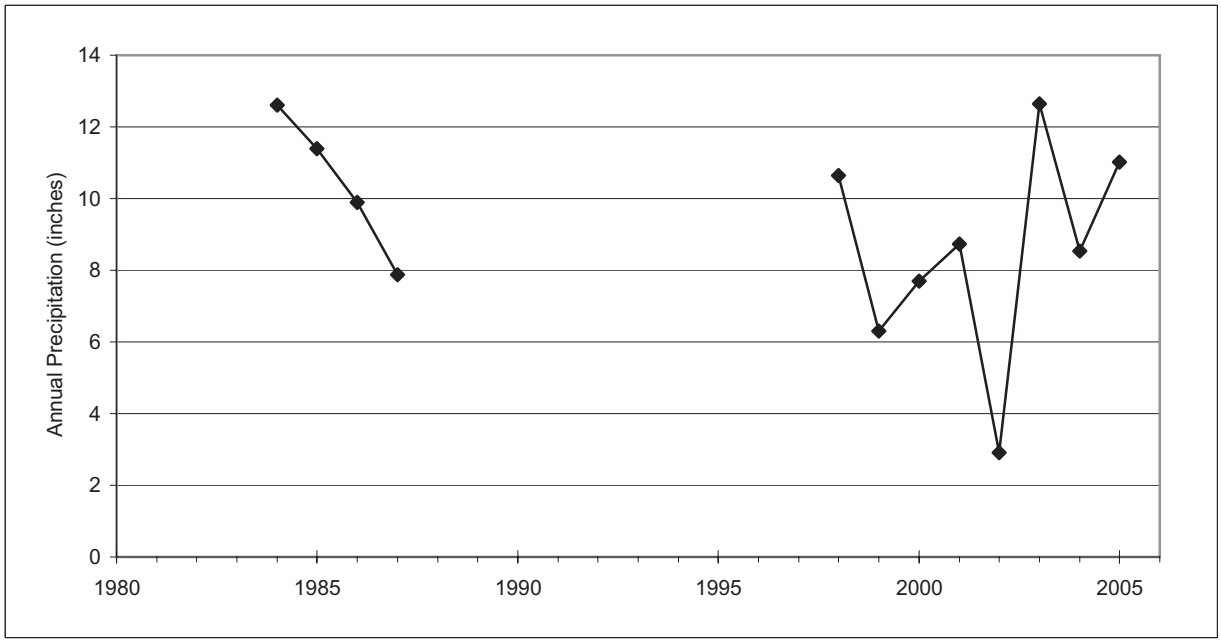


Figure C-14a. Annual precipitation at Bates Well rain gauge (two locations), 1982 to 2005.

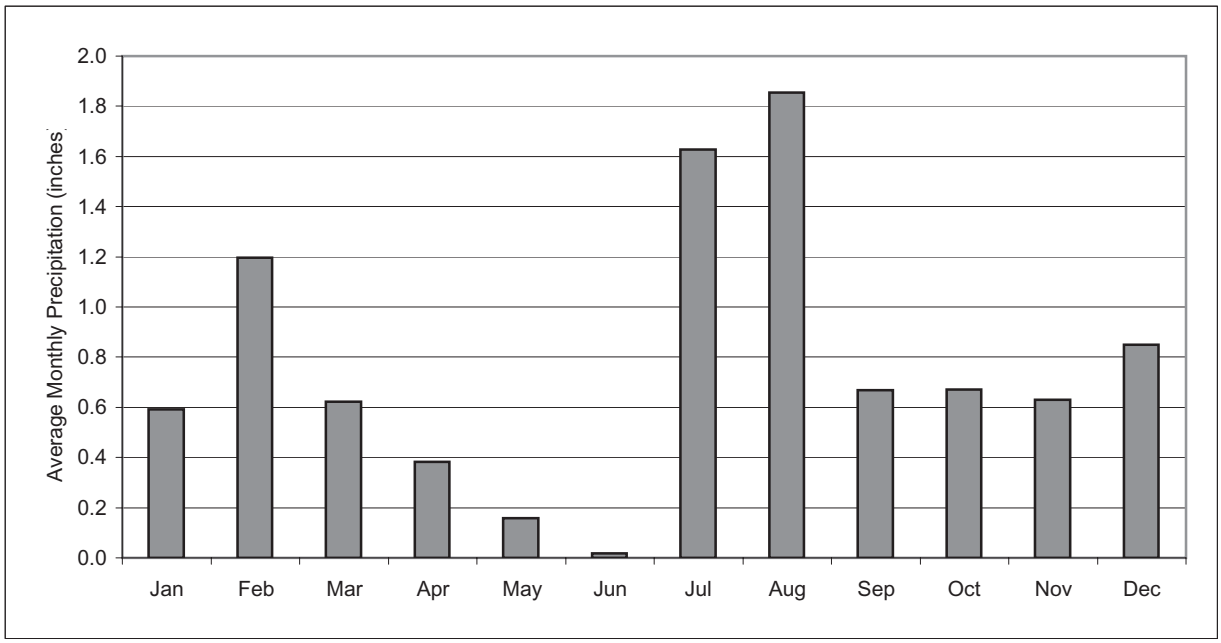


Figure C-14b. Average monthly precipitation at Bates Well rain gauge (two locations), 1982 to 2005.

Table C-15. Summary statistics for precipitation at Dos Lomitas raingauge, 1982 to 2005, Organ Pipe Cactus N.M. Average annual total is 9.08 inches (230.6mm).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	0.75	0.88	0.81	0.29	0.07	0.11	1.06	1.79	0.97	0.76	0.54	1.04
S.D.	0.76	0.87	1.01	0.59	0.14	0.37	0.87	1.02	1.14	0.91	0.69	1.19
Skew	1.37	0.99	1.59	3.48	2.70	4.57	0.46	0.48	1.48	1.27	1.82	1.18
Max	2.66	3.22	3.29	2.75	0.55	1.83	2.98	4.46	3.80	2.90	2.67	3.93
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.00	0.00	0.00	0.00
Years	24	24	24	24	24	24	24	24	24	23	24	24

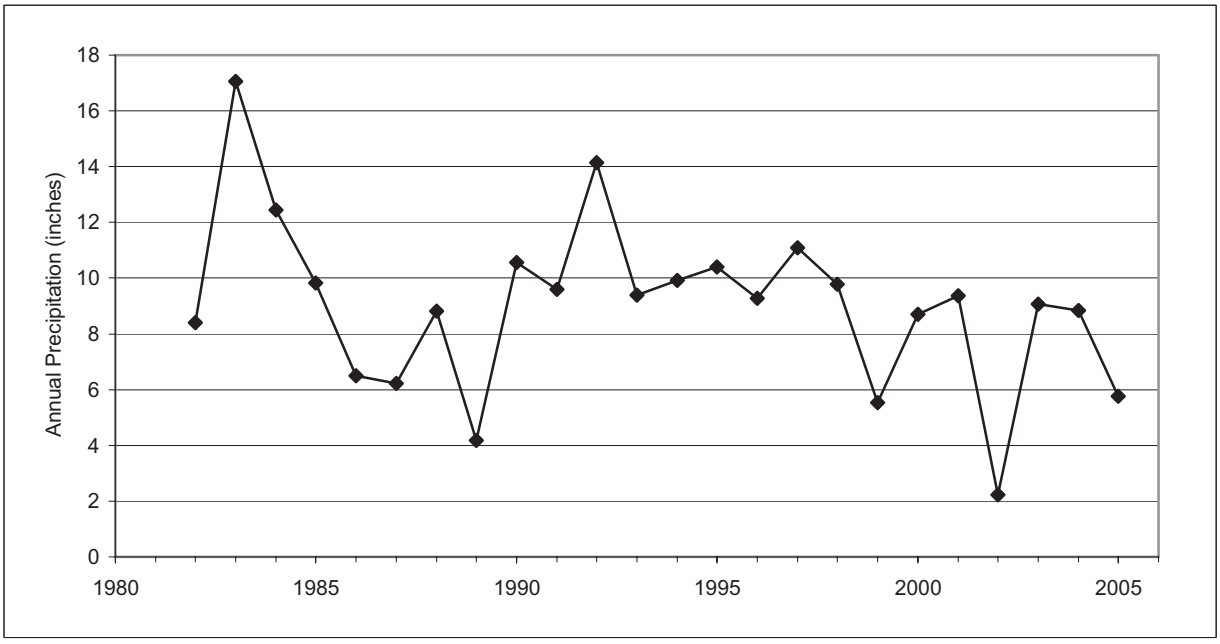


Figure C-15a. Annual precipitation at Dos Lomitas rain gauge, 1982 to 2005.

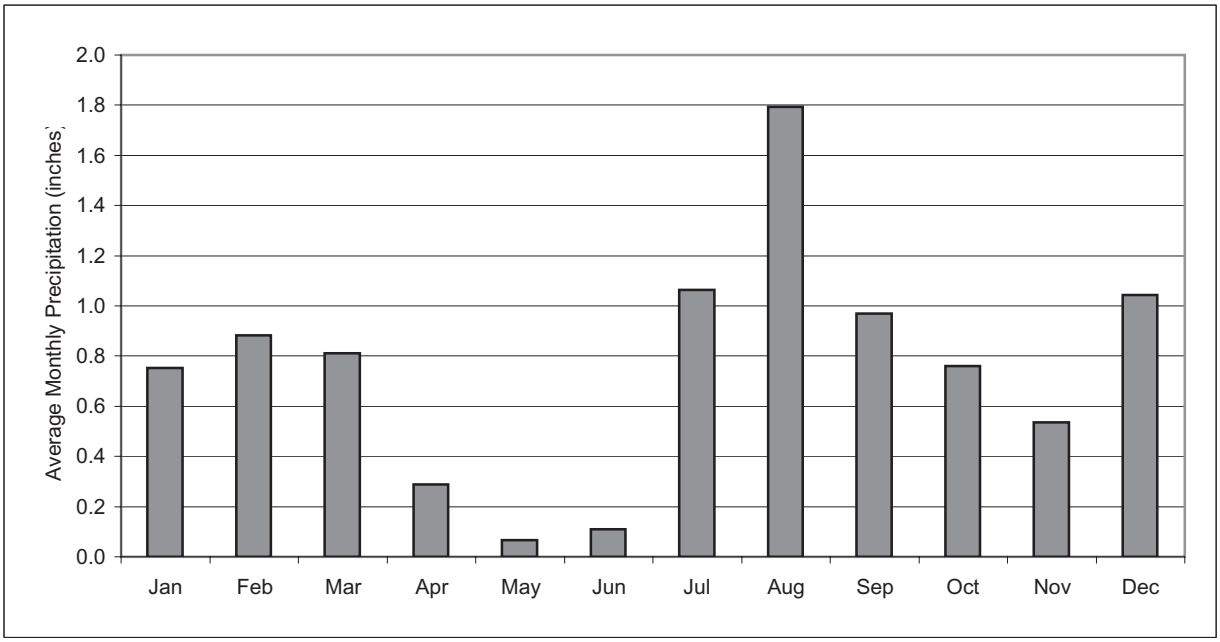


Figure C-15b. Average monthly precipitation at Dos Lomitas rain gauge, 1982 to 2005.

Table C-16. Summary statistics for precipitation at Dowling Ranch rain gauge, 1982 to 2005, Organ Pipe Cactus N.M. Average annual total is 9.30 inches (236.2mm).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	0.86	0.86	0.82	0.26	0.05	0.08	1.39	1.84	0.88	0.57	0.49	1.18
S.D.	0.97	0.74	0.86	0.44	0.10	0.21	1.25	1.37	1.12	0.75	0.63	1.36
Skew	1.94	0.89	1.48	2.36	2.48	3.15	1.09	0.76	1.73	1.77	1.99	1.16
Max	4.09	2.95	3.37	1.79	0.40	0.84	4.86	5.29	3.66	2.76	2.33	4.33
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.13	0.00	0.00	0.00	0.00
Years	24	24	24	24	24	24	24	24	24	24	24	23

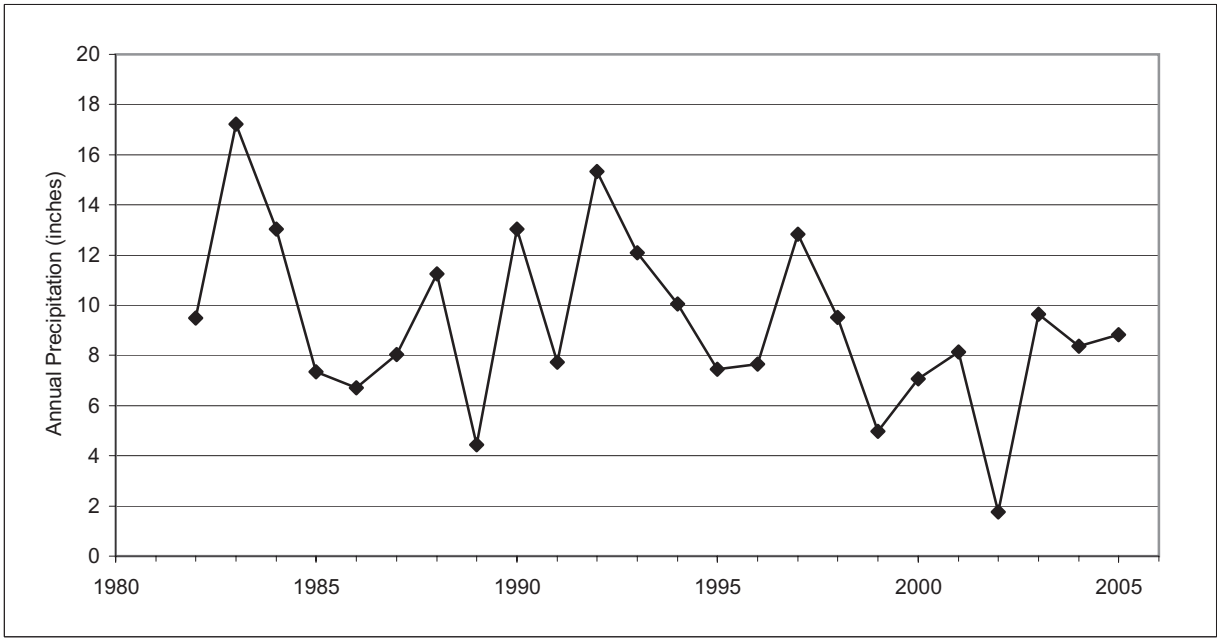


Figure C-16a. Annual precipitation at Dowling Ranch rain gauge, 1982 to 2005.

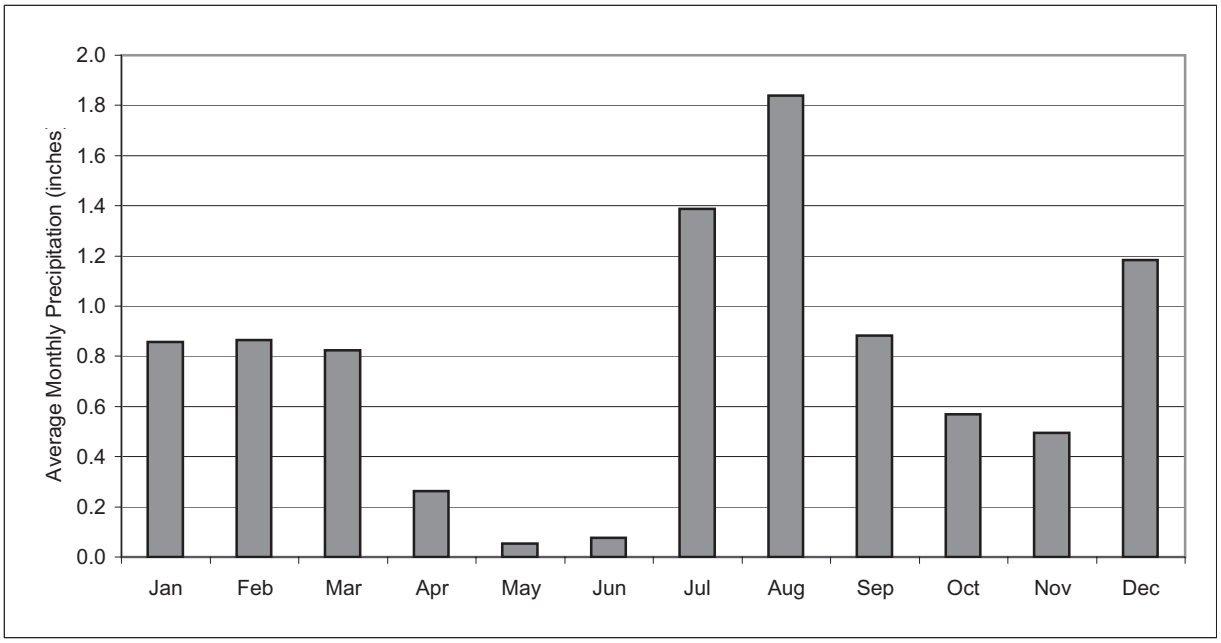


Figure C-16b. Average monthly precipitation at Dowling Ranch rain gauge, 1982 to 2005.

Table C-17. Summary statistics for precipitation at Dripping Springs rain gauge, 1982 to 2005, Organ Pipe Cactus N.M. Average annual total is 9.90 inches (251.5mm).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	0.87	1.08	0.89	0.35	0.07	0.04	1.23	2.07	0.87	0.59	0.51	1.34
S.D.	0.91	1.04	0.92	0.49	0.13	0.14	1.13	1.21	0.91	0.80	0.54	1.39
Skew	1.26	0.85	1.12	1.41	2.49	4.46	0.73	0.03	1.63	1.69	1.09	0.90
Max	3.21	3.80	2.99	1.75	0.54	0.66	3.69	4.30	3.70	2.84	1.72	4.80
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.00	0.00	0.00	0.00
Years	24	24	24	24	24	24	24	24	24	24	24	24

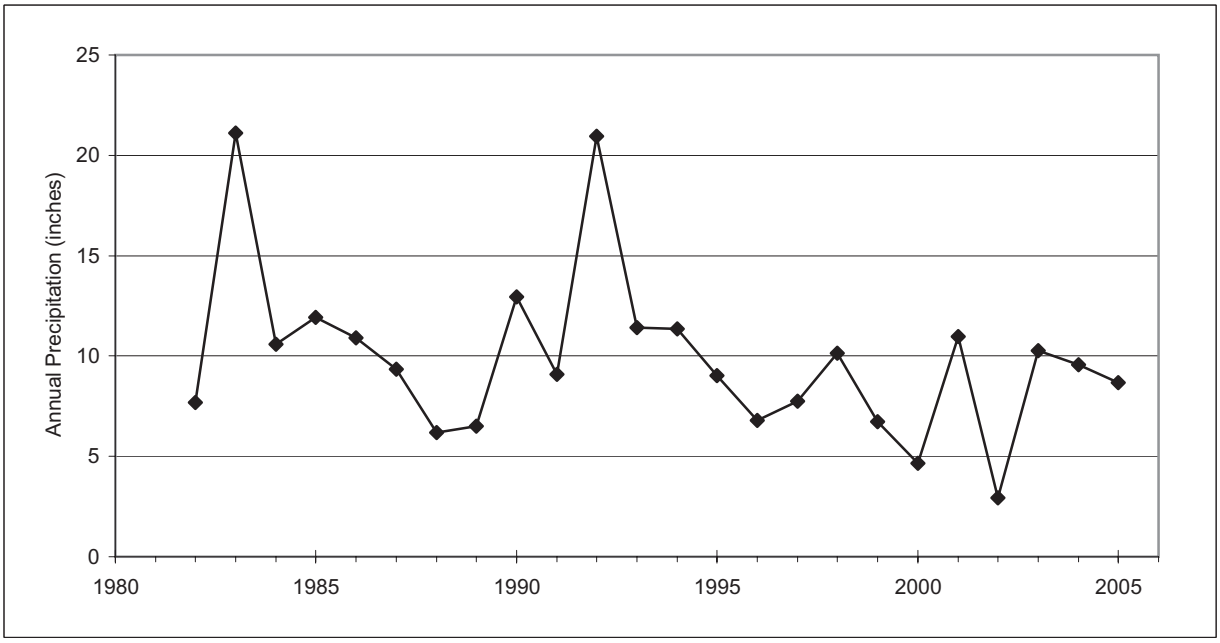


Figure C-17a. Annual precipitation at Dripping Springs rain gauge, 1982 to 2005.

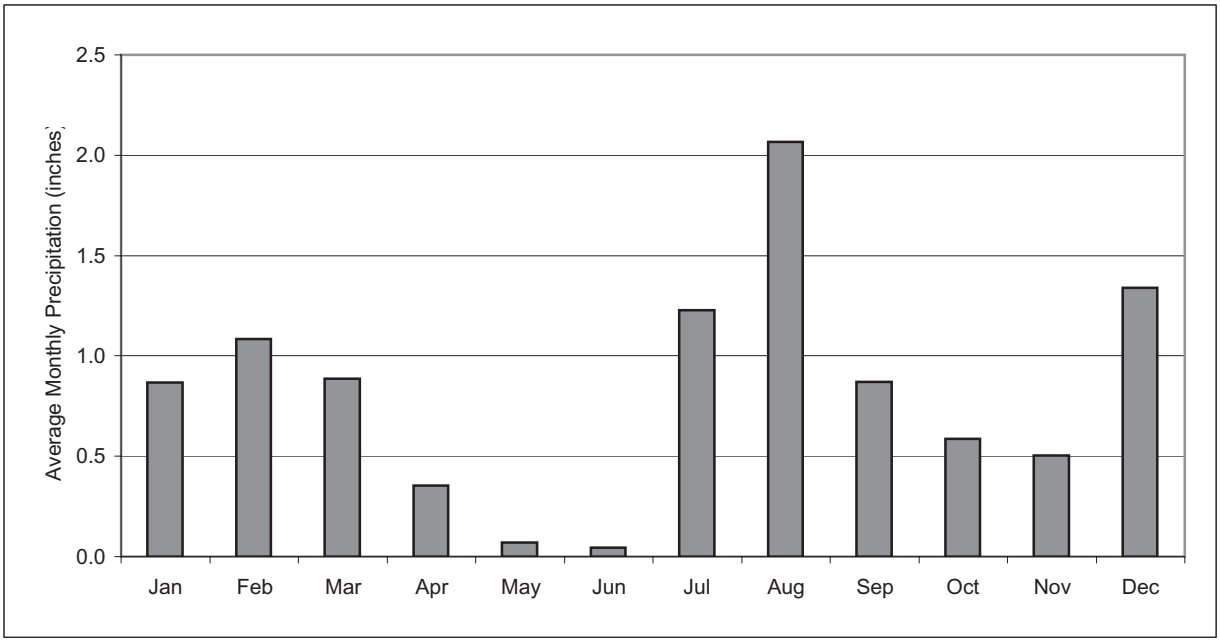


Figure C-17b. Average monthly precipitation at Dripping Springs rain gauge, 1982 to 2005.

