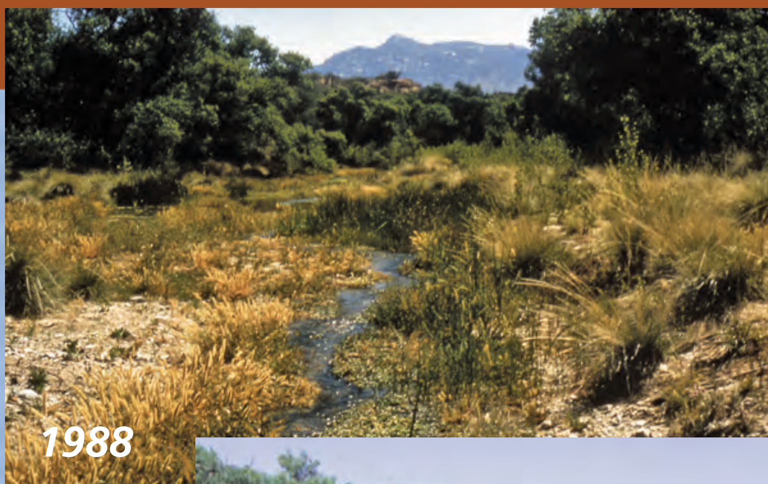
REVIEW OF MONITORING IN SOUTHERN ARIZONA:

Lessons for the Development of the Pima County Ecological Monitoring Program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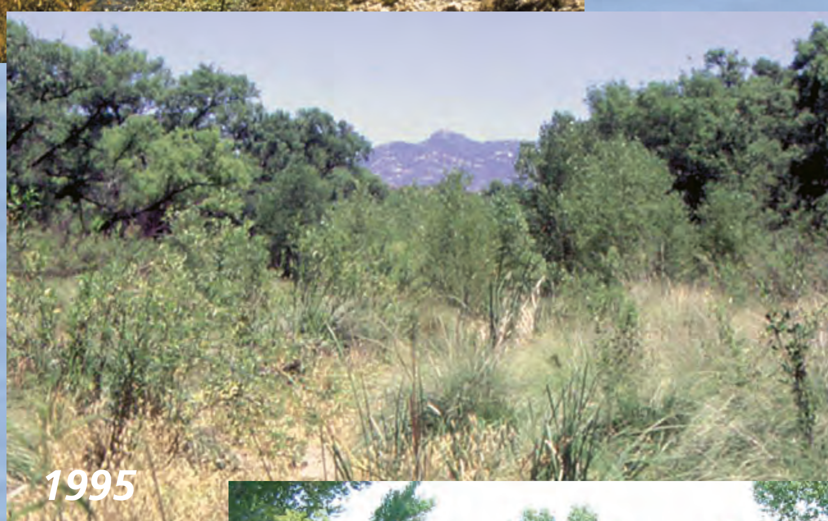
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Report to the Pima County Board of Supervisors

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Cover: Three pictures of the same segment of Cienega Creek showing a dramatic increase in cottonwood trees and emergent aquatic vegetation, all signs of a healthy riparian area. Management practices that likely led to this increase included exclusion of livestock and off-road vehicles.

Executive Summary

The Sonoran Desert Conservation Plan is a comprehensive strategy to preserve the biological diversity and cultural heritage of Pima County, Arizona in response to human population growth and its associated impacts.

The Sonoran Desert Conservation Plan (SDCP) is a comprehensive strategy to preserve the biological diversity and cultural heritage of Pima County, Arizona in response to human population growth and its associated impacts. The SDCP is now being implemented through a host of conservation measures including development set asides, purchase and lease of open space, and restoration efforts. Pima County is now developing a monitoring plan to complete a Section 10 permit application to the U.S. Fish and Wildlife Service (USFWS) to ensure that development-related activities comply with the Endangered Species Act.

Ecological monitoring provides a means for assessing management action and informing decision makers and constituents about long-term trends in natural resources. Despite its importance, designing and implementing long-term ecological monitoring remains a challenge, most notably because of its perceived high cost and historical lack of institutional support for this long-term endeavor. This report provides a review of eight monitoring efforts in southern Arizona to highlight their accomplishments and to critique their efficacy. Monitoring indicators and programs are: water resources at Cienega Creek Preserve; vegetation at the Santa Rita Experimental Range, Tumamoc Hill, Arizona-New Mexico borderlands, and Las Cienegas National Conservation Area; vertebrates at Organ Pipe Cactus National Monument, Tucson metropolitan area, and Las Cienegas National Conservation Area; and a stream monitoring program at National Park Service units throughout southern Arizona.

The report then provides an overview of important attributes of a monitoring program. Of primary importance is for a program to help determine if management objectives are being achieved. Other attributes of successful monitoring programs include ensuring sufficient field sampling to detect trends if they are occurring, providing timely dissemination of data to decision makers and the general public, and ensuring that funding is adequate and consistent. This review of projects and successful attributes will provide an assessment framework to better guide the development of the Pima County Ecological Monitoring Program.

INTRODUCTION

In addition to providing a tool for compliance with the Endangered Species Act, the Pima County Ecological Monitoring Program will also ensure that status and trend data be provided to land managers, decision makers, and the general public regarding a wide range of ecological "indicators."

Pima County initiated the Sonoran Desert Conservation Plan (SDCP) in 1998 in response to the listing of the cactus ferruginous pygmy-owl (*Glaucidium brasilianum cactorum*) by the U.S. Fish and Wildlife Service (USFWS; Pima County 2000). The listing prompted the development of this comprehensive, long-term strategy for conservation of biological and cultural resources threatened by human population growth and its associated impacts. One of the guiding principals of the SDCP is it's comprehensive biological goal: to "ensure the long-term survival of the full spectrum of plants and animals that are indigenous to Pima County through maintaining or improving the habitat conditions and ecosystem functions necessary for their survival." The SDCP became the guiding document and principal to help ensure that these impacts comply with the regulatory requirements of the Endangered Species Act, which prohibits "take" (i.e., harassment, hunting, killing, etc.) of listed species. However, Section 10(a)(1)(B) of the Endangered Species Act allows incidental take of listed species provided that a Habitat Conservation Plan or Multi-species Conservation Plan (MSCP) is in effect. Though many activities have taken place to implement the SDCP including, but not limited to, acquisition of open space and developer set asides, Pima County has yet to apply for a Section 10 permit. Most of the work to finalize an MSCP is complete (RECON 2006). All that remains is the development of a monitoring plan.

RECON (2007) recently completed a "Phase I" monitoring report that provides a foundation for further development of the Pima County Ecological Monitoring Program (EMP), which will be a part of the MSCP. In addition to providing a tool for compliance with the Endangered Species Act, the Pima County EMP will also ensure that status and trend data be provided to land managers, decision makers, and the general public regarding a wide range of ecological "indicators" (characteristics that inform managers of important ecological change). More specifically, the goal of the monitoring program will be to:

> *Detect and quantify changes to select ecosystem components at appropriate spatial and temporal scales to inform adaptive management and to determine if the SDCP biological goal is being achieved (RECON Environmental Inc. 2007).*

In fall 2007 Pima County received a grant from the U.S. Fish and Wildlife Service to further develop the Pima County EMP. The key focus of the "Phase II" report will be to identify appropriate environmental indicators along with solid justification for their inclusion into the program. A draft of the Phase II report will be completed by December 2008. In preparation for that planning effort it is prudent to review existing ecological monitoring programs in southern Arizona and to provide an overview of attributes that make for successful implementation and long-term support of monitoring programs. These reviews and evaluations are the focus of this report.

Monitoring and Adaptive Management: Definitions

The Phase I report provided an in-depth discussion of the relationship among monitoring, inventories, research, and adaptive management (RECON 2007). This section provides a brief review of the topic. *Monitoring* is the repeated measurement of a resource over time with the goal of detecting trends. For monitoring to be successful, it should to linked to management activities and decisions through a process known as *adaptive management*, which is an iterative learning process that identifies gaps in understanding, facilitates action, and modifies management based on information gained through monitoring activities (Fig. 1; Walters 1986, Salafsky et al. 2002, Williams et al. 2007). In the adaptive management cycle it is critical to constantly improve the quality of information used for decision making so that actions can be focused and effective, therefore leading to a refined understanding of the system of interest. Monitoring plays a critical role in the adaptive management cycle by providing high-quality data that informs management actions.

