MEMORANDUM

Date: August 18, 2008

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

From: C.H. Huckelberry
County Administrator

Re: **Multi-Species Conservation Plan Update**

Background

This memorandum provides an update about the Pima County Multi-Species Conservation Plan. We undertook a planning process in 1999, adopted the Preliminary Sonoran Desert Conservation Plan in 2000, and incorporated the biological reserve into the Conservation Lands System of the Comprehensive Plan in 2001. What remains is completion of the federal permit under Section 10 of the Endangered Species Act. This permit will organize our mitigation strategies with the United States Fish and Wildlife Service, and provide predictability for Pima County's regulatory commitments. It will also assure funding for certain conservation programs.

There have been a number of drafts for the Multi-Species Conservation Plan and Environmental Impact Statement, with the latest released in August of 2006. There are two reasons we have not submitted the earlier drafts for a Section 10 permit.

The first is that the immediate need for a permit was reduced by the United States Fish and Wildlife Service delisting of the pygmy-owl, and the annexation of County lands containing Pima Pineapple cactus by other local jurisdictions. Section 10 of the Endangered Species Act is an exception to the prohibition on "take" that is found in Section 9 of the law. In general, local jurisdictions do not seek such permits unless they need regulatory relief from this limitation. For the moment, Pima County does not need a "take" permit. But, while the immediate need for a permit has been reduced, it is reasonable to anticipate that wildlife species will continue to be listed, whether it is the western yellow-billed cuckoo, the Tucson shovel-nosed snake, or the Mexican garter snake in the near term, or another species. The pygmy-owl may even be re-listed in the wake of current federal review. As long as growth continues in Pima County there will be a need for a Section 10 permit at some point. Therefore, we continued to develop the elements of a well-crafted effective conservation proposal that achieves actual conservation and prevents the disruption that endangered species listings and lawsuits cause to local plans and investments.

The second reason the August 2006 draft was not submitted for a permit is that we became aware that other jurisdictions were mired down in failed conservation programs, particularly in the areas of adaptive management and monitoring. In June of 2001, the United States Fish and Wildlife Service adopted a Five Point Policy that clarified the responsibilities of permit-holders for adaptive management and monitoring programs.

Effective programs were not defined, yet permits were issued on the premise that the jurisdictions would figure out how to meet the federal requirement later. These premises were not achieved, and the Service itself has been unable to provide reliable guidance about how to meet the requirements of their own policy. These failures have proven expensive for communities and shaken the confidence of participants in the federal Section 10 program.

To help repair this broken aspect of the federal Habitat Conservation Program so that an achievable permit would be available to us in the future, Pima County along with University of Arizona scientists submitted a proposal and won a grant from the Cooperative Endangered Species Conservation Fund Grant program to design a science-based cost-effective monitoring approach which will inform our adaptive management program and set an example for other jurisdictions.

That study process has progressed on-schedule since 2007. It is nearing completion, and it sets the stage for our federal permit application. This memorandum provides:

1. A summary of studies that have been issued to date,

2. A summary of the four studies that are attached, and

3. A description of the upcoming public and peer review process.

<u>Studies Issued To Date</u>

On June 10, 2008, three reports were forwarded to the Board and made available to the public on the Pima County site (http:// www.pima.gov/cmo/sdcp/Monitoring/index.html).

The first study was a review of ecological monitoring efforts in Southern Arizona. Since Southern Arizona has some of the oldest monitoring sites in North America (Tumamoc Hill and the Santa Rita Experimental Range), the lessons learned from these long-term projects are important to understanding how to design a monitoring program under the Endangered Species Act.

The second study was an assessment of photo monitoring efforts to help determine the efficacy of photo monitoring for application to the Pima County ecological monitoring program.

The third study was a primer on groundwater-dependent ecosystems and describes methods used to measure change in shallow aquifers that are linked to the condition and extent of riparian and aquatic ecosystems. The report reviewed existing groundwater monitoring efforts and identified a subset of shallow groundwater systems that would be of highest priority if groundwater monitoring is deemed appropriate for inclusion into the program. Pima County and the Sonoran Desert Conservation Plan Science Team's Monitoring Subcommittee will use this information to weigh the significance of expanding current groundwater monitoring versus employing other measures of ecosystem health such as vegetation.

Current Studies

Today I am forwarding four studies that significantly advance the monitoring design project.

The first study is a recommended approach for the Pima County Multiple Species Conservation Plan Monitoring Program. Under the Five Point Policy, the Service requires both compliance monitoring to show the terms of the permit are being met, and effectiveness monitoring to show that the conservation plan is achieving the biological goal of conserving species. Effectiveness monitoring is the requirement that is most challenging, and has traditionally involved data collection about individual species that has not led to comprehensive knowledge about habitat or ecosystem change.
Therefore, the County is proposing to undertake effectiveness monitoring at four levels: 1) at the species level; 2) at the habitat level; 3) at the ecosystem level; and 4) at the level of threats.

This approach will be more cost-effective and science-based than the traditional method. All of these methods are described in the attached study, but the focus is on species level monitoring. The study provides an explanation of when it makes sense to monitor at the species level, and proposes which covered species Pima County may want to monitor in such a manner, along with a suggestion about how to understand costs.

The second study is a comprehensive review of adaptive management efforts by the major Multi-Species Conservation Plans, including Balcones (Austin), Clark County (Las Vegas), and San Diego. The lessons learned sections are perhaps the most valuable in informing our future program, and in confirming that we are fortunate to be able to define our own program in advance of seeking a permit with the United States Fish and Wildlife Service. In general the study found that no program had been successful in evaluating management effectiveness, and though they have been implemented for as long as a decade, they are searching for a proper program design.

The third study has a focus on how remote sensing can contribute to monitoring ecosystem level change. It is a good companion to the study on species level monitoring, and will be followed soon with a report that uses satellite imagery from 1992 and 2001 to examine landscape change in Pima County by land ownership and jurisdiction. The followup study substantiates some of the key claims made for the National Land Cover Dataset in the Remote Sensing report. The analyses result in new information regarding trends in riparian forests and urban development.

The final study proposes a data management plan for the ecological monitoring program, which we will need to track trends over time.

Time Line, Public Process and Peer Review

The design team plans to complete the last studies and formalize their recommendations for program implementation in the next months.

Following peer review and public process, the monitoring approach will be incorporated into the Multi-Species Conservation Plan draft and the Environmental Impact Statement.

We can begin to draft the framework of important plan elements in anticipation of applying for our Section 10 permit and seek public input with the release of these studies.

We can also begin to describe how the Multi-Species Conservation Plan suggests solutions to permit problems under the Clean Water Act.

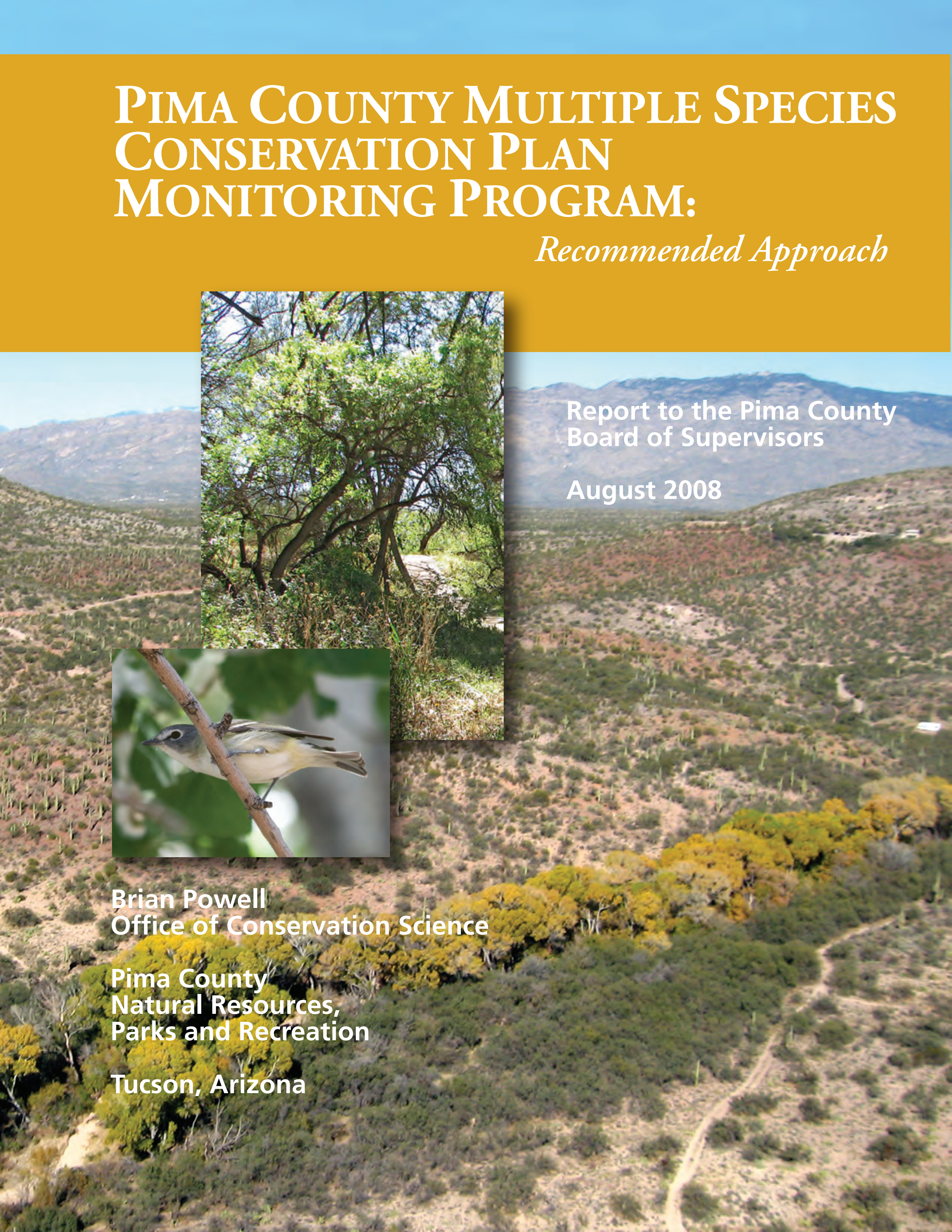
CHH/jj

Attachments

c: John Bernal, Deputy County Administrator - Public Works
Rafael Payan, Natural Resources, Parks and Recreation Director
Maeveen Behan, Deputy Director, Natural Resources, Parks and Recreation

PIMA COUNTY MULTIPLE SPECIES CONSERVATION PLAN MONITORING PROGRAM:

Recommended Approach



Report to the Pima County Board of Supervisors

August 2008

Brian Powell
Office of Conservation Science

Pima County
Natural Resources,
Parks and Recreation

Tucson, Arizona

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1. Abstract

Monitoring is a required element of all Habitat Conservation Plans, such as is being developed for the Pima County Multi-species Conservation Plan (MSCP). This document provides an overview of the issues related to monitoring the 36 species proposed for coverage under the forthcoming Section 10 permit to the United States Fish and Wildlife Service. By integrating the requirements for MSCP compliance and effectiveness monitoring with the challenges inherent in single-species monitoring, this document seeks a balance between species-specific monitoring and other habitat, ecosystem and threats-based measures (parameters). By designing such a program, Pima County will be in a better position to anticipate and adjust management actions for the conservation of covered species and the ecosystems that support them.