Table C-18. Summary statistics for precipitation at Mile Post 69.4 rain gauge, 1982 to 2005, Organ Pipe Cactus N.M. Average annual total is 11.11 inches (282.2mm).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	0.95	1.16	0.93	0.40	0.10	0.03	1.42	2.43	1.07	0.69	0.60	1.23
S.D.	1.02	1.00	0.98	0.66	0.17	0.07	0.96	1.43	1.08	0.85	0.68	1.39
Skew	1.26	0.49	1.14	3.03	1.86	3.27	0.50	0.46	1.27	1.52	1.43	1.21
Max	3.65	3.39	3.04	3.02	0.58	0.30	3.35	5.51	3.91	2.89	2.40	4.69
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.11	0.00	0.00	0.00	0.00
Years	24	24	24	24	24	24	24	24	24	24	24	24

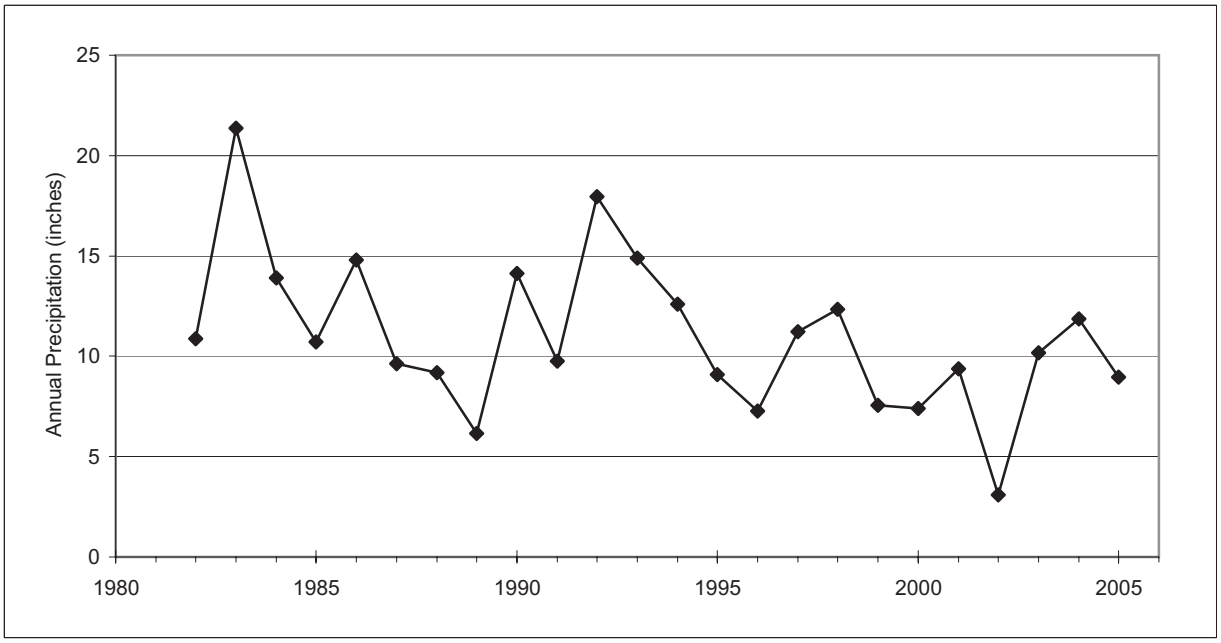


Figure C-18a. Annual precipitation at Mile Post 69.4 rain gauge, 1982 to 2005.

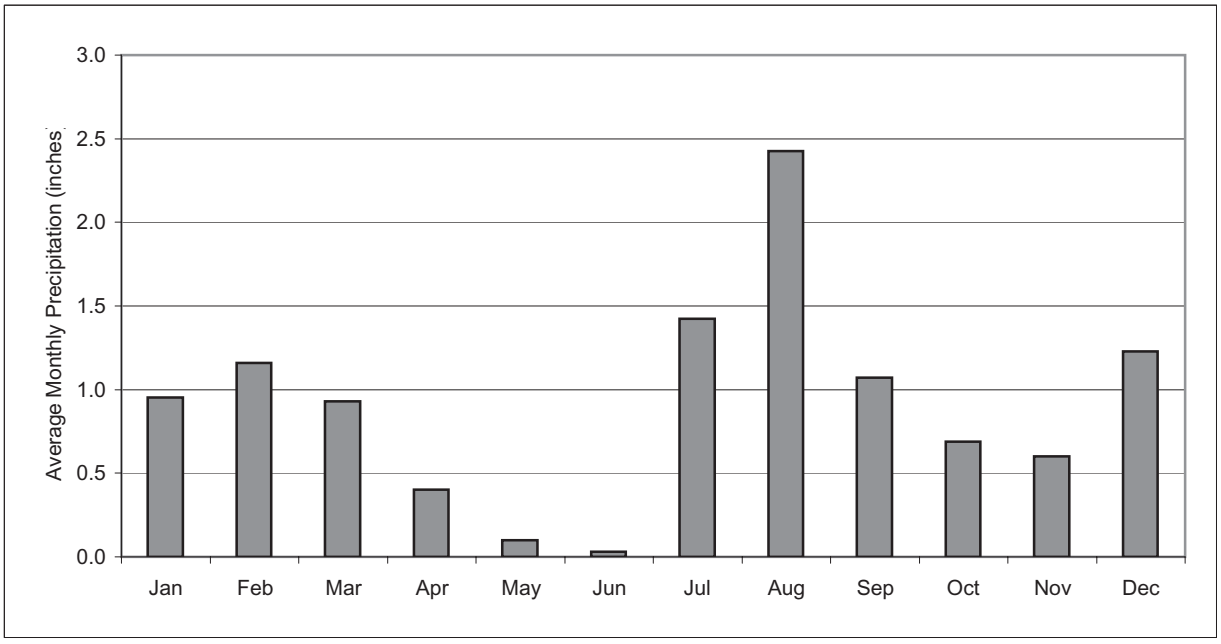


Figure C-18b. Average monthly precipitation at Mile Post 69.4 rain gauge, 1982 to 2005.

Table C-19. Summary statistics for precipitation at Quitobaquito rain gauge, 1982 to 2005, Organ Pipe Cactus N.M. Average annual total is 8.81 inches (223.8mm).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	0.77	0.94	0.85	0.33	0.10	0.03	0.95	1.86	0.83	0.58	0.45	1.12
S.D.	0.81	0.81	0.82	0.41	0.19	0.10	1.15	1.44	1.15	0.81	0.55	1.22
Skew	1.21	0.64	1.09	0.91	1.70	4.66	2.40	0.51	2.05	1.76	1.72	1.04
Max	2.75	2.65	2.89	1.22	0.57	0.48	5.23	5.14	4.15	2.90	2.12	4.37
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00
Years	24	23	24	24	24	24	24	24	24	24	24	24

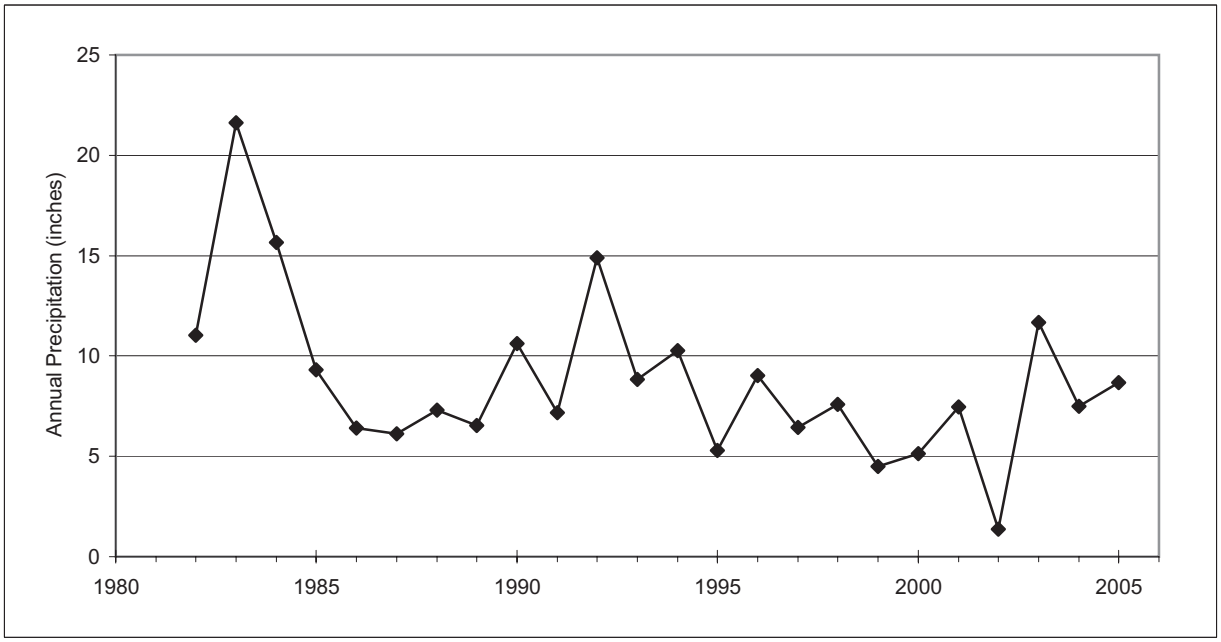


Figure C-19a. Annual precipitation at Quitobaquito rain gauge, 1982 to 2005.

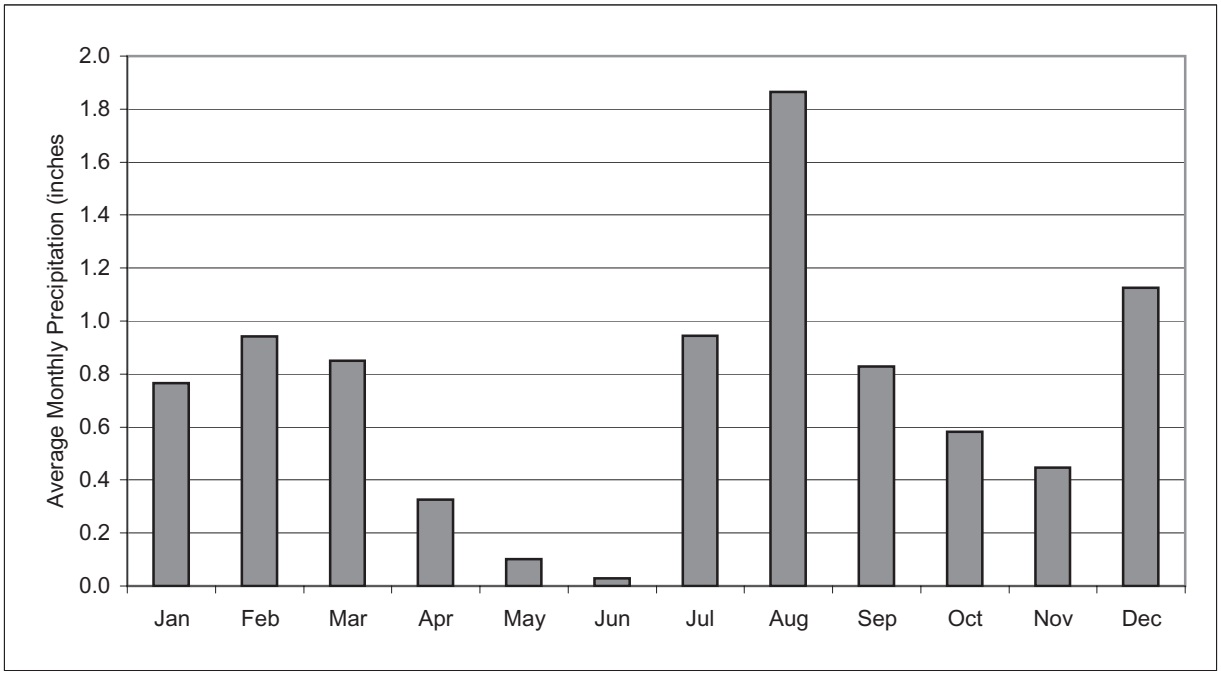


Figure C-19b. Average monthly precipitation at Quitobaquito rain gauge, 1982 to 2005.

Table D-1. Summary statistics for monthly average temperature at Acuña Site weather station, 1995-2005, Organ Pipe Cactus N.M. Average annual temperature is 22.95 °C.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	14.11	14.54	18.27	21.13	27.16	30.70	32.76	31.91	29.95	23.82	17.75	13.32
S.D.	1.52	1.63	1.89	1.70	1.36	1.00	0.72	0.64	1.00	1.61	2.35	1.20
Skew	0.50	0.08	1.34	-0.19	0.17	0.56	-1.23	0.82	-0.89	0.36	-0.68	0.02
Max	17.13	16.61	21.89	23.51	29.08	32.48	33.58	32.98	31.14	26.49	20.63	14.90
Min	11.62	12.46	16.41	18.20	25.32	29.39	31.16	31.26	27.79	21.82	13.99	11.53
Years	10	10	9	9	9	10	10	10	11	10	10	11

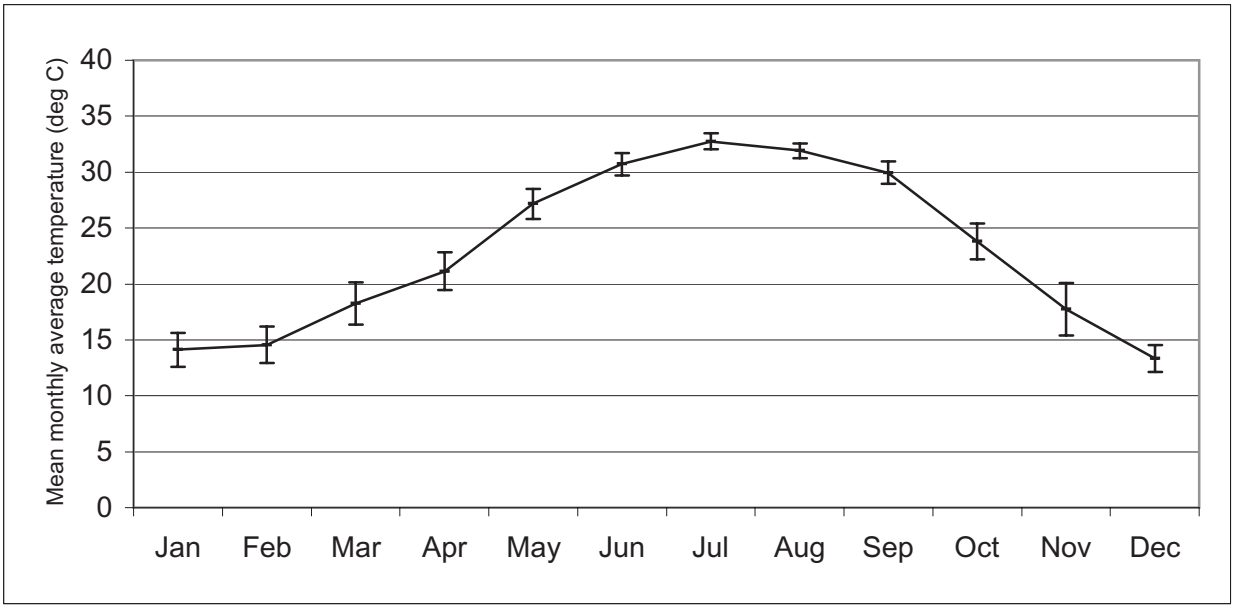


Figure D-1a. Mean monthly average temperatures at Acuña Site weather station, 1995-2005.

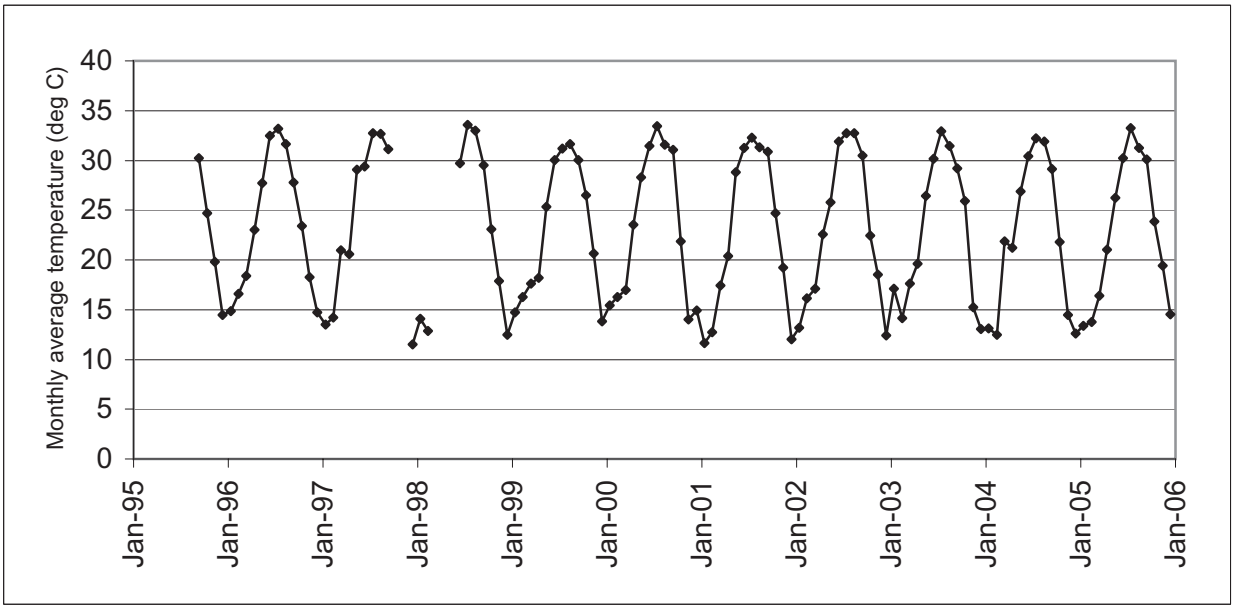


Figure D-1b. Monthly average temperatures at Acuña Site weather station, 1995-2005.

Table D-2. Summary statistics for monthly average temperature at Aguajita Wash weather station, 1995-2005, Organ Pipe Cactus N.M. Average annual temperature is 21.36 °C.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	12.30	12.81	17.03	19.38	24.92	28.31	32.37	32.04	28.74	21.82	15.49	11.07
S.D.	1.29	1.64	2.04	1.46	1.79	1.22	0.52	0.97	1.15	1.21	1.58	0.95
Skew	0.44	1.05	0.44	0.55	-1.03	1.48	-0.48	-0.58	0.06	0.96	-0.44	0.30
Max	14.16	15.68	19.86	21.75	27.14	30.33	32.94	32.85	30.25	24.17	17.69	12.35
Min	10.78	11.07	14.72	17.52	21.75	27.24	31.63	30.84	27.02	20.45	13.17	9.97
Years	5	6	6	6	6	5	5	4	8	8	8	7

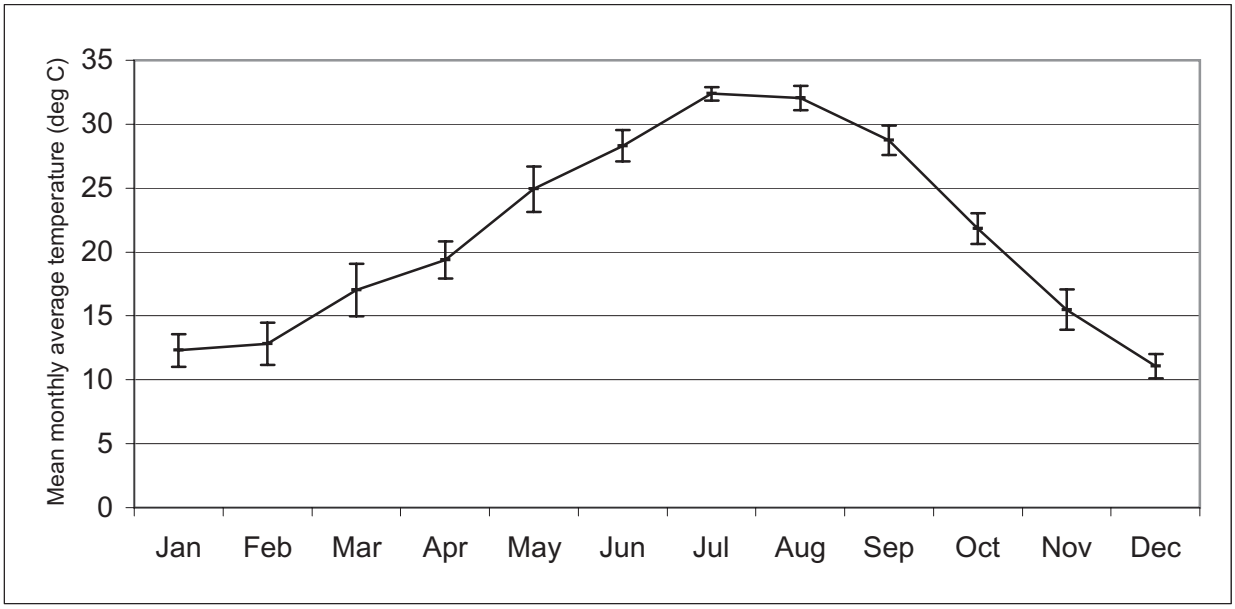


Figure D-2a. Mean monthly average temperatures at Aguajita Wash weather station, 1995-2005.

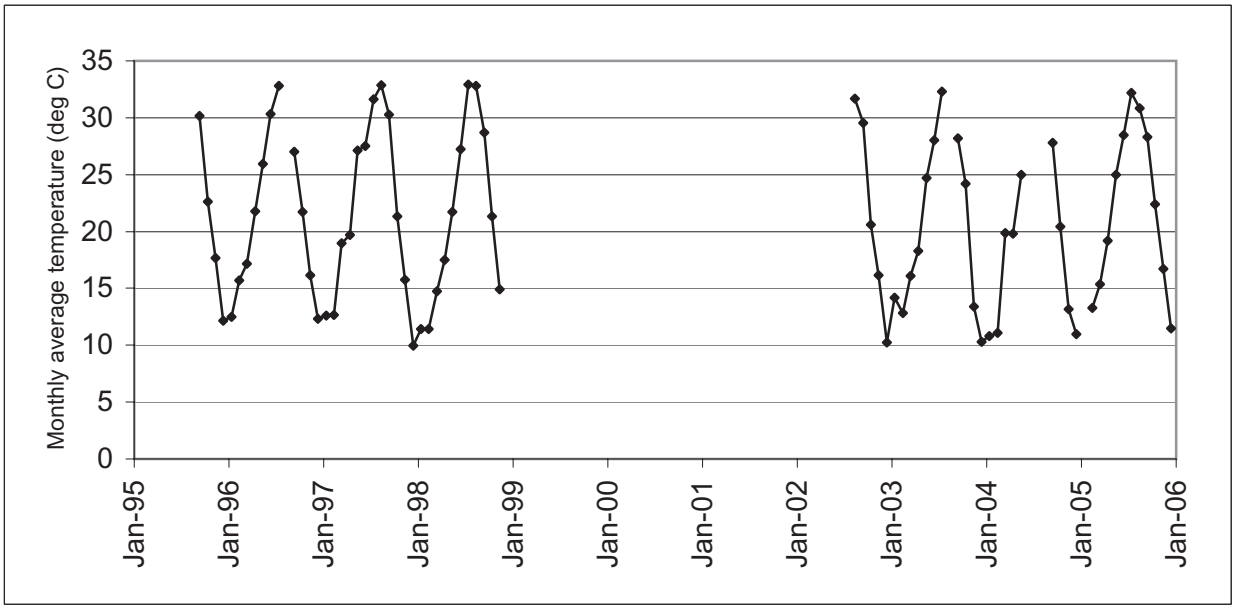


Figure D-2b. Monthly average temperatures at Aguajita Wash weather station, 1995-2005.