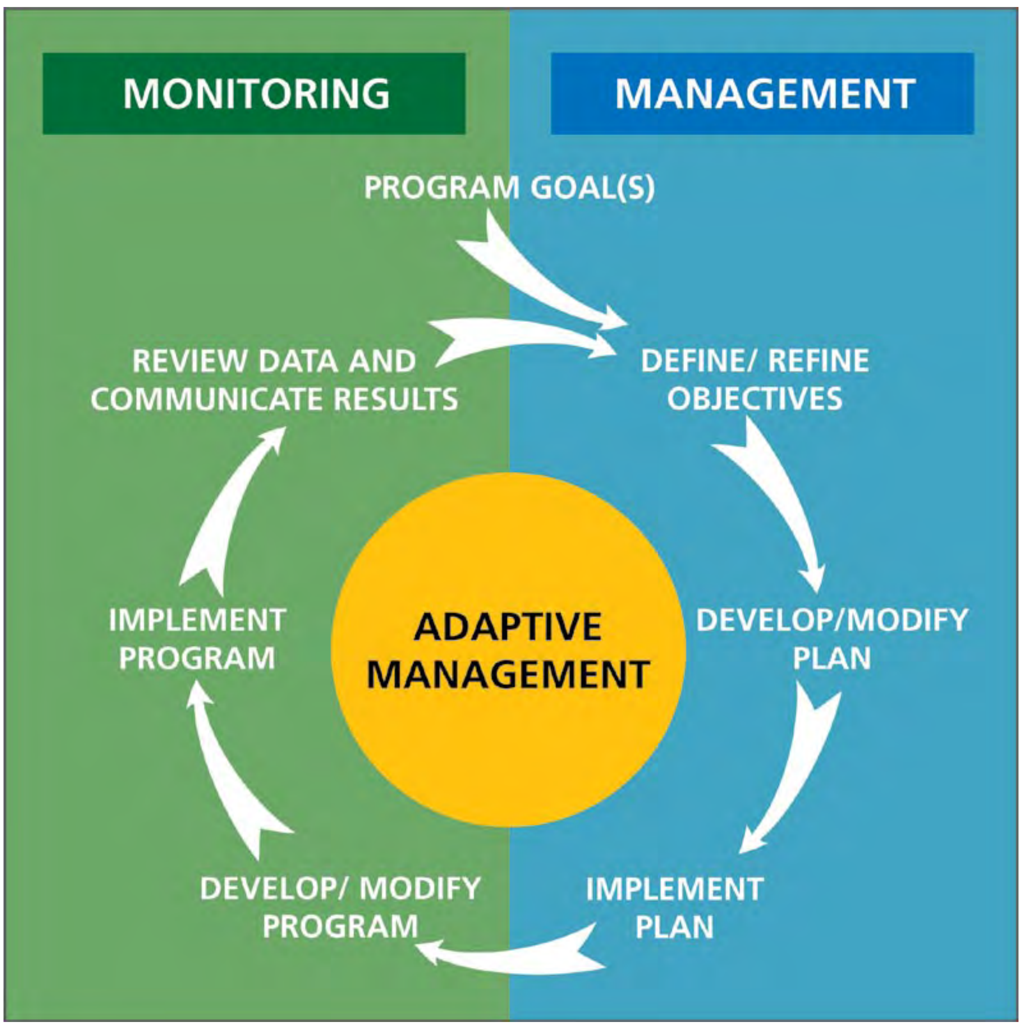

Figure 1. The adaptive management cycle involves a feedback between management and monitoring. In Pima County, the biological goal of the Sonoran Desert Conservation Plan (SDCP) is to maintain all the plants and animals and proper functioning ecosystems upon which they depend. Management activities include development set asides, open space acquisition, and changes to zoning. The Pima County EMP is being developed, in part, to determine if these activities are sufficient to achieve the SDCP goal.

Adaptive management typically takes one of two forms: passive and active (Walters and Holling 1990). Passive adaptive management uses observational data to infer likely causes of the observed pattern(s), while active adaptive management is more powerful and involves applying management actions as experiments so that cause-and-effect relationship can be clearly established (see review in Morrison et al. 2001). Examples of applications for active adaptive management in the SDCP include assessment of grazing practices, reestablishment of wildland fire for shrub control, and eradication of invasive, non-native species. However, for most SDCP management actions there will be limited opportunities for application of active adaptive management due to funding constraints and an inability to manipulate sensitive or rare resources. For example, experiments on the effects of management actions on threatened and endangered species or critical riparian resources may be legally and/or ethically irresponsible to perform.

Why Monitor?

Ecological monitoring is a relatively new endeavor, one born from a need for more informed stewardship of natural resources. In recent decades ecological monitoring has grown in importance as policy makers and the general public demand more accurate information on the status and trends of a wide range of natural resources, from air quality to wildlife populations, from entire ecosystems to individual species. The catalyst for initiating most monitoring efforts results from compliance with environmental regulations such as the Endangered Species Act, National Forest Management Act, and the Clean Air Act. Some monitoring programs assess conditions at the site level and compare them to national or regional standards. For example, the U. S. Environmental Protection Agency is charged with setting and enforcing air quality standards. To assess compliance, the agency coordinates monitoring of six Criteria Air Pollutants (carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter, and sulphur dioxide) at over 4,000 sites nationwide. Progress is measured at each site, leading to "data rollups" at the local, regional, and national scales.

Monitoring also arises from the need to assess effects of management actions and to determine the status and trends in resources to characterize environmental conditions. These monitoring programs are broadly defined as *effectiveness monitoring* because they may not be directed related to legal obligations, but rather more directly to the adaptive management process at the local or bioregional scales. For example, monitoring often takes place before and after restoration efforts, such as in planting vegetation or reestablishing wildland fire.

The Pima County Ecological Monitoring Program is being designed for both compliance and effectiveness monitoring. The legal requirement is expressed through the MSCP and the need to comply with the terms of the forthcoming Section 10 permit application. In this context, monitoring is seen as an essential tool to determine if the impacts to and mitigation for developed lands are complying with terms of the Endangered Species Act. At the same time, the broader biological goal of the SDCP needs to be assessed by monitoring trends in additional indicators and through assessment of management actions to achieve the broader SDCP goal. These two end uses for monitoring data should be viewed as complementary given the program's focus on monitoring a broad suite of indicators that affect the distribution and abundance of the 36 Priority Vulnerable Species that are the focus of the MSCP (RECON 2007).

Review of Monitoring Programs and Projects in Southern Arizona

A select group of monitoring programs has a significant record of effort and accomplishment.

Ecological monitoring is not new to southern Arizona. Appendix A lists a host of monitoring-related efforts in Pima County alone. This chapter provides a more in-depth analysis of a select group of monitoring programs and projects in and near to Pima County that have a significant record of effort and accomplishment. A brief introduction to the programs and projects highlights how each of these efforts has informed our understanding of ecological change in southern Arizona and how their successes and shortcomings can inform the Pima County EMP. Section 5 of the report focuses on how each of these monitoring efforts rates in comparison to the five attributes of a successful program, which are outlined in Section 4. Figure 6 (following Appendix A) maps the locations of monitoring efforts referenced in the text. Note that Saguaro National Park and Tumacacori National Historical Park are part of the Sonoran Desert Network of parks at which streams monitoring takes place.

Water Resource Monitoring at the Cienega Creek Natural Preserve

In 1987 the Pima County Regional Flood Control District (herein the District) began water monitoring at a perennial-flow reach of Cienega Creek within what is now called the Cienega Creek Natural Preserve (NP). At the time, a large planned community was anticipated at Empirita Ranch, which lies upstream of the Cienega Creek NP, and the District was concerned about the development's impacts on the water resources of Cienega Creek NP. In response, the developers of the Empirita Ranch began groundwater monitoring to identify baseline hydrologic conditions to address the District's concerns. Water monitoring in the area was expanded in 1989 when the District began preparing for water rights protections for the Cienega Creek NP. To achieve these multiple objectives, the District contracted with the Pima Association of Governments (PAG) to make monthly groundwater level and instantaneous flow measurements and to map the extent of streamflow in the perennial reaches of the Cienega Creek NP. This monitoring program has since expanded to account for the termination of the developer's monitoring program and the acquisition of that land by the District.

The Cienega Creek water monitoring program has provided information used by decision makers. Specifically, the Pima County Board of Supervisors used the data to justify reducing the intensity of planned land uses at the upper end of the Cienega Creek NP and to acquire additional land within the hydrogeologic basin to protect water resources and rights. The District has since eliminated agricultural irrigation and, in 1993, they used data collected from the monitoring program to submit an instream-flow application to the Arizona Department of Water Resources to protect baseflows, which contribute to the extraordinary wildlife and recreational values of the Cienega Creek NP (Fonseca 1993). The threat of upstream groundwater pumping at Empirita Ranch has diminished over time, yet the project remains relevant because the threat to the water resources of the Cienega Creek NP have shifted to the lower end of the Cienega Creek NP and Davidson Canyon, where County acquisitions have recently occurred. To adapt to the new challenges, the program has been modified through the addition of more monitoring wells in the lower reach of Cienega Creek and expansion of monitoring along Davidson Canyon.

Monitoring data is presented periodically to the Pima

Association of Government's Watershed Planning Committee, which includes members of various jurisdictions in the area around Cienega Creek. PAG uses field data collection events to educate other resource agencies and the general public about the importance of preserving the integrity of the Cienega Creek watershed. Because of its long-term nature, the program is now being tapped to provide data to the State of Arizona as part of a drought monitoring effort. In addition, some of the monitoring methods employed at the Cienega Creek NP are being applied to other regional monitoring efforts such as along the San Pedro River and recommendations have been made to expand the program to other key groundwater-dependent areas in Pima County including Arivaca and Rincon Creeks. Finally, the monitoring program also provided a platform to augment the regional flood warning system that provides decision-makers with real-time data about flood flows in eastern Pima County (data are now available to the general public at http://www.rfcd.pima.gov/alertsys/).

Another important process during the implementation of the program was a thorough review of the data and sampling design by Pima Association of Governments (1998). The review was initiated, in part, to determine if the sampling design was sufficient to detect impacts from upstream pumping. It highlighted some efficiencies that could be gained by making minor changes to the spatial sampling design by way of reinstatement of one discontinued well monitoring site. The temporal sampling design was also changed so that summer streamflow discharges be made at the same time of day, thereby minimizing diurnal fluctuation due to evapotranspiration. In addition to reviewing data, the Pima Association of Governments also maintains a database, protocols, and archiving procedures that are sufficient in detail for the data's long-term use and integrity.