The need to adopt a new, hybrid approach to Pima County's MSCP monitoring program arises from lessons learned from other MSCP monitoring efforts, most of which have struggled to maintain a balance among biological relevance, management significance, and cost effectiveness. Many early MSCP programs are now revising their monitoring strategies, which often lacked clear goals and measurable objectives. Perhaps most importantly, the focus on monitoring a large number of vertebrate species presents challenges to detecting trends because of the highly variable nature of many populations and their complex response to changes in their habitat across multiple spatial and temporal scales. This report addresses issues of species variability and sampling error that make trend detection of many vertebrates difficult. The aim is not to discredit a species-level approach to monitoring, but rather to assert that species should be one component of a monitoring program that seeks to detect change to a host of ecological features known to affect a broader suite of biodiversity. Integrating a suite of parameters spanning spatial scales also matches with the vision of the Sonoran Desert Conservation Plan, of which the Pima County MSCP is but one component.

Single-species monitoring should play an important role in the proposed Pima County MSCP monitoring program (known as the Pima County Ecological Monitoring Program) and this report identifies a suite of species that meet an important criterion: those that are spatially restricted to and whose extirpation from those areas would constitute biodiversity loss in the County. Further, there are a host of species that do not occur on lands owned or managed by the County, but which are candidates for re-introduction; those species should be monitored after such re-introduction efforts. For the remaining covered species, a habitat, ecosystem, and/or threats-based approach are likely a more appropriate approach. The planning effort underway with the University of Arizona cooperators is developing this approach and it will be the subject of future reports.

2. Introduction: Sonoran Desert Conservation Plan and Multiple Species Conservation Plan

The Sonoran Desert Conservation Plan (SDCP) is a visionary plan that seeks to address multiple conservation needs in the rapidly urbanizing Pima County, Arizona, including cultural resources, riparian, and ranch conservation and maintenance of wildlife habitat (Pima County 2000a). The SDCP is now being implemented through a land acquisition program (funded primarily by County bonds) and through mitigation measures such as revisions to numerous Pima County ordinances, including protection of native plants and restoration efforts.

The SDCP was primarily driven by its ambitious 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" (Pima County 2000a). To help ensure this goal is realized and to provide regulatory certainty, Pima County (herein referred to as the County) drafted a Multi-species Conservation Plan (MSCP) that embodies the scientific principles of the SDCP biological goal and specifies mechanisms for addressing legal conservation requirements of the Endangered Species Act. The current draft Pima County MSCP lists 36 Priority Vulnerable Species (RECON Environmental 2006) (Appendix A) proposed for coverage in County's forthcoming Section 10(a)(1)(B) permit application (herein the permit) from the U.S. Fish and Wildlife Service (USFWS).

2.1 Permit Area and the Conservation Lands System

The SDCP planning process began with the evaluation of approximately 2.7 million acres in the County as part of a biological reserve design assessment. Through the collection and synthesis of biological data and anticipated land-use and economic impacts, the County developed the Conservation Lands System (CLS), which represents the County's core implementation strategy for the MSCP. Focused primarily in eastern portion of the County, the CLS cuts across federal, state, and local jurisdictions (Fig. 1) and provides the blueprint for reserve design (Fig. 2). More than 80% of the CLS is managed by the State and Federal land management agencies. Within the CLS, lands are categorized based on their biological value and land-use type (the principal category designations being: Biological Core Management Areas, Important Riparian Areas, and Multiple Use). For each designation, conservation targets were set, ranging from 66% conservation (Multiple Use) to 95% conservation (Important Riparian Areas). These goals were incorporated within the most recent Comprehensive Land Use Plan, thereby providing conservation mechanisms through the County's regulatory authority.

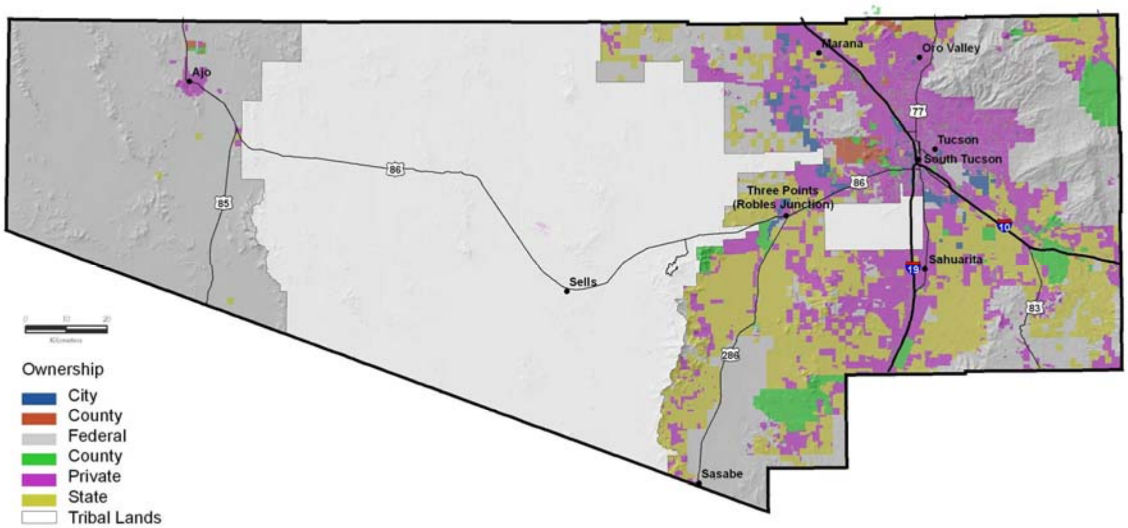

Figure 1. Land Ownership in Pima County.

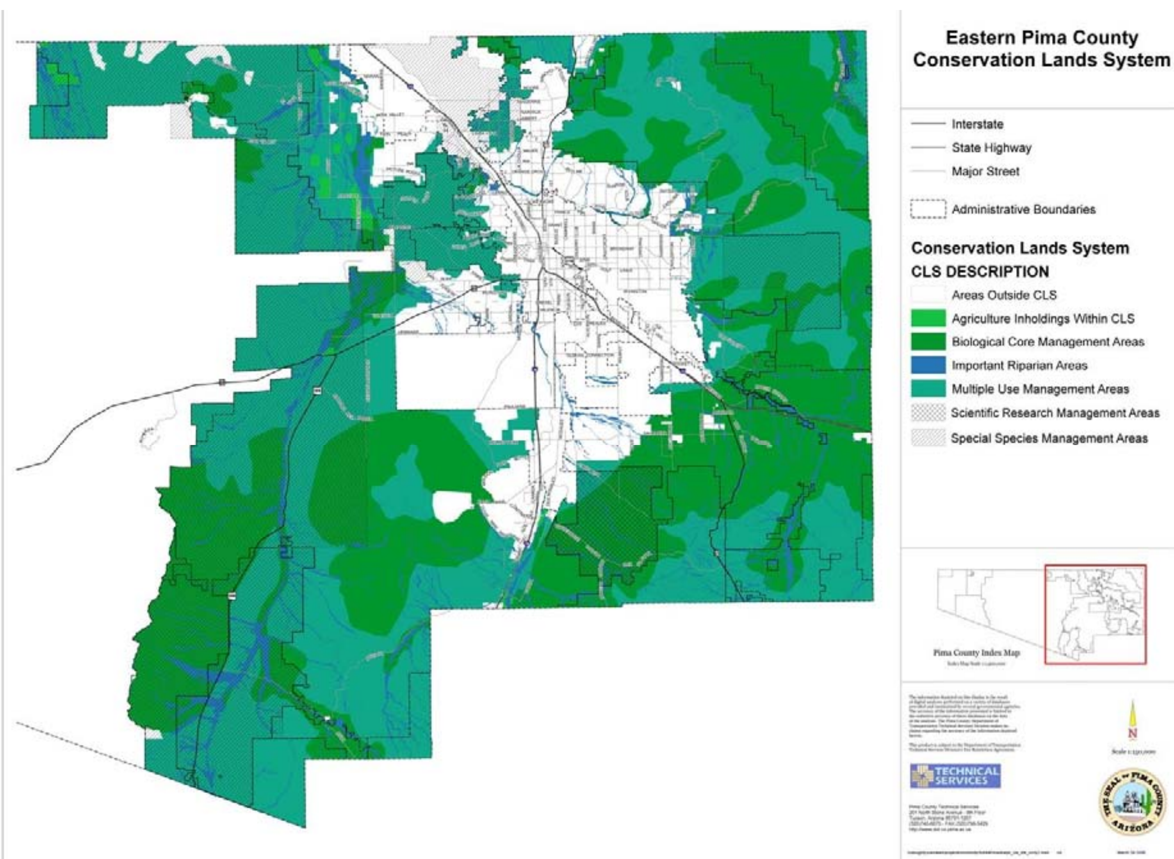

Figure 2. The Conservation Lands System (CLS) for eastern Pima County. Maps of potential habitat for Priority Vulnerable Species were used to create the CLS, which has guided land management and acquisitions activities for the Sonoran Desert Conservation Plan and Multiple-species Conservation Plan.