Table D-3. Summary statistics for monthly average temperature at Alamo Canyon weather station (in canyon), 1996-2005, Organ Pipe Cactus N.M. Average annual temperature is 21.98 °C.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	13.49	13.57	17.29	19.98	25.97	29.77	31.76	30.59	28.76	22.86	16.98	12.72
S.D.	1.79	1.90	2.12	1.91	1.94	1.27	0.96	0.81	1.08	1.77	2.41	1.42
Skew	0.96	0.06	1.07	-0.10	-0.89	-0.16	-1.25	0.66	-1.15	0.55	-0.60	-0.34
Max	17.10	16.05	21.25	22.63	28.16	31.78	32.72	32.22	30.35	25.71	20.28	14.66
Min	11.03	10.69	14.62	17.08	22.02	27.75	29.72	29.51	26.26	20.76	12.94	10.03
Years	9	9	9	10	9	9	9	9	10	9	10	10

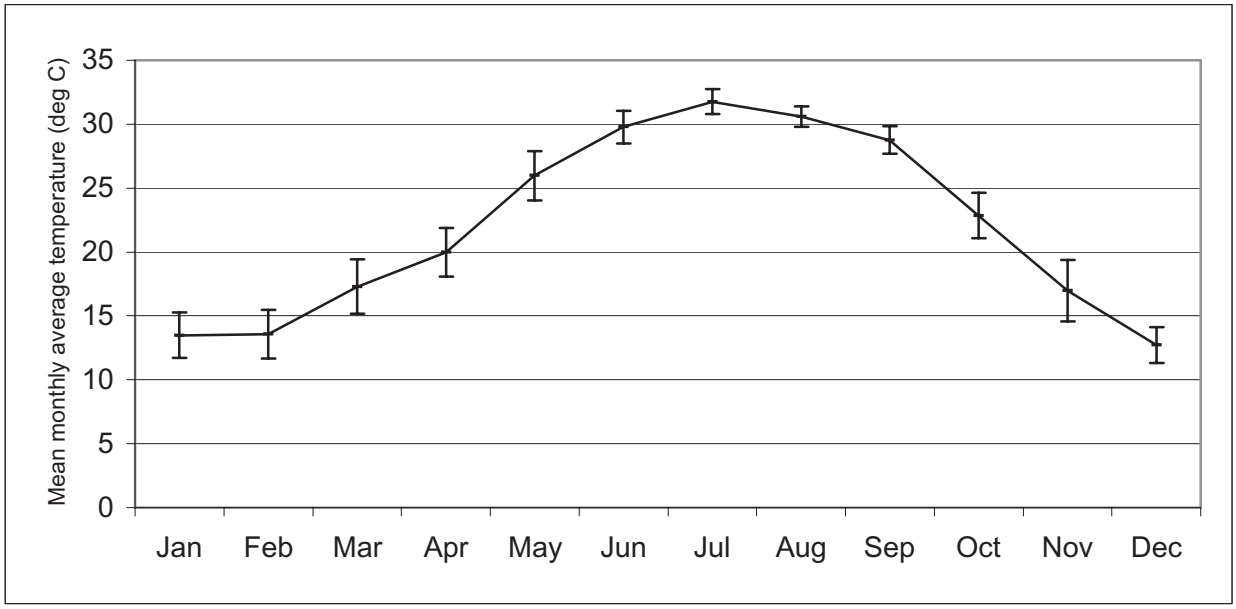


Figure D-3a. Mean monthly average temperatures at Alamo Canyon weather station (in canyon), 1996-

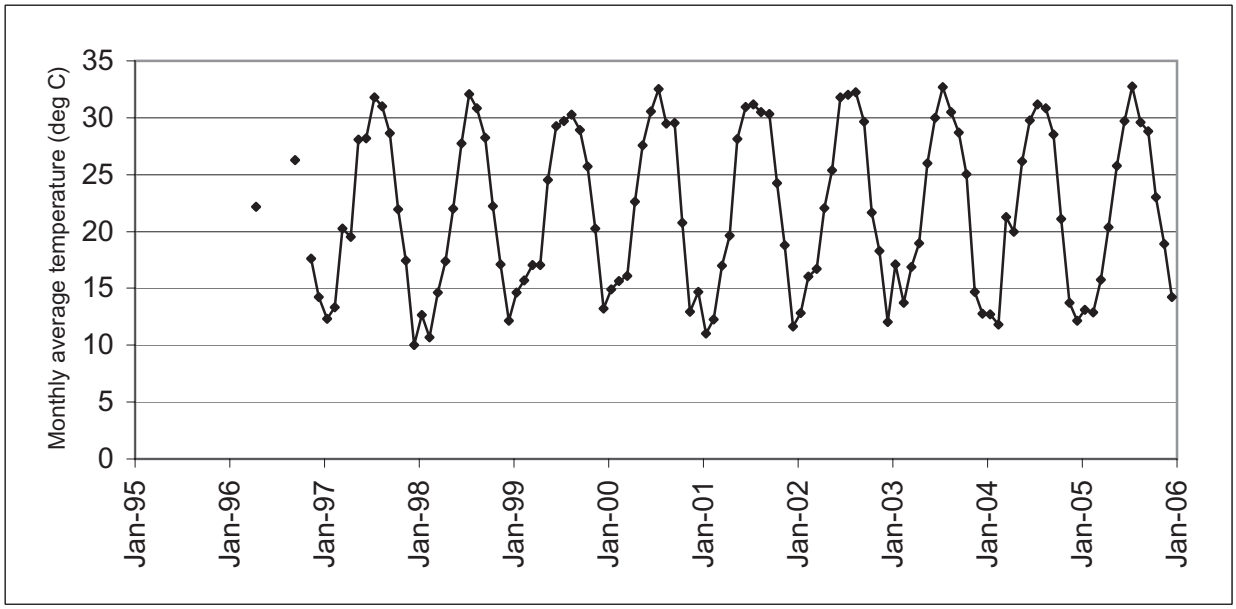


Figure D-3b. Monthly average temperatures at Alamo Canyon weather station (in canyon), 1996-2005.

Table D-4. Summary statistics for monthly average temperature at East Armenta weather station, 1995-2005, Organ Pipe Cactus N.M. Average annual temperature is 21.45 °C.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	11.71	12.58	16.65	19.32	25.57	29.59	32.03	31.41	29.08	22.54	16.17	10.80
S.D.	1.35	1.52	1.88	1.54	2.04	1.22	0.75	0.63	1.18	1.38	1.80	0.96
Skew	0.87	0.51	0.94	0.20	-0.34	0.15	-0.76	0.34	-0.82	0.10	-0.97	0.36
Max	14.64	15.32	20.34	21.76	28.08	31.24	32.92	32.20	30.50	24.52	17.88	12.28
Min	9.99	10.70	14.13	17.05	22.30	28.04	30.56	30.66	26.66	20.51	12.82	9.32
Years	10	10	10	11	11	11	11	10	10	10	11	11

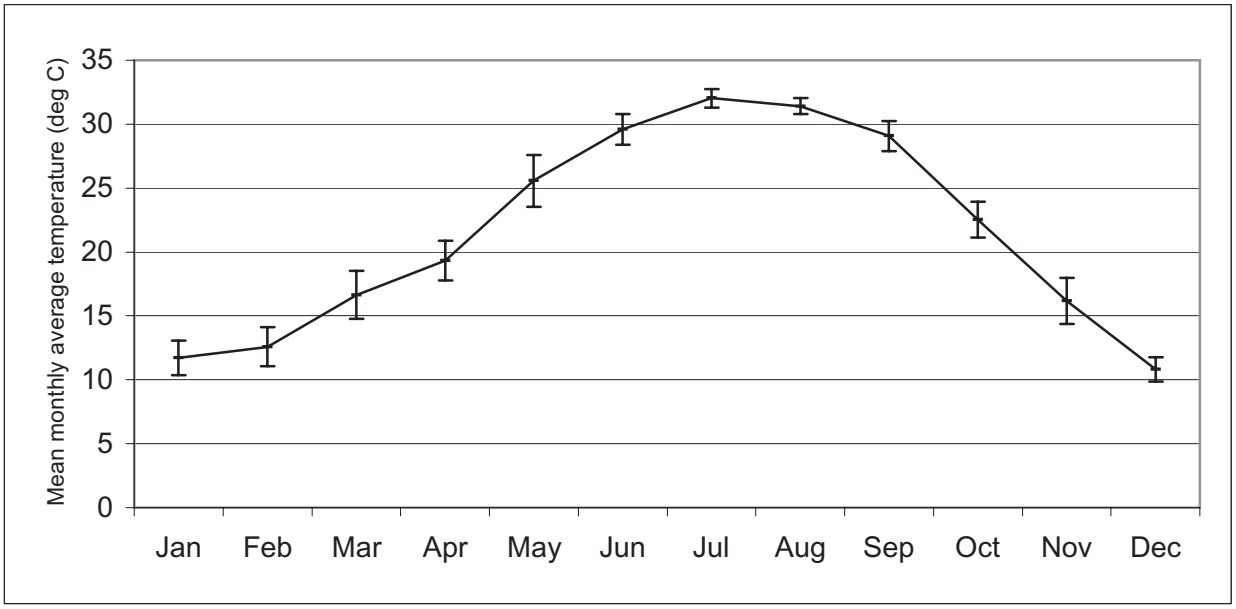


Figure D-4a. Mean monthly average temperatures at East Armenta weather station, 1995-2005.

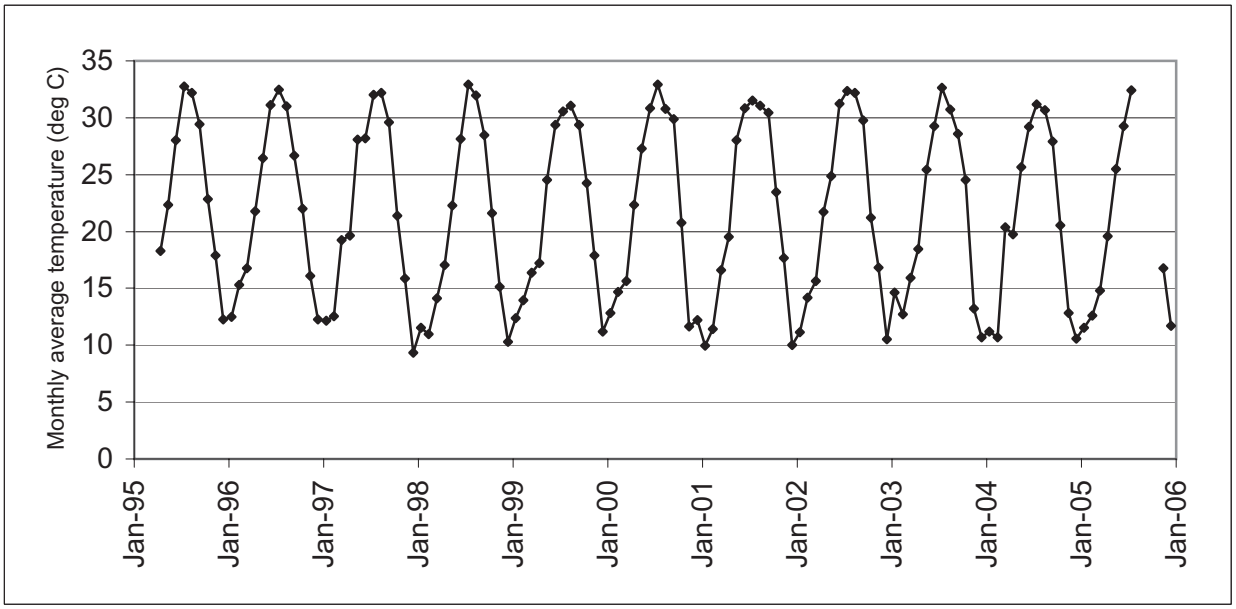


Figure D-4b. Monthly average temperatures at East Armenta weather station, 1995-2005.

Table D-5. Summary statistics for monthly average temperature at Bull Pasture weather station, 1995-2005, Organ Pipe Cactus N.M. Average annual temperature is 20.69 °C.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	13.02	12.72	15.86	18.24	24.15	27.83	29.53	28.58	27.18	21.90	16.68	12.54
S.D.	1.85	2.07	2.06	1.97	1.94	1.25	0.87	0.52	1.19	1.97	2.45	1.58
Skew	0.58	0.02	1.16	0.15	-0.87	-0.04	-1.30	0.76	-1.30	0.49	-0.48	-0.35
Max	16.55	15.22	19.94	21.36	26.52	29.66	30.49	29.62	28.68	25.34	20.48	14.91
Min	10.28	9.58	13.20	15.29	20.06	26.04	27.59	27.94	24.45	19.56	12.79	9.44
Years	10	10	10	10	10	10	10	10	10	11	11	11

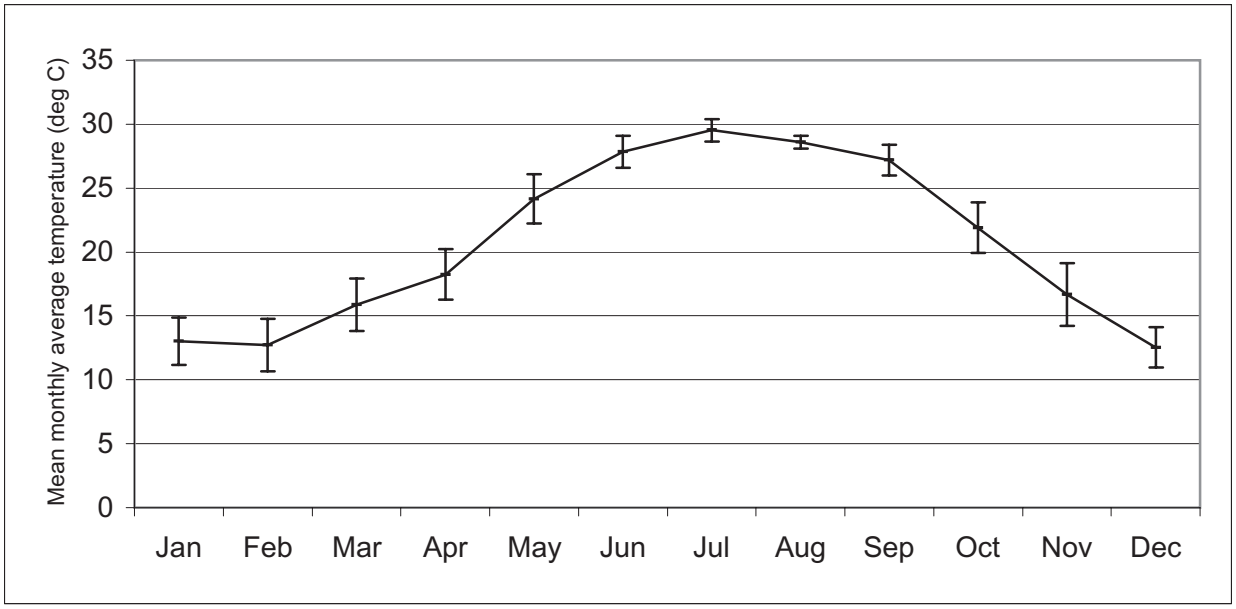


Figure D-5a. Mean monthly average temperatures at Bull Pasture weather station, 1995-2005.

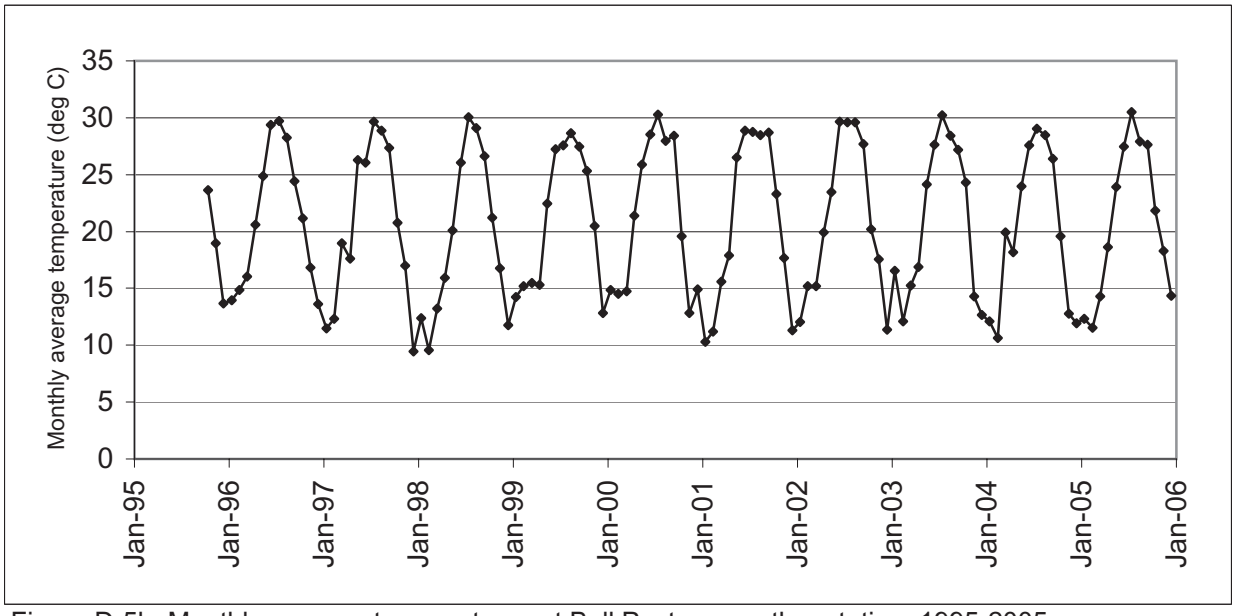


Figure D-5b. Monthly average temperatures at Bull Pasture weather station, 1995-2005.

Table D-6. Summary statistics for monthly average temperature at Growler Valley weather station, 1995-2005, Organ Pipe Cactus N.M. Average annual temperature is 22.61 °C.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	13.00	14.06	17.86	20.85	26.72	30.45	33.33	32.58	30.14	23.18	17.05	12.05
S.D.	1.33	1.61	2.04	1.84	1.87	1.29	0.75	0.66	0.96	1.12	1.96	1.14
Skew	0.64	0.40	1.00	-0.26	-0.57	0.05	-1.33	0.06	-0.83	0.62	-1.04	0.23
Max	15.55	16.86	21.45	23.26	29.30	32.29	34.19	33.58	31.32	25.17	19.37	13.72
Min	11.17	12.08	15.51	17.94	23.05	28.66	31.60	31.52	28.17	21.99	13.20	10.26
Years	9	9	9	10	10	11	11	11	10	10	10	11

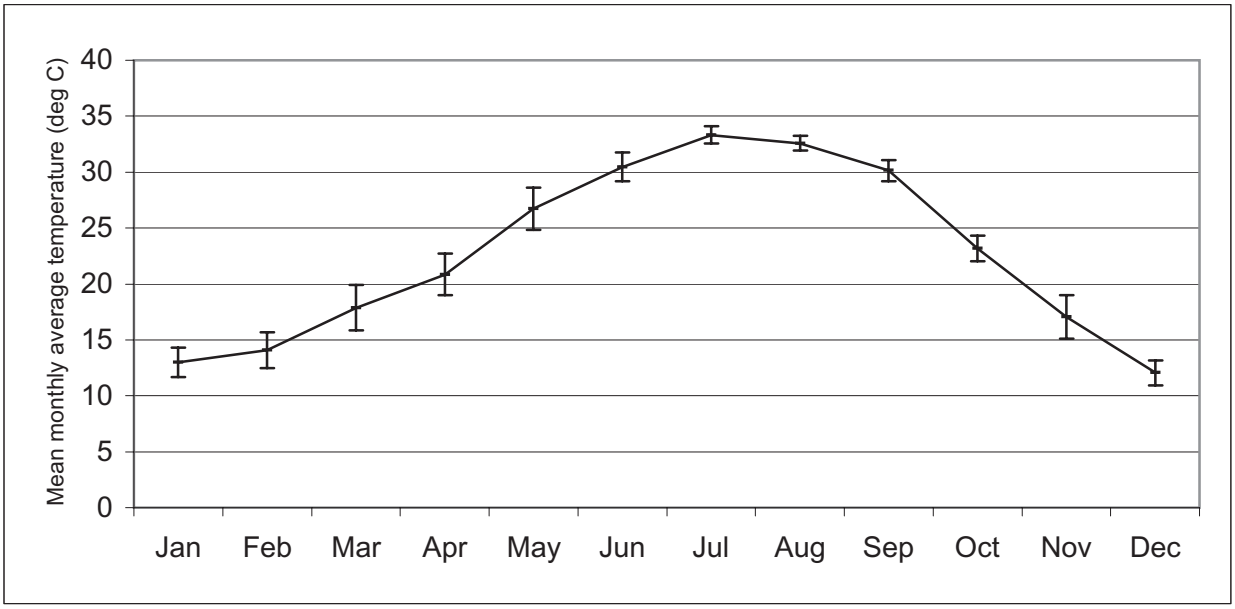


Figure D-6a. Mean monthly average temperatures at Growler Valley weather station, 1995-2005.

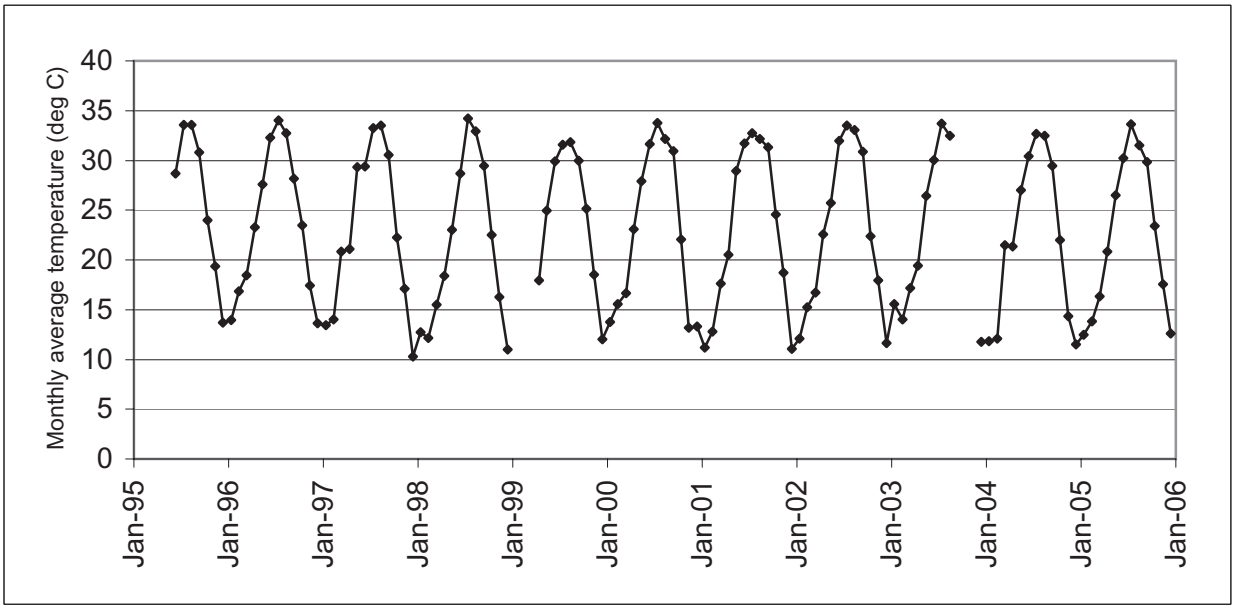


Figure D-6b. Monthly average temperatures at Growler Valley weather station, 1995-2005.

Table D-7. Summary statistics for monthly average temperature at Middle Bajada weather station, 1996-2005, Organ Pipe Cactus N.M. Average annual temperature is 21.59 °C.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	12.70	12.93	16.73	19.66	25.75	29.72	31.75	30.71	28.77	22.14	16.42	11.86
S.D.	1.65	1.62	2.01	1.83	1.82	1.23	0.78	0.69	1.20	1.46	2.23	1.19
Skew	1.17	-0.02	1.11	-0.07	-0.80	-0.31	-1.41	0.29	-1.23	1.13	-1.16	-0.12
Max	16.24	15.08	20.61	22.04	27.93	31.31	32.51	31.91	30.27	25.05	18.66	13.47
Min	10.39	10.51	14.24	16.98	21.97	27.61	29.97	29.76	26.16	20.70	12.30	9.88
Years	9	9	10	10	10	10	10	10	9	9	9	10

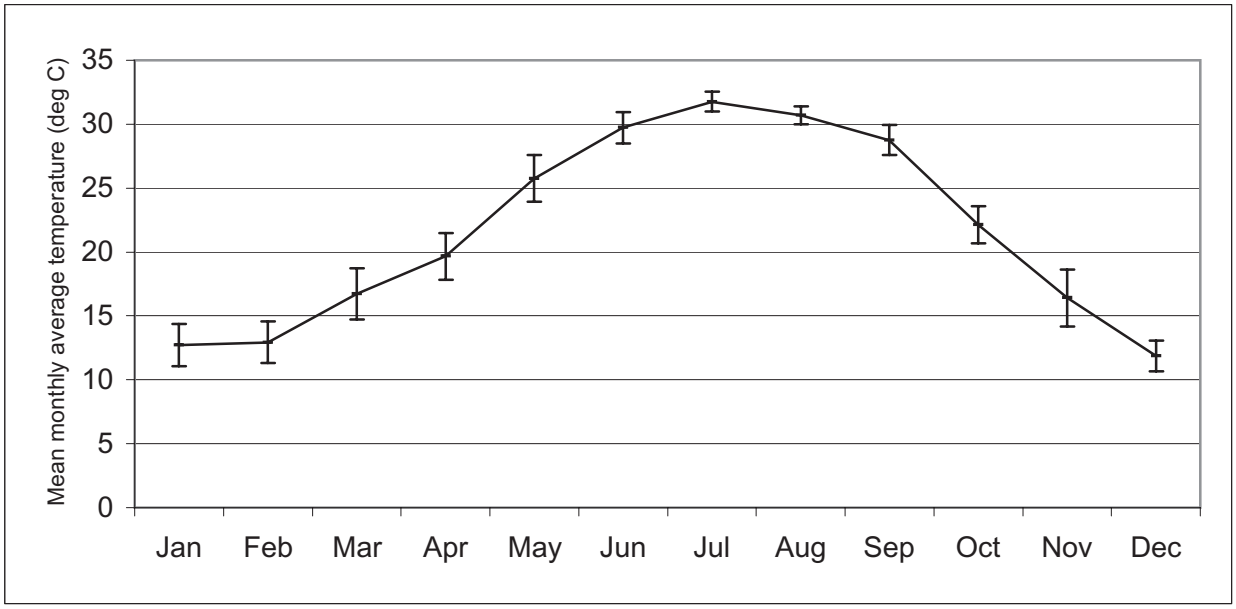


Figure D-7a. Mean monthly average temperatures at Middle Bajada weather station, 1996-2005.