Vegetation Monitoring at Santa Rita Experimental Range

The Santa Rita Experimental Range (ER), which was established in 1903, is the longest-running rangeland research facility in the United States (McClaran et al. 2003). The Santa Rita ER was originally established by the U.S. Department of Agriculture, but ownership was transferred to the State of Arizona in 1988 and today it is managed by the College of Agriculture and Life Sciences at the University of Arizona. The Santa Rita ER was established to assist managers in determining livestock grazing capacity in the region's semi-desert grasslands and it is still managed for livestock grazing research. Yet a new goal has emerged:

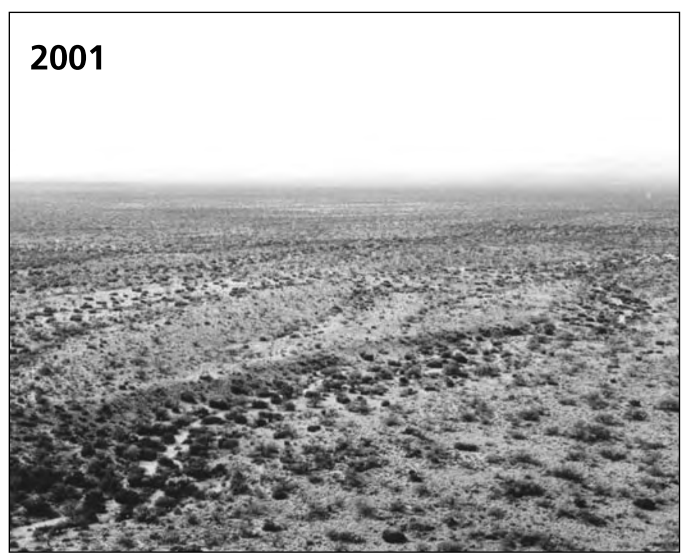

Figure 2. Repeat photography from the Santa Rita Experimental Range (Plot #335), southern Pima County, showing the increased density of woody shrubs between 1902 and 2001. Photo accessed from: http://ag.arizona.edu/SRER/ (McClaran et. al. 2002).

to monitor long-term patterns of vegetation change. Indeed, few areas have contributed more to our understanding of vegetation dynamics in semi-desert grasslands of North America than has research and monitoring at the Santa Rita ER; to date there have been over 500 professional publications produced using data from the Santa Rita ER (Medina 1996, McClaran et al. 2002).

Though the primary focus of the Santa Rita ER has been and will be research, the long-term datasets are perhaps the most important legacy from the research program. One hundred and thirty vegetation transects have been read approximately every three years since 1972, and one half of those transects date back to 1957. Also essential for interpreting these data is precipitation data from 24 gauges spread throughout the Santa Rita ER. In addition to the quantitative transect data, there is also an impressive series of repeat photographs that serve to complement those data and convey change in a way that quantitative data can not (Fig. 2).

Of all the monitoring and research programs in southern Arizona, the Santa Rita ER provides the best example of proper archiving procedures and data access tools. Physical data are archived at the University of Arizona and most electronic data are accessible via a user-friendly website that is updated periodically (McClaran et al. 2002). These data are accompanied by metadata along with a host of spatial data such as locations of plots, fences, roads, rain gauges, etc. Taken together, these products provide for a host of resources that will bevaluable for the development of the Pima County EMP by way of estimates of anticipated rates of changes in vegetation resources.

Perennial Vegetation Monitoring at the Desert Laboratory, Tumamoc Hill

The longest continuously running ecological monitoring plots in North America were established in 1903 at the Desert Laboratory west of Tucson (Goldberg and Turner 1986). Originally established by the Carnegie Institution, the University of Arizona purchased the Desert Laboratory in 1956 and today it is cooperatively administered by the University's departments of Geosciences and Ecology and Evolutionary Biology and the U.S. Geological Survey. The 11 original plots and subsequent additions have produced a wealth of information on the dynamics of vegetation communities in the Sonoran Desert (e.g., Pierson and Turner 1998, Bowers et al. 2006). Topics of research have ranged from population dynamics of saguaro cacti and other perennial vegetation, and annual plant survival and reproduction (Fig. 3). More recent work has focused on the spread of non-native grass species. Particularily striking has been the changes in frequency and density of bufflegrass (*Pennisetum ciliare*), which increased from a few small patches to dense stands that now dominate much of the eastern portion of the Desert Laboratory as well as around the west and south boundaries (Fig. 4; Bowers et al. 2006).

The long-term data from the Desert Laboratory, along with other research and monitoring efforts in the region, have provided data that highlight the threat that some non-native plant species pose to the structural and functional integrity of many natural areas in the greater Sonoran Desert (e.g., Franklin et al. 2006, Morales-Romero and Molina-Freaner 2007). Public outreach efforts by scientists at the Desert Laboratory (Julio Betancourt and Travis Bean) along with other concerned scientists and citizens have created a more informed and active citizenry. For example, public interest has led to citizen-based removal efforts (funded by Pima County since 2005) to address the growing problem of non-native plants.

The close proximity of the Desert Laboratory to Tucson and long-term nature of the monitoring plots provides an extraordinary opportunity to gain historical perspective on ecological change to natural areas experiencing nearby exurban development. In this regard, the results from the long-term monitoring at the Desert Laboratory will be important for the development of the Pima County EMP and for success of the SDCP in general because many of the impacts that

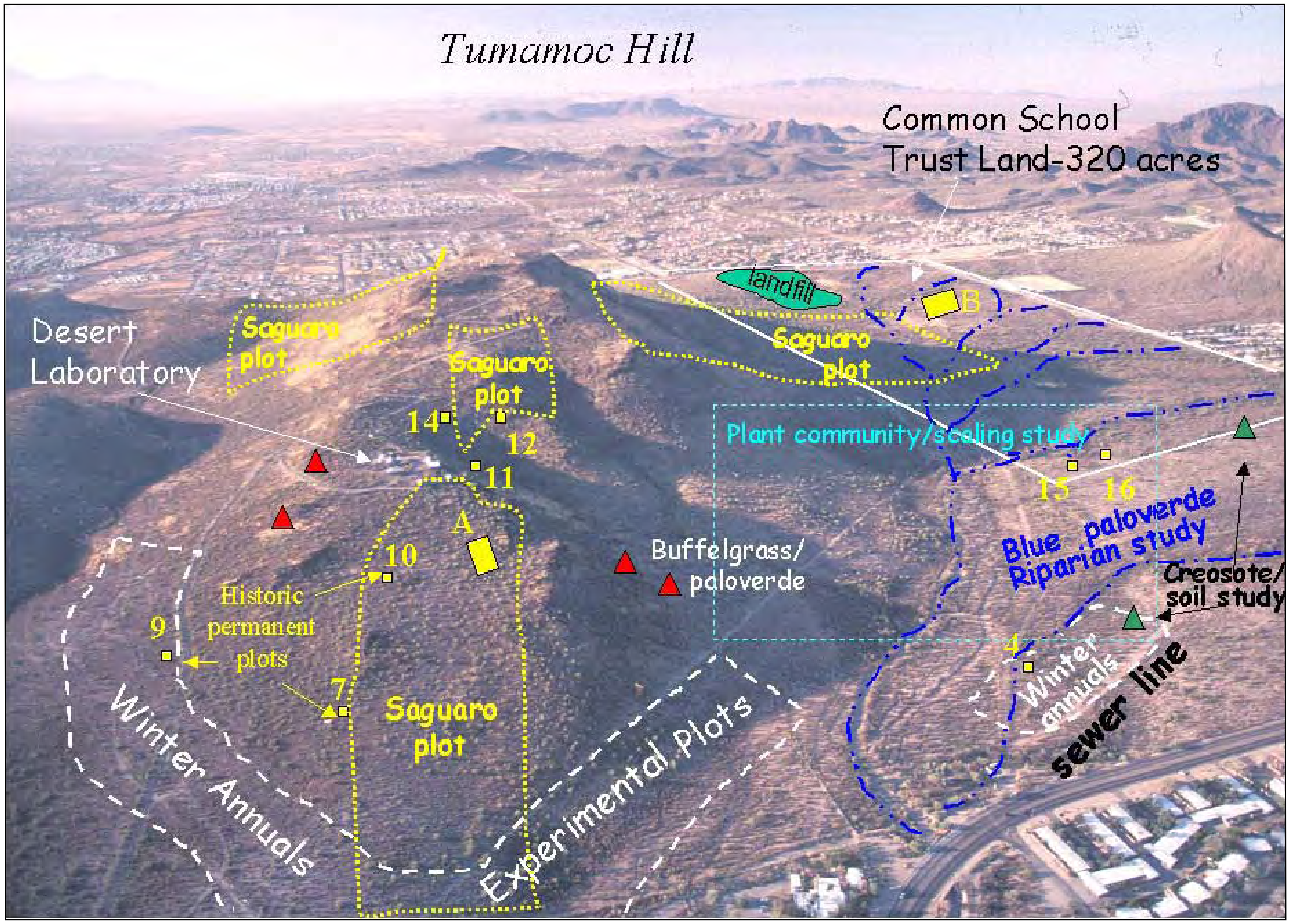

Figure 3. Aerial view of the Desert Laboratory at Tumamoc Hill, west of Tucson, showing the location of research and monitoring plots including long-term (historic permanent) plots for saguaros and perennial vegetation, many established in 1903. Urban expansion along its boundaries has facilitated the invasion of non-native plant species into the Desert Laboratory (see Fig. 4). Image courtesy of Julio Betancourt.

have been well documented at Desert Laboratory will likely be mirrored throughout the increasingly urbanized environment in eastern Pima County. Many of the methods used at the Desert Laboratory were also used in other areas of the Sonoran Desert (including Sonora, Mexico) and together provide a foundation for a larger, ad-hoc saguaro cactus and perennial vegetation monitoring effort (see for example, Steenbergh and Lowe 1977, McAuliffe 1993). Bringing together these datasets could provide a powerful tool for an ecoregional assessment of vegetation dymanics. Even more pressing is the long-term preservation of the Desert Laboratory itself, which is threatened by a possible sale for real estate development.