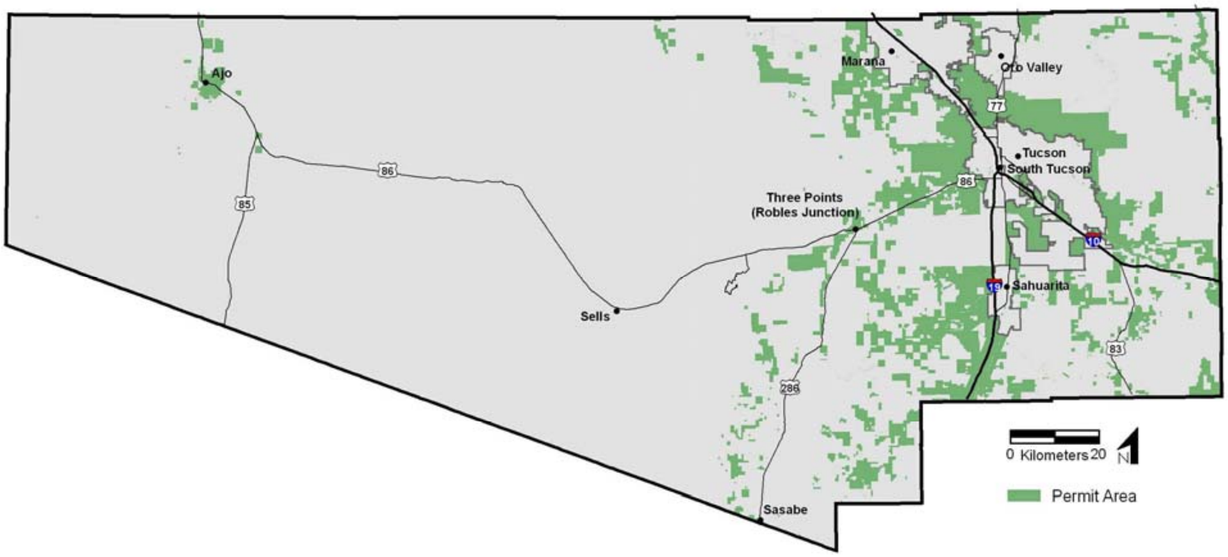

Figure 3. Pima County MSCP Permit Area (607,000 acres)

The Permit Area, to which the permit applies, defines the present limits of the County's land-use regulatory authority; it comprises of approximately 607,700 acres scattered within a matrix of state, federal, tribal and municipal lands (Fig. 3).

2.2 Covered Species

Pima County is currently considering permit coverage for 36 species (Appendix A). Species were chosen for permit inclusion for a variety of reasons, most notably because of their current, anticipated, or possible designation as a Threatened or Endangered species and because of their anticipated decline as a result of the proposed "take" actions, primarily those related to development and associated infrastructure projects. As part of the design process, the County, its Scientific Technical Advisory Team (STAT), and RECON Environmental Inc., modeled the potential habitat of these and other species (the original PVS list contained 55 species). Planners then developed conservation targets (i.e., percentages of modeled and known habitat needing conservation) and determined if the CLS provided adequate coverage to meet these conservation targets. Overall, the CLS provides substantial coverage to meet the covered species goals, which ranged from 75-100% conservation for all PVS. Species that were initially proposed for permit coverage but for which the minimum goals were not attainable were largely exempted from permit coverage (See RECON Environmental 2006).

Based on projections by RECON (2006), covered activities would result in the permanent loss of 73,000 acres of potential habitat for the 36 covered species through buildout (30 years). If these projection hold, Pima County would be responsible for mitigating for and monitoring up to

258,000 acres through buildout. This assumes that "impacts within the CLS (approximately 45,000 acres) will be mitigated within the CLS (approximately 123,000 acres) and impacts outside of the CLS (approximately 29,000 acres) also will be mitigated within the CLS (approximately 135,000 acres)" (RECON Environmental 2006).

2.3 SDCP Conservation Measures to Date

Development-related activities (housing, roads, and other infrastructure) pose a significant threat to the proposed covered species and their habitats (RECON Environmental 2006). Though avoidance, minimization, and restoration activities are important components of the MSCP, the scope of development-related activities necessitates that mitigation will be the County's primary conservation tool. To date (August 2008), Pima County has made substantial progress towards meeting the proposed mitigation goals (Fig. 4), with the principal mitigation mechanisms being:

- Conservation Land System subdivision set asides;
- Leased open space;
- County-owned open space;

Leased open space is primarily on Arizona State Trust Land, with leases being renewed every 10 years. In the County's current version of the MSCP, there is an indication that leased lands contribute to the mitigation strategy (RECON Environmental 2006; pp. 3-16), yet it is unclear as to whether the continued renewal of short-term leases will be acceptable to the USFWS. Though unresolved, it has been the position of the County to establish more permanent conservation on these lands through longer-term leases or fee acquisition. (A precedent has been set for a longer-term lease with the Town of Marana, which holds 99-year lease in the Tortolita Mountains). Lands committed to the MSCP by the County include fee acquisitions whose primary purpose is biological conservation. Some of these acquisitions were originally purchased for other purposes, but have since been reclassified as committed Section 10 lands. Uncommitted lands (e.g., Tucson Mountain Park, Tortolita Mountain Park, Southeast Regional Park, etc.) are important components of the CLS, and they may be proposed for mitigation credit in the future if conservation commitments are secured.

In addition, conservation goals have been set for ecological communities and special elements as expressed percentage and total acres conserved (Table 1; Bundrick et. al. 2000, Pima County 2000b, RECON Environmental Inc. 2000a, Fonseca and Connolly 2002, RECON Environmental Inc. 2006).

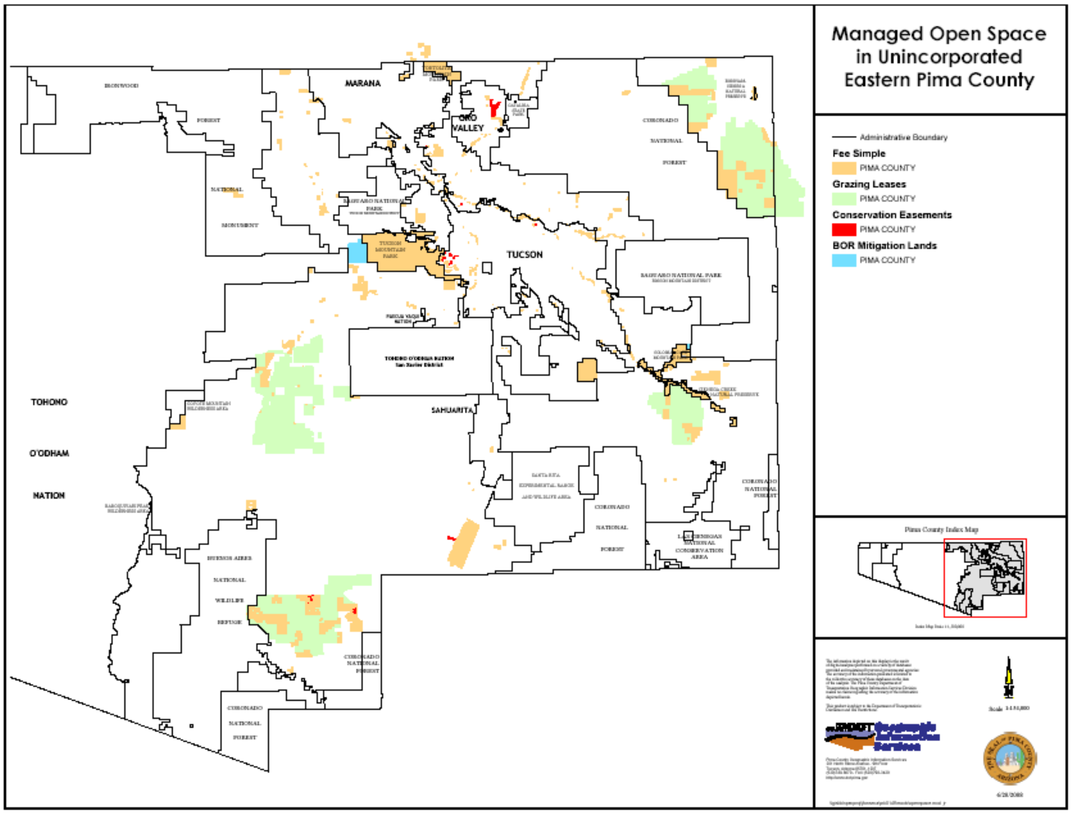

Figure 4. Lands owned and leased by Pima County and which are committed for mitigation of permitted activities.

Table 1. Acres of land preserved by Pima County, by vegetation and land cover type, 2002-2006. Figures include leased lands.

Cover Type	Acres
Agriculture	2,498
Chihuahuan Desertscrub (Creosotebush--Tarbush)	6,492
Madrean Evergreen Forest (Encinal)	766
Mogollon Chaparral Scrubland (Mixed Evergreen Sclerophyll)	157
Mogollon Deciduous Swampforest (Cottonwood--Willow)	21
Mogollon Deciduous Swampforest (Mixed Broadleaf)	68
Scrub Grassland (Mixed Grass--Scrub)	88,728
Sonoran Deciduous Swamp and Riparian Scrub (Mixed Scrub)	835
Sonoran Desertscrub (Creosotebush--Bursage)	4,357
Sonoran Desertscrub (Paloverde--Mixed Cacti)	31,751
Sonoran Riparian and Oasis Forest (Cottonwood--Willow)	35
Urban	3,254
Water	13
Total	138,973

3. Pima County Ecological Monitoring Program Goals and Objectives

"The monitoring program will be based on sound science"
USFWS Five-point policy

The numerous activities undertaken by the County prior to submitting a permit (e.g., adoption of an ambitious Comprehensive Land Use Plan, purchase and lease of open space, etc.) demonstrates an extraordinary commitment to the MSCP. Yet to be completed is the development of a monitoring program to ensure that these mitigation measures are achieving the desired effect. Throughout this document, I borrow heavily from the USFWS monitoring guidelines, as set out in the USFWS's HCP handbook (U.S. Fish and Wildlife Service 1996) and Five-point policy (U.S. Fish and Wildlife Service 2000). Together, these documents provide guidelines to ensure permit compliance and determine if agreed-upon conservation strategies are achieving the desired results.

There is an important distinction between compliance and effectiveness monitoring, both of which must be addressed in an HCP:

- *Compliance Monitoring* verifies that the permittee (i.e., Pima County) is carrying out the terms of the permit. Activities include annual reporting of take and relevant avoidance, minimization and mitigation activities.

- *Effectiveness monitoring* evaluates the impact of the permitted action(s) and determines whether the HCP is achieving the biological goals and objectives. Effectiveness monitoring is the most difficult component of monitoring and is the focus of this report.

This section of the report provides an overview of a proposed approach to setting program goals and objectives and for implementing effectiveness monitoring and adaptive management activities. Taken together, this approach should satisfy, and in many ways surpass, the HCP effectiveness monitoring requirements, as outlined by the USFWS. Development of a scientifically sound program is especially critical given the recent criticisms of MSCPs and other HCPs (Harding et al. 2001, Atkinson et al. 2004, Hierl et al. 2005, Rahn et al. 2006).

3.1 Monitoring Goals and Objectives

Like all scientific endeavors, developing a monitoring program must begin with well defined goals and objectives (Christensen et. al. 1996, Slocombe 1998). In the context of HCPs, *biological goals* are broad, guiding principles around which conservation efforts (avoidance, minimization, and mitigation) are focused. In the case of Pima County, the SDCP biological goal provides conservation guidance:

> *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.* (Pima County 2000a)

As mentioned previously, compliance measures aimed at meeting this goal (especially land acquisition and set asides) have been undertaken (See Pima County 2000a, RECON Environmental Inc. 2000b, 2001, 2006). The Pima County Ecological Monitoring Program (PCEMP) is being developed to determine if these measures are proving effective at meeting the SDCP biological goal and the species-specific MSCP goals. Specifically, the goal of the PCEMP is 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 2007)

Objectives are a step down from the biological goals; they are clearly articulated descriptions of a measurable standard, desired state, or trend and are articulated in understandable units that identify trigger points (a.k.a., thresholds) for management actions (Elzinga et. al. 2001, Atkinson et. al. 2004, Tear et. al. 2005). Elzinga et al. (2001; pp. 248-270) makes an important distinction between management objectives and sampling objectives. First, *management objectives* provide a measure of management success by describing a desired future state of a resource; they should be realistic, specific, and measurable. Management objectives can be either related to the *condition* of a resource (e.g., maintain the current population of Pima pineapple cactus within the reserve system) or a *change* in the resource (e.g., increase the population of Pima pineapple cactus by 20% over the 30-year permit period).