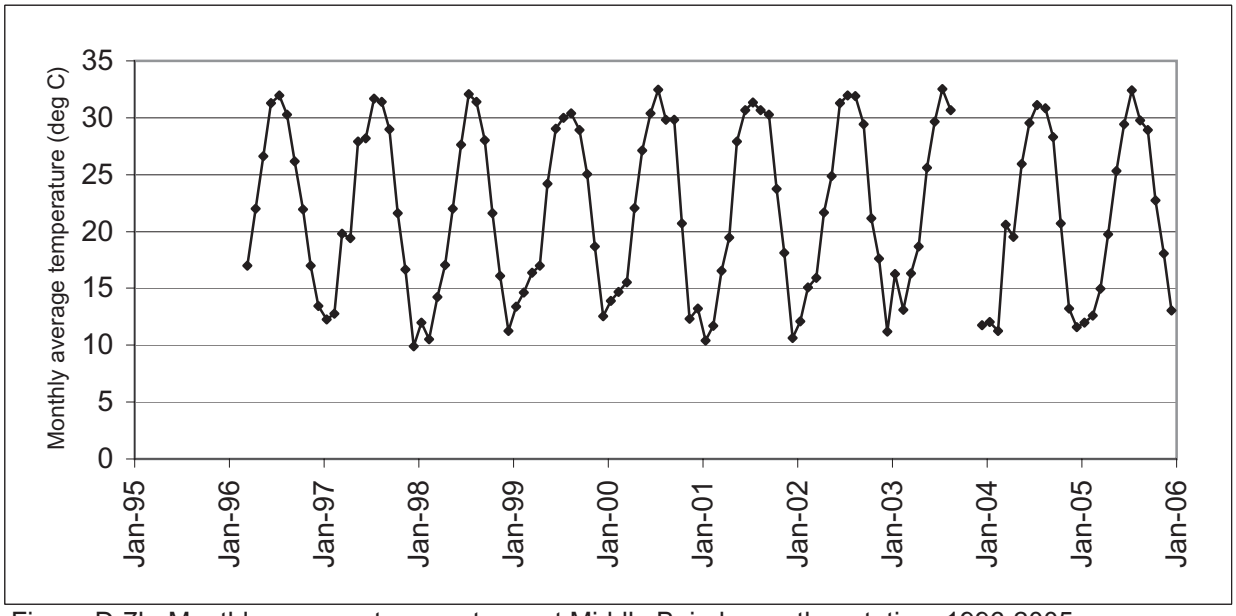


Figure D-7b. Monthly average temperatures at Middle Bajada weather station, 1996-2005.

Table D-8. Summary statistics for monthly average temperature at Pozo Nuevo weather station, 1996-2005, Organ Pipe Cactus N.M. Average annual temperature is 22.12 °C.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	12.51	13.60	17.42	20.49	26.36	30.14	32.64	32.07	29.59	23.13	16.02	11.52
S.D.	1.31	1.35	1.80	1.81	1.72	1.14	0.60	0.63	1.00	1.35	2.04	1.00
Skew	0.75	-0.29	1.11	-0.17	-0.61	-0.20	-0.64	0.67	-1.33	0.41	-0.62	-0.04
Max	15.14	15.26	21.02	23.04	28.70	31.77	33.43	33.08	30.62	25.12	18.26	12.97
Min	10.61	11.70	15.11	17.80	22.96	28.21	31.46	31.37	27.42	21.48	12.30	9.88
Years	9	10	10	10	10	10	10	10	9	9	10	10

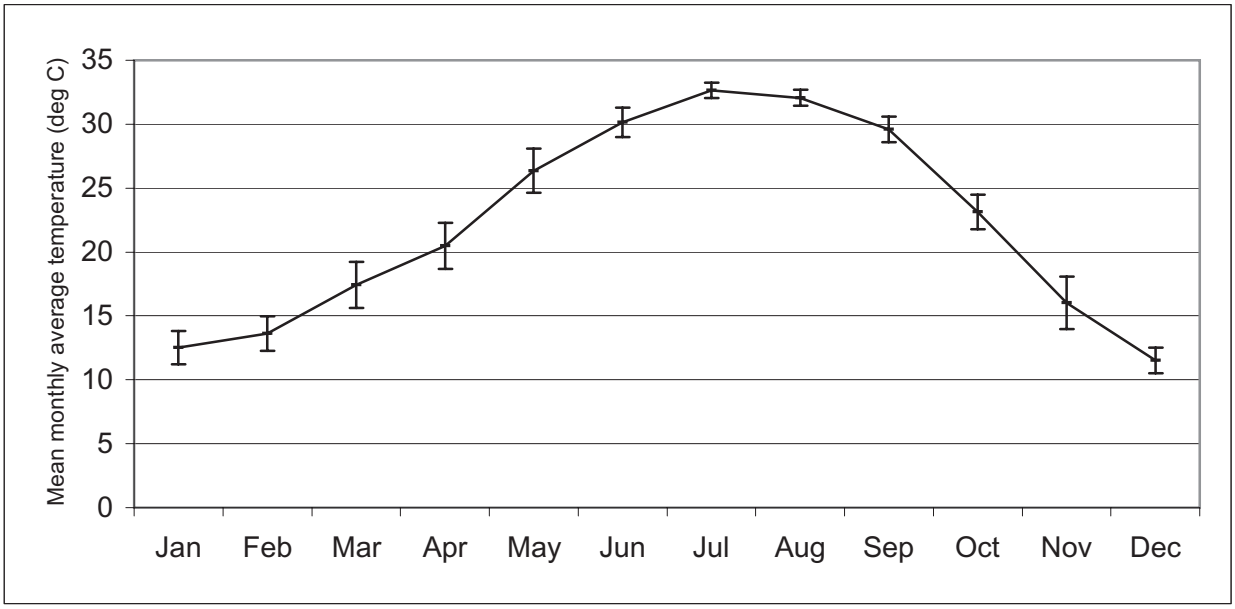


Figure D-8a. Mean monthly average temperatures at Pozo Nuevo weather station, 1996-2005.

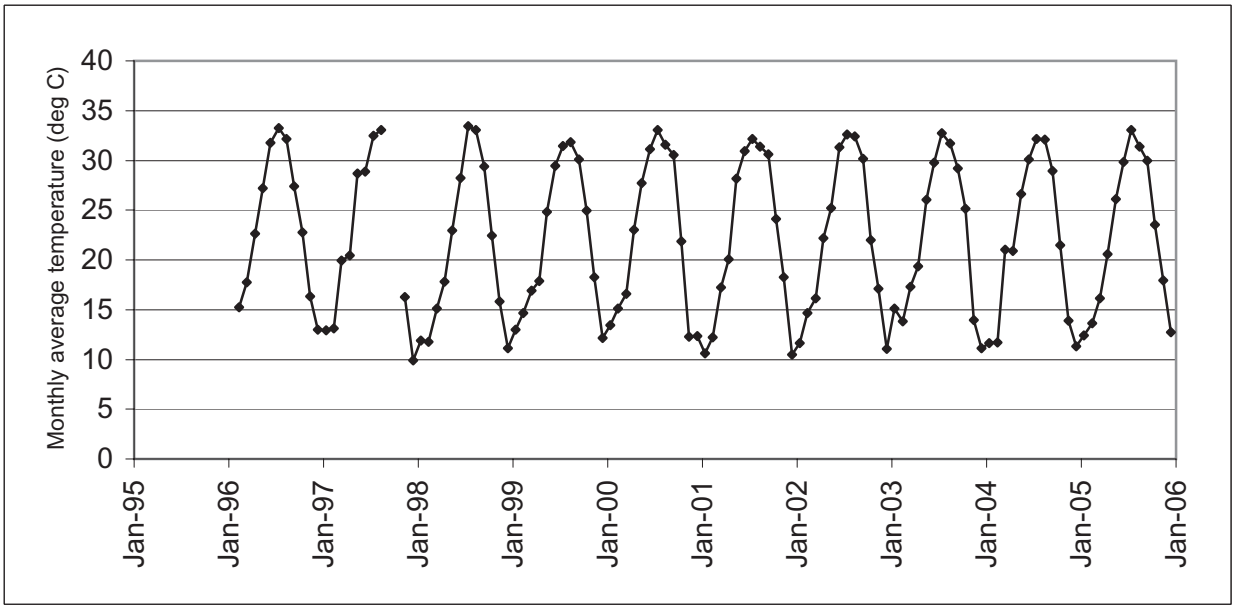


Figure D-8b. Monthly average temperatures at Pozo Nuevo weather station, 1996-2005.

Table D-9. Summary statistics for monthly average temperature at Salsola Site weather station, 1995-2005, Organ Pipe Cactus N.M. Average annual temperature is 20.26 °C.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	10.71	11.70	15.05	18.58	24.30	28.15	31.46	30.67	28.13	20.71	13.94	9.72
S.D.	1.11	1.29	1.83	1.58	1.81	1.08	0.64	0.61	0.45	1.31	1.82	0.63
Skew	0.71	-0.50	2.30	-0.10	-0.38	-0.02	-0.63	0.64	0.22	0.95	-0.70	-0.26
Max	13.03	13.30	19.37	20.88	26.69	29.66	32.17	31.70	28.91	23.27	16.03	10.57
Min	9.15	9.64	13.49	16.13	21.06	26.66	30.26	29.90	27.45	19.06	10.60	8.83
Years	10	8	8	10	9	10	10	10	10	9	9	9

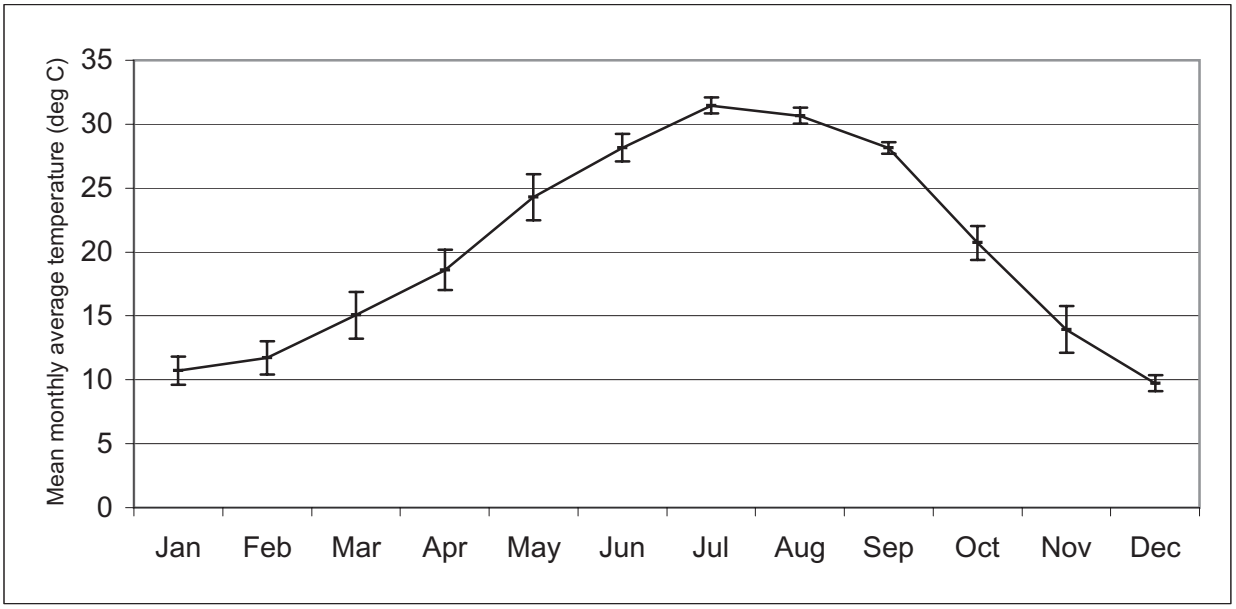


Figure D-9a. Mean monthly average temperatures at Salsola Site weather station, 1995-2005.

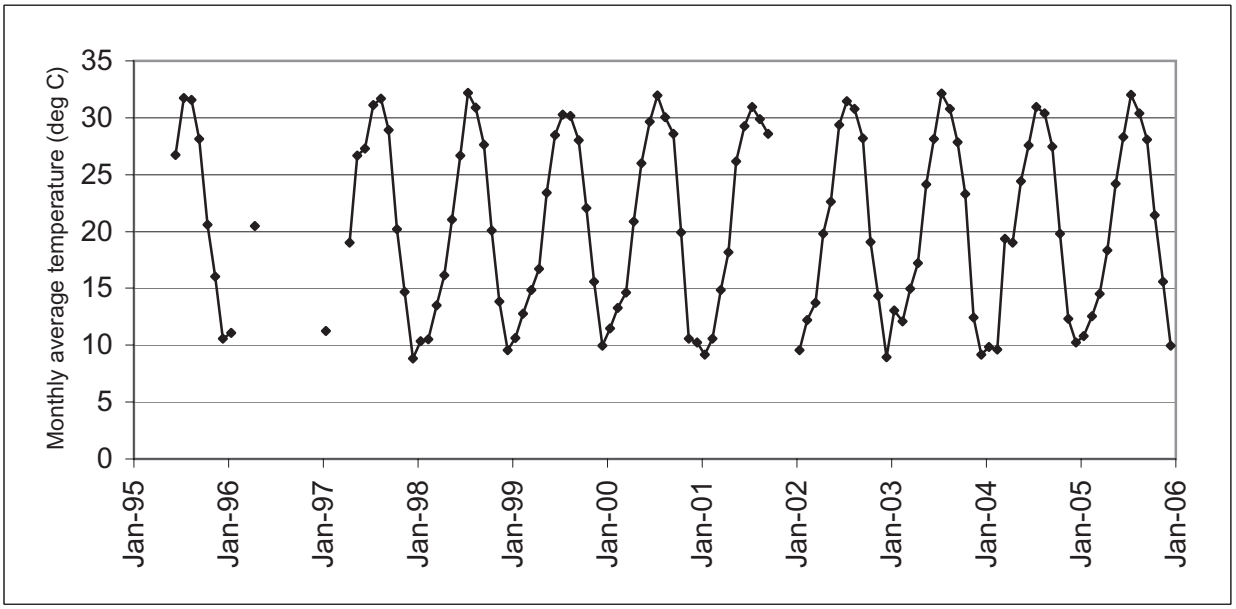


Figure D-9b. Monthly average temperatures at Salsola Site weather station, 1995-2005.

Table D-10. Summary statistics for monthly average temperature at Senita Basin weather station, 1995-2005, Organ Pipe Cactus N.M. Average annual temperature is 22.26 °C.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	13.61	14.13	17.45	20.52	25.77	29.40	32.08	31.44	29.16	23.29	17.28	12.98
S.D.	1.45	1.80	2.09	1.63	1.93	1.35	0.64	0.61	0.93	1.56	2.16	1.35
Skew	1.19	-0.28	0.95	-0.23	-0.87	-0.11	-2.42	0.50	-0.55	0.36	-0.61	-0.30
Max	16.88	16.43	21.24	22.50	28.07	31.23	32.66	32.42	30.42	25.61	19.68	14.73
Min	11.57	11.34	14.85	17.87	21.97	27.27	30.30	30.68	27.30	21.40	13.81	10.57
Years	10	9	9	8	9	10	11	10	10	10	10	10

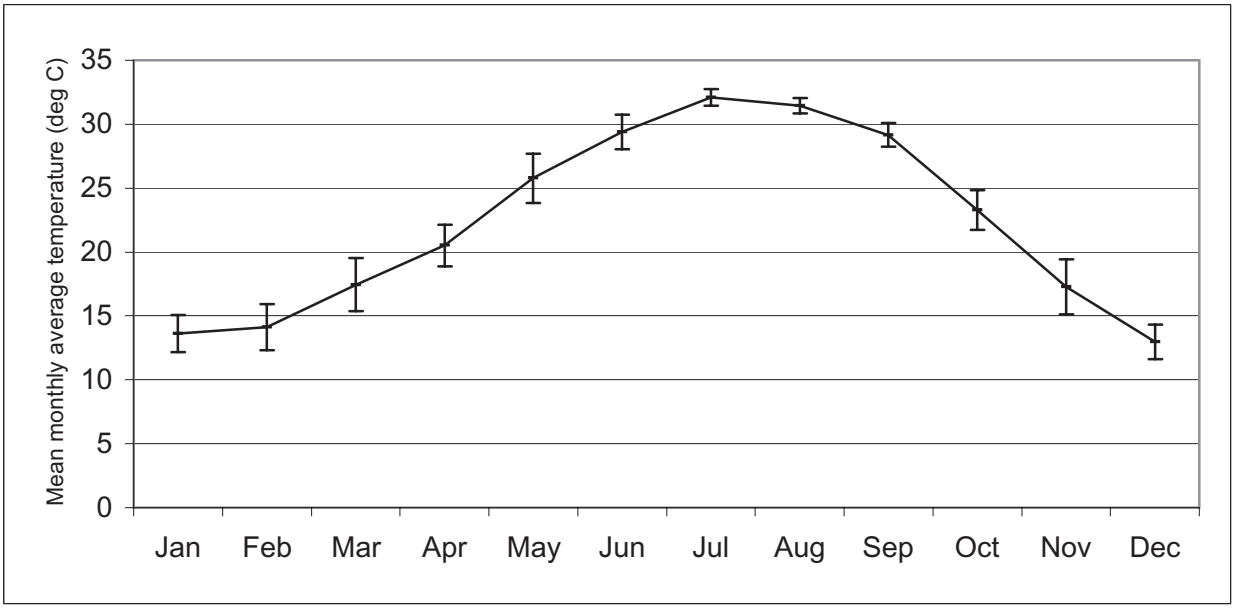


Figure D-10a. Mean monthly average temperatures at Senita Basin weather station, 1995-2005.

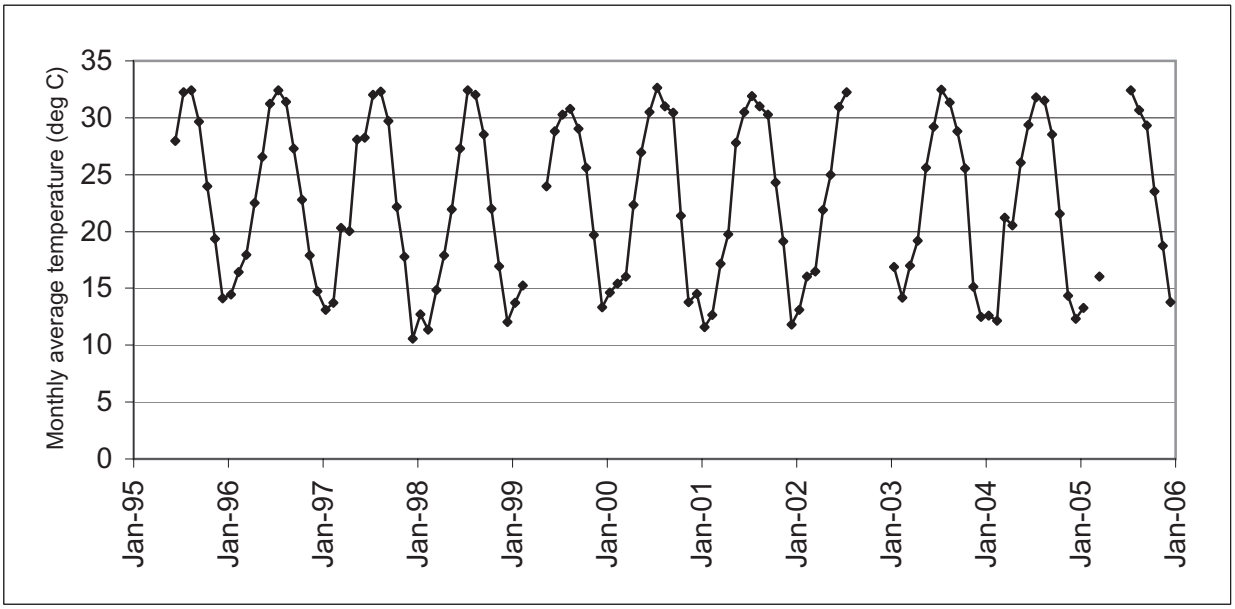


Figure D-10b. Monthly average temperatures at Senita Basinweather station, 1995-2005.

Table D-11. Summary statistics for monthly average temperature at Valley Floor weather station, 1996-2005, Organ Pipe Cactus N.M. Average annual temperature is 20.82 °C.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	10.76	11.77	15.92	19.19	25.44	29.49	32.27	31.25	28.66	21.38	14.09	9.62
S.D.	1.24	1.09	1.84	1.81	1.84	1.17	0.81	0.55	1.03	1.26	1.89	0.74
Skew	0.65	-0.41	1.06	-0.37	-0.45	-0.12	-0.74	1.18	-0.79	0.41	-0.70	1.00
Max	13.26	13.29	19.59	21.26	28.07	30.94	33.03	32.32	29.97	23.38	16.44	11.19
Min	8.82	10.02	13.73	16.27	21.86	27.58	30.83	30.69	26.60	20.13	10.56	8.78
Years	9	9	10	10	10	10	9	9	9	8	10	10

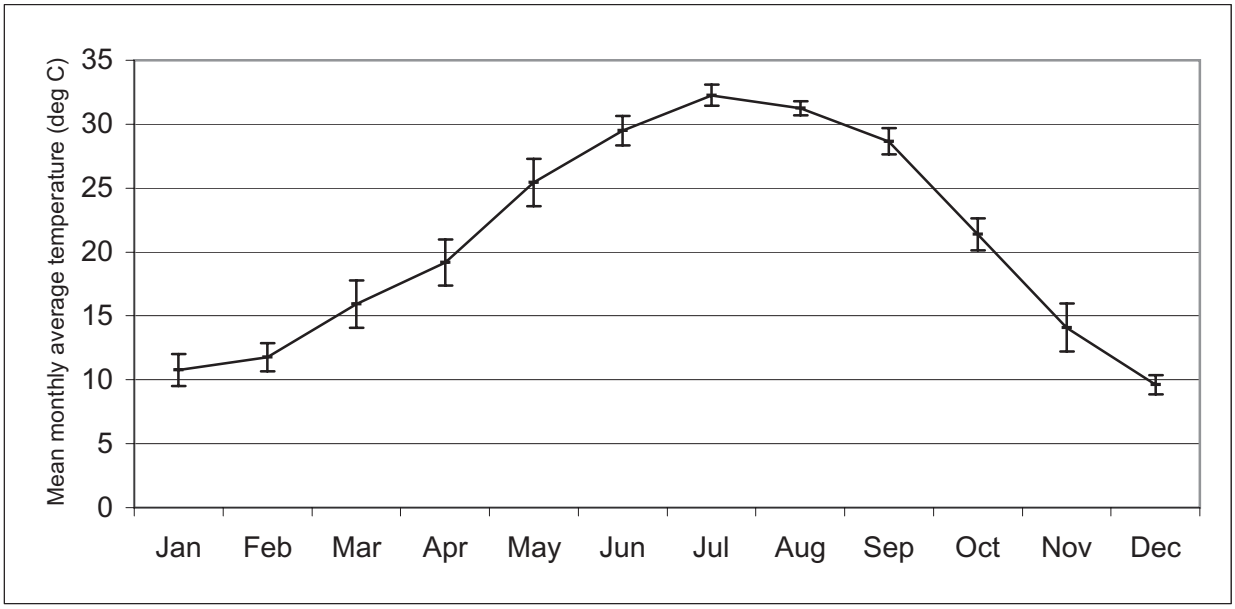


Figure D-11a. Mean monthly average temperatures at Valley Floor weather station, 1996-2005.