Grasslands Function and Condition Monitoring in the Arizona-New Mexico Borderlands

One of the largest relatively unfragmented areas of semi-desert grassland in North America is found in the southeastern corner of Arizona and southwestern corner of New Mexico. Known generally as the Arizona-New Mexico Borderlands, this area of approximately 780,000 acres is a mix of private, state, and federal lands, with cattle grazing as the dominant land use. Following a dramatic increase in wood shrubs into areas dominated by perennial grasses from the 1970s to the 1990s, local ranchers and conservationists formed a non-profit group known as the Malpai Borderlands Group (MBG) in 1994 (Curtin 2002). Ranchers and conservationist were also concerned about the loss, degradation, and fragmentation of the semi-desert grassland ecosystem through shrub encroachment, subdivision, and altered fire regimes.

In 1993 the MBG established 200 monitoring plots throughout the Arizona-New Mexico Borderlands to track changes in vegetation. Unfortunately, data from the program have never been adequately summarized to determine trends (Peter Warren, *pers. comm.*). In addition to monitoring, the MBG and a host of outside cooperators established an ambitious research program to separate the effects of fire, herbivory (native and from cattle), and climate on the long-term health of the grasslands (Brown et al. 1997, Curtin et al. 2002, Curtin 2005). This research program is one of the largest of its kind in North America. Because the monitoring and research programs are directly tied to the management objectives of the BMG (i.e., to improve rangeland conditions), the programs are carried out with the full support, partici-

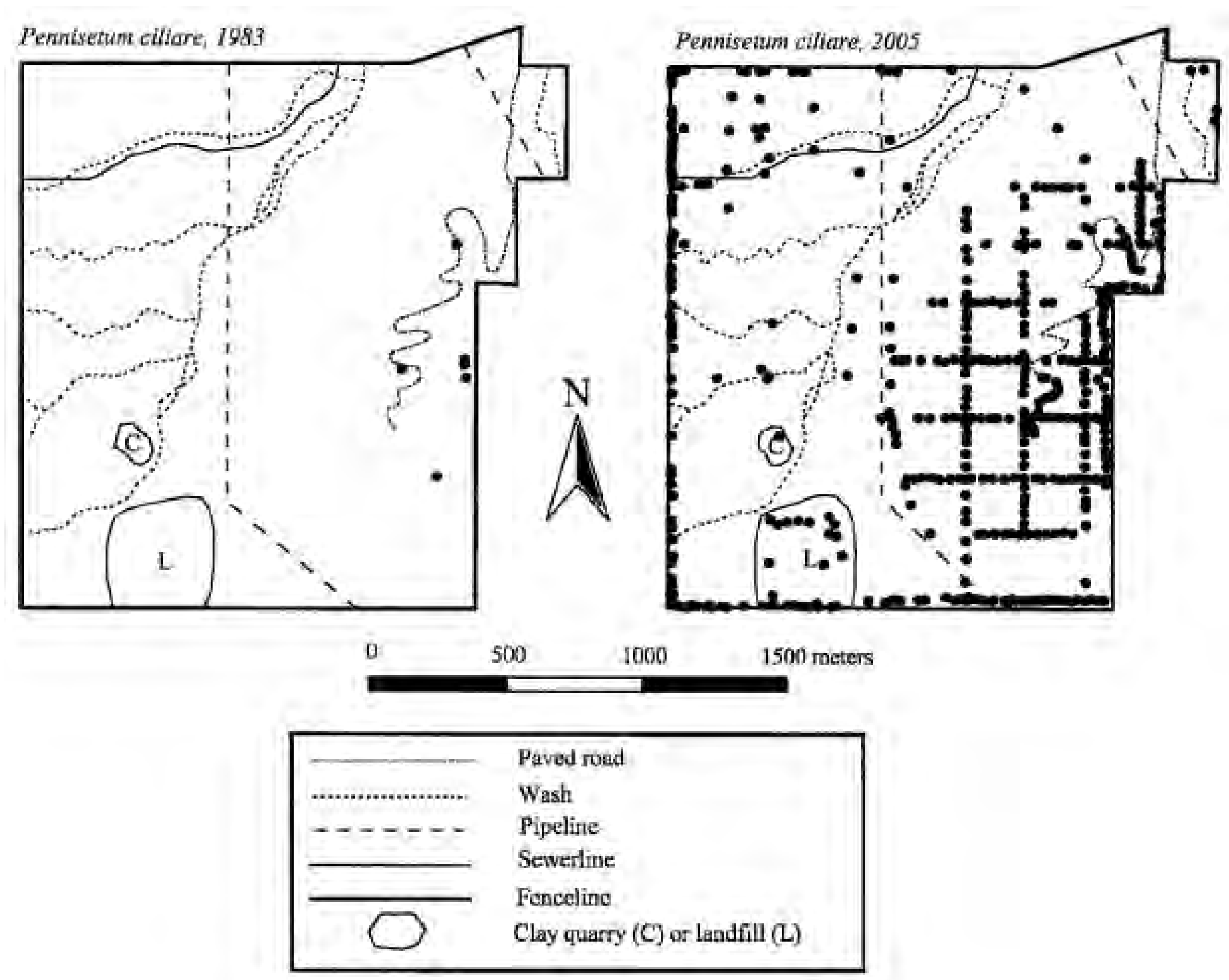

Figure 4. Changes to the distribution of buffelgrass (*Pennisetum ciliare*) a non-native and invasive grass species native to the Old World, at the Desert Laboratory, Tucson, 1983 and 2005. Reprint from Bowers et. al. (2006) courtesy of the California Botanical Society.

pation, and oversight of the ranching community. The monitoring and research program has also received considerable interest from outside institutions because of the BMG's approach to integrating landscape-scale conservation within a working landscape (Sayre 2005).

Upland Vegetation and Fish Monitoring at Las Cienegas National Conservation Area

Las Cienegas National Conservation Area (NCA), located in the southeastern corner of Pima County, is administered by the Bureau of Land Management (BLM). In its recent management plan, the BLM articulated a host of science-based management objectives for Las Cienegas NCA using benchmarks of riparian and upland vegetation conditions and improvements to wildlife habitat (Bureau of Land Management 2002). In a landscape that is actively grazed, benchmarks allow for assessments of management actions such as herd rotation and riparian fencing. To help determine if the benchmarks were being met, The Nature Conservancy of Arizona evaluated data from vegetation and fish monitoring programs established in the 1980s and 1990s.

Upland vegetation monitoring began in 1995 at 26 sites throughout the 42,000 acre Las Cienegas NCA and adjacent cattle allotments (Gori and Schussman 2005). At each site, a total of 10 grassland condition indicators were monitored and compared to benchmark desired conditions. Despite some problems with the data (most notably lack of data for some years and paucity of rainfall data) they showed a range of conditions as compared to the benchmarks, with improvements in conditions in some areas and degradation in others. Monitoring data have subsequently led to changes in livestock grazing practices at Las Cienegas NCA to better meet the benchmarks as well as a revamping of the monitoring program itself to better detect trends.

The upper reach of Cienega Creek runs through Las Cienega NCA and contains two species of endangered fish, Gila chub (*Gila intermedia*) and Gila topminnow (*Poecilopsis occidentalis*). Gila topminnow in particular is a critical resource at Las Cienegas NCA, home to the largest remaining population in the U.S. Jeff Simms (BLM) began population monitoring for Gila topminnow along two stretches of Cienega Creek in 1989 and surveys have taken place most years since then. Bodner et al. (2007) summarized data from the program and found significant population declines in the upper reach of the creek and no significant changes in the lower reach. (Causes of the observed patterns were unclear, but habitat modification from increased riparian vegetation near the stream channel appears to be the most likely explanation). Bodner et al. (2007) used the data to suggest modifications to the sampling design that would allow the program to use monitoring resources more efficiently and to provide more reliable estimates of population change.

The BLM and their cooperators in the Sonoita Valley Partnership (government agencies, user groups, citizens) and Mac Donaldson (grazing permittee) have had early success at implementing an adaptive management process at Las Cienegas NCA. This has been due, in part, to the development of specific and measurable objectives that use monitoring data to inform progress. The application of adaptive management at Las Cienegas NCA is held up as a national example within the BLM and the lessons learned and tools gained from the program have direct application to the development of the Pima County EMP, especially with the County's recent purchases of ranchland and commitment to maintaining sustainable ranching practices.