The following management objectives were developed by STAT (Pima County 2000a). They are vague and would need to be "stepped down" to conform to the standards outlined above, but nevertheless are good starting objectives for the proposed monitoring program:

1. Maintain or improve the status of unlisted species whose existence in Pima County is vulnerable;
2. Where feasible and appropriate, re-introduce and recover species that have been extirpated from this region;
3. Promote recovery of federally listed and candidate species to the point where their continued existence is no longer at risk;
4. Identify biological threats to the region's biodiversity posed by exotic and native species of plants and animals, and develop strategies to reduce these threats and avoid additional invasive exotics in the future;
5. Identify compromises to ecosystem functions within target plant communities selected for their biological significance and develop strategies to mitigate them;
6. Promote long-term viability for species, environments and biotic communities that have special significance to people of this region because of their aesthetic or cultural values, regional uniqueness, or economic significance.

Sampling objectives are companions to management objectives whenever monitoring employs sampling procedures (i.e., when not all areas can be surveyed; see Section 4.2.1.2). Sampling objectives specify information such as target levels of precision (a measurement of the repeatability of a sample), and the magnitude of change that we are hoping to detect. (Power and false-change [Type I] errors are also important, but are not covered here; see Elzinga et al. [2001] for more information.) The difference between management objectives and sampling objectives is best summarized by Elzinga et al. (2001): “whereas a management objective sets a specific goal for attaining an ecological condition or change, sampling objectives sets a goal for the measurement of that value”. For example, a management objective might be to maintain the total number of Pima pineapple cactus within the reserve system. The companion sampling objective might state a desire to be 90% confident that our sampling-based estimates of the population are within ±20% of the estimated true value.

In setting objectives, efforts should be made to link them to thresholds for each species and/or habitat component (e.g., Stromberg 2001). It should be kept in mind, however, that ecological objectives and thresholds, though intuitively appealing, can be difficult to establish for many species and communities with naturally variable populations, distributions, habitat occupancy, etc. (Walker and Meyers 2004) (see Section 4.2, for discussion on the challenges of trend and [by extension] threshold detection).

In the context of an HCP, management objectives for individual species are often framed by thresholds related to the maintenance of populations on mitigated lands. Where appropriate, sampling objectives should be framed as being able to detect both declines and increases in populations. Species-specific sampling objectives will be developed for each species that will targeted monitoring.

4. Effectiveness Monitoring Approach for the Pima County MSCP

This chapter outlines the approaches that Pima County proposes to undertake to meet the monitoring and adaptive management requirements of the forthcoming Section 10 permit, as outlined in previous section. The approach proposed for the Pima County MSCP involves four types of monitoring:

- *Species-level monitoring* seeks to detect changes in the status and/or trend in the presence, abundance, or occupancy of a select set of PVS. In this report I propose a criterion for evaluating whether a species should be monitored directly. As part of this analysis, I investigate the methodological and cost constraints to monitoring covered species. Species-level monitoring is the main focus of this report.

- *Habitat-based monitoring* focus on monitoring environmental features that are thought to control the distribution and abundance of covered species. Habitat-based monitoring would be undertaken under the premise that changes in the configuration or quality of habitat would be reflected in changes in species. Though this approach provides a measure of uncertainty due to a possible disconnect between species and modeled habitat, it would likely provide an appropriate way for understanding broad-scale changes and be more linked to management actions.

- *Ecosystem-based Monitoring.* Parameters related to the spatial configuration of major community types are critical leading indicators of changes to the distribution of species. Parameters of ecosystem change include land cover type and fragmentation (e.g., configuration of undeveloped lands and conversely, roads). Ecosystem-level monitoring is a critical feature of any ecological monitoring program, and that topic is being addressed by Fonseca (2008).

- *Threats-based monitoring* focuses attention on possible underlying causes of potential decline of species and/or habitat components. In the context of the Pima County MSCP, threats monitoring may go beyond the monitoring permitted activities (for compliance) to include parameters such as extreme climatic events, wildlife diseases, and pollution.

This report focuses particular attention on species-based monitoring and future reports will focus on the other elements.

By developing an integrated framework of monitoring species, habitat, ecosystem, and threats, this approach seeks to accomplish a number of goals:

1. Satisfy USFWS monitoring requirements;
2. Have the best chance of detecting ecological changes, and

3. Be financially reasonable for the County to undertake and maintain.

Taken together, these represent a mix of “course” and “fine” filters that are essential to landscape-level conservation. These principals were a hallmark of the SDCP planning process and lie at the heart of current tenets of biodiversity conservation (Noss 1990, Parrish et. al. 2003)

4.1 Species-level Monitoring

Plants and vertebrates have a long history of being used for conservation planning activities (Morrison et. al. 1998: pp. 3-10), in large part due to their public appeal and because they are widely believed to be indicators of changing environmental conditions (Belnap 1998, Canterbury et. al. 2000, Niemeijer and de Groot 2008; but see Section 4.2.2). The SDCP and Pima County MSCP relied heavily on plant, vertebrate, and invertebrate species in their planning processes, most notably in development of the CLS. The assumption has been that, collectively, the conservation of these species will lead to broader, community-level conservation for those species not included on this list (an extension of the “umbrella” species concept; see review in Carignan and Villard [2002]).

Yet it is for compliance with the Endangered Species Act that drives the Pima County MSCP and it is for this reason that the PCEMP must focus attention on monitoring individual species, where such an approach is warranted. The single-species approach is most often adopted in HCPs. Based on the guidance provided by the USFWS, I have highlighted a set of parameters that I believe should be considered for most of the covered species that warrant species-level monitoring for the PCEMP. These parameters are scientifically valid and avoid many of the pitfalls of the parameters often chosen for monitoring programs.

4.1.1 Monitoring Parameters

The goal of most species-level monitoring efforts is to detect changes in abundance over time. In many cases abundance (or its corollary, density) may be the appropriate measure, but it is important to note other parameters can also be informative, among them are demographic measures (e.g., reproductive success, number young fledged, survivorship, immigration, and emigration), population structure parameters (e.g., ratio of females to males, breeding to non-breeding individuals, and size structure), and others (diet, disease, condition, etc). These parameters are important to consider, because changes in them can often be precursors to changes in abundance. Indeed, if the PCEMP was focused on a single species or a few species, these parameters would be very useful to building detailed population models and provide a framework for specific investigations. Yet in the context of the proposed monitoring program, these parameters are inappropriate because of their high cost. Experts attending the Phase I vertebrate workshops concurred with this assessment (RECON Environmental 2007). As a result, the discussion of potential parameters will be limited to those that seek to detect changes in a population over time.

4.1.1.1 Indices and the Importance of Accounting for Detectability

Before providing an overview of the two most desirable parameters, abundance and occupancy, it is important to discuss indices and their proper use—and often misuse—in vertebrate monitoring. An abundance index (e.g., relative abundance, number of animals seen per hour, catch per unit effort) is a statistic assumed to be correlated to the true abundance of a population. Abundance indices are prevalent in vertebrate monitoring programs (e.g., Robbins et. al. 1989). The primary limitation of an index is that observed changes might result from many factors unrelated to a change in abundance, including observer skill, weather, differences in habitat (Thompson et. al. 1998, White 2005). For example, Martin et al. (2007), using the example of the Snail Kite (*Rostrhamus sociabilis plumbeus*) in Florida, recounts the misuse of an index that had significant consequences. In that case, program managers increased search effort for the species over time, and therefore recorded a greater number of individuals. As a result of these increased field efforts, the abundance index indicated that populations were stable, when in fact snail kite population declined by 55% and the number of young decreased by 70% during the monitoring period.

Implicit in abundance indices is the assumption that a species' detectability (the probability of correctly noting its presence) is constant over space and time, which may not be the case. The need to ensure that changes in wildlife populations are in fact happening, and not simply an artifact of sampling effort, personnel, or environmental characteristics, is important because the ratio of the index count to actual abundance can vary, thereby confounding trend estimation (Lancia et al. 1996). The use of index counts has been so severely criticized that, with a few exceptions (noted below), its use is not appropriate for long-term monitoring of vertebrates (Rosenstock et al. 2002, Thompson 2002b, Norvell et al. 2003). As noted by Thompson et al. (1998):

> "For an index to be useful either the sampling variance of the index must be small or the measure must easily be obtained so that the sampling variance can be reduced with large sample sizes. Otherwise, the index is not cheap to measure and the investigator would be better off to put effort into actually measuring the population. A really fine index would have much smaller sampling variation than direct estimation of the population. Unfortunately, such is seldom the case."

An index can be appropriate for monitoring population size if the ratio of the index count to the population size does not vary systematically over time and if detectability does not change over time. As an example, Flesch and Steidl (2007) surveyed for the cactus ferruginous pygmy owl in Sonora, Mexico using broadcast calls. They found response rates (an index) to be nearly perfect for most of the breeding season, suggesting that this index to population size is appropriate. In addition to restricting sampling to appropriate times of year (as in the previous example), surveys using indices can reduce error by measuring covariates such as weather and vegetation. In summary, the use of indices can be used for monitoring in circumstances where it is shown that the index has a known (often linear) relationship to abundance, is significantly cheaper to survey for, and if goal of the program is relaxed to detect such significant changes in abundance that they swamp any error associated with the index. Because of the requirement for HCPs to mitigate loss of individuals or their habitat, accepting higher sampling error and therefore missing any significant change in abundance may be problematic. The solution is to adjust for detectability, and fortunately there are many ways to do this (See Section 4.1.1.3).

4.1.1.2 Ideal Parameters: Abundance and Occupancy

Although indices have some use in monitoring programs, as indicated in the previous section, use of an index requires validation of its relationship to true population size or consistency of detectability under a number of field conditions and over time. We have this information for very few species, and therefore the remainder of this report will focus on employing abundance, density, or occupancy. Below I give a brief description of each.