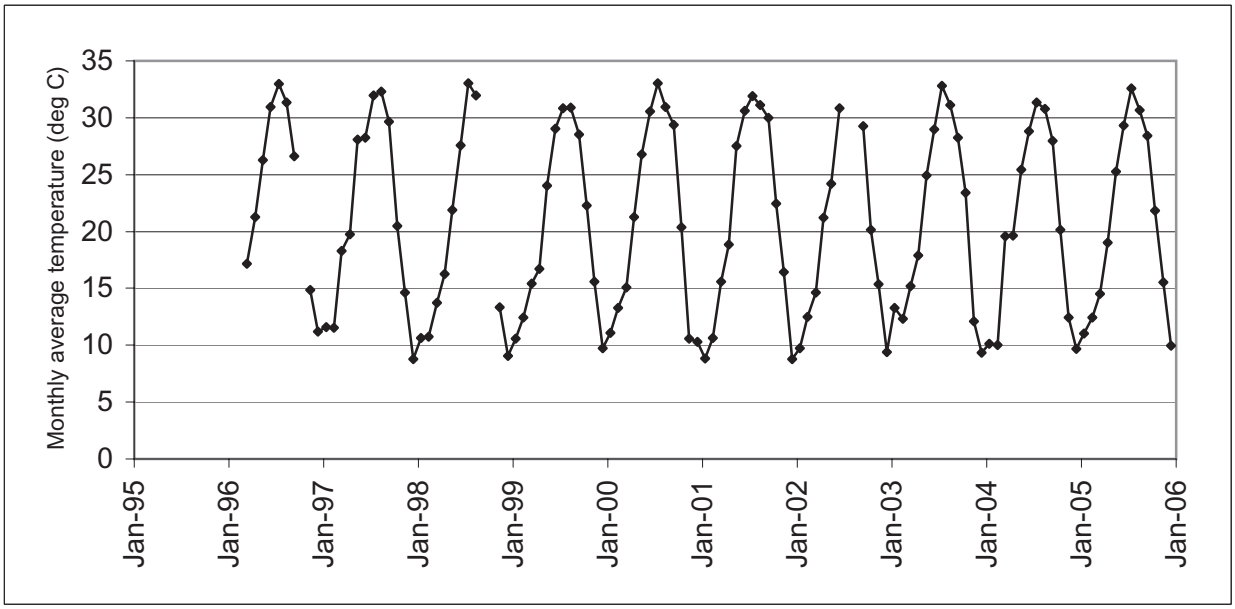


Figure D-11b. Monthly average temperatures at Valley Floor weather station, 1996-2005.

Appendix E: Physical Conditions of Dripping Springs, 2001

Peter G. Rowlands

Introduction

Description of the Dripping Springs Environment

> *"Dripping Springs is on a hillside in an indentation of the northeast side of the Dripping Springs Mountains[1], below a small pass in whitish rock which forms the 'puerto blanco' (white gateway). The approach to the spring leads through a valley that opens off of the valley of the Ajo…The water flows from cracks in the rock into a cave with an entrance 6 feet high and about 4 feet wide; within, the cave widens to 8 feet and is about five feet deep. A small concrete dam has been built across the entrance, and from this dam, a pipe leads to the foot of the slope. The water is milky and opalescent and has a temperature of 69.5° F. (Bryan 1925)*

The spring (actually a seep) lies in a well-protected rock cavity about 31 vertical m above the base of a steep, north-facing slope located on the north-central side of the Puerto Blanco Mountains (UTM 3544600N x 321400E). Dripping Springs can be accessed by walking about 0.8 km up an abandoned dirt road, which joins the North Puerto Blanco Road approximately 16 km from its beginning near Organ Pipe Cactus National Monument (OPCNM) headquarters. According to Brown et al. (1982), OPCNM staff had at one time established a picnic area and parking lot nearby. The facilities were removed and the access road closed in 1972. The spring is improved in that a small concrete dyke was installed across the mouth of the catchment basin (pool) below the spring to increase its capacity (Bryan 1925). Wherrell (1981) believed that the pool was dug out and enhanced as a catchment. There is a saddle about 62 vertical m. above the spring and a well-worn migrant trail connects the old road to the springs and the saddle above. Dripping Springs is surrounded by thick, woody vegetation, mostly paloverde, mesquite and bitter condalia. There appears to be no surface flow manifesting from the pool cavity at the present. Ami Pate, a Biological Technicians who has worked in the Monument for 10 years, has observed the pool overflowing the lip of the small retaining dam, generally during winter rainy periods, as it did in the winter of 1991-1992 (Pate, personal communication).

In March 2001, two volunteers visited the springs and took physical measurements. Their data were consistent with earlier studies (e.g., Brown et al 1982, Brown and Johnson 1983) and show the spring pool to be ellipsoidal in shape (W = 2.25 m, L = 2.46) with a depth of 1.60 m. "Normal" maximum depth is 152 cm, but there has been a recent drop in volume of the pool (from 2 cm below the lip of the small "dam" on 14-Apr-01 to about 100 cm below the lip on 12-June-01 to about 60 cm below the lip on 16-July-01). Present shallow spots, unreported by Bryan (1925) may have been created by rock debris being thrown into the cave or falling naturally from the roof.

Significance of Dripping Springs

Dripping springs is one of only two permanent sources of wildlife water in OPCNM, the other being Quitobaquito Springs, and is located in the Puerto Blanco Mountains within a designated wilderness area. Water chemistry of the spring is monitored several times a year as part of the OPCNM Ecological Monitoring Program (EMP). OPCNM also maintains a nearby weather station, permanent small mammal sampling grids, and vegetation monitoring plots. The spring site proper is also an important bat monitoring location. Mist netting is done at least once a year and occasionally twice a year.

Dripping Springs has some moderate cultural

.

1 Puerto Blanco Mountains on recent USGS quads

and historical significance. Periodic human use and occupancy of the seep site has occurred over many years. Several bedrock mortars and smoked overhangs are located in very close proximity to the springs and indicate Native American use (Hoy 1968). United States Geological Survey hydrologist, Kirk Bryan, who first observed the site in 1917 described nearby abandoned mine workings, as well as other signs of disturbance due to historic mineral extraction and ranching

> "*At the end of the pipeline* [running from the spring to the foot of the slope][2] *is a small pool fed by it, and a well dug in the rock, 54 feet deep and 28 feet to water. The watering place is covered by mining claims belonging to the owners of the Dripping Springs Mine, half a mile southwest. The amount of water is sufficient to supply a few men only.* Bryan (1925)"

Local ranchers, Bill and Birdie Miller, probably dug the well mentioned by Bryan (1925) around 1913. There is no indication of any well in the area at the present time. Very probably it has become filled in with debris from periodic runoff. Hoy (1968) mentions that Dripping Springs was "a major water stop during early travel from Sonoyta – Santo Domingo, etc. to Ajo" and that "the route [was] also used by prohibition bootleggers.

Currently, undocumented aliens (UDAs) rest or set up temporary camp here as they migrate north, seeking a better life in the United States. The great majority of UDAs are Mexican Nationals, but migrants from Central American countries are commonly encountered. Occasionally, drug smugglers moving contraband northward from Mexico also use the site.

The Problem

As a result of EMP activities, frequent visits are made to the Dripping Springs area and there are numerous recorded visual observations of the springs, proper. Since 1991, according to Ami Pate, OPCNM biological technician (Pate, personal communication), the water level in the spring has not been known to vary more than a few centimeters and is always at or near the maximum capacity of the reservoir.

On June 19 2001, EMP personnel, Ami Pate, Nancy Favour, Brian Barns and Bryan Milstead, visited the springs to complete annual bat monitoring. They were surprised to find that the area had been severely degraded and that the water level in the spring was about one meter below the reservoir lip. All around the spring site, there was a large quantity of rubbish and evidence of campfires. They deduced that UDAs created these impacts. The labels of the various discarded containers were in Spanish and the contents were made in Mexico. Great quantities and varieties of rubbish including food and beverage containers made of paper products, plastic or glass; cigarette packages; toilet paper; garments and other odd bits of debris had been scattered abroad. Refuse was abundant at the spring itself, along the trail from the base of the slope below the springs, the slopes above the springs and over the surface of the saddle itself. The most impacted areas of the immediate landscape had the appearance of a landfill.

There were so many honeybees collecting water from seepage along the rock walls of the cavity above the spring pool that one could not hear the normal sounds of water dripping into the spring. The surface of the water was completely covered with dead bees to a depth of several centimeters, along with floating milk jugs and a large piece of plastic sheeting. The stench emanating from the water was reminiscent of an open sewer. The monitors conjectured that either migrating humans and / or thirsty bees were taking more water than was being replenished by the spring. Their initial inclination was to leave the site as rapidly as possible, but then decided to proceed with their plans to mist net for bats in order to see if the observed changes in the spring affected bat activity.

The results from the bat netting were striking (Figure E-1); capture success was much lower

[2] Text within brackets by Rowlands

than in previous years, as was species richness. Heretofore, Dripping Springs had been an important bat watering site but now they appeared to be avoiding it. To ascertain whether this decrease was specific to Dripping Springs, data from White Horse Tank was also analyzed (Figure E-2). The results appear to indicate that the phenomenon was restricted to Dripping Springs.

Having made these preliminary findings, the OPCNM EMP team decided to undertake a small mitigation project at Dripping Springs. Our objectives were to take a closer look at Dripping Springs, determine the cause of the stench and the drastic reduction in reservoir capacity, perform a general clean up of the springs and remove rubbish from the immediate area and both upslope and downslope of the springs proper. On Jul 16, 2001, Bryan Milstead, Ami Pate, Peter Rowlands, Scott Sweet, Tim Tibbitts, Brian Barns, Izar Izaguirre, Nancy Favour and Charles Conner traveled to Dripping Springs to perform water quality tests, clean out the floating debris and decomposing organic matter and remove refuse discarded by UDAs. Figures E-3 though E-11 consist of digital photographs, which were taken as part of the project documentation.

Project Results

General Observations

The pool, itself was found to be fetid. Almost the entire surface was covered with decaying organic material and some of us were almost overcome by the overwhelming stench of hydrogen sulfide (H_2S) and organic compounds produced by the putrefaction. The water was brown and murky, rather than its normal, pale milky color due to the high content of silica [101 mg/l] and suspended silica [92 mg/l]. During the clean up, approximately 3048 cm^3 or more of decomposing and putrefying organic matter was removed from the pool surface by Charles Conner, who skimmed it off with a dip net. This organic material consisted primarily of the remains of dead Italian honeybees (*Apis melifera*), an introduced insect. Water is an essential item for bees since they use it to dilute the honey to feed to the brood and in the hot weather they bring the water back to the hive and evaporate it to cool the hive. Bees will drown, however, if they land in the water. Domestic honeybees require access to at least four L/day of clean water per hive (hives average about 40,000 individual bees). Over 94 % of bees that are collecting water for commercial or hobby hives are found within 500 m of home apiaries (Gary et al. 1979). However, according to Justin Schmidt of the USDA Agricultural Research Service (personal communication) feral colonies, which number around 30,000 individuals can subsist on about 200 ml/day. Considering the relatively small difference in population numbers between commercial and feral colonies, the two independent estimates are somewhat incongruous. It may well be that feral colonies are simply more "thrifty" when it comes to resource utilization. At the time of the clean up, there was a steady and dense stream of visiting honeybees, which may have represented several hives, foraging for water. The pool also contained dead animals including 2 red-spotted toads; one partially decomposed, one intact and bloated; a highly decomposed white-winged dove and another unidentified animal, which Charles could not retrieve. Decomposition of all this organic matter had driven this small aquatic system into near-anoxia and eutrophication as evidenced by the low dissolved oxygen readings and low pH.

Some physical parameters of the pool water taken during the Spring over the past four years are shown in Table E-1, below along with the most recent measurements taken on the day of the clean up. All measurements in Table E-1 were taken between approximately 1100 AM and 1500 PM. Rates of inflow are not estimated during monitoring visits. In the future this should be done.

After the cleanup, Charles Conner attempted to oxygenate the pool by agitating the water with the dip net for several minutes. This action caused some increase in dissolved oxygen concentration (D.O.) of the pool to 1.11 µg/L, not a particularly

Table E-1. Summary of periodic water quality measurements of the Dripping Springs pool over the past three years. ([1] Eight days later, on 24-July-01, the water level had increased by ≈ 8 cm.)

Parameter	27-May-98	04-Mar-99	14-Apr-00	16-Apr-01	16-July-01
Air Temperature °C	25°	21°	31°	35°	36.7°
Water Temperature °C	16°	14.5°	16°	13.8°	21°
pH	7.2	7.18	7.18	7.24	6.58
Dissolved Oxygen µg/L	1.79	0.48*	1.75	4.90	0.91
Alkalinity mg/L as $CaCO_3$	92	97.6	86	52.8	375
Conductivity µSiemens	365	340	360	295	895
Comments	none	none	none	Water 2 cm below dam lip	Water 60 cm below dam lip1

substantial improvement. In the past, D.O. has varied from a low of 0.48 to a high of 4.90. The minimum low D.O. concentration (0.20 µg/L) was recorded during a visit to the spring on 5-Sept-01. This is about 4 times lower than it was on 16-July-01 during eutrophication and may be the result of an equipment malfunction. Eutrophication notwithstanding, it is possible that D.O. concentrations may be related to inflow. Water dripping into the pool from the roof of the spring cave undoubtedly oxygenates the pool water in relation to the number of drops (or intensity of the flow, in the inflow is in the form of a stream), which disturb the pool surface.

Alkalinity on 16-July-01 was approximately 4 – 6 times as high as on previous occasions; conductivity was approximately 2 – 3 times as high. These observations may argue in favor of evaporative water loss as a major factor in the decline of the pool volume. Dissolved salts would become more concentrated as pool volume decreased. Also, byproducts of decomposition, in part, may be responsible for these increases.

Dripping Springs is a so-called "fracture spring" because it is fed by water circulating though fault fractures and water feeding the spring is due to local recharge from precipitation and that regional aquifers no longer play a role (Bryan 1925). This finding has never, to my knowledge, been reevaluated. Inflow to the pool is in the form of drip-points ("dozens" according to Wherrell 1981) on the roof of the cavity. The pool is approximately 2.1m wide x 3 m long x 1.5 m deep and was estimated to have a maximum capacity of approximately (including sediment) of approximately 9,513 L. A recent survey by OPCNM staff revealed that the correct dimensions are, in fact, 2.25 m long x 2.46 m wide x 1.6 m deep giving an estimated volume of 4,637 L, assuming a half - ellipsoid. Flow rate in the past has varied from less than 48 – 761 L/day (Brown et al. 1982). I estimated the flow rate to be 16 – 32 L/hr (or 384 – 768 L/day) (based on visual observations of the flow from various rated emitters on my home drip irrigation system). The latter is a crude estimate, founded on a somewhat dubious method, but agrees, within an order of magnitude, with Brown et al (1982). These estimates will have to suffice until future monitoring can produce a meaningful time series of flow fluctuations.

Daily evaporation in June and July in southern Arizona is approximately 12.3 mm/day (Sellers and Hill 1974) as measured by standard class A evaporation pans (122 cm in dia. and 25.4 cm deep). Converted to volume, this is approximately $\pi*(0.66\ m)^{2}*.012\ m/day = .01642\ m^3/day$ or 16.42 L/day. The surface area of the Dripping Springs pool (assuming an ellipse) is about 3.7 times that of an evaporation pan. Evaporation from the pool in July could be as high as 61 L/day, admittedly a rough estimate. In any case, it may be possible, under conditions of high heat and low inflow (working in a short lag time for replenishment by local precipitation), for evaporation to exceed

inflow. Therefore, the decline in the pool's water level by almost 0.3 m during the past several months could have been due to a simple imbalance between a naturally occurring drop[3] in inflow coupled with high May, June and July evaporative losses.

Obviously, this conjecture is based on "ball-park " figures. The Dripping Springs pool is not entirely comparable to a standard evaporation pan. For one thing, a pan is exposed to surface airflow and turbulence, which reduces the boundary layer over the water and increases evaporation. The pool is protected within a cave and has a completely different shape and surface to volume ratio. Water consumption by wildlife, including swarms of honeybees, and UDAs would have exacerbated evaporative water losses.

Very likely, inflow varies over time, especially if it is highly correlated with local precipitation as Bryan (1925) infers. However, if this is true, there should have been ample water in the local system. The Dripping Springs rain guage recorded above average winter and spring precipitation between October, 2002 and April 2001 and there was an early monsoonal storm in June (16.8 mm). The only dry months were December 2000 when total monthly precipitation was zero and May 2001 when total monthly precipitation was only 0.5 mm (Table E-2). If flow rate responds to local precipitation then it must do so very quickly. Indeed, the lowest pond level was observed on June 19, 2001, after a month of near drought and approximately the same time as the early monsoon cell brought precipitation. By July 16, the water level had risen by ≈ 40 cm. This is by no means conclusive evidence of cause and effect for at least two reasons. The June precipitation filled or partially filled local tinajas and could have attracted water-consuming wildlife elsewhere, thus relieving pressure on Dripping Springs. Second, over the past ten years, long-time OPCNM biological technician Ami Pate has observed a full pool at Dripping Springs, with little variance in level, between repeated visual observations, even after extended dry periods (Pate, personal communication).

Table E-2. Monthly precipitation measurements from the Dripping Springs rain guage, October, 2000 through June, 2001.

Month	Precipitation (mm)
October-00	41.4
November-00	8.6
December-00	0.0
January-01	55.6
February-01	28.7
March-01	24.9
April-01	21.1
May-01	0.5
June-01	16.8

Causes of water withdrawal other than evaporation, such as consumption by wildlife, human consumption by UDA's; increased evapotranspiration from surrounding phreatophytic vegetation (as foliage emerged during the spring and early summer); or, a combination of several or all of these factors cannot be ruled out. The water balance dynamics of Dripping Springs appears to be a complicated interaction of physical and biological variables. Honeybee use is probably not a significant factor, unless a very large number of separate colonies are involved, such as 20 or more within the flight area. For example, 20 colonies could consume water at a rate of about 4 L/day. According to periodic observations by Monument resources management staff, large numbers of bees are always present at the springs during the warm season regardless of the water level.

Since Dripping Springs is only one of two permanent water sources in ORPI and is of great importance as a wildlife-watering site, an extensive bio-hydrological study is recommended. Several questions come to mind as a result of above observations:

1. What are the extremes of fluctuations and the long-term average of inflow into the Dripping

[3] If Kirk (1925) is correct, this could happen simply due to a protracted dry period which, in our climatic region often occurs from mid-April through the beginning of July.

Spings pool?

1.1. What exactly is the source of water; is it an aquifer, local precipitation as inferred by Bryan (1925) or both?

1.2. How does the inflow rate change over annual, seasonal and daily time periods?

1.3. How responsive is the rate of inflow to local and regional precipitation and is there a lag?

1.4. Are the time series stationary or nonstationary over time?

2. What is the water balance maintaining the Dripping Springs pool?

2.1. Can all sources of outflow or usage be quantified and measured?

2.2. How do rates of outflow or usage change over annual, seasonal and daily time periods?

3. Could unusually high concentrations of honeybee colonies (10-20 within the fight area during a good year) coupled with water consumption by other wildlife severely deplete a small water source such as Dripping Springs?

4. Could the protracted decomposition of accumulations of dead, non-native honeybees render a small water source with a variable inflow unusable to native wildlife and for how long? The primary cause of the eutrophication of the spring pool appears to be the decomposition of the accumulated bodies of dead honeybees, which, like almost all insects are very high in protein. A search of archived OPCNM files after the site examination and cleanup revealed that this might not have been a singular occurrence. On April 1, 1981, National Park Service hydrologist William Wherrell described the pool as containing "many dead bees (Wherrell 1981)." On June 12, 1958. USGS hydrologist, L. Hiendel described the water quality as being "poor…slightly fetid" and the level "about 1 ft. below lip of sump [i.e, pool]." He recommended that the spring be cleaned out. On June 3-7, 1942, H.V. Peterson, also from the USGS, wrote, "the entire flow was being consumed by birds and insects." Since honeybees are an exotic species, the above question may have significance with respect to NPS natural resources management policy.

5. What is the role of water consumption by UDAs on the hydrology of Dripping Springs?

6. How long would it take Dripping Springs to recover from a eutrophication episode with and without management intervention?

Trash Removal

Nineteen bags of trash were eventually collected (600± kg.) from the vicinity of the seep, some from ridge above Dripping Springs and some from area around and below the spring. I estimate that this is about half the trash, which has been discarded on the spring site and the saddle above it. The trail to the springs from the North Puerto Blanco Drive is well worn, as is the trail up to the springs from the southwest on the other side of the peak. The latter is well illustrated in Figure E-10.

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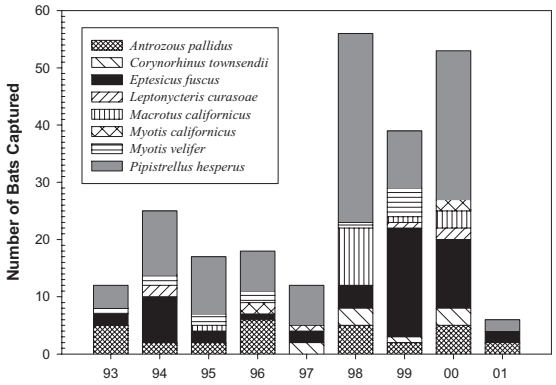

Figure E-1. Bat captures at Dripping Springs (1993-2001).

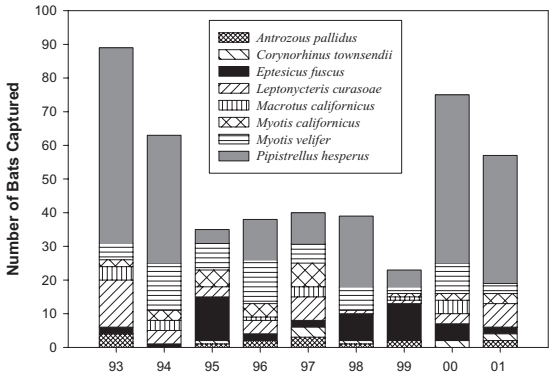

Figure E-2. Bat captures at Wild Horse Tank (1993-2001)

Figure E-3. Dripping Springs pool. Note the floating debris and organic matter, mostly dead bees.

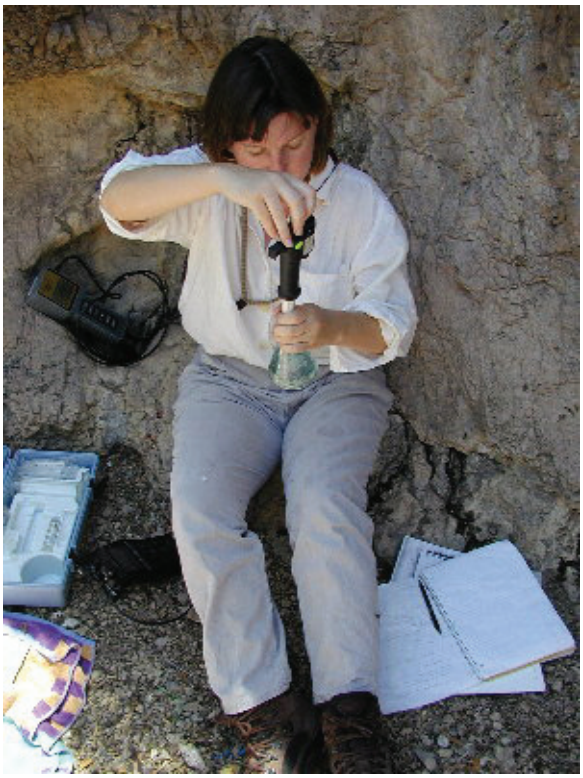

Figure E-4. Nancy Favour measuring total alkalinity by titration.