Vertebrate Monitoring at Organ Pipe Cactus National Monument

The Ecological Monitoring Program at Organ Pipe Cactus National Monument in western Pima County is the longest-running program in Pima County principally dedicated to monitoring vertebrates. The program began in 1984 with baseline surveys of plants and animals, and was expanded in 1991 with the development and implementation of monitoring protocols for a variety of indicators (National Biological Service 1995). Monitoring has taken place

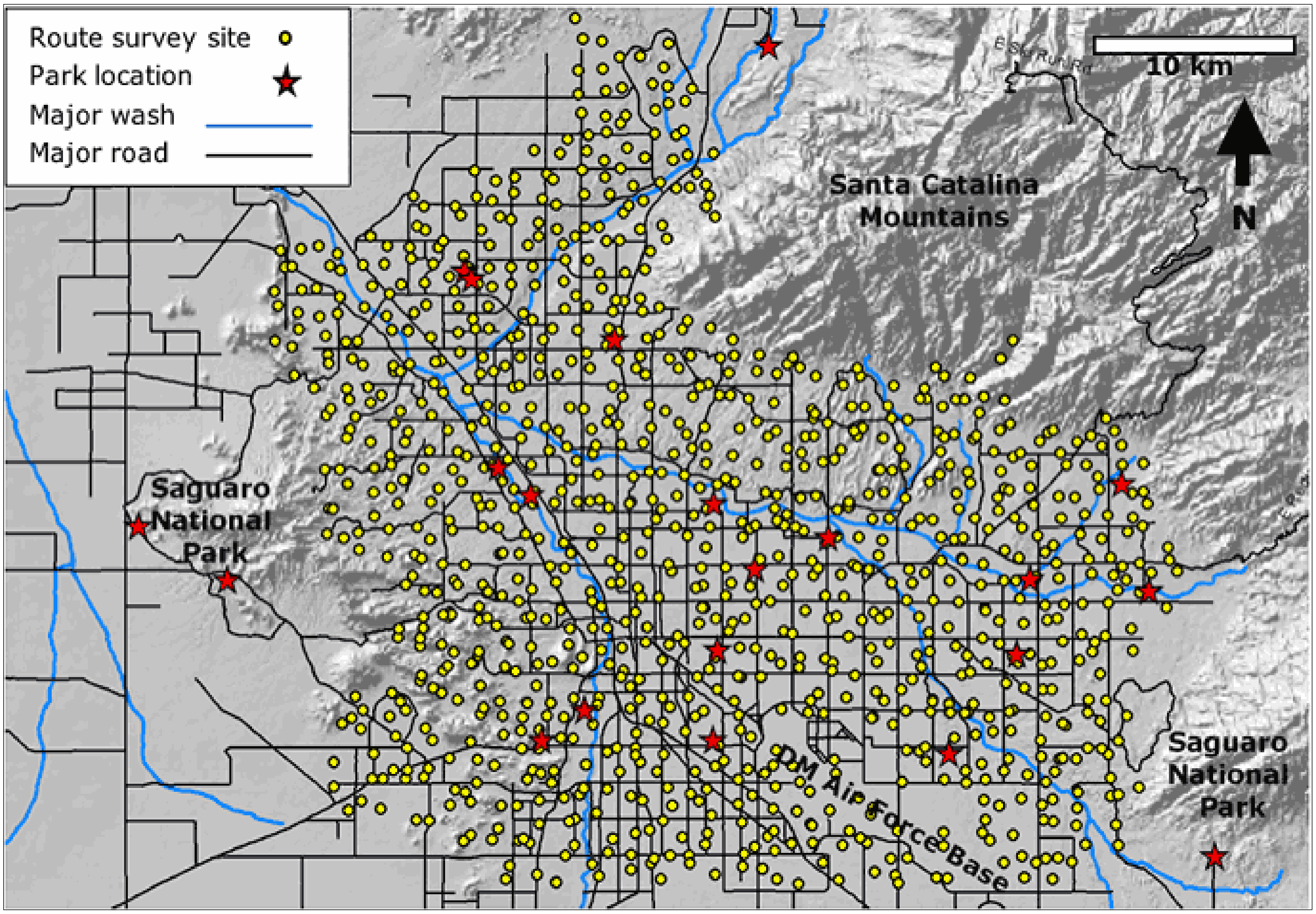

Figure 5. Bird survey sites for the Tucson Bird Count showing locations of survey points for spring surveys (yellow dots) and sites that are visited quarterly (red stars). Image courtesy of Rachel McCaffrey.

on nine permanent sites, with particular emphasis on lizards, rodents, birds, and climate monitoring. Because of the long record of sampling, the work at Organ Pipe Cactus NM is an important early effort in ecosystem-level monitoring in the Sonoran Desert and therefore is a valuable "prototype" program from which others may learn.

After a long hiatus from producing reports, park staff recently released a comprehensive report that provides summary data collected through 2005 (Organ Pipe Cactus National Monument 2006) and there is currently an effort to conduct a thorough evaluation of trend data for lizards (Aaron Flesch, report in preparation). Unfortunately, field sampling has been curtailed in recent years because of field safety issues associated with illegal border crossers from Mexico. More broadly, the program's value toward meeting management objectives has been called into question because of the park's ever-changing management challenges, which are currently focused on determining the effects of illegal immigration on park resources. Ilegal immigration was not considered during the development of the monitoring program and therefore the program is not sufficient to detect changes from this new stressor. The Organ Pipe Cactus National Monitoring program is an important reminder that management priorities can change, thereby presenting challenges to the viability of a monitoring program (see Ringold et al. 1996).

Landbird Monitoring in the Tucson Basin

Started in 2001, the Tucson Bird Count (TBC) is now one of the largest volunteer-based regional bird monitoring programs in the U.S (Turner 2003, McCaffrey 2005). Each spring, volunteers survey a transect of points throughout the Tucson metro area and surrounding landscape (Fig. 5). Additional monitoring takes place on a quarterly basis at selected parks, washes, or other areas of interest (Fig. 5). Data are used to monitor changes in the distribution and relative abundance of most species of landbirds and to identify those areas that contribute disproportionately to providing habitat for select native species.

The Tucson Bird Count is an excellent example of how a citizen-science program can contribute to our knowledge of natural systems as well as provide avenues for creating a more informed and active citizenry. By tapping into the large and dedicated bird-watching community in Tucson, the TBC has enabled collection of data on a scale that would have been prohibitively expensive to collect if the program relied on paid staff. The use of volunteers also creates a sense of ownership of the program, which helps ensure long-term financial support. Data are also useful for planners who can use the data to promote habitat components (e.g., vegetation) to attract native birds. Educational products from the TBC are impressive because data entered by volunteers is quickly translated to both raw data for use in scientific investigations and distribution maps for many applications (see: www.tucsonbirds.org). Having volunteers collect and enter data also keeps program costs low.

The TBC is not without its challenges. Although citizen volunteers are dedicated and inexpensive, there is more error in data collection because of the varying skill level of the volunteers, who range from professional biologists to casual birders. This error can be so high as to obscure the detection of trends until significant changes have occurred. However, if the goal of the program is detect more widespread and significant changes (e.g., >50%), then these sampling issues may be insignificant. The TBC is currently under review to address methodological and logistical considerations and to see if the data collected through 2007 show trends for a subset of common species (Rachel McCaffrey, *pers. comm.*).

Integrated Aquatic Monitoring at National Park Service Units in Southern Arizona

In 2001 the National Park Service funded the Sonoran Desert Network (SODN) Inventory and Monitoring Program, one of 32 national monitoring networks specifically tasked with detecting status and trends of resources in National Park Service units. The SODN is comprised of eleven park units in central and southern Arizona and one unit in southwestern New Mexico, including Saguaro National Park and Organ Pipe Cactus National Monument in Pima County. The SODN is currently developing detailed monitoring protocols for a wide range of monitoring indicators categories: air quality and climate, water quality and quantity, landscape pattern, biological integrity (birds, fish, vegetation, invertebrates), soils and geomorphology (Mau-Crimmins et al. 2005). Protocols for these indicators are currently being developed and implementation has begun for a few including landbirds (e.g., Powell *et. al.* 2007). Much of the effort of the SODN since 2006 has focused on the “streams” monitoring (Sonoran Desert Network, *unpublished report*). This is a unique approach combines a host of riparian indicators (stream channel morphology and physical characteristics, vegetation, water quality, and aquatic macorinvertebrates) to provide a comprehensive assessment of stream condition. It is premature to evaluate the effectiveness of this program because it has only recently begun, but it is worth noting one early success by alerting managers of one park that water-quality data revealed conditions were of concern for public safety (Andy Hubbard, *pers. comm.*).

Attributes of Sucessful Monitoring Programs

Pima County has an opportunity to build a monitoring program that leads to greater understanding and stewardship of its natural resources.

Pima County has an opportunity to build a monitoring program that provides new and innovative information tools to land managers, decision makers, and the general public, thereby leading to a greater understanding and stewardship of Pima County's natural resources. The task is at once critical and challenging. While a solid conceptual foundation has been built (RECON 2007) significant challenges remain for the design, implementation, and long-term commitment that the program will require. Indeed, hundreds of monitoring projects and programs have been carried out in the U.S. in the past few decades by government agencies and private organizations looking to capitalize on the extraordinary potential that monitoring holds. Many programs fail (Noon 2003). This section provides an overview of attributes of successful monitoring programs and highlights these attributes through examples from both outside and within southern Arizona. This overview is intended to provide a set of qualities that Pima County EMP should seek to adopt throughout the development and implementation of the program.