- <u>Abundance/Density</u>: Abundance or density (abundance scaled by area) is often the “holy grail” of population monitoring parameter; it facilitates estimates of total population change (i.e., number of individuals lost or gained) over time (Buckland et al. 2001, Rosenstock et al. 2002). Abundance is the most appropriate parameter for application to HCPs. Abundance is often more sensitive than occupancy to underlying changes in population size. It is the most common choice for some species groups that are highly detectable such as landbirds and for species that are abundant such as rodents, lizards, and fishes. It’s main drawback is cost, which can be significantly higher than occupancy for most species groups.

- <u>Occupancy</u>: the proportion of area, patches, or sampling units that is occupied (i.e., species presence). Like density and abundance, techniques for estimating occupancy explicitly account for variation in detectability, thereby adjusting estimates for individuals that are present yet undetected during surveys. Recent advancements in occupancy theory and modeling have provided sound justification of its application in monitoring programs (MacKenzie et al. 2003, Field et al. 2005, MacKenzie et al. 2006). Changes in occupancy can occur more slowly than abundance measures, because, for example, the number of individuals might be declining, but occupancy may be unchanged, a situation that is frequent for species that are common, widely distributed, and/or not at the edge of their geographic range. Occupancy is almost always the choice parameter for species that are rare and/or difficult to detect. Based on the general guidelines provided for by the USFWS, occupancy is an appropriate parameter with which to determine status and trend and estimates of “take” of many of the PVS for which it would otherwise be impossible to monitor for abundance.

Making a decision between employing abundance or occupancy is one of cost, the biology of the species, and how we count the animals. In general, abundance measures should be employed for species that (1) are abundant but restricted to small geographic areas, (2) have high detectability. Occupancy is suggested for species that (1) are widespread and rare and (2) have low detectability.

4.1.1.3 Estimators that Account for Detectability

Many accepted survey methods allow for unbiased population and occupancy estimates. These survey methods can be combined with one of the three primary estimators that allow for detectability-adjusted estimates of abundance: capture-recapture, removal, and distance sampling, each of which is discussed below. (Another method not discussed is double sampling; see Pollock et. al. [2002]). It is important to note that the underlying models are only valid if a key set of assumptions are met and we refer the reader to the many treatments of this subject for that information (e.g., Thompson et al. 1998, Schwarz and Seber 1999, Buckland et. al. 2001, Morrison et. al. 2001).

- Capture-recapture and related estimators. Capture-recapture is type of partial count in which a subset of the population is caught, marked and returned to the population. In essence, subsequent re-sampling allows for the estimate of population size by comparing the ratio of marked to unmarked individuals. Species groups for which capture-recapture methods and models are used include any species that can be easily trapped (e.g., rodents, turtles, lizards, and amphibians). Recent advances in genetics also allow for the application of capture-recapture of larger animals using hair snares, in this case the unique marker is the genetic signature. Recently, this framework has been extended to occupancy estimation (see Section 4.1.1.3).

- Removal methods. The removal of individuals from a population has long been used in estimating the population in sport hunting and commercial fisheries. This framework has been extended to non-harvestable fish sampling, such as for many of the endangered fishes in the southwestern U.S. Known as depletion sampling, fish are temporarily removed from pools in a series of “passes” and a calculation of the rate of decline in the number of individuals caught on each successive pass allows for estimates of population size. More recently, this method has been used to estimate abundance of songbirds (Farnsworth et. al. 2002).

- Distance sampling. Methods incorporating distance to an animal from a line or point has been used for a few decades to estimate population density. In this case, the distance of an animal from a point or line is used to correct for biases that result from detectability (Buckland et al. 2001). This tool has been used most often in the southwest U.S. for songbirds, large mammals, and lizards.

4.2 Challenges to Species-level Monitoring

The typical protocol for ensuring compliance and effectiveness of MSCPs is to monitor all of the species proposed for coverage under the Section 10 permit. Yet most MSCP monitoring has been criticized for not providing sufficient information to detect changes or for informing the adaptive management process (See critiques in Harding et. al. [2001], Wilhere [2002], Rahn et. al. [2006]). After decades of species-specific monitoring efforts a few important patterns have emerged that present biological and economic challenges to its adoption. In this section I summarize challenges and thereby provide a framework by which to evaluate the feasibly of species-level monitoring efforts for the PCEMP. For this discussion, I assume the goal of the MSCP monitoring is to detect changes in status and trend in detectability-adjusted estimates of abundance or occupancy, which provide a measure of effectiveness of mitigation efforts. As noted earlier, indices of abundance are not being evaluated.

My goal in addressing a host of challenges to species-level monitoring is not to discredit it nor is it a suggestion that the County abdicate its species-specific monitoring responsibilities. Rather, a frank assessment is essential if the County is to develop a monitoring program that detects ecologically significant changes in a timeframe that might allow for management intervention if data indicate undesirable trends. Further, because of the time frame of the permit (30 years), being explicit about these issues helps ensure that future program managers, decision makers, and taxpayers inherit a program that is of reasonable cost. Striking a balance between program effectiveness and cost efficiency is one of the tenets of the Five-point Policy (USFWS 2000).

4.2.1 Factors Affecting Trend Detection: Separating “Signal” from “Noise”

Ecological monitoring seeks to detect biologically significant changes to resources. Change, if it is occurring, is the “signal” we hope to detect. Inherent in ecological monitoring is the “noise”, or error, from natural process variation (i.e., difference in abundance of resources from place to place and over time) and sampling error (i.e., problems with how we conduct monitoring) (Fig. 5). These elements obscure our ability to detect change. Some sources of error can be minimized or accounted for in the design of a monitoring program, and others can not. A failure to understand these differences, especially in the design phase of a program, can potentially lead to an imprudent allocation of monitoring resources, and potentially a premature end to the monitoring program. The challenge for development of the PCEMP is to address these issues and attempt to provide an accounting of sources of error that are thought to be relevant to the covered species.

Process variation and sampling error are not unique to plant and animal populations; everything that can be monitored has these elements. Yet of all potential parameters to include in am ecological monitoring program, vertebrates and invertebrates, in particular, pose some of the most difficult challenges to monitoring (Elzinga et al. 2001) due to primarily to their complex responses to environment conditions, mobility, and the inherent challenges in enumerating them.

This section will provide a brief introduction to the concepts of process variation and sampling error as they relate to vertebrate monitoring. The many concepts presented here can be found in many excellent primary sources (e.g., Urquhart et. al. 1998, Steidl and Thomas 2001, Fleishman and Mac Nally 2003, Thomas et. al. 2004).

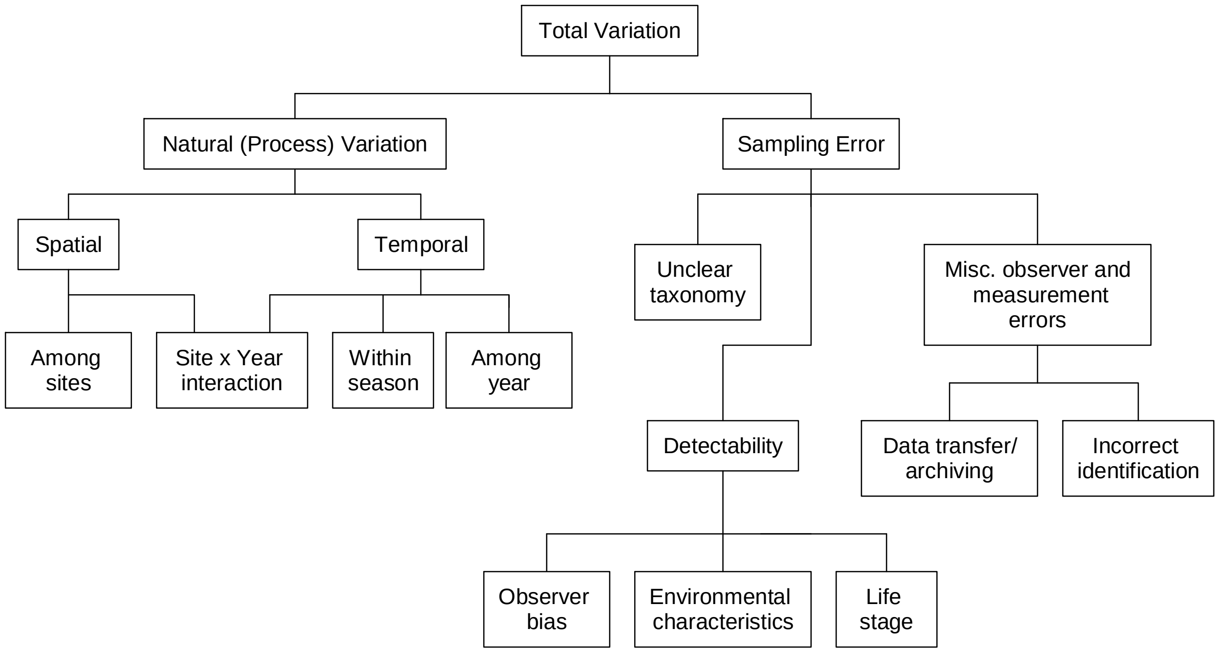

Figure 5. Types of variation (error) in vertebrate monitoring.

4.2.1.1 Spatial and Temporal Variability

Species whose abundance is highly variable from place to place (spatial) and/or over time (temporal) present significant challenges to detecting changes in abundance. (Spatial and temporal variation, two types of process variation, are unrelated to sampling error and which is addressed below). Changes to spatial variation in abundance is the result of many factors, most importantly because to the spatial configuration of a species' habitat across a landscape, along with its ability to occupy that habitat (Scott et. al. 2002). Spatial variability in abundance can be addressed, to varying degrees, in the design the program, for example by stratifying the sampling frame (total area available to be included in the study) based on characteristics that are thought to influence the distribution of the species (e.g., vegetation type for most birds, soil type for rodents and some reptiles, etc.) (Elzinga et al. 2001, Thompson 2002). Revisiting the same sites, or a subset of sites, over time is another way to account for spatial variability (Larsen et. al. 2001).

Temporal variation in abundance, particularly changes from year-to-year and within sampling season, is the most vexing type of variation for trend detection because there is little that can be done to account for it in the sampling design (Larsen et. al. 1995, Thompson et al. 1998, Urquhart et al. 1998, Urquhart and Kincaid 1999, Sims et. al. 2006). In other words, adding additional samples or collecting co-variates does nothing to our ability to detect trend; all that can be done is to wait for the passage of time. Species exhibit significant temporal variation because of changes in reproductive output and survival, which are often liked to changes in key resources (usually food), that also vary. Species with significant temporal variation include most invertebrates, fishes, rodents, and lizards (as well as some annual plants). Mobile organisms (e.g., birds, bats, medium and large mammals) can also exhibit considerable temporal variation, particularly in lower-quality habitats and/or because of spatial changes in key resources to which they respond. This site x time interaction is another source of variation, but is not covered here; see Kincaid et. al. 92004) for additional information.