Figure E-5. Decomposing organic matter skimmed from the surface of the Dripping Springs pool. Note the remains of a bird, probably a White-Winged Dove. The bulk of the putrefying material is composed of honeybee bodies, which remains are quite visible

Figure E-6. Mound of all the organic matter removed from the pool. The plastic gallon jug is included for scale.

Figure E-8. Refuse discarded by undocumented aliens (UDAs) and accumulating under vegetation adjacent to the Dripping Springs pool.

Figure E-10. Nancy Favour removing trash from saddle above Dripping Springs.

Figure E-7. Refuse scatter on the saddle above Dripping Springs. View toward the SSW.

Figure E-9. Telephoto view of UDA trail from the saddle above Dripping Springs. View toward the SSW.

Figure E-11.Tim Tibbitts with the final haul of refuse and debris from Dripping Springs and the areas adjacent to it.

Appendix F: A Short History of Human Traffic in Organ Pipe Cactus National Monument, 1937-2001

Brenna Lissoway

In recent years, the dramatic increase in clandestine human traffic transiting the Organ Pipe Cactus National Monument has developed into the Monument's most critical resource issue.[1] However, the movement of peoples through the area of the Sonoran Desert, which is now Organ Pipe Cactus National Monument, is not a recent phenomenon. The presence of limited natural water sources and the contour of the landscape have dictated human routes in the area for hundreds of years.

The border region between Mexico and the United States represents a unique space; it is the only global dividing line between a First and Third World country. Century old migration ties between the two nations persist due to continued economic discrepancies. But since the 1990s, unprecedented numbers of undocumented aliens (UDAs) are choosing the Monument as a crossing point in their strategy to enter the United States. It is the increased human presence, both illegal traffic and law enforcement, which have contributed to the current alteration of the Monument landscape. However, it is the perception of this space and its administration as a wilderness area, which have made the changes in the land so apparent.

Establishing Routes

Archeological evidence points to the early development and long-term use of several trails within the modern Monument boundaries. In particular, the presence of a major north-south route connecting water sources in the eastern portion of the Monument indicates consistent travel between what are now Sonora, Mexico and Arizona. One of the most staid historic trails in the Monument, it reflects use by numerous cultures from as early as 1500BC through the early 20th century. Hohokam shell collecting expeditions trod the path from present day Central Arizona to the Sea of Cortez, the Tohono O'odham people utilized the route to collect sea salt from the same body of water, and later the same route was adopted by Spanish, Mexican, and finally Anglo inhabitants of the Sonoran Desert region from the 17th to the 20th century.[2]

The conquest of Mexico by the Spanish Empire enhanced the tradition of movement and connection between interior Mexico and it's northern frontier. *El Camino del Diablo*, or the Devil's Highway, which passes just to the south and east of the Monument, became one of many arteries of travel and trade between towns in northern Mexico and the villages and presidios of the *Pimaría Alta*.[3] After the Mexican Revolution, political control of Arizona lands passed from Spain to Mexico in 1820, and finally to the United States through the Gadsden Purchase of 1853. American ownership of the land south of the Gila River established a new international boundary in the

[1] Environmental concerns were expressed by Bill Wellman (Monument superintendent), Bryan Milstead, (Ecological Monitoring Coordinator), and Dale Thompson (Chief Ranger) in an interview with the author March 29, 2002.

[2] Rankin, Adrianne G. "Archeological Survey at Organ Pipe Cactus National Monument, Southwestern Arizona: 1989-1991". Special report prepared for the U.S. Department of the Interior, National Park Service (Western Archeological and Conservation Center, 1995), 365-371.

[3] Wyllys, Rufus K. Arizona; The History of a Frontier. Phoenix: Hobson & Herr, 1950, 268.

Southwest where none had existed before, bisecting traditional human travel corridors.

New economic opportunities quickly developed with Arizona's new ties to American enterprise. From 1876 to 1911, Mexican leadership committed the country to a program of economic modernization whereby the Mexican government sold or gave large tracts of land to investors. The removal of these communal lands resulted in an epidemic of landlessness among Mexico's rural population. In order to alleviate their poverty, these displaced peoples began seeking wage labor opportunities in the United States. By the 1890s, pacification of the Apache Indians and the construction of American owned railroad spurs into Mexico provided unprecedented transportation for Mexican laborers to reach employment opportunities in American railroad, agricultural, and mining industries. The penetration of railroad lines into the Western Plateau region of Mexico encouraged American labor recruiters to target the states of Guanajuato, Jalisco, and Michoacán, the primary source states of migration to the U.S. for the remainder of the 20th century. Soon, large numbers of undocumented Mexican workers regularly crossed the U.S.-Mexican border establishing a pattern of seasonal return migration that would become a part of Mexican culture.[4]

In the early part of the 20th century, the central Arizona borderlands experienced an increase in human traffic. After the opening of the Ajo copper mine in 1917, currents of Mexican migrant traffic accelerated through lands now encompassed by the Monument.[5] At least by the 1920s, the increased and regularized movement of people precipitated the building and maintenance of a principal road between Ajo, Arizona and Sonoyta, Mexico that evolved into Arizona Highway 85.[6] Mexican and American bootleggers engaged in a brisk cross-border illegal alcohol trade in the Ajo vicinity, often skirting authorities in the vast undeveloped desert.[7] In 1917, one Ajo local observed the "great many roads leading to Mexico" in the Ajo area reflecting the increase in transnational movement.[8] During this period, several ranchers began operation in the Organ Pipe area. The Gray family began a cattle business in 1919 that lasted well into the mid-20th century. The Gray men worked their cattle on both sides of the border, recalling that the "Mexican border didn't amount to nothing" in the years before the cessation of the *Bracero* program.[9] Like the legal and illegal Mexican workers, the Gray brothers passed back and forth across a porous border running their cattle between Ajo and Sonoyta.

Prior to 1924, U.S. customs officials provided little effective international border regulation in the Southwest. Growing concern over Mexican immigration, particularly the smuggling of Chinese immigrants through Mexico, prompted the Commissioner General of Immigration to assign a token force of inspectors to patrol

[4] Cardoso, Lawrence. Mexican Emigration to the United States; 1897-1931. (Tucson: University of Arizona Press, 1980), 18-19.

[5] Harner, John P. "Patterns and Processes of Undocumented Mexican Migration to Arizona". Master's thesis (Arizona State University, 1993), 45.

[6] Road repair reported in the *Ajo Copper News*, February 10, 1923.

[7] Based on over 20 newspaper articles addressing instances of bootlegging found in the *Ajo Copper News*, 1916-1945.

[8] Excerpt from article on C.H. Lester, firewood distributor between Yuma and Tucson, AZ, *Ajo Copper News*, May 26, 1917.

[9] Bobby Gray, transcript of interview by William Werrell, January 1975; 15. Transcript housed in the office of Organ Pipe Cactus Plant Ecologist.

the entire U.S.-Mexico Border beginning in 1904[10] Fanned by national anti-immigration sentiment, the Johnson-Reid Act of 1924 both imposed an immigrant quota system and created the United States Border Patrol, the first permanent border authority assigned to begin shoring up America's perimeters against an increasing "immigrant tide". This directive introduced a new law enforcement presence in the U.S.-Mexico border region. However, the onset of the Great Depression in 1929 greatly reduced migrant flow from Mexico as many laborers remained in their own country for lack of work in the United States. Significant northward movement of workers did not resume until the WWII induced labor shortages of the following decade.[11]

During the relatively quiet period of migrant flow on the Southwest border, politicians and conservationists took an active interest in the desert landscape around Ajo. Once regarded as a barren tract on the national periphery, scientists argued for the value of preserving a section of Sonoran Desert terrain as open space.[12] After Washington had marked a reservation for the Tohono O'odham Nation in 1874, land along the border west of the reservation had remained largely open range. In 1937, President Franklin Roosevelt invoked the Antiquities Act of 1906 to transform a 331,000 section of land abutting the reservation to the west into Organ Pipe Cactus National Monument. Two years later, congress established the Cabeza Prietta National Wildlife Refuge neighboring the Monument, and in 1940 the U.S. Department of Defense acquired the remaining surrounding land into the Barry Goldwater Airforce Range. Within four years, federal authorities had remade land management divisions along the western portion of the Arizona-Mexico border, significantly altering the administration of the desert acreage. Increased federal presence did not immediately affect the fixed human transit patterns in the region, but established new administration practices and perceptions of land values.

Upon his arrival in 1939, the first custodian of the Monument, William Supernaugh, found a landscape marked by countless years of human movement through the area. He was so impressed with the travel networks manifest in the desert landscape that he made a notation of the "many miles of car trails just winding through the desert" in his first monthly report.[13] In 1939, Supernaugh initiated the construction of a perimeter fence for the Monument. The fencing project ostensibly targeted the exclusion of hunters, woodcutters, and stray stock, not the prevention of undocumented migration flows.[14]

The Southwest Border and WWII

The outbreak of WWII renewed the American need for Mexican labor as thousands of young men left the U.S. to fight overseas. The 1942 initiation of the cooperative labor agreement between the United States and Mexican governments known as the *Bracero* Program arranged for temporary legal entry into the U.S. for Mexican workers. Because of the persistence of rural poverty in the region, over 50% of the *Bracero* contracts were

[10] Harner, 118-120.
[11] Ibid., 11-12.
[12] Rothman, Hal. Preserving Different Pasts; The American National Monuments. (Urbana, IL.: University of Illinois Press, 1989): 170-171.

[13] Organ Pipe Cactus National Monument. "Superintendent's Monthly Report, October 1939". Photocopies of original reports are located in the Monument library while the originals reside at the Western Archeological and Conservation Center in Tucson, AZ.
[14] Ibid. Sup Monthly report May1939

awarded to inhabitants of the states of Guanajuato, Jalisco, and Michoacán, thereby reinforcing the out-migration from that region. These established networks have influenced migration patterns clear through the 1990s.[15]

The presence of military and Border Patrol personnel along the Southwest border grew during the War years. Intensified patrols of the 31-mile stretch of international border shared between the Monument and Mexico caused the Organ Pipe superintendent some consternation, but ultimately he found the U.S. cavalry officers very cooperative and respectful of park policies.[16] Also during the 1940s, park laborers constructed the first monument patrol road just inside the international boundary in 1946, and the Department of Agriculture established several border inspection stations apparently to prevent the spread of hoof and mouth disease by Mexican drift stock, not to address problems with migrant traffic.[17]

The Eisenhower administration's massive deportation of undocumented Mexicans during "Operation Wetback" in 1954 signaled growing American alarm at the increased numbers of Mexican newcomers spurred by the *Bracero* Program. The *Bracero* program had actually stimulated both legal and illegal immigration as undocumented migrants followed the social networks established by legal contract workers. Despite the changing American social atmosphere, Mexicans were continually compelled to seek work in the United States. Starting in 1940, Mexico's "Green Revolution" perpetuated the displacement of rural labor as a series of Mexican administrations sought to modernize agricultural production. In addition to the sending states of the Western Plateau, more migrants traveled to the U.S. from the states of Zacatecas, Durango, and San Luis Potosí.[18]

The Post-*Bracero* Border

In 1964, under mounting domestic pressure, Congress repealed the federal authority for the *Bracero* program. However, rather than halting the influx of migrants from south of the border, the legislation simply drove illegal immigration to unprecedented covert levels. In the three years after the termination of the legal apparatus for Mexican labor entry, the number of apprehensions of undocumented persons more than doubled along the Southwest border from 40,020 in 1964 to 96,641 in 1968. Throughout the 1970s and into the 1980s the number of apprehensions in the Southwest made by the Border Patrol increased yearly almost without exception.[19] According to recent scholarship, the interpretation of post-*Bracero* Border Patrol apprehension statistics as indicators of actual illegal traffic flows have been underestimated by as much as half, making these numbers even more striking.[20]

Successive amendments to the U.S. Immigration and Nationality Act during the 60s and 70s attempted to address the growing numbers of undocumented people entering the United States through Mexico. Simultaneously, the U.S. and Mexican governments negotiated several agreements

[15] Harner, 13.
[16] Organ Pipe Cactus National Monument. "Superintendents' Monthly Report, January 1942".
[17] "Superintendent's Monthly Report, April 1947".
[18] Cross and Sandos, 73.
[19] "INS Southwest Border Patrol Apprehensions By Sector; Fiscal years 1960-2001", unpublished statistics from Tucson Border Patrol Intelligence Office database, current as of February 25, 2002.
[20] Espenshade, Thomas J. "Using INS Border Apprehension Data to Measure the Flow of Undocumented Migrants Crossing the U.S.-Mexico Frontier", *International Migration Review*, 29 (summer, 1995): 545-565.

to create new trade zones based on export processing along the border. American companies placed factories, or *maquiladoras*, in close proximity to the border where products could be assembled with inexpensive Mexican labor and then easily shipped to markets in the U.S. The *maquiladora* system initiated a rapid wave of economic and demographic growth along the border.[21] *Maquiladora* programs may have contributed to the emergence of "Stepwise migration", a phenomenon of the last twenty years where migrants temporarily move to a Mexican border town before entering the U.S. Some major border redistribution cities include Ciudad Juarez, Agua Prietta, Nogales, San Luis Rio Colorado, and Tijuana. It is unclear whether or not these cities were intended to be stopovers to an ultimate American destination or if they became temporary residences because of failed opportunities there.[22]

In the early 1960s, apprehensions in the Tucson Border Patrol sector, in which the Monument is located, ranked low among the nine sectors. This suggests that fewer numbers of clandestine migrants and smugglers were attempting to cross in the rural desert interior than in the more urban sectors such as San Diego and El Paso. However, like the rest of the Southwest border, apprehensions rose in the decade after removal of the formalized migrant program culminating in a decade high of over 50,000 seizures in 1974. This number was not exceeded in the Tucson sector until 1985.[23]

Meanwhile, in the midst of growing covert human transit flows, Monument managers implemented the first systematic study of the Monument's ecology initiating such investigations as the first desert bighorn sheep census in 1967 and the Monument's first sustained "monitoring" project in 1970.[24] Initiatives such as these served to both deepen the understanding of the natural systems extant in the Monument as well as to establish a credible baseline from which to measure future environmental change. In 1978, after the lapse of the remaining grazing and mining permits, Congress designated 95% of the lands within the Monument as federal wilderness. This legal mandate governing the treatment and regulation of the Monument's desert holdings transformed it from a multiple use unit of the national park system to an area managed primarily for its wilderness character. This conversion bore serious implications for future migration trends.

In 1978, the same year as the wilderness designation, the current superintendent recorded in his annual report the first significant reference to the apprehension of undocumented aliens within the monument boundaries.[25] From that point, park records indicate modestly increasing concern over the presence of illegal migrants and drug traffickers in the Monument throughout the 1980 s. In July 1980, the tragic deaths of 13 immigrants from El Salvador attempting to traverse the Monument highlighted the emergence of a disturbing trend. These travelers were led into the harsh monument environment and then abandoned by the guides they had paid to lead them safely into the U.S. Many authorities acknowledged those border crossers and smugglers alike were beginning to target the Monument not only due to the convenient presence of Highway 85, but

[21] Durand, Massey, Parado, 519.
[22] Harner, 112-116.
[23] "INS Southwest Border Patrol Apprehensions by Sector; Fiscal Years 1960-2001"
[24] Department of the Interior National Park Service, "The Division of Natural and Cultural Resources Management - Organ Pipe Cactus National Monument, Annual Report, 1996", 11-12.
[25] "Superintendent's Annual Report 1978".

also because of the management of the Monument as a wilderness area. The absence of maintained roads, relatively small numbers of rangers, and motorized vehicle restrictions all increased the odds of evading capture.[26]

A "New Era" of Immigration

By the early 1980s the United States government felt it had lost control of it's southwestern borders. High immigration, stagnant American wages, and widespread unemployment (particularly in California) all contributed to the rise of nativist sentiment in the U.S. The Immigration Reform and Control Act of 1986 (IRCA) attempted to control and deter illegal immigration by providing amnesty for long term workers, penalties for employers hiring undocumented workers, and a significant infusion of money and personnel for the Border Patrol. The first three years after the legislation, border apprehensions decreased overall, but by the early 1990 s the Border Patrol again reported a rise in unauthorized entries across the southwestern border.[27]

In their 1999 study, Jorge Durand et al found that "more than any other factor, IRCA is responsible for creating a new era in Mexican immigration to the United States".[28] Instead of discouraging illegal immigration through Mexico, IRCA seems to have transformed the pattern of undocumented migration. Before the passage of IRCA Mexican workers tended to travel seasonally to work abroad for a specific economic goal. One family member was typically sent, and the fundamental objective was to return to Mexico. After IRCA, the relative security offered by legal status in the U.S. and turmoil at home encouraged many migrants to remain north of the border. Consequently, IRCA became a trigger for more migration as families moved from Mexico to reunite in the U.S. Family reunification translated into higher numbers of female and urban migrants. One study found that the probability of a family illegally immigrating to the U.S. increased by a factor of seven if a family member had been recently legalized.

In addition, IRCA influenced a wider geographic dispersal of Mexican immigrants throughout the U.S. and away from traditional gateway regions. The employment of workers in agricultural areas such as California and Texas fell in the 1980 s and early 1990 s while employment in urban areas grew. Legalization permitted more freedom of movement toward economic opportunities in the interior. In 1986 82% of legal immigrants settled in California, Texas or Illinois. A decade later, large numbers of Mexican immigrants were settling not only in the traditional states of California, New Mexico, Arizona, Texas, and Illinois, but in Colorado, Florida, Georgia, Nevada, Oregon, Washington, and the NewYork-New Jersey area.[29]

One study in Arizona from 1989 to 1991 demonstrated a change in the almost century old Mexican migration paradigm. Arizona reflects slightly different connections to Mexico than the rest of the U.S. as Arizona historically retains a stronger affiliation with the Mexican state of Sonora. Evidence seems to suggest network links between specific Mexican municipalities and Arizona. Culiacán, Sinaloa represented the dominant single source for undocumented migrants to Arizona and Nogales was found to be the most important redistributor city.[30]

[26] *Tucson Star,* July 5, 1981.
[27] "INS Southwest Border Patrol Apprehensions by Sector"
[28] Durand, Massey, Parrado, 522.
[29] Durand, Massey, Parrado, 525-530.
[30] Harner, 115.

Although no evidence exists to confirm or refute national trends extant within the Monument, the national data implies change across the southwestern border as a whole, including the Monument region.

Throughout the 1980s Organ Pipe managers reported an increase in law enforcement activities related to the presence of UDAs. Monument officials report the apprehension of 26 UDA's in 1991 and 66 in 1992. The removal of boundary fence, more perceptible apprehensions of border crossers, increasing drug related clashes, and a rash of thefts at Monument installations all indicated a rise in illicit activity. The acceleration of drug trafficking in the Monument precipitated the initiation of multi-agency coordinated drug interdiction activities. In 1991, law enforcement conducted 31 special operations followed by 49 operations in 1992.[31] Although migration and smuggling flows appeared on the rise, it was not until the mid-1990s that the Monument experienced prominent change.

The Tightening U.S.-Mexico Border

In response to the early 1990s return to increased cross-border illegal traffic flows, the INS launched a series of aggressive Border Patrol initiatives in the mid-1990s. In September 1993, the El Paso sector began "Operation Blockade" later renamed "Operation Hold-the-Line". Increased Border Patrol staffing and activities appeared successful as apprehension fell by more than half the following year. In the San Diego/Tijuana area, "Operation Safeguard" met with similar results in 1995. However, numerical declines in these areas did not necessarily indicate overall border deterrence. Instead, INS statistics demonstrate a dramatic shift in immigrant corridors after the urban initiatives. Sociologist Thomas Espenshade has developed what he terms the "Repeated Trials Model" which demonstrates that migrants typically repeat attempts to enter the U.S. until they are successful. In the words of one migrant interviewed for his research, "It's harder to cross, but we do get across, if not on the first try, then on the second, third, or fourth."[32] As crossing at urban points became more unsuccessful, immigrants gravitated to the interior deserts of the Southwest.

The failure of the North American Free Trade Agreement to alleviate significant economic inequalities and the Mexican financial "bail out" in 1994 perpetuated the high number of immigrants entering the U.S., unleashing a renewed nativist sentiment in the United States as witnessed by California law makers approval of Proposition 187. In 1996, the Mexican congress voted to change the Mexican constitution to permit dual citizenship. These two factors have combined to touch off a new flood of applications for naturalization in the late 1990 s producing a new influx of illegal immigrant family members seeking entry into the U.S.[33]

Redirected migrant flows through rural sections of the border materialized as border crossers adopted new strategies to enter the U.S. Immediately after the implementation of the El Paso and San Diego border initiatives, the regions most impacted were the El Centro, CA sector, where apprehensions doubled, and the Tucson Sector, where apprehensions tripled between 1993 and 1996. By 2000, the Tucson sector far outdistanced all others in number of apprehensions with a staggering 616,346, followed by El Centro with just over a third that number. Again in 2001,

[31] Organ Pipe Cactus Annual Reports, 1978-1992.

[32] Espenshade, 550.

[33] Duran, Massey, Parrado, 533.

the Tucson sector emerged with the most apprehensions followed by the El Centro sector.[34]

Within the Tucson Sector, the Border Patrol apprehended the highest number of UDAs in the Nogales and Douglas stations through the mid-1990s. Despite an overall increase in apprehensions during the same period, the Ajo station maintained the lowest number of arrests until 1994. However, in 1995, the station reported an increase to 2,656 from 938 the year before. A dramatic increase to 9,100 apprehensions followed in 1996, elevating the Ajo area to the sixth busiest station. For the next four years, the Ajo station consistently ranked seventh in arrests, but in 2001 again emerged as the sixth most active area.[35] Statistics indicate the continued popularity of the Douglas, AZ area as a crossing point while the Ajo station seems to be gaining in popularity. Although statistics are not complete, apprehensions within the Monument seem to confirm an increase in migrant movement through the National Park Service lands, with the most pointed increase in 1999.[36]

Statistics from the 1990 s indicate the presence of a noticeable seasonal cycle of movement. In concert with other stations in the Tucson Sector, the Ajo station experienced the highest number of apprehensions during spring and early summer with particularly heavy movement in the months of March and April. Movement typically declines in the late summer and early fall, plummeting to the lowest numbers of the year in November and December.[37] Monument law enforcement records parallel the Ajo statistics.[38] This pattern suggests the largest influx of traffic in the early part of the year with immigrants either returning south of the border or staying home at the end of the year, possibly due to the Christmas holiday season.