Results Inform Management Objectives

The most important attribute of a monitoring program is that is provides data that *directly address management goals and objectives*. As such, monitoring becomes the essential link in the adaptive management cycle so that the information gained from monitoring informs managers if action is necessary and it so, what management action is most appropriate (see Fig. 1). To ensure this link is strong, management goals and objectives must first be clearly articulated, then a monitoring program can be designed to directly inform progress towards meeting those objectives. In addition to providing high-quality data, it is also essential that the data be provided periodically to managers. The timely release of quality information and its interpretation should ensure that managers receive the information on schedules that assist them in all aspects of their work, especially with long-term planning and budgeting. To facilitate widespread understanding of the methods and results, data need to be "served up" in a variety of formats, from technical publications for scientific reviewers to general information brochures for the general public.

An excellent example of monitoring that directly relates to management objectives is the most extensive, coordinated wildlife survey in North America—the U.S. Fish and Wildlife and Canadian Wildlife Services' Waterfowl Breeding Population and Habitat Survey. Since 1955, these annual aerial surveys cover over 2.0 million square miles of the principal duck and goose breeding areas of North America (e.g., U. S. Fish and Wildlife Service 2004). Information from these counts feeds directly into the adaptive management process whereby counts dictate the annual duck harvest in all states and provinces in North America. This adaptive management application results in a sustainable annual duck harvest. Local examples of programs that provide timely and relevant data for managers include vegetation monitoring at Las Cienegas NCA and water resources monitoring at Cienega Creek NP.

Careful Selection of Indicators

The most important task in the design of a program is choosing appropriate indicators (Noon and McKelvey 2006). For many monitoring programs, indicator selection is straightforward because the indicator is explicitly linked to the management objective, for example to increase the abundance of a particular species. However, in an ecosystem monitoring context, such as is being developed for the Pima County EMP, there are hundreds of potential indicators, thereby necessitating a framework for chosen among them.

There are many criteria for choosing indicators such as their ability to inform management, their cost, and how they vary in time and space (Table 1; from Noon et al. 1999, Hilty and Merenlender 2000, Dale and Beyeler 2001, Tegler et al. 2001). The process of choosing indicators should start from an understanding of how systems operate, how known stressors affect those systems, and an honest assessment of the level of information that is both known and unknown about the system of interest. In essence, the selection of indicators must be rooted in ecological theory and natural history. Conceptual models provide a framework that allows program developers to articulate these components by showing connections among the host of potential indicators, stressors, and drivers (Manley et al. 2000, Atkinson et al. 2004). By showing how system components interact, conceptual models should illustrate why a particular indicator was favored over others. Development of conceptual models will be a critical component in the design of the Pima County EMP, and they have been used successfully at Las Cienegas NCA and by the National Park Service's SODN.

Sufficient and Appropriate Sampling to Detect Change

The goal of a rigorous, long-term monitoring program should be to accurately detect the magnitude and direction of change in resources. This is an inherently quantitative endeavor and one that is receiving increasing attention as natural resource managers require information beyond simple qualitative resource assessment such as "good," "fair," or "poor." Instead, managers require information that are framed in the language of statistics, such as how much an indicator has changed (e.g., 2% annual change), what level of confidence one has in an assertion of change, and how biased is the chosen spatial sampling design.

Obscuring the ability to detect trends, also known as the *signal*, is error associated with estimates. Error, also known as *noise*, derives from many factors such as temporal and spatial changes in the indicator of interest, irrespective of any trend. Error also derives from the act of sampling itself, for example when monitoring methods or instruments provide inaccurate or imprecise information. To illustrate these types of error, let's say one wishes to estimate the amount of surface water flow in the Santa Cruz River. The natural variation would be the actual amount of water in the river at various points in time and space, which in the case of the Santa Cruz would be no water for most of the year but significant volume following rain events. Sampling error would be introduced if we had only enough money to hire a technician to visit one site every few weeks and take measurements. Given the extreme variability in flow, this would result in a biased and inaccurate estimate of flow. The difference between the actual flow and the measured flow is the sampling error.

Natural variation and sampling error play a critical role in trend detection, because the greater are these types of error, the more sampling that needs to take place. Insufficient sampling to separate the signal (trend of interest) from the noise (error) is one of the most consistent shortcomings of monitoring programs. Inconclusive trend estimates leave managers wondering what action, if any, is appropriate. This wastes money and precious resources, but it can often be avoided with proper planning. In fact, statistical tools such as prospective power analysis were designed to address these needs (Steidl et al. 1997, Gibbs et al. 1998). Recent work by Urquhart et al. (e.g., Urquhart et. al. 1998) has extended the tools of earlier workers to provide a powerful framework for account for variation and error when designing long-term monitoring programs. These tools will be developed further for application to the Pima County EMP.

During the initial planning stage it is imperative that a variety of sampling elements be considered so that an optimal design can be determined. Sampling elements include how many samples to take, when to sample, and with what method. Any chosen sampling design must be reviewed within a few years of the beginning of data collection to ensure that enough data has been collected and to suggest adjustment of the

Table 2. Criteria used to evaluate potential monitoring parameters during the Phase I planning process for the Pima County Ecological Monitoring Program (from RECON 2007).

Criteria Group	Criterion
Management relevance and utility	Has value for informing county's acquisition and management programs
Ecological relevance	Changes parallel those of a larger component or system of interest
	Changes quickly in response to changes in the larger component or system
Response variability	Low inherent natural variation
	Low sampling error
Feasibility of implementation	Cost efficient
	Survey and estimation methods are well established
	Survey protocols capture information on more than one species or parameter

sampling effort. After a thorough analysis of the data, for example, it may be discovered that more samples were taken than are necessary, thereby leading to cost savings. This was exemplified by the review of the fish monitoring data by Bodner et al. (2007) at Las Cienegas NCA. Conversely, it may be determined that there is insufficient sampling and therefore either more sampling needs to take place or the objectives need to be revisited. Despite the importance of a thorough review process, many programs fail to incorporate it into their activities because it can be laborious and may require technical skill that is outside the expertise of existing staff.

Data Integrity and Proper Documentation

Assuming indicators are chosen to address management objectives and there are sufficient data and appropriate designs to detect trends, program success then rests with data quality and its long-term integrity (Palmer and Mulder 1999). Throughout the program's design, implementation, and reporting, every attempt must be made to ensure that program data undergo thorough quality assurance activities. This process begins with documenting major decisions in the design of the program: why a particular indicator was chosen, and why one sampling method and design was chosen over another. Documenting administrative and technical decisions such as these provide a means for future program managers to understand, defend, or reverse past decisions. These decisions should be captured in the narrative of a detailed protocol for data collection, which also included step-by-step instructions for how to collect data, locations of study sites, copies of data sheets, roles and responsibilities of staff, and how to analyze data (Oakley et al. 2003). Protocols are considered working documents and changes to it must be justified, documented, and archived. This rigorous approach to ensuring data integrity provides the best chance of ensuring continuity of high-quality data collection, especially considering the high-turnover in these programs and the long-term nature of the endeavor. The SODN of the National Park Service is a local example of a program that has placed emphasis on developing detailed protocols.

Most errors in ecological monitoring result from data collection. Therefore, emphasis must be placed on training technicians, calibrating instruments, and other quality control procedures that reduce data collection errors. Once data are collected, attention should be paid to proper archiving of data sheets, specimens, and photographs. In addition to physically archiving materials, the increasing reliance on information technologies necessitates that considerable resources be devoted to developing databases and Geographic Information System tools. These electronic media, along with their associated hardware, need to be updated periodically to ensure access to data is not compromised by older technology. A good data management plan addresses the development and updating of information technology resources in addition to issues of data ownership and custodianship, dissemination and access, metadata procedures, and data documentation. The Santa Rita ER has been exemplary in their data management and archiving activities.

Long-term Commitment

To realize success, long-term monitoring programs must have sufficient and sustained financial support. Even with a well-designed program that engenders relevance to management and attributes of sound sampling design, loss of or erratic financial support can be devastating for programs. In addition to adequate initial funding, it is important that a program be shielded from cyclical fluctuations in budgets and that funding keep pace with inflation. Consistent funding is especially critical because most monitoring activity must take place at regular intervals (e.g., quarterly, annually, bi-annually) and deviations from those schedules can be detrimental for trend detection.

The high cost of monitoring has been noted as major impediment to implementing ecological monitoring (Noon 2003). Yet it must be understood that monitoring is an inherently long-term endeavor, and therefore the time horizon for many programs is often longer than the careers of the decision makers who initially fund the project. For example, a project that monitors an indicator such as perennial vegetation would likely employ a method whereby vegetation is measured every three to five years. If a trend were taking place, it may only be evident after year three and most likely not until later in the program (e.g., 10-15 years). Balancing sufficient funding with the need for patience in trend detection is one of the most difficult political aspects of ecological monitoring, one that must be recognized by all parties involving the development, implementation, and funding of a monitoring program. Clearly, a program that provides relevant and timely data can mitigate for the perceived high cost and this speaks to prudent program design. In particular, designers must develop and maintain a cost-effective program that seeks ways to keep administrative costs low and capitalize on partnerships, seek outside funding opportunities, and provide outside researchers with opportunities to tier off of existing programs. These efficiencies are now considered essential for the long-term success of ecological monitoring programs.