The net result for monitoring program development is that high variation, especially temporal, makes it very difficult to detect change except where it is significant. For example, in a review of the Organ Pipe Cactus National Monument landbird monitoring program Powell and Flesch, (In prep) investigated the spatial and temporal patterns of variation on the ability to detect trends for three species. Using data from a 3-year pilot effort, they conducted power analysis to determine the amount of time required to detect a linear negative trend of 2% per year with 80% power (In essence, power is a statistical measure of the risk of not detecting a trend in a population when one actually exists; see Gerrodette [1987]). They found that detecting a 2% annual decline would take 10 years for the black-tailed gnatcatcher, 19 years for the phainopepla, and 27 years for the black-throated sparrow. The most significant reason for differences among species was because of differences in annual variation.

It is difficult to determine in advance what the within-season and among-year temporal variation (irrespective of a trend) might be for a particular species. For most species this has not been estimated and patterns that emerge in one area may not be applicable to another. Often such patterns must be elucidated through the analysis of monitoring data within the first 3-5 years of a project. However, patterns of high annual variation for some species groups have emerged in the literature, most notably for fish, rodents, lizards, and frogs and toads. We anticipate that it would difficult to detect changes in abundances smaller than 50 to 75% over the 30-year permit for many of these species. For these groups, it may be more appropriate to detect change in occupancy and/or being willing to accept a diminished level of change detection. And for some species, such as the Gila topminnow, annual changes in abundance of up to 90% are not uncommon (e.g., Bodner et al. 2007), so course level of change in abundance might not be cause for concern.

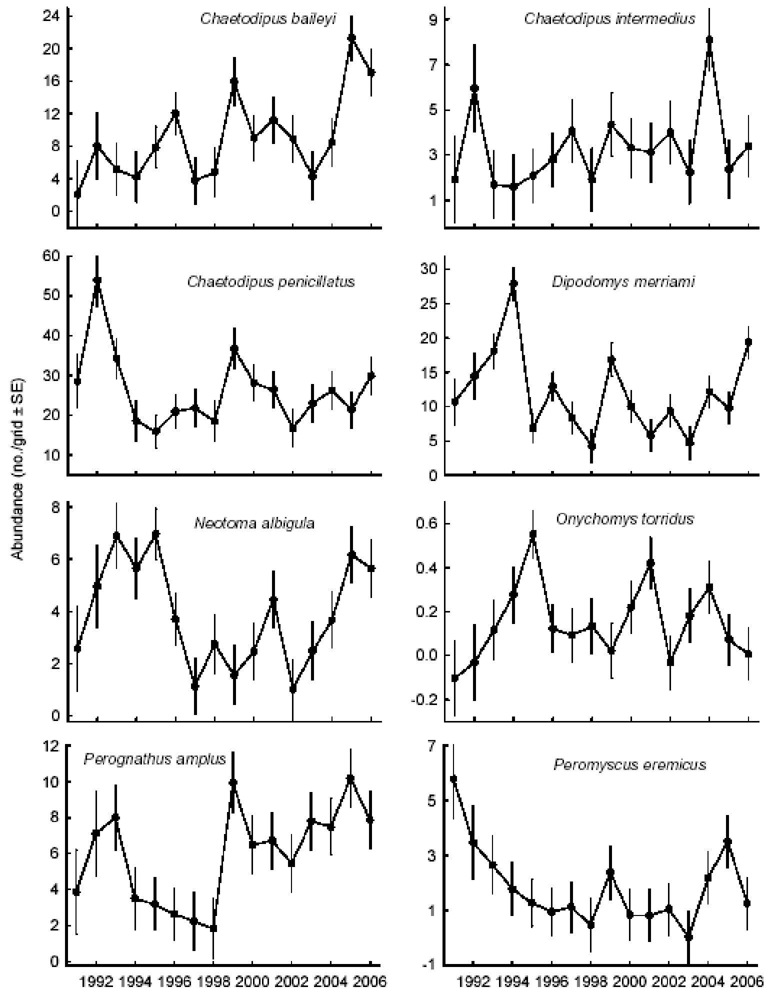

Figure 6. Abundance of rodents at Organ Pipe Cactus National Monument showing variation across time (Flesch 2008). Annual variation, irrespective of a trend, can make trend detection difficult.

4.2.1.2 Sampling Error: Sampling Design

Among the remaining sources of error that make monitoring vertebrates challenging (Fig. 5), sampling design—the process of choosing where and when to monitor—is critical (for more detailed discussions of sampling design see Thompson and Seber [1996], Lohr [1999], Morrison et al. [2001], Thompson [2002]). It is often not possible to survey all areas where a species might occur because of financial or logistical limitations. To increase the efficiency of monitoring, *sampling* is employed, which is the process of selecting units from a larger population so as to draw inferences to it. The method of selecting where and how often to sample is referred to as *sampling design*; these choices ultimately determine the precision of our estimates, their spatial and temporal inference, and overall cost of a monitoring program.

To determine status and trends in abundance or occupancy over time, there are a number of critical elements of sampling design that must be met. First, a collection of *sampling units*, at which sampling occurs, must be drawn from a larger population of interest and each unit must have a known likelihood of being included in the sample. This is known as *probability-based sampling* and it employs a component of randomization in selecting sampling units to ensure that the true value of the parameter is estimated accurately and with a known level of precision. Random sampling allows inference to a larger population from which samples are drawn and estimates the true value of a parameter. While precision is largely a function of variation in a parameter, bias is determined by the spatial sampling design and can only be controlled by using a probability-based design.

Probability-based sampling contrasts with a variety of non-probability based approaches that are often used in ecological monitoring because of budgetary constraints or ignorance (Olsen et. al. 1999). Subjective approaches include judgment sampling (investigator knows best where sites should be placed) and haphazard sampling (any site will be sufficient; (Morrison et al. 2001). At best these approaches provide limited information and at worst can lead to erroneous conclusions (Yoccoz et. al. 2001). For example, if bat monitoring takes place only in caves that an investigator believes to suitable habitat, no inference can be drawn to caves outside those sampled. Perhaps more importantly, any observed changes in the distribution or abundance of the bat may not represent those of the population at large (i.e., it is biased and inaccurate). The challenge is to design a monitoring program that has high precision and the results are applicable to those units for which no sampling occurs. Regardless of the parameter chosen for monitoring, it will be imperative to articulate the sampling design chosen and its limitations, if any.

4.1.2.3 Sampling Error: Observer Differences

The ability to correctly identify an animal to species is an obvious and fundamental requirement of monitoring. Differences among observers regarding their ability to identify species correctly has long been recognized as a problem for monitoring for some species, even for skilled observers (Kepler and Scott 1981, Diefenbach et. al. 2003). Species groups such as birds, lizards, and small mammals can present significant identification challenges. For example, field identification of the mesquite mouse (a proposed covered species) is very difficult to differentiate from other species in its genus. Other observer errors include biases such as differences in where to search (common in reptile monitoring). Some estimation tools can account for observer differences and this is another reason that projects need to rely on detectability adjusted estimates.

Box 1. Challenges to monitoring bats; an example of the difficulty with species-level monitoring for the Pima County MSCP.

There are 7 species of bats proposed for permit coverage, but bats present a unique set of challenges for monitoring because of their high variability (Hayes 1997), highly mobile and secretive nature, and general lack of proven methods for abundance estimates (O'Shea et. al. 2003). Bat monitoring has traditionally taken place at bat roosts, netting bats, or using passive acoustic sampling devises. Each of these methods warrants brief reviews.

Roost Site Visits. Monitoring at known roost sites usually involves inspection of bats clinging to the walls of the structure or counting bats as they leave the roost. For some species and genera, such as *Myotis*, visual observation can fail to produce a positive identification. Assuming that species can be correctly identified, exit counts can be subjective and rarely is it possible to locate all individuals in a roost (some species roost in trees and so this method will not appropriate for these species: western red bat and southern yellow bat). Exit counts are in used in monitoring the lesser long-nosed bat and this approach would be useful for detecting gross changes in abundance.

Netting. Netting bats, which usually takes place over water sources, is the best way to make a positive identification of bats and its use is common practice in biological inventories (e.g., Kuenzi et al. 2003, Powell et al. 2006). Yet for monitoring, netting has many inherent biases and often counts are highly variable from one trap night to the next, making population estimation difficult. Perhaps more importantly, failure to record an individual that is present but not captured results in a "false negative," meaning that species lists from one time to the next are likely biased.

Passive Acoustic Recorders. The use of passive acoustic recording devises is becoming increasingly popular as a means to monitor relative activity (an index) and more recently for occupancy estimation using an array of recording devises (Duchamp et al. 2006, Gorresen et al. 2008). Such an approach shows promise for monitoring occupancy for a subset of bat species, though there are considerable technical and cost challenges to its implementation. Assuming these can be overcome, this method would be appropriate for a subset of covered species: Allen's big-eared bat, southern yellow bat, and western red bat. The California leaf-nosed bat and pale Townsend's big-eared bat have faint calls that are not easily picked up by these recorders, though technology may improve.

Summary. Despite the conservation importance of bats, as evidenced by the number of species proposed for coverage on the County's MSCP and other efforts (e.g., Hinman and Snow 2003), developing a comprehensive monitoring program presents challenges. If single-species monitoring efforts are desired, participation in regional monitoring efforts (such as is being carried out for lesser-long nosed bats) and adopting monitoring methods that rely on unadjusted indices may well be the only viable options. An alternative approach would be to monitor threats such as cave condition, as well as habitat and ecosystem parameters (See Section 5.3 for overview).

4.2.2 Interpreting Change and Linking to Management

The previous section focused on the challenges with detecting trends. Assuming that trends can be elucidated and for a reasonable cost, the challenge of determining the effect of management actions or mitigation strategies remains. Particularly as it relates to detecting a negative trend in a covered species, the question must be asked: what was the cause of the decline? While it may seem intuitive that such answers will emerge from a good monitoring program, in reality this can be difficult because of complex population dynamics, changing habitat conditions, and environmental stoicasticity that is inherent in ecological systems (Fleishman and Mac Nally 2003). The result may be that observed changes within County owned and leased lands may result from regional, national, and international forces that may exert overwhelming influence on the populations of covered species. Though the USFWS agrees to No Surprises and Changed Circumstances from the time a monitoring program is approved, it nevertheless is important to be forthright about the limitations of monitoring data and the possibility that the County may be responsible for changes in populations that are completely beyond our control.

Undertaking active adaptive management activities and integrating local monitoring efforts with national or international monitoring effort will more easily tease apart these causal relationships. Local monitoring partnerships and monitoring on lands outside of the mitigated lands will also lead to stronger conclusions. Yet even these measures have limitations, especially considering that it may be unrealistic to employ active adaptive management for most covered species. Focusing monitoring efforts solely on individual species misses a critical reality of vertebrate and many plant species; that they are following indicators of broader-scale ecosystem change.