Concurrent with rising apprehensions of illegal migrants, the 1990 s reflect a staggering increase in the smuggling of illegal drugs through Monument lands. Interestingly, drug confiscation in the Tucson sector have dropped overall from 1999-2001, yet the amount of illegal substances captured by agents of the Ajo station have significantly increased. Statistics for the actual number of drug related cases are not available, therefore it is not possible to determine whether activity or shipment amounts increased. Since the maintenance of consistent record keeping in 1996, Monument law enforcement rangers annually seized larger amounts of illegal drugs, rising from 902 pounds in 1997 to 14,731 pounds in 2001. The number of drug related violation have paralleled the growing drug confiscation amounts so that the relationship between citations and quantity appear to have remained comparable.[39]

As the Southwest borders have become more militarized, many scholars and activists have focused on the human costs of undocumented border transit. Since 1997 there have been an estimated 1,600 possible fatalities associated with illicit border crossing, mostly due to hypothermia, hyperthermia, and dehydration. Migration flows had shifted away from California by 1997 explaining the decrease in deaths in

[34] "INS Southwest Border Patrol Apprehensions by Sector"
[35] "Tucson Sector Arrests; Fiscal Year 1992-2002", unpublished INS statistics.
[36] Monument apprehensions in 1998 totaled 215 while they reached 447 in 1999, Organ Pipe Cactus National Monument "Law Enforcement Monthly Reports", November 1993-February 2002.
[37] Ibid.
[38] Organ Pipe Cactus National Monument "Law Enforcement Monthly Reports", 1993-2002.
[39] Ibid.

that state while death counts along the rest of the border grew. In response to humanitarian concern, the INS partnered with the Mexican government in the summer of 1998 to launch a safety campaign; coordinators initiated civil air patrols, an aggressive advertising drive promoting the dangers of desert passage, and special training for law enforcement field agents.[40] Migrant death tolls did not increase in Arizona from 1993 to 1997, however confirmed deaths in the Tucson Sector escalated from 29 in 1999, to 74 in 2000, and 78 in 2001. In this three-year period, deaths in the highly isolated West Desert Corridor, where the Monument is located, remained significantly higher than either the Douglas or Nogales Corridors.[41] In 2000, Monument staff made a highly controversial decision to place two water barrels along an already impacted powerline track in an attempt to channel the illegal traffic thereby reducing environmental impact and saving lives.

The reported rise in border activity in traditionally quiet Border Patrol sectors can be partially accounted for by congressional increases in INS funding, Border Patrol personnel, and staff hours devoted to physical patrol of the border. From 1975 to 1986, congress steadily raised the INS fiscal budgets almost doubling the agency allotment to $754 million by 1986. Steady increases over the next 10-year period resulted in another twofold increase in funding by 1995 to $2,044 million. The past six years have seen larger yearly increases resulting in an annual INS budget of $4,378 million in 2002.[42]

Reflecting INS budgetary change, INS staffing, and more importantly, Border Patrol staffing, increased as well. Southwestern border enforcement hours increased relatively evenly from 1986 to 1992. Among the nine southwestern Border Patrol sectors, the traditionally busy San Diego Sector remained among the top two of the nine sectors in border enforcement hours from 1992 to 2001. The Tucson Sector was consistently sixth in the expenditure of staff hours from 1992 to 1996. As staffing increases deflected migrant flows away from urban crossing areas such as San Diego, the Tucson Sector responded by hiring more agents. Consequently, Tucson reported the third highest number of hours in 1997, second in 1998 and 1999, and led all other southwest sectors by 2001.[43] The eight stations within the Tucson Sector experienced change in patrol hours concurrent with the overall border adjustments. In 1999 the Ajo station, which encompasses the Monument, ranked seventh among the stations in enforcement hours reporting 89,182 in 1999. Activity dropped to 79,610 hours in 2000, and made a leap to 134,161 hours in 2001 placing it fifth among the Tucson stations.[44]

Today, monument managers face a number of environmental issues resulting from the dramatic numerical increase in undocumented human traffic maneuvering through the Monument, often utilizing the historic roads and trails. Large numbers of clandestine migrants and smugglers as well as magnified law enforcement presence compromise the movements of endangered species such as the pronghorn antelope,

[40] Eschbach, Karl et al. "Death at the Border", *International Migration Review* 33 (Summer, 1999): 430-454.
[41] "Migrant Deaths; Fiscal Year 199-2001", unpublished INS statistics.
[42] Budget numbers are calculated in 1993 dollars. "Immigration and Naturalization Service; Authorized Positions - Fiscal Years 1975-2002." At http://www.usdoj.gov/jmd/budgetsummary/btd/1975_2002/btd01ins.htm [cited 3 March 2002].
[43] "Border Enforcement Man Hours (Non-Administrative hours)" INS unpublished statistics.
[44] Ibid.

create semi-permanent paths in the delicate desert vegetation, and leave behind trails of trash, abandoned automobiles, and human waste. Although movement of peoples through the Monument landscape has a long history, the construction of a protected wilderness space along the border combined with shifting federal immigration policy, particularly since the mid-1990s, have altered the impact intensity upon lands within the Monument. Since the wilderness designation in 1978, and particularly since the tightening of urban border crossings, the area has drawn clandestine traffic as individuals wishing to enter the U.S. from south of the border have shifted and adapted their crossing strategies. In many ways though, it is the nature of the Monument as a preserved, monitored, and highly public landscape that has invited as well as highlighted environmental change resulting from transnational human passage.

Appendix G

Determining Foraging and Roosting Areas for Underwood's Mastiff Bat (Eumops underwoodi) Using Radiotelemetry, At Organ Pipe Cactus National Monument, Arizona

Final Summary Report, Year Two – December 2002

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Abstract

Underwood's mastiff bat (*Eumops underwoodi*) is a large, little-understood tropical species, reaching its northern distribution limit in extreme southern Arizona. One of the few locales where it occurs is Quitobaquito Pond in Organ Pipe Cactus National Monument. Quitobaquito is located on the U.S. - Mexico border next to a busy highway, and is subject to various threats. Further, the border area nearby is undergoing changes due to increasing human population, tourism, increasing industrialization, and changes in land uses. Quitobaquito and the border area are clearly of importance to this bat for foraging, roosting, and accessing water in an arid landscape. To expand our knowledge of this bat's life history and to identify potential management issues, we sought to determine foraging and roosting areas using radiotelemetry. *E. underwoodi* were found to forage widely across and along the international border area. Foraging habitat ranged from rugged wilderness topography to agricultural and semi-urban areas. Unexpectedly, they were found to be roosting in woodpecker cavities in saguaro cactus (*Carnegia gigantea*). This is the first documentation of this species roosting in cactus cavities, and a rare documentation of any bat species doing so.

Introduction

Organ Pipe Cactus National Monument (OPCNM) lies in southwestern Arizona, and is comprised of approximately 330,689 acres of Sonoran Desert plains, bajadas, and rugged mountains. OPCNM is located on the international border with Mexico, with its "sister" park, El Pinacate Reserva de la Biosfera, nearby to the southwest.

Two species of mastiff bats are found in OPCNM; the western mastiff bat (*Eumops perotis*), and Underwood's mastiff bat (*E. underwoodi*). In contrast to the rest of Arizona and the southwest, the widely-distributed *E. perotis* is encountered rarely in OPCNM. However, the regionally "uncommon" *E. underwoodi* is encountered commonly in OPCNM, at Quitobaquito Pond. Underwood's is a little-studied bat of Mexico and Central America (Kiser 1995). The northernmost subspecies, *E. u. sonoriensis*, is limited in distribution to southern Arizona and Sonora, Mexico. In the U.S. it is known only from OPCNM and several other locales southwest of Tucson (Cockrum and Gardner 1960, Hoffmeister 1986, Petryszyn et al. 1996 and 2000). At these southern Arizona locations, *E. underwoodi* has been observed and captured as it visits open ponds to drink on the wing. It seems likely that for this large, fast-flying bat, relatively large, open bodies of water may be important resources for drinking. Quitobaquito Pond (approx. 0.5 ac/ 0.2 ha in extent) is one of very few locations in the arid border area of southcentral and southwestern Arizona where such water resources exist. Quitobaquito is located approximately 100m (328 ft) north of the international boundary.

Quitobaquito is heavily used by park visitors, researchers, and as an illegal border crossing point. The latter use ranges from serving as a *de facto* rest stop along Mexico Highway 2, to smuggling activity. The National Park Service manages

Quitobaquito to ensure the continued survival and security of the endangered endemic Quitobaquito pupfish (*Cyprinodon eremus*), and to provide shallow water habitat for the Rio Sonoyta mud turtle (*Kinosternon sonoriense longifemorale*). The importance of Quitobaquito to local *E. underwoodi* is also a management concern, and was a motivating factor in undertaking this study. Quitobaquito likely faces a variety of increasing pressures and threats. Human activities in general are increasing in the area, as the Sonoran city of Sonoyta is expanding westward along Mexico Highway 2 toward Quitobaquito, and as plans progress to expand Highway 2 from two lanes to four. It has become important to determine the locations of the foraging and roosting habitats of the local *E. underwoodi* so that any conservation issues can be identified. Because of the rarity of *E. underwoodi* in the United States, and the desire to assure that it is being adequately conserved, OPCNM's Resources Management Plan (1994) identified investigating the status of this species as a priority (Project Statement ORPI-N-266). Petryszyn et al. (2000) ultimately recommended attempting to find the local *Eumops* roost site(s) using radiotelemetry.

Recent investigations in OPCNM have developed intriguing preliminary information on *E. underwoodi*. Banding operations by Petryszyn et al. (1996 and 2000) and general bat monitoring by OPCNM staff resulted in high rates of recaptures of *E. underwoodi* banded at Quitobaquito Pond. This implies several things. First, Quitobaquito is clearly a very important watering resource for these bats, as individuals return regularly throughout the year, and over several years. Second, although Petryszyn et al. (1996 and 2000) did not intend their banding project to be a mark-recapture population estimate, the high recapture rate of banded *Eumops* could imply a fairly small local population. In 2000, OPCNM staff carried out a light-tagging project to gain preliminary indications of where the *Eumops* bats frequenting Quitobaquito are foraging and roosting. Visual observations suggested the bats were foraging over a fairly wide local area, including the Quitobaquito area, adjacent Aguajita Wash, desertscrub and hill slopes in both the United States and Mexico, the Rio Sonoyta, and along Mexico Highway 2 (OPCNM unpubl. data). In the latter case, bats were observed foraging low over the highway, sometimes in the headlights of the busy truck traffic.

With preliminary indications suggesting a general area used for foraging (OPCNM unpubl. data), published literature led us to expect *E. underwoodi* would roost in locations where they would have a substantial vertical drop to return to flight after roosting. This expectation paralleled speculations of others, that because of its morphology of long, narrow wings designed for fast, long flight *E. underwoodi* may need a vertical drop of considerable distance to achieve flight (e.g. Kiser 1995), and roosting in cliff crevices should be expected (Kiser 1995, M. Rabbe, AGFD pers. comm.). However, roosting in tall trees and palms has also been described (Watkins et al. 1972 and Hellebuyck et al. 1985, both in Kiser 1995), suggesting a height of perhaps 10m (33 ft) may be adequate. We expected to find that *E. underwoodi* roosts in crevices in rocky outcrops or cliffs on steep mountain slopes, possibly considerable distances from Quitobaquito.

Methods

We captured bats September 20-22, 2001, June 4, 5 and 10, 2002, and August 2-3, 2002. Bats were captured using two 2.6m x 12m mist nets deployed across Quitobaquito Pond end-to-end. The nets were opened at dusk, and kept open until after midnight. We serviced the nets using an aluminum jonboat and two kayaks. Only personnel with current rabies pre-exposure vaccines handled bats. Bats were removed from the net and taken to shore for processing. Bats of non-target species (chiefly *Nyctinomops femerosacca*) were identified to species and sex, then released. *Eumops* bats were identified to species, sex, and age, and measured for weight and forearm length. For radiotelemetry, we used BD-2 transmitters (Holohil Systems, Ltd), weighing 1.53g each, with pulse rates ranging from 1.88 to 1.90 pulses/second. Before attachment on *Eumops* bats, the transmitters were turned on and the signal tested with a receiver setup. We then slightly trimmed the intrascapular fur and attached the radiotransmitter between the shoulder blades, using non-toxic Skin-Bond® medical adhesive. We trimmed the radio antenna so that it extended slightly beyond the tail.

We carried out radiotelemetry tracking September 22 - October 2, 2001, June 4-16, 2002, and August 2-6, 2002. We used 5-element directional antennae (Wildlife Materials, Inc.) mounted on 2-meter aluminum masts and secured in Bogen 3126 tripods. To read directional bearings, we fixed a compass to an aluminum bracket mounted on the aluminum mast and calibrated to geographic north. We used R-1000 (Communications Specialists, Inc.) and TRX-1000 (Wildlife Materials, Inc.) telemetry receivers. Radio trackers monitored for radio signals from sunset onward, from hilltops, from roving stations based in the back of a pickup truck, and on foot. Trackers recorded compass bearings for every minute they received a signal, until the signal was lost or the bat had returned to its roost site. During 2001 and the initial nights of 2002, radiotracking continued through the night. In 2001, we found that after a bat returned to a roost near midnight, it virtually never re-emerged until after sunset the following day. As a result of this observation, and because of travel limitations and security concerns imposed by the international border, in 2002 we rarely maintained nightlong monitoring after the bats had returned to a roost near midnight. When observations indicated that, after significant foraging movements, a bat was remaining stationary in a known roost area near midnight, monitoring was often terminated.

The general locations of bats were followed through the night in real-time, by observers using two-way radios to communicate their respective compass bearings on the radio signals. Specific bat locations were determined for as many 1-minute intervals as possible for each night, by finding the crossbearings of two to five simultaneous compass readings for the radio signal direction, as measured by observers. All observers recorded the locations of their stations using geographic positioning system (GPS) units. The observers' directional readings were then projected from their observation points in a geographical information system (ArcView 3.2) to plot the bats' positions.

Results

We captured, outfitted with radiotransmitters, and tracked four *E. underwoodi* and no *E. perotis*. We captured two *E. underwoodi* in 2001 and another two in 2002. This was an unusually low number of *E. underwoodi* captures for Quitobaquito. It is possible that more *Eumops* were not caught because of the large numbers of non-target species that were captured - primarily *Nyctinomops femerosaccus*. In 2001, we captured two *Eumops* bats and 328 bats of other species, for a ratio of non-target to *Eumops* of 164 to 1, or *Eumops* comprising 0.6% of all captures. In 2002, we captured two *Eumops* bats and 259 bats of other species, for a ratio of non-target to *Eumops* of 129.5 to 1, or *Eumops* comprising 0.77% of all captures. These large numbers of non-target captures resulted in nearly constant bat handling activity at the nets, with headlamps and other associated activities. During most evenings we often heard *E. underwoodi* flying over the net, identifiable by their distinctive vocalizations (Cockrum and Gardner 1960, Constantine 1961). We suspect that the high level of activity by humans and captured non-target bats were likely to be scaring *E. underwoodi* away from the net, thus preventing capture. In 1994-1995, Petryszyn et al (1994) caught 35 *Eumops* and 267 non-target species, for a total proportion of captures of 11.6% *Eumops*. In 1996, Petryszyn et al (2000) caught 10 *Eumops* and 413 non-target species, for a total proportion of captures of 2.3% *Eumops*. Petryszyn et al. (2000) noted a rise in *Nyctinomops* captures coincidental with reduction in *Eumops* captures between the 1994-1995 work and 1996, and suggested there may be a connection. Our large numbers of captures of *Nyctinomops* in 2001-2002 may indicate an increasing trend in that species, with concomitant and consequent reductions in *Eumops* capturability. However, it is also possible that *Eumops* numbers, or their use of Quitobaquito, have experienced a true decline since 1994-1995. Of the four *E. underwoodi* that were instrumented, three yielded valuable data. These three individuals, *Eumops* #218, #239, and #284, were each tracked almost nightly for up to two weeks. For all three bats, we were able to determine foraging areas, travel routes, and roost sites, with a high degree of precision. The other bat, *Eumops* #198, was radiotracked September 21, 2001 and may have been detected briefly on September 22, but never afterwards. We speculate that contact with *Eumops* #198 was lost early because either the bat left the general region, or the radiotransmitter fell off, or

ceased to transmit. No data from *Eumops* #198 are presented here.

For *Eumops* #218, #239, and #284, roosting habitat and roost sites were located relatively easily. On the first several mornings of the project in 2001, stationary radio signals from *Eumops* #218 indicated the bat was roosting in low-lying desertscrub habitat in Mexico, between the international boundary and the nearby Rio Sonoyta. We suspected roosting in woodpecker cavities in saguaro cactus. This suspicion was based on the lack of other conceivable alternatives, the abundance of potential roost cavities in saguaros, and a pronounced directionality of the radio signal suggesting it was passing through a narrow opening. On September 27, 2001 this suspicion was confirmed. A 9-meter (30 ft) tall saguaro approximately 415m (1361 ft) south of the international border was located as the suspected roost, based on pre-dusk radio signal. Beginning at 1858hr, two probable *Eumops* were observed flying in succession out of a cavity near the top of the saguaro. Soon after, *Eumops* #218 emerged. We located subsequent roost sites for *Eumops* #218, #239, and #284 in similar fashion, and found all three roosting in woodpecker cavities in saguaro cactus, in the western portion of the Rio Sonoyta valley (Figure G-1). All three bats changed cavities from night to night, but seemed to cycle between a fairly small number of cavities. These favored roosts were typically within 1 km (1.6 mi) of one another. Each bat was confirmed day-roosting in only two individual saguaros each, and *Eumops* #284 used a third as a temporary night roost on one occasion. However, several nights for each bat

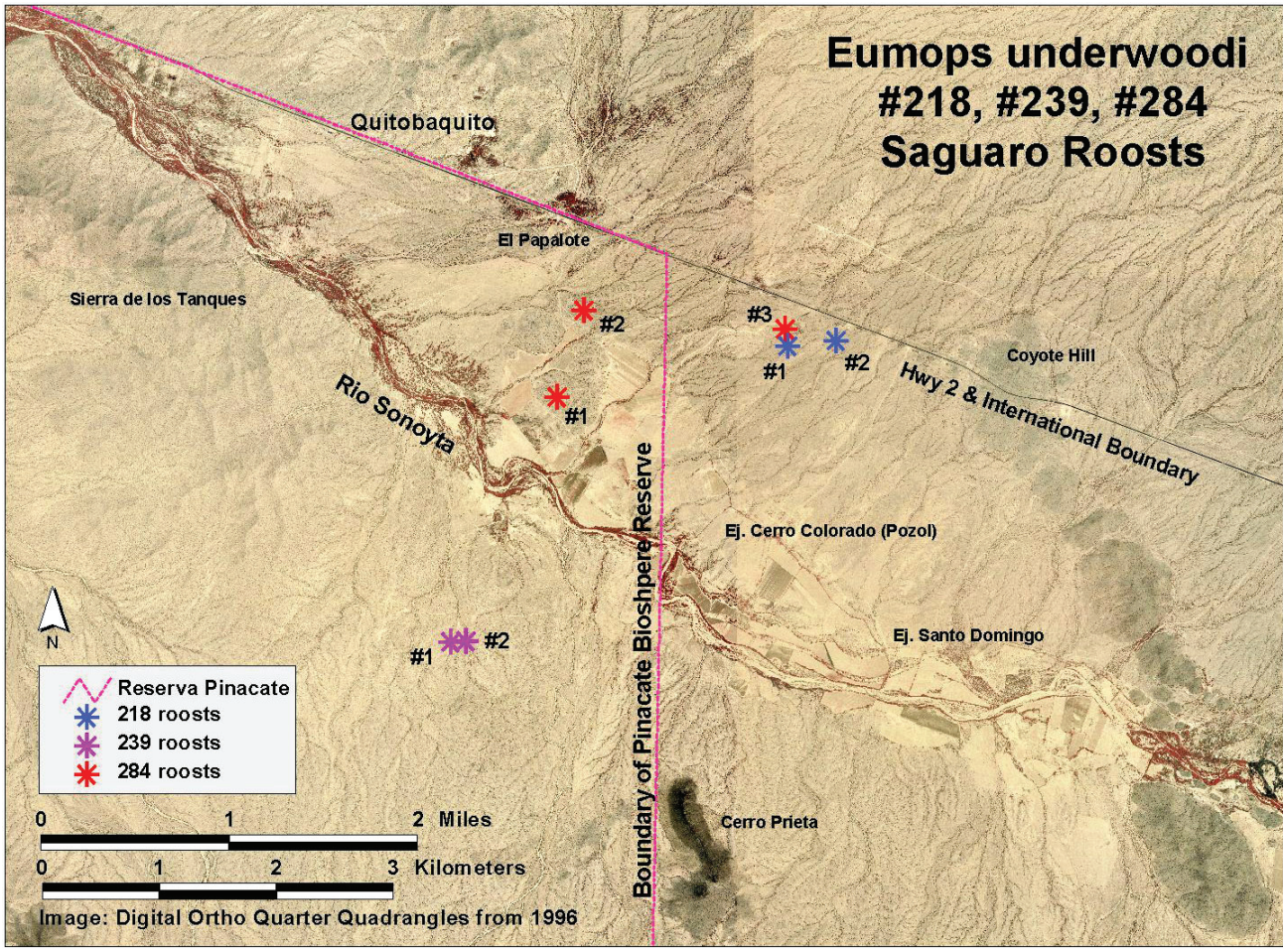

Figure G-1. Locations of roost sites in saguaro cactus, for Eumops underwoodi #218, #239, and #284, along the U.S./Mexico border.

we did not confirm the specific roost saguaro, but only confirmed that the bat radio signal had gone stationary and faint near midnight (typical of a roosting bat), at the cross bearings of a known roost saguaro. It is possible that in those cases, the bat may have roosted in a saguaro other than a known one, but so close as to be indistinguishable by radiotelemetry triangulation.

Roost saguaros different only slightly in setting. *Eumops* #239 used saguaros in rolling, undeveloped bajada topography south of the Rio Sonoyta (Figure G-1.) *Eumops* #284 roosted in a small area of undeveloped, slightly undulating topography surrounded by agricultural fields, and also used a saguaro within a few hundred meters of Mexico Highway 2 as a temporary night roost (Figure G-1.). Eumops #218 day-roosted in several saguaros also located within a few hundred meters of Mexico Highway 2 (Figure G-1.). Saguaros selected for roosting were all fully mature, large individuals with several arms and multiple cavities (Figure G-2). While the roost cavity was often high on the plant, on several occasions the bats selected lower cavities, sometimes on an arm. We determined that *E. underwoodi* roosts both solitarily, and in small groups. As noted above, on September 27, 2001, *Eumops* #218 had roosted with two other probable *Eumops*. On September 30, 2001, we videotaped four probable *Eumops* emerging from a cavity, followed soon after by *Eumops* #218. In 2002, we observed *Eumops* #239 and #284 roosting singly, never with other bats.

The three *Eumops* bats displayed comparable home ranges and foraging areas (Figure G-3.). All three roosted in the western part of the Rio Sonoyta valley, approximately 1.5 to 4.2 km (1-2.6 mi) south or southeast of Quitobaquito, near the northeastern corner of El Pincate Biosphere Reserve. (Figure G-3). All three ranged eastward and southward during probable foraging movements. All three engaged in movements generally along the axis of the Rio Sonoyta valley, but ranged north and south onto adjacent bajadas and mountain slopes. All three incorporated the city of Sonoyta, Sonora, in their home ranges.

Figure G-2. Eumops underwoodi roost site in saguaro cactus (note woodpecker cavities). Pinacate Biosphere Reserve, Sonora, Mexico. June 2002.

Nightly activity and home range summaries for Eumops #218, #239, and #284 are presented in Tables G-1, G-2, and G-3, respectively. Geographic mapping of nightly and cumulative home ranges are presented in Appendix 1 (*Eumops* #218), Appendix 2 (*Eumops* #239), and Appendix 3 (*Eumops* #284). Our radiotelemetry data suggested that *Eumops* #218 did not return to Quitobaquito Pond in the two weeks between its capture and October 2, 2001. It is possible this individual avoided Quitobaquito for some period after the capture experience, instead taking water at reservoirs or sewage ponds near Sonoyta. In 2002, radiotelemetry data suggested both *Eumops* #239 and #284 returned to Quitobaquito within several days of their capture. However, they did not make nightly visits to the pond.