LESSONS FOR THE PIMA COUNTY EMP

A creative mix of science and politics will lead to informed decisions that ensure the relevance and success of an ecoregional monitoring program for Pima County

This report provides a brief review of the most critical attributes of successful monitoring programs, which are summarized by Noon (2003) who asserts that to be successful, monitoring must be "less abstract, its purpose more relevant, and its contributions more apparent." This is no small task and at times speaks to the need for a creative mix of science and politics to forge a program that will eventually lead to an institutional use of monitoring data to make informed management decisions. Integrating natural resource science into management can take time, but understanding and incorporating these attributes will help ensure the relevance and success of long-term ecoregional monitoring programs such as is being proposed for Pima County.

The review of monitoring programs in southern Arizona reveals that each program has elements that are admirable and worthy of duplication (Table 2). The use of adaptive management at Las Cienega NCA and data management at Santa Rita ER are two excellent examples. An assessment of the programs reveals that no one program gets high marks for the full set of attributes that are important to the long-term success of a monitoring program, though a number of programs come close (e.g., water monitoring at Cienega Creek NP). Indeed, all monitoring programs face design challenges in the face of limited funds, which often mean that tradeoffs must be made among a host of attributes outlined in this report. The real challenge will be to be explicit about these tradeoffs and investigate creative solutions, such as partnerships, to achieve an acceptable balance that still achieves the program's goals.

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Table 2. Analysis of monitoring efforts in southern Arizona and how each addresses the attributes that have been established as benchmarks of successful monitoring program design and implementation.

		Attribute					
Indicator	Program (dates)	Informs management objectives	Careful selection of indicators	Sufficient sampling for change detection	Thorough protocols and long-term data integrity	Periodic review	Long-term funding commitment
Water resources	Cienega Creek Preserve (1986- present)	Important management decisions based on program data.	Yes, direct measures of indicators affected by threat. Sample size and spatial allocation were not key design considerations.	Yes, modified after review in 1998.	Protocols and quality assurance/quality control procedures are well documented. Metadata status unknown.	Review in 1998 led to changes in protocol. More current review would be appropriate.	Yes
Vegetation	Santa Rita Experimental Range (1957-present)	Direct link to management is not primary goal of program. Instead, program is designed to observe changes and provide information for long-term assessment of grassland condition.	Plots established for livestock management, but now provide important historical data on dynamics of grassland vegetation.	Sampling design is spatially biased but plots are representative of the range of conditions.	Yes, outstanding on-line database and periodic data summaries.	No objectives or thresholds have been established, but periodic surveys continue. Data are used extensively in publications.	Yes, College of Agriculture continues to operate as long-term research site.
	Desert Laboratory, Tumamoc Hill (1903-present)	Yes, because management objectives are to understand dynamics of plant communities on site and not directed toward adaptive management or restoration activities.	Vegetation was chosen for monitoring because of early interest in topic.	Only a few long-term plots, but frequency and distribution data is sufficient to detect change.	Protocols are written and copies, along with original data, are archived at the University of Arizona Special Collections. Most data have been digitized. Data entered into Excel spreadsheets.	Data have been used for a variety of research questions but no thorough review of data is necessary because of small sample size. Efforts are under way to combine data with other plots in the region.	No because future of site is uncertain. No plans to resample (Julio Betancourt, *pers. comm.*).
	Malpai Borderlands Group: Arizona-New Mexico Borderlands (1986-present)	Monitoring program was deemed inadequate for determining effects of grazing, climate, and fire, so research program started.	Standard vegetation measures relate to management objective.	Unknown because data review has not taken place.	Protocols are not well documented but use standard procedures. Data are maintained in Excel spreadsheets.	As of mid 2007, data had not been analyzed (Peter Warren, *pers. comm.*).	No; private foundations pay for monitoring. Periodic grants are needed.
	Las Cienegas National Conservation Area (1995-present)	Yes, links to grazing practices and desired future conditions of rangeland health.	Standard vegetation measure link to grazing effects.	Inadequate sampling was highlighted in 2004 review and has been changed.	Protocols are reasonably detailed. Metadata and software used unknown.	Review in 2004 included power analysis and trend detection.	Moderate because BLM must seek funding outside of their regular budget. Success in using monitoring data for management has led to strong support.

		Attribute					
Indicator	Program (dates)	Informs management objectives	Careful selection of indicators	Sufficient sampling for change detection	Thorough protocols and long-term data integrity	Periodic review	Long-term funding commitment
Fish	Las Cienegas National Conservation Area (1989-present)	Yes; maintenance of endangered fish is an important management objective.	Yes; focused on population change of one species.	Yes because observed change was very large.	Protocols are not well established. Data entered into Excel spreadsheets. No metadata.	In 2007 program was reviewed and included suggestions for increasing sampling efficiency and efficacy	Surveys are inexpensive and one staff member (Jeff Simms) is committed to monitoring. If Jeff Simms leaves position, long-term commitment may erode.
Vertebrates (birds, reptiles, small mammals	Organ Pipe Cactus National Monument, Ecological Monitoring Program (1989-present)	Some disconnect because management needs have changed since the program's inception. Program is now trying to align with management objectives.	A broad suite of indicators were chosen without consideration of some sampling issues, yet data now have some of the longest-term data in the region for vertebrates.	Mostly a small number of sites, but each site has climate data as explanatory variables when interpreting trends.	Mixed. Early effort to document protocol were insufficient, but recent work has focused on database design and protocol clarification have improved.	Annual summary reports were discontinued in 1999 and have recently been restarted. Detailed analysis of data is now underway for reptiles and rodents.	Uncertain, but data reviews and the program's contributions to trend information should warrant further consideration.
Birds	Tucson Bird Count (2001-present)	No specific management objectives except to provide information to regional land managers on trends in birds and in identifying areas that promote native birds.	Yes: focus always on birds	Considerable network of monitoring sites. There may be error with data collected by volunteers.	Protocols are sufficient for volunteers to use. Data stored at the University of Arizona.	Currently underway	No, but has received funding from a variety sources and maintains community support.
Streams (water, invertebrates, vegetation, channel characteristics	National Park Service Inventory and Monitoring Program (2006-present)	Yes, but stream segments where monitoring takes place is often a small part of watershed that is under different ownership.	Rigorous vetting of each indicator.	To be determined; small sample size will be an issue.	Considerable effort expended on protocol development, database design, and long-term preservation of data.	Scheduled for 2008 for most indicators.	Yes, part of base funding.

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APPENDIX A

Appendix A. List of monitoring programs, expertise, and related projects within Pima County.

Partner Group	Partner	Monitoring-related Activities and Expertise
Federal Government	Agriculture Research Service	Watershed research; Interest in developing stream-channel monitoring protocol; Expertise in developing conceptual ecological models.
	BLM, Tucson Field Office: 1) Las Cienegas National Conservation Area (LCNCA) 2) Ironwood National Monument (IMN)	Monitoring Avian Productivity and Survivorship (bird) monitoring (LCNCA); Southwestern willow flycatcher monitoring (LCNCA); Cactus ferruginous pygmy owl, desert tortoise, and Turk's head cactus monitoring (IMN) Bat roost inventory (INM); Stream gauge monitoring (LCNCA); Recreation impacts (inventory) (LCNCA and INM).
	Department of Defense–Barry M. Goldwater Range	Currently developing land-use and monitoring plans- held scoping session in November to determine parameters; Endangered species monitoring: lesser long-nosed bat and cactus ferruginous pygmy-owl.
	EPA, Environmental Monitoring and Assessment Program	National program with monitoring assessment for water-quality, fish, and air-quality monitoring, but with no known sites in Pima County; Protocols are developed and can be adapted.
	National Park Service, Sonoran Desert Network	Currently implementing long-term protocols for 11 park units in Arizona and w. New Mexico for the following parameters: 1) integrated aquatic monitoring program (channel geomorphology, aquatic macroinvertebrates, fish, water quality, paraphyton, and algae, 2) climate, and 3) birds; Future protocol implementation includes vegetation (including non-native species), air quality, soils, visitor impacts, and adjacent land use; Database development for all monitoring parameters; Communications plan development; Vegetation mapping (to formation level) now underway. Plant and vertebrate inventories of all 11 units completed with coordination with USGS Sonoran Desert Research Station.
	NPS, Organ Pipe Cactus National Monument	Environmental Monitoring and Assessment Program began in 1986 and have been monitoring parameters at 9 "core" sites: atmospheric deposition, air quality, climate, water quality, well depth, vegetation bats, lizards, birds, Quitobaquito desert pupfish, and nocturnal rodents. Program currently being reviewed and may include monitoring impacts from illegal immigrants crossing into the park; Endangered species (mandatory) monitoring: Sonoran pronghorn, Quitobaquito desert pupfish, and cactus ferruginous pygmy owl.
	NPS, Saguaro National Park	Long-term vegetation plots for saguaros and woody plants; Cactus ferruginous pygmy-owl and desert tortoise monitoring; Lowland leopard frog and water-availability monitoring project; Air quality and climate monitoring stations; Study on road kill.
	National Weather Service	Gathers and compiles weather data from sites throughout southern Arizona; Developing models for predicting precipitation.