5. Recommendations for Monitoring Covered Species

5.1 Species Recommended for Species-level Monitoring

The previous chapters have highlighted challenges to species-level monitoring and the difficulty of determining effectiveness actions. In this section I suggest why monitoring a subset of species is both warranted and possible. I recommend that Pima County adopt an approach to individual species monitoring that focuses on four groups of species. First, there is a group of species that are rare by virtue of being restricted to just a few sites in the current reserve system (Table 2). These species should be monitored directly because any further reductions in populations could result in extirpation from the County (i.e., monitoring habitat would be insufficient for these species). By closely monitoring for significant loss of individuals or populations, immediate land management actions (e.g., reintroductions and/or acquisition of additional potential habitat) could be undertaken by Pima County or its SDCP partners, if such an approach is feasible. In addition to being rare and spatially restricted, these species have accepted survey methods and in many cases ongoing monitoring activities.

The second group of species is the two cactus species, Pima pineapple cactus and needle-spined pineapple cactus (Table 3). These are fairly conspicuous species and can easily be monitored following intensive inventory efforts. In the case of the Pima pineapple cactus, the County has an ongoing monitoring program in conservation banks.

The third group of species is not currently found in the permit area, but could be reintroduced or naturally disperse into appropriate habitat (Table 4). If re-introduction occurs, these species would receive species-specific monitoring effort, because it is anticipated that monitoring for these species would also be logistically feasible and cost effective. In practice, there would be some overlap between the first and third groups. For instance, if a species from the first list is extirpated, reintroduced populations of species would be monitored. Monitoring methods and frequency of surveys would be evaluated on a species-by-species basis.

The final species, the lesser long-nosed bat, does not have the same biological or sampling rationale for monitoring as for the other groups (in part because of lack of known roost sites within the County's reserve system) (Table 2). Yet because of the ongoing research and monitoring activities by other jurisdictions and entities, monitoring activities would likely consist of participation in simultaneous exit counts at roosts throughout southern Arizona.

Two additional species may warrant species-specific monitoring, but additional information is needed before a determination can be made. First, the cactus-ferruginous pygmy owl likely no longer occurs on County owned or leased lands and therefore a review of its status within the reserve system is warranted, in consultation with Arizona Game and Fish Department and the

U.S. Fish and Wildlife Service. A cooperative monitoring program with the City of Tucson might be appropriate for this species. The second species, the giant spotted whiptail, falls within the group of spatially restricted species, but additional investigations are warranted to determine if the sampling issues regarding its correct field identification can be adequately addressed.

For the remainder of the covered species (Table 5), monitoring abundance or occupancy can be achieved for many of the species, but the level of effort required to do so and the difficulty in detecting trends for most of these species presents significant challenges. For these species, a more appropriate approach will likely be to monitor habitat and ecosystem parameters that regulate the distribution of the species.

The single-species approach outlined in this section provides a starting place for discussion among County staff, USFWS personnel, and the public. As such, these recommendations are subject to significant revision throughout the planning process.

5.2 Rationale for Integrating Other Program Components: Habitat, Ecosystem, and Threats

> "Ecology is a science of contingent generalizations, where future trends depend…on past history and on the environmental and biological setting"
> Robert May

Species-level monitoring is warranted for a subset of species, but it represents a narrow view of environmental change, one that is often difficult and expensive to detect. Because of the diverse group of covered species and a limited budget, the question must be asked: is it appropriate to focus entirely on the covered species as is often the case with HCPs? The USFWS offers some guidance in this regard, and adopting a habitat-based approach to monitoring has been deemed appropriate. Specifically, the five-point policy states that "goals and objectives may be stated in habitat terms" and there must be a tie back to the species.

Habitat is a species-specific term that is the sum of the environmental features that a species uses and needs for its survival and reproduction throughout its life cycle (Hall et. al. 1997). Habitat can be a range of features, from specific water resources (e.g., range of water-quality values) to vegetation features. Due to the crucial importance of habitat, any changes to it can be leading indicators of change to the species themselves. By contrast, it is well known that the response of many species to environmental change can be delayed (Fleishman and Mac Nally 2003), sometimes for years (Wiens 1985). Monitoring habitat features can provide broader conservation targets that are easily understandable and measureable by multiple jurisdictions and stakeholders. This is has been and will be the case with riparian monitoring efforts, where the conservation targets are often type and extent of water and plant resources, both important features for many covered species.

Table 2. Species proposed for permit coverage and which are recommended for species-level monitoring. Any re-introduction efforts to other areas with the reserve system would be coordinated with Arizona Game and Fish Department and would also lead to increased costs. Monitoring for range expansion will require periodic assessments or surveys of potential habitat. Annual cost are based on the current distribution of the species and the cost for monitoring and data management (see Appendix B for additional information on cost estimates).

Species	Reason for Monitoring	Sites to be surveyed within reserve lands[a]	Proposed parameter, protocol, and frequency	Annual Cost	Notes
Huachuca Water Umbel	Restricted to a few locations within the County's Reserve system.	Currently two known location within the reserve system: Bingham Cienega and Cienega Creek	Parameter: Presence Protocol: Visual encounter surveys. Frequency: Varies by site. Also, monitoring for threats (especially desiccation) while conducting other work.	Initial inventory: $2,760 Annual monitoring: $2,070	Monitoring represents a challenge for this species because it very difficult to find, even if present on a site. Annual surveys will take place at Bingham Cienega, and biennially at Cienega Creek Preserve. Initial mapping effort at Cienega Creek will be necessary.
Lesser long-nosed bat	Existing efforts underway. Contribute time toward regional efforts	No known roost sites within the current reserve system, but investigation of potential roost sites will be important	Parameter: Relative abundance from exit counts Protocol: Estimating bat exiting known roosts Frequency: Annually	Initial inventory of reserve lands: 5-10K. Annual monitoring: $1,380	Coordinate exit counts with Arizona Game and Fish Department. Investigate potential roost sites on County-owned or leased lands as they are acquired. If additional roost sites are discovered, annual monitoring costs would increase.
Southwestern willow flycatcher	Very rare, spatially restricted. Restoration efforts along mesic riparian likely to benefit species	Historical sites (2) that are currently surveyed.	Parameter: Abundance Protocol: Tape-playback using protocol by (Tibbitts et. al. 1994). Frequency: Annual surveys at known sites including habitat sampling at sites where animals are found.	$4,140	Monitoring will continue to occur on known or historical sites along portions of Cienega Creek and the San Pedro River. Data will contribute to state-wide effort by AZGFD (e.g., Graber et. al. 2007).
Western yellow-billed cuckoo	Very rare, spatially restricted to known locations.	One known population in the reserve system: Cienega Creek Preserve	Parameter: Abundance Protocol: Tape-playback using protocol by (Wiggens 2005) Frequency: Annual surveys at known sites including habitat sampling at sites where animals are found.	$4,140	AZGFD conduct periodic assessments at other places in the County such as at Arivaca Creek and we will obtain these data. Also being considered for monitoring by City of Tucson and Town of Marana, so coordination of field efforts and sharing of survey results with those entities will be important.
Gila chub	Rare, spatially restricted, and vulnerable to extirpation from the County.	One known location: Cienega Creek Preserve.	Parameter: Abundance Protocol: Depletion sampling using block nets and backpack shocker. Also habitat and water-quality sampling Frequency: Annually	$2,070 (work contracted to personnel who possess packpack shocker unit and water-quality probe)	Monitoring data from sites in Sabino Canyon will be obtained from the Arizona Game and Fish Department. Pima County will employ a review of habitat conditions within the reserve system to investigate the potential for species re-introductions. Monitoring at Cienega Creek Preserve will include surveys for exotic fishes and crayfish.

Species	Reason for Monitoring	Sites to be surveyed within reserve lands[a]	Proposed parameter, protocol, and frequency	Annual Cost	Notes
Longfin dace	Rare, spatially restricted, and vulnerable to extirpation from the County.	Two known populations: Cienega Creek Preserve and Binghamton Pond	Parameter: Abundance Protocol: Depletion sampling using block nets and backpack shocker. Also habitat sampling Frequency: Annually	$690 for Bingham Cienega. Sampling would be concurrent with that for Gila topminnow and longfin dace	Pima County will periodically review the possibility of reintroducing species to other areas in the County reserve system. Monitoring will include surveys for exotic fishes and crayfish.
Gila topminnow	Rare, spatially restricted, and vulnerable to extirpation from the County	Only known populations occur in Cienega Creek Preserve	Parameter: Abundance Protocol: Depletion sampling using block nets and backpack shocker. Also habitat sampling Frequency: Annually	$1,380	Species is abundant upstream of Cienega Creek Preseve at Las Ciengas National Conservation Area, but one of two populations are declining there, most likely due of habitat changes (Bodner et. al. 2007). Data from Las Cienegas will be obtained from the Bureau of Land Management and The Nature Conservancy of Arizona (Simms et. al. 2006, Bodner et al. 2007). Pima County will employ a biennial review of habitat conditions within the reserve system to investigate the potential for species re-introductions. Monitoring will include surveys for exotic fishes and crayfish.
Lowland leopard frog	Rare and spatially restricted. Detect invasive species and disease.	Occurs at a few sites in the county reserve system (Youtsy Canyon, Cienega Creek, Espiritu, Edgar, and possibly Bingham)	Parameter: Occupancy Protocol: Survey of known locations using visual searches. Also mapping potential habitat and habitat sampling Frequency: Annually	$8,900	All new ranch acquisitions would need to be surveyed (not reflected in estimated cost). Reintroductions are possible in a number of locations in the County. Track other monitoring, mapping, and research efforts in the region e.g., (Rosen and Caldwell 2004, Wallace et. al. 2006). Also, assist where possible in monitoring threats, most importantly chytrid fungus (Bradley et. al. 2002).
Mexican garter snake	Rare, spatially restricted, and vulnerable to extirpation from the County	Cienega Creek Preserve	Parameter: Occupancy, abundance Protocol: Trapping, mark-recapture Frequency: Biennially	UNKN, but probably <$6,000.	Also occur upstream of Cienega Creek Preserve in Las Cienegas National Conservation Area (Rosen and Caldwell 2004). A number of areas for re-introduction occur with the Reserve system.
Arkenstone Cave Pseudoscorpion	Spatially restricted	Occurs at Colossal Cave Mountain Park	Parameter: Presence Protocol: Survey of known locations using visual searches. Frequency: Annually	$690	Monitor for new threats such as disturbance.

Table 3. Potential monitoring program for the Pima pineapple cactus and needle-spined pineapple cactus. Inventories represent a one-time cost and will be used to refine the level of annual effort needed for monitoring. The general monitoring objective for these plant species is to identify populations and track survival and growth of individuals over the permit period. Annual costs are based on the suggested protocol and sampling frame, but could be subject to revision based on the first few years of data and will increase as new lands are acquired.