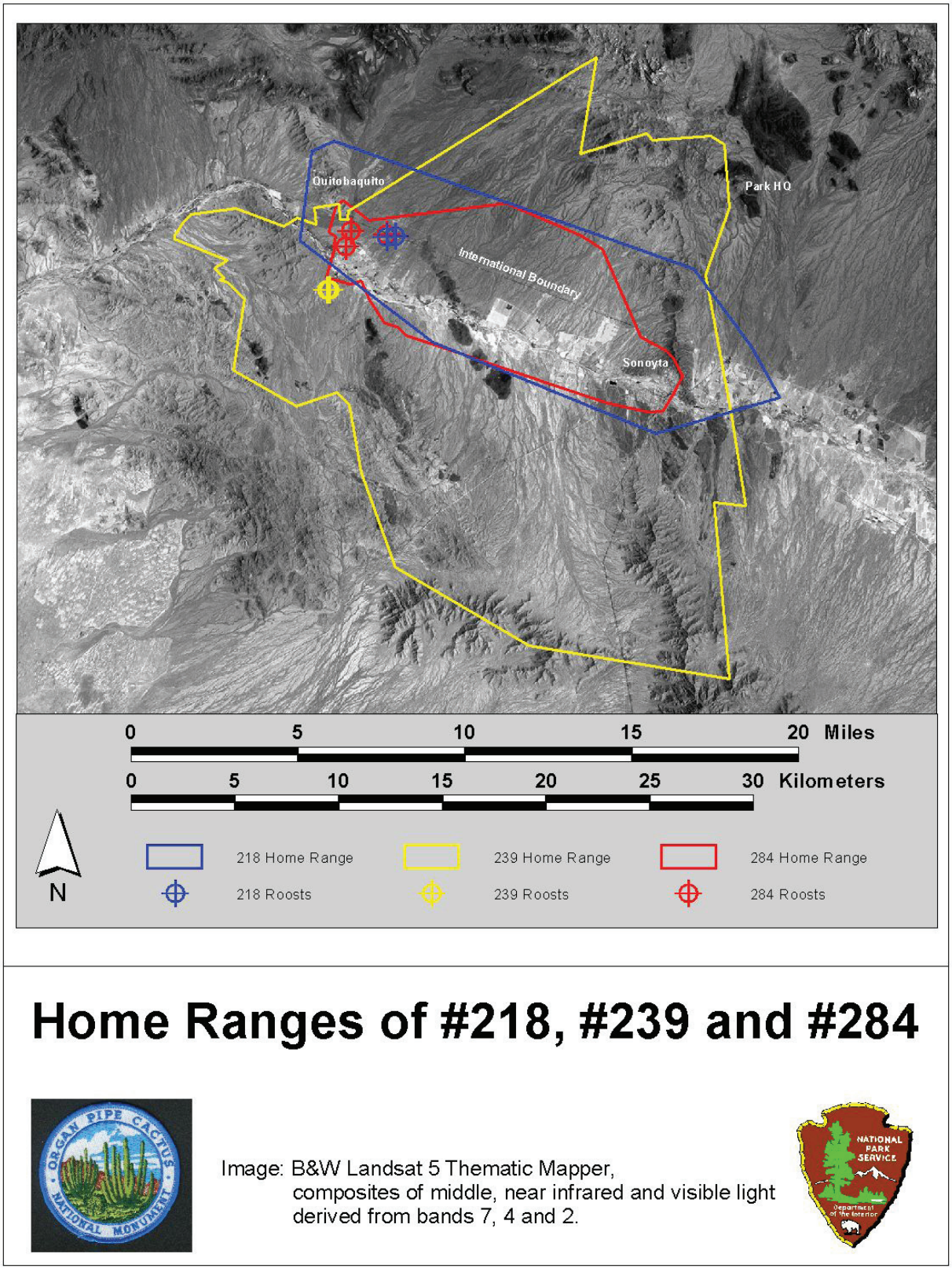

Figure G-3. Total cumulative home ranges for *Eumops underwoodi* #218, #239, and #284. Organ Pipe Cactus N.M., Arizona.

Table G-1. Daily time, activity, and home range summary for Eumops #218, Organ Pipe Cactus N.M., Arizona.

Date	[1]Time exit from roost	[2]Time return to roost	Elapsed time	Nightly Home Range Area				Movements / Comments
				Acres	Miles^2	Hectares	Km^2	
9-21-01	[3]0000 hr	0520 hr	5 hr 20 min	2,673	4.18	1,082	10.8	From Quitobaquito and Quitobaquito Hills southeastward to near Coyote Hill obs. Point, then return west to roost.
9-22-01	1900 hr	0530 hr	10 hr 30 min	24,534	38.33	9,928	99.3	Western Sonoyta Valley, then southeastward to Sonoyta, Sonoyta Hills, then return west to roost.
9-23-01	1855 hr	2310 hr	5 hr 15 min	15,377	24.02	6,223	62.2	Western Sonoyta Valley, then southeastward to Sonoyta, Sonoyta Hills, then return west to roost.
9-24-01	1905 hr	2035 hr	1 hr 30 min	7,141	11.15	2,890	28.9	Remained in western and middle Sonoyta valley
9-25-01	1855 hr	2305 hr	4 hr 10 min	6,136	9.58	2,483	24.8	Remained in western and middle Sonoyta valley
9-26-01	1905 hr	2250 hr	3 hr 45 min	6,060	9.46	2,452	24.5	Western Sonoyta Valley, then southeastward to Sonoyta Hills, then return west to roost.
9-27-01	1905 hr	2300 hr	3 hr 55 min	7,640	11.93	3,092	30.9	Western Sonoyta Valley, then southeastward to Sonoyta and beyond to eastern edge of city, then return west to roost.
9-30-01	1837 hr	Unknown	Unknown	-	-	-	-	Weather cancellation
10-2-01	1830 hr	>2330 hr	>5 hr	9,329	14.57	3,775	37.8	Western Sonoyta Valley, then soutgheast to Sonoyta, Sonoyta Hills, then return west to roost.
		Total net home range:		39,624	61.91	16,035	160.4	"Total" figures are the total *net* home range areas, not the sum of nightly ranges, which had substantial nightly geographical overlap.

[1]Time certain; direct observation.
[2]Time approximated by suddenly diminished signal strength at fixed location, observed by several stations. Often confirmed shortly afterward by direct local signal location.
[3]Time released after capture/instrumentation at Quitobaquito.

Table G-2. Daily time, activity, and home range summary for Eumops #239, Organ Pipe Cactus N.M., Arizona.

Date	[1]Time exit from roost	[2]Time return to roost	Elapsed time	Nightly Home Range Area Acres	Miles^2	Hectares	Km^2	Movements / Comments
6-4-02	0252 hr[3]	0307 hr	15 min	1,572	2.46	636	6.4	Flew almost directly from Quitobaquito release to roost
6-5-02	2005 hr	0015 hr	4 hr 10 min	30,008	46.89	12,144	121.4	From roost eastward to Sonoyta and return to roost
6-6-02	2021 hr	>2315 hr	>2 hr 54 min	23,678	36.99	9,582	95.8	From roost eastward to Sonoyta and return to roost
6-7-02	2015 hr	2243 hr	2 hr 28 min	27,590	43.11	11,165	111.6	From roost eastward to Sonoyta and return to roost
6-8-02	2022 hr	2243 hr	2 hr 21 min	3,861	6.03	1,563	15.6	Remained in roost vicinity in western Rio Sonoyta valley. High winds from southeast.
6-9-02	2008 hr	2241 hr	2 hr 31 min	15,609	24.39	6,317	63.2	From roost eastward to Sonoyta and return to roost
6-10-02	2008 hr	2109 hr	1 hr 1 min	12,483	19.50	5,052	50.5	Remained in western Rio Sonoyta valley.
6-11-02	2015 hr	2250 hr	2 hr 35 min	21,357	33.37	8,643	86.4	From roost northeastward to Sonoyta Mts, possibly Senita Basin area (?) and return to roost.
6-12-02	2013 hr	2130 hr	1 hr 17 min	10,670	16.67	4,318	43.2	Remained in western Rio Sonoyta valley.
6-13-02	2014 hr	0010 hr	4 hr 13 min	46,444	72.57	18,795	187.9	From roost northeastward to Sonoyta Mts, Senita Basin, southern Puerto Blanco Mts, return to roost.
6-14-02	2009 hr	0050 hr	4 hr 41 min	70,333	109.89	28,463	284.6	Remained in western Rio Sonoyta valley.
6-15-02	2015 hr	>2130 hr	>1 hr 15 min	15,907	24.85	6,437	64.4	From roost eastward to midsection of Rio Sonoyta valley
6-16-02	2018 hr	0020 hr	4 hr 2 min	53,889	84.20	21,808	218.1	From roost northeastward to Senita Basin area (?), then Sonoyta, then return to roost
6-20-02		-	-	-	-	-	-	Informal check: radio still operational. Based on radio signal, bat appeared to emerge from favored saguaro roost.
			Total net home range:	117,066	182.92	47,375	473.7	"Total" figures are the total *net* home range areas, not the sum of nightly ranges, which had substantial nightly geographical overlap.

[1]Time certain; direct observation.
[2]Time approximated by suddenly diminished signal strength at fixed location, observed by several stations. Often confirmed shortly afterward by direct local signal location.
[3]Time released after capture/instrumentation at Quitobaquito.

Table G-3. Daily time, activity, and home range summary for Eumops #284, Organ Pipe Cactus N.M., Arizona.

Date	[1]Time exit from roost	[2]Time return to roost	Elapsed time	Nightly Home Range Area				Movements / Comments
				Acres	Miles^2	Hectares	Km^2	
8-2-02	2247 hr [3]	0046 hr	1 hr 59 min	250	0.39	101	1.0	From release at Quitobaquito to local activity near roost
8-3-02	2008 hr	2103 hr	55 min	845	1.32	342	3.4	Remained in western Rio Sonoyta valley, including probable return to Quitobaquito
8-4-02	2001 hr	2356 hr	3 hr 55 min	21,826	34.10	8,833	88.3	From roost northeastward, probably to Senita Basin, then Sonoyta, and return to roost.
8-5-02	1958 hr	2340 hr	3 hr 42 min	1,861	2.91	753	7.5	Remained in western Rio Sonoyta valley. Intermediate roost 2045-2329 hrs near Highway 2; then return to original roost.
8-6-02	2002 hr	2044 hr	42 min	15,834	24.74	6,408	64.1	From roost eastward to Sonoyta and return to roost
		Total net home range:		24,617	38.46	9,962	99.6	"Total" figures are the total *net* home range areas, not the sum of nightly ranges, which had substantial nightly geographical overlap.

[1]Time certain; direct observation.
[2]Time approximated by suddenly diminished signal strength at fixed location, observed by several stations. Often confirmed shortly afterward by direct local signal location.
[3]Time released after capture/instrumentation at Quitobaquito.

Discussion

Roosting

Woodpecker cavities in saguaro cactus were the only roost habitat documented in this study. All saguaros used for roosting were located in the Rio Sonoyta valley, in Mexico, in an area just south and southeast of Quitobaquito Springs (Arizona) and approximately 21-24 km (13-15 miles) west of the city of Sonoyta (Figures 1 and 2). This general area was also used extensively in roving movements assumed to constitute foraging, just after emerging from and just prior to returning to roosts. Near the roost sites, bats moved over low, relatively flat terrain, and also along low hills and rocky ridges of the Sierra los Tanques in Pinacate Biosphere Reserve in Mexico, and the Quitobaquito Hills in the U.S.

To our knowledge, this study provides the first documentation of *E. underwoodi* or any *Eumops* bat using woodpecker cavities in saguaro cactus for roosting. Concurrent with our study, and in northwestern Sonora near our study area, A. Flesch observed probable *Eumops* bats roosting in saguaro cavities. Flesch was inspecting saguaro cavities in daytime, using a micro-video camera as part of his study on ferruginous pygmy-owls (*Glaucidium brasilianum*) (A. Flesch, University of Arizona, pers. comm. August 2002). Use of saguaro cavities for roosting has been documented for the big brown bat (*Eptesicus fuscus*) (Cross and Huibregtse 1964). Pape (1998) also observed several bats, believed to be *E. fuscus* and/or the pallid bat *(Antrozous pallidus*), emerging from a saguaro cavity. S. Morales observed one probable bat of unknown species inside a saguaro cavity in the Tucson region (S. Morales, Harris Environmental Group, Inc. pers. comm. September 2002*).* Also in the Tucson area, Stutchbury (1991) observed a small bat entering a saguaro at dawn. These records are all those we could verify, for any bats species roosting in saguaro cavities. However on consideration, saguaro cavities may offer a valuable roost habitat, at least for solitary roosting or roosting in small numbers. Saguaro cavities provide a dark environment, with thermal protection and considerable security from predators. Saguaro cavities are typically approximately 2 to 4 liters (122 - 244 in^3) in volume. Considering that *E. underwoodi* is the second-largest North American bat, the roost site height above ground should be adequate for any other resident species to achieve flight. In Sonoran Desert bajadas, plains, and valley landscapes where caves, mines, and rock crevices may be rare or absent, saguaro cavities are a typically abundant and well-distributed potential roost resource.

At the start of this project, we accepted the prevailing view that *Eumops* bats would be found roosting in a site where they would be afforded a considerable free-fall to gain flight – perhaps 10m (32 feet) or more. We anticipated roost sites in cliffs or steep rocks of the Bates, Puerto Blanco, or Cubabi mountains. Our visual observations (and documented in the September 30, 2001 videotape) found that *E. underwoodi* exiting a saguaro cavity and swooping downward only 2 to 4 meters were able to achieve level or ascending aerodynamic flight. This conforms with records of *E. underwoodi* roosting in tall trees and palms as described by Watkins (et al. 1972) and Hellebuyck (et al. 1985, both in Kiser 1995). Saguaro cactus are abundant across many bajada settings of southern Arizona, although not at the higher elevations of *E. underwoodi* records in the upper Altar Valley area reported by Cockrum and Gardner (1960). *E. underwoodi* may also find roosting opportunities in tall to relatively small cliffs across the region.

The saguaro-cavity roost sites used by *E. underwoodi* appear to be, on the surface, a nearly unlimited resource. These cavities are excavated by Gila woodpeckers (*Melanerpes uropygialis*), and northern flickers (*Colaptes auratus*, including the "gilded flicker" form). Many other bird species in the study area use these cavities subsequently for nesting, and are known as "secondary cavity nesters" because they are unable to excavate cavities themselves. These include: ash-throated flycatcher (*Myiarchus cinerascens*), brown-crested flycatcher (*M. tyrannulus*), purple martin (*Progne subis*), house finch (*Carpodacus mexicanus*), American kestrel (*Falco sparvarius*), western screech-owl *(Otus kennicottii*), elf owl (*Micrathene whitneyi*), and ferruginous pygmy-owl (*Glaucidium brasilianum cactorum*). In addition, honeybees (*Apis mellifera*) are not uncommonly seen using saguaro cavities – although usually cavities of greater extent (e.g.

injury) than woodpecker cavities. Despite this competition, it is likely that because of their abundance, saguaro cavities are widely available for roosting by *E. underwoodi* in the study area. However, it is possible that with the expansion of Sonoyta and associated changes in land use, the anthropogenic-associated house finch and the non-native European starling (*Sturnus vulgaris*), also secondary cavity nesters, may increase.

The ability of *E. underwoodi* to range up to 24 km (15 mi) or more on foraging bouts from its roost site demonstrates that roost sites do not need to be available in close proximity to foraging areas. Still, some concerns may exist regarding saguaro-cavity roost sites. First, despite a widespread availability of saguaros throughout the study area, all roost sites were in a relatively limited area, low in the Rio Sonoyta Valley, near the western end of this valley. This may suggest that the western Rio Sonoyta valley may have specific attraction as a roosting area – possibly specifically because the water source of Quitobaquito is nearby. On the other hand, our study may have been biased toward detecting roosts in this area because all bats were captured nearby at Quitobaquito. It is possible that other *E. underwoodi* roost elsewhere in saguaro stands, but do not visit Quitobaquito because they are able to find water elsewhere, or selected other saguaro stands for other reasons. At this point, there is not adequate information to speculate what attributes might make one area of saguaros superior or inferior to others for *Eumops* roosting.

Several factors may affect saguaro cactus abundance over time. Livestock grazing is extensive in Mexico in the area of the roost sites. Saguaro seedling establishment and survival are negatively affected by long-term livestock grazing, so some long-term sustainability questions exist. Also, buffelgrass (*Pennisetum ciliare*) infestation is extensive in northern Sonora and especially along the Highway 2 corridor through the Rio Sonoyta valley. This raises medium-range concerns for the viability of saguaro populations. Currently, buffelgrass is intensively eradicated from OPCNM. As long as that program persists, saguaro-cavity availability in OPCNM should remain high.

Foraging

In movements that we assumed to constitute foraging, we found *E. underwoodi* to be foraging in a range of habitats, including undeveloped wilderness, Sonoran desertscrub, mesquite-tamarisk riparian woodland, agricultural areas, rural development, topography ranging from flat to very steep, and the semi-urban small city of Sonoyta (Figure 3). The differences among the three *Eumops* in total cumulative home ranges (Figure 3) seem likely to have been correlated with the amount of movement data collected. The bat tracked the least number of nights (*Eumops* #284) had the smallest cumulative home range, while the bat tracked the longest (*Eumops* #239) accumulated data points defining a much larger home range. This effect may have been compounded by bats engaging in aberrant and restricted foraging movements for the first several nights after the trauma of capture and instrumentation. As illustrated in Tables G-1 – G-3), each bat exhibited night-to-night variation in the location and areal extent of its movements. *Eumops* #239 was radiotracked over the most nights, and likely represents the minimal total home range for the species in this area over the longer term.

We observed bats moving widely throughout the Rio Sonoyta valley and adjacent desert bajadas. At local scales, the bats seemed to be foraging low in desertscrub plains, also above desertscrub, along rocky ridges and mountain slopes, and in artificially lighted areas of Sonoyta. Kiser (1995) reported that the diet of *E. underwoodi* in Arizona east of OPCNM included scarab beetles, short-horned grasshoppers, leafhoppers, and moths. In Michoacan, Mexico, one *E. underwoodi* had remains of large June beetles and long-horned beetles in its stomach (Kiser 1995). It is reasonable to expect that in our study area *E. underwoodi* are feeding on a variety of terrestrial and flying arthropods.

The three *Eumops* bats we examined spent the majority of their flight time over relatively flat terrain in the Rio Sonoyta valley and adjacent bajadas. However, as in a light-tagging project undertaken in 2000 (OPCNM, unpubl. data), we also observed radioed *Eumops* flying around and along topographic features ranging from small

hills (e.g. Quitobaquito Hills) to steep, high, rocky ridges (e.g. Puerto Blanco Mountains). This use was best illustrated by *Eumops* #239, which was radiotracked the longest. Other bats (e.g. #284) may also have visited these topographical features, but this was not detected or confirmed due to limited or inconclusive radiotelemetry data. Observers on ridgetops commonly heard the distinct vocalizations of non-radioed *Eumops* overhead, sometimes seen and heard in groups of six or more, indicating that these bats fairly commonly forage along ridgelines, hilltops, and other raised topographic feature. Our observations suggested *Eumops* may favor windward slopes, as if the bats used favorable wind currents for flight energetics, and/or that upslope winds created predictable concentrations of nocturnal aerial invertebrate prey.

As the western end of the combined home ranges of the three radioed bats was centered on the roost area, the eastern end of their ranges was centered on and defined by the city of Sonoyta, Mexico (Figure 3 and Appendices). Roving telemetry stations in Sonoyta found the bats to be visiting business and residential areas, lighted areas, as well as rocky slopes at the southern base of the Sonoyta Mountains, at the city's edge. The time spent by our radioed *E. underwoodi* in or near Sonoyta - usually 1- 3 hr per visit - strongly suggests the bats foraged for arthropods attracted to artificial lights or other anthropogenic sources, and/or was visiting water sources in or near Sonoyta.

The species demonstrated an ability to cover large areas in a single evening. The largest single- night home range recorded was 284.6 km^2 (109.89 mi^2), for *Eumops #239* on June 14, 2002. All three bats commonly ranged over approximately 100 km^2 (37 mi^2) on a typical night. It is difficult to estimate total linear distances flown per night, because of the meandering routes often used by individual bats. However, most bats on most nights traveled 20-30 km (32-48 mi) at the very least, and often more in the range of 50-100 km (80-160 mi) as a minimum estimate. We observed extensive back-and-forth movements within a given night's home range, e.g. back and forth along long mountain ridges or back and forth across Sonoyta. Such movements suggest that bats may fly hundreds of kilometers per night – and often in just several hours.

Eumops bats varied their foraging habitats from night to night, sometimes favoring undeveloped desert areas, sometimes favoring semi-urban Sonoyta. Even discounting extremes of foraging time (as little as 42 minutes, to as much as 10 hours), bats often varied their foraging time between 1-2 hours and 4 -5 hours (Tables 1-3). This suggests differential foraging success from night to night – or perhaps other phenomena – but also indicates that just several hours of foraging in current habitats were sufficient to sustain an individual bat. Bats usually returned to a roost by midnight, but on two occasions remained active until nearly dawn. Infrequently, an interim short-term night-roost was confirmed (e.g. *Eumops* #284 on August 5, 2002). As noted above in "Methods," nightlong monitoring in 2001 and early 2002, indicated bats usually returned to a roost near midnight, and did not re-emerging until after sunset the following day. Petryszyn et al (1996 and 2000) found that the great majority of *E. underwoodi* were captured at Quitobaquito before midnight, further suggesting little activity in the second half of the night. In the latter stages of the project in 2002, we continued to track bats back to a roost by midnight, but did not monitor for subsequent movements through the night. On one occasion we find that a bat had moved to a different roost between the middle of the night and the following day.

In our study area, *E. underwoodi* clearly has adapted to human influences on the environment, foraging in downtown Sonoyta as well as relatively pristine desert plains and rocky ridges. This suggests that *E. underwoodi* may be able to adapt to continuing human development in the Rio Sonoyta valley, as long as natural preserves also remain available nearby. Ultimately, foraging habitat quality is determined by prey availability. If large-scale insecticide applications took place in the Rio Sonoyta valley, for purposes of agricultural or public health concerns, a negative effect on *Eumops* prey could result. Also, if the Rio Sonoyta itself were to undergo substantial changes, foraging habitat could be negatively (or positively) affected. Even

in its current degraded condition, the Rio Sonoyta does support a mesquite-tamarisk riparian corridor with limited water, which together probably contribute to *Eumops* foraging habitat quality. If the river is further degraded (e.g. through dewatering, overgrazing, etc.) even this diminished resource could be lost. Conversely, if the Rio Sonoyta were rehabilitated, improvements in foraging habitat quality and water availability would likely result.

Water Sources

If it is true that *Eumops* require a relatively large, open water source, such sources in the study area are limited to Quitobaquito Pond, a sewage lagoon just west of Sonoyta, and Xochimilco, an intermittent reservoir on the Rio Sonoyta just east (upstream) of the city. Quitobaquito Pond is tentatively stable. The pond has remained largely unchanged since 1969, when it was last dredged and enlarged. Emergent plants (*Scirpus americana*) are encroaching on the pond perimeter, but have probably reduced the pond diameter by no more than a meter or two in the last 20 years. National Park Service hydrologists have noted that the retaining dam will need maintenance to continue to function. And its location on the border leaves Quitobaquito vulnerable to a wide variety of impacts, malicious or unintended, that could affect water quality and/or water availability. The three bats that were radiotracked extensively did not return to Quitobaquito nightly, or even very often. Several interpretations of this are possible, including: 1) They do not need to access free water nightly; 2) Quitobaquito is one of several water sources that are visited alternatively; 3) The experience of being captured, handled, and instrumented at Quitobaquito served as a deterrent to making return visits for some time.

Other potential water sources exist in the Rio Sonoyta Valley. Based on radiotelemetry data, we suspect that *E. underwoodi* may have visited the sewage treatment ponds just west of Sonoyta. At least during this project, these ponds presented a greater surface area than Quitobaquito. The bats may have used these ponds to drink effluent, or the ponds and surrounding vegetation may also have been a source of arthropod prey. The Rio Sonoyta in its current state seems unlikely to serve as a watering source. Its current surface flow is greatly diminished, reaching as little as 1.5 km in late summer 2002 (Juan Miranda, El Pinacate Reserva Biosfera, pers. comm.). That surface flow is generally a small stream about 2m (6.5 ft) wide, several cm deep (1 to two inches), and narrowly confined within a corridor of mesquite and tamarisk. *Eumops* bats may have difficulty accessing this small, shallow, confined water source. However, the fact that their roost sites were in the broad Rio Sonoyta valley, and transit routes between roost sites and Sonoyta followed the river valley, may suggest that they are in fact using the river as a water source.

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