Partner Group	Partner	Monitoring-related Activities and Expertise
Federal Government (cont.)	Natural Resource Conservation Service	Developing national vegetation monitoring guidelines for rangelands- 30 test sites in southern Arizona; Various vegetation and soils monitoring projects on private ranches in Pima County.
	USFWS– Ecological Services	Provides regulation assistance
	USFWS, Buenos Aires National Wildlife Refuge	Vegetation monitoring plots; Active fire program; Amphibian Research and Monitoring Initiative (ARMI)- monitoring occupancy of spadefoots and other anurans (by Cecil Schwalbe of USGS Sonoran Desert Research Station; Endangered species (mandatory) monitoring: cactus ferruginous pygmy and masked bobwhite;
	USFWS, Cabeza Prieta National Wildlife Refuge	Undocumented immigrant and Border Patrol impacts monitoring Vegetation monitoring plots, including invasive species; Endangered species (mandatory) monitoring: Sonoran pronghorn and cactus ferruginous pygmy owl Other species: desert bighorn sheep, mule deer.
	U.S. Forest Service	Fire management and effects monitoring; Water-quality monitoring; Air particulate monitoring; Range condition monitoring and soil assessment for all leased land for grazing; Multiple-species Inventory and Monitoring Program beginning to be developed; Bat exit flight monitoring; Single-species monitoring: fishes, Chiricahua leopard frogs, Mexican spotted owl, peregrine falcon nest sites;
	USGS and University of Arizona–Desert Laboratory (Tumamoc Hill)	Historic vegetation monitoring plots; Invasive plants research and monitoring; Coordinates Cooperative Weed Management group.
	USGS–Water Resources Division	Regional stream gage monitoring program and website maintenance
	USGS–Biological Resources Division	Developing comprehensive landbird monitoring protocol; Expertise in vegetation and amphibian monitoring; Beginning National Phenology Network program to include monitoring.
	USGS–Water Resources Division	Maintains gauging stations throughout region; Some water-quality monitoring; National Water Quality Assessment Program (NAWQA)-sampled from Santa Cruz at Cortaro (from 1996 to 1997)
State Government	Arizona Department of Transportation	Roadkill monitoring projects; Bufflegrass removal and effectiveness monitoring
	Arizona Department of Water Resources	Regional groundwater monitoring; Protocols for aquatic macroinvertebrate and water-quality monitoring;

Partner Group	Partner	Monitoring-related Activities and Expertise
State Government (cont.)	Arizona Game and Fish Department	Monitoring many species in Pima County: Bats, Sonoran pronghorn, bighorn sheep, coyotes, deer, javelina, doves, southwest willow flycatcher, all native fishes;
		Developing state-wide monitoring protocols for birds (especially landbirds and water birds) and bats. Other taxa groups to be developed in the future;
		General field-method expertise in personnel;
	University of Arizona–School of Renewable Natural Resources–general	Sampling design expertise;
		Watershed modeling;
		Data analysis expertise;
		Tucson Bird Count: Citizen-science bird monitoring throughout the greater Tucson area since 2000.
	University of Arizona–School of Renewable Natural Resources, Santa Rita Experimental Range	Long-term vegetation monitoring program;
		Photo-plot monitoring;
	University of Arizona–Office of Arid Lands Studies	Remote sensing expertise;
		Development of land cover and vegetation formation protocol for NPS, SODN.
	University of Arizona-Department of Soil, Water, and Environmental Sciences	Water-quality monitoring protocol development;
		Aquatic-macroinvertebrate monitoring protocol development.
County and Local Governments	Pima County- Department of Environmental Quality	Air quality monitoring at 18 stations: Air particulates, wind speed and direction, ozone, CO, NO2, SO2.
	Pima County Natural Resources, Parks & Recreation	Open-space acquisition;
		Rangeland monitoring;
		Undocumented immigrant effects monitoring.
	Pima County Flood Control District	Precipitation monitoring at 65 self-reporting sites;
		Climate monitoring- 4 weather stations;
		Streamflow gauges (A.L.E.R.T. system).
	Pima Association of Governments	Regional orthophoto program;
		Water-quality monitoring;
		Stream extent and groundwater level monitoring (monthly) at Cienega Creek Natural Preserve (2001);
		Water-quality monitoring at Agua Caliente Spring;
		Public involvement in monitoring activities.
	City Of Tucson	Land-use regulation;
		Potential HCP permittee;
		Interest in regional monitoring.
	Town of Marana	Land use regulation;
		Potential HCP permittee;
		Interest in regional monitoring partnerships.
Non-governmental organizations	Arizona-Sonora Desert Museum	Non-native species monitoring program;
		Research expertise;
		Public education and outreach.

Partner Group	Partner	Monitoring-related Activities and Expertise
Non-governmental organizations (cont.)	Coalition for Sonoran Desert Protection	Public education and outreach; Regional monitoring advocates.
	Sky Island Alliance	Road-status monitoring; Land restoration; Wildlife monitoring (large carnivores);
	Sonoran Institute	Monitoring protocol development (in cooperation with the National Park Service); Fostering regional partnerships (especially in Mexico).
	The Nature Conservancy of Arizona	Species monitoring programs (fish and vegetation in cooperation with the Bureau of Land Management); Land restoration.
	Tucson Audubon Society	Land restoration along Santa Cruz with bird and vegetation monitoring to assess effectiveness of restoration efforts; Citizen-science bird monitoring (Important Bird Area program) at sites throughout Arizona

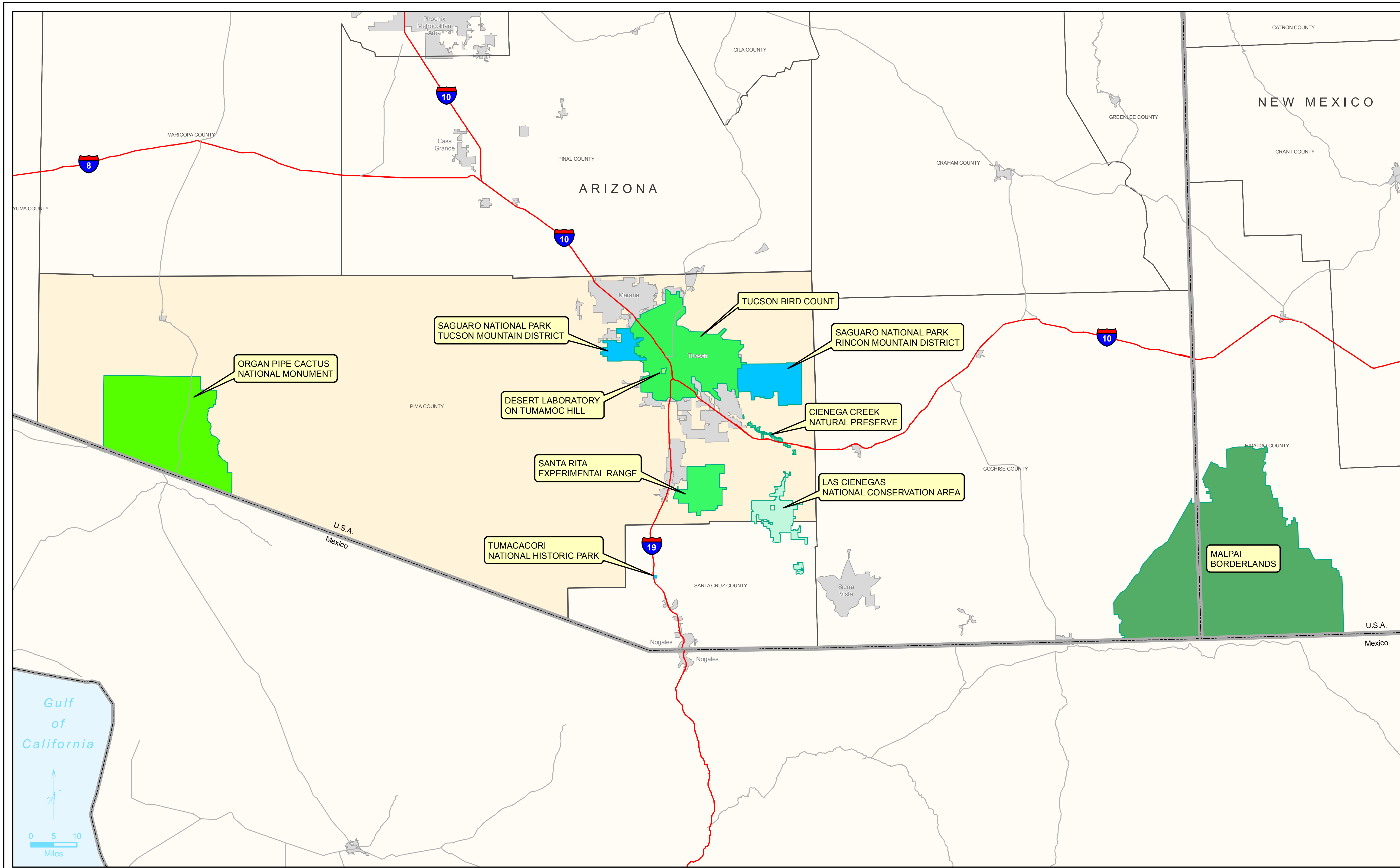

Figure 6. Locations of the eight monitoring programs highlighted in this report.