Species	Protocol	Annual Costs	Notes
Pima Pineapple Cactus	Parameter: Abundance, survival, and recruitment Protocol: Visual encounter surveys Frequency: Annual surveys of known individuals. Surveys every 3 years for recruitment	Inventory: Unknown, but may be covered by closing costs. Monitoring: $10,350 (average of 2 sites visited per day)	Ongoing monitoring efforts are likely sufficient to detect trends. Mitigation and monitoring activities are in place including mitigation banks and acquisition of habitat. Attempts will be made to make inventories of potential acquisitions as part of the closing costs. Monitoring partnerships with the City of Tucson and State Land Department will be investigated. Monitoring climate and poaching will be important threats to monitor. Attempts will be made to improve habitat models, thereby leading to greater efficiency of field surveys and better estimates of take and mitigation efforts. Also, investigation of the use of alternative sampling designs (e.g., adaptive cluster sampling) that may increase precision
Needle-spined Pineapple Cactus	Parameter: Abundance, survival, and recruitment Protocol: Visual encounter surveys Frequency: Annual surveys of known individuals. Surveys every 3 years for recruitment	Inventory: $9,000. Monitoring: $5,175	Initial inventory of plants has been performed for some lands (Cienega Creek) but additional work is needed. Coordinate with City of Tucson for monitoring efforts. Note: Baker (2005 and 2007) searched an average of 4.5 ha per day/person.

Table 4. Covered species that are not thought to currently occupy lands within the Permit Area, but which will receive species-level monitoring if their range expands or are reintroduced into the Permit Area.

Species	Current Distribution in Pima County	Annual information collection activities and other notes
Desert pupfish	Occurs naturally at Quitobaquito Springs at Organ Pipe Cactus National Monument (Pearson and Conner 2000)	Status and trend information will be obtained from annual surveys carried out by the National Park Service. Pima County will periodically review the possibility for reestablishment within the County's reserve system.
Desert sucker	Occurs upstream of Pima County in the Santa Cruz and San Pedro Rivers.	Arizona Game and Fish periodically survey for this species in known locations. Fish monitoring proposed by the National Park Service at Tumacacori National Historical Park, upstream in the Santa Cruz River.
Sonora sucker	Occurs upstream of Pima County in the Santa Cruz and San Pedro Rivers	Arizona Game and Fish periodically survey for this species in known locations. Fish monitoring proposed by the National Park Service at Tumacacori National Historical Park, upstream in the Santa Cruz River.
Chiricahua leopard frog	Las Cienegas National Conservation Area, Buenos Aires National Wildlife Refuge, Florida Canyon?	Data from Arizona Game and Fish Department, USFWS (Buenos Aires National Wildlife Refuge), and BLM (Las Cienegas National Conservation Area) will be obtained annually. All new ranch acquisitions will be surveyed for presence. In addition, Pima County will periodically review the possibility of reintroducing species to other areas in the County reserve system.
Red-backed whiptail	Ajo Mountains at Organ Pipe Cactus National Monument	Periodic monitoring reports from the Organ Pipe Cactus National Monument Ecological Monitoring Program (e.g., National Biological Service 1995) will provide information on trends of the species there. May expand its range into the planning area in western Pima County. Reports of sightings that expand the species' range will be tracked and it may be necessary to convene an expert team to design a monitoring program if it occurs in the Permit Area.

Table 5. Species not currently recommended for species-level monitoring. Cost estimates are for monitoring trends (not status) in the potential parameter of interest. Costs estimates are subject to significant revision because the sampling frame for this species has not been established. This list is subject to significant revision based on public input and ability to apply habitat and ecosystem-level monitoring efforts in lieu of species-level monitoring. See Appendix B for cost estimates.

Species	Potential parameter	Proposed protocol	Annual Costs	Notes	Recommendation
Tumamoc Globeberry	Abundance of known populations	Cluster sampling around known locations from inventory	Unknown because extent within County's reserve system is unknown.	Populations are extremely dispersed and an initial inventory would need to be conducted. Detectability is very low for this species, making surveys a difficult.	No monitoring suggested at this point, but coordination with ongoing USFWS efforts should be investigated.
Mexican Long-tongued Bat	Occupancy	Visual search of caves	UNKN	Occupancy at caves is the best option for this species, but this species is easily disturbed at roosts (caves), thereby presenting significant sampling challenges.	No direct monitoring, but monitor cave condition
Allen's Big-eared Bat	Occupancy	Acoustic recording devise	$30-45K/ year for all bats.	Can be surveyed by acoustic recording devises, but high cost is prohibitive	No monitoring at this time, but monitor cave condition
Western Red Bat	UNKN	Acoustic recording devise	$30-45K/ year for all bats.	Can be surveyed by acoustic recording devises, but high cost is prohibitive	No monitoring at this time
Southern Yellow Bat	UNKN	Acoustic recording devise	$30-45K/ year for all bats.	Can be surveyed by acoustic recording devises, but high cost is prohibitive	No monitoring at this time.
California Leaf-nosed Bat	Occupancy	UNKN	UNKN	Not easily picked up by acoustic recording devises because of faint call.	No monitoring at this time, but monitor cave condition
Pale Townsend's Big-eared Bat	Occupancy	UNKN	UNKN	Not easily picked up by acoustic recording devises because of faint call.	No monitoring at this time, but monitor cave condition
Merriam's Mouse	Occupancy	Trapping	$10,300	Identification of this species makes implementing monitoring extremely difficult. Can be easily confused with other *Peromyscus* spp.	No monitoring because of identification problems. Monitoring habitat through focus on riparian areas
Western Burrowing Owl	Occupancy/ abundance	Tape-playback	$15,500	3 visits to 15 sites each year. Note: detection probability = 64%. No co-location with other species is possible.	Cooperative monitoring efforts with Town of Marana and City of Tucson may make it efficient to monitor this species. Habitat monitoring may be difficult for this species
Rufous-winged Sparrow	Abundance	Distance sampling	$15,500	3 visits to 15 sites (<5% of mitigation lands). Can not co-locate with other bird species, except Swainson's hawk in some places	No monitoring. Trends are unlikely because species is high variable annually (Steven Russell, pers. comm. to Brian Powell, June 2000) .
Swainson's Hawk	Abundance, reproduction?	Distance sampling	$15,500	3 visits to 15 sites. 5-km line transects and search for nests	No monitoring. Habitat monitoring of fragmentation and grassland condition
Abert's Towhee	Abundance	Distance sampling	$15,500	3 visits to 15 sites. Point transects. Some co-location with Bell's vireo, but models may not be reliable.	No monitoring. Riparian vegetation and condition is likely high priority for monitoring program
Bell's Vireo	Abundance	Distance sampling	$15,500	3 visits to 15 sites. Point transects. Some co-location with Abert's towhee	No monitoring. Riparian vegetation and condition is likely high priority for monitoring program

Species	Potential parameter	Proposed protocol	Annual Costs	Notes	Recommendation
Desert Box Turtle	Occupancy	Plot surveys	$2,5875	15, 3-ac plots surveyed 5 times/year with 2 plots surveyed/day. Low detection probability means additional visits to sites might be warranted.	No monitoring. Habitat monitoring may present difficulty. Habitat fragmentation may be important.
Sonoran Desert Tortoise	Occupancy	Plot surveys	$25,875	15, 3-ha plots surveyed at least 5 times each/year with 2 plots surveyed/day. Detection probability = 0.45.	Uncertain. AZGFD will be developing monitoring protocol this fall.
Tucson Shovel-nosed Snake	Occupancy	Plot surveys	>$60,000	8, 5-ha plots. Detectability is extremely low for this species, thereby requiring approximately 12 visits per plot. Yet, extremely low occupancy and possible extirpation from permit area likely may mean that trend estimation is not possible.	No monitoring, but possibility for cooperative monitoring effort with Town of Marana and City of Tucson. Roads and fragmentation would be important to monitor.
Ground Snake	Occupancy	Plot surveys	$>40,000	20, 5-ha plots surveyed at least 10 times each/year (low detectability = higher survey effort.	No monitoring. Detectability is major concern for this species

A potential weakness of the habitat-based approach is providing a clear link between the habitat feature(s) and the species themselves. The PCEMP design team is currently working to identify a host of habitat features that are thought to control the distribution and abundance of the covered species (and 100+ other species in Pima County) in an attempt to identify those features. Yet is must be recognized that these models will have incomplete information. Yet equally important is that it is too costly and impractical for our efforts to develop extremely detailed models of species habitat. (This approach was developed for the Northwest Forest Plan an endeavor that has taken years and millions of dollars (Palmer and Mulder 1999). Instead, monitoring habitat (and ecosystem and threats) will be developed toward identifying critical parameters that are thought to have the most influence on the species. It is too early to identify those features and future reports will focus on that effort.

As its name implies, ecosystem monitoring takes a broader view than does the single-species monitoring or habitat monitoring. The ecosystem approach often incorporates structural and compositional environmental parameters (Busch and Trexler 2003) at scales up to that of the County. Ecosystem features would include land cover type, land use and a variety of derived parameters such as fragmentation, roads, and in some cases, spread of exotic plants. This approach is even more anticipatory than habitat-based monitoring in that many of these features are among the best leading indicators of change. Threats monitoring is similarly broad scale and anticipatory, and could include types and spatial arrangement of development, mining, off-road vehicle use, non-native species, and disease. Because of the effects of threats on species, their habitat, and landscape features, they are essential to include in a monitoring program (Salafsky and Margoluis 1999, Ervin and Parrish 2006). In the context of an HCP, monitoring should incorporate other threats than the covered activities, provided those data are cost effective. As with the design approach to identifying habitat features, the program is also currently evaluating the effects of a broad range of threats (+50) on habitat, species, and ecological processes. That work will conclude in the spring of 2009.

6. Next Steps in the Development of the Pima County EMP

Much work remains in the development of the PCEMP. Phase II, which is currently underway, will culminate in a list of the most appropriate parameters to include in the program. Phase III represents the implementation phase of the program. The primary focus of Phase III will be the development of protocols for the species, environmental features (i.e., habitat), ecosystem characteristics, and threats chosen for monitoring. Considerable effort will be invested in the development of these protocols, which will detail the method of data collection, its frequency, timing, and data management (Oakley et. al. 2003, U.S. Environmental Protection Agency 2007). In addition, we will undertake a number of activities that relate to the covered species: assessing opportunities for adaptive management, creation of the Covered Species Information Database and Sonoran Desert Ecosystem Clearinghouse, and coordination of research activities with other entities. These are covered in more detail below.

6.1 Asses Adaptive Management Opportunities in the Pima County MSCP

The USFWS suggests that monitoring activities be placed within the broader framework of adaptive management. The intent of incorporating adaptive management in the HCP process is to use data from the monitoring program to assess management action(s) and to refine knowledge of the covered species, such as population dynamics and habitat relationships. USFWS broadly defines adaptive management as “a method for examining alternative strategies for meeting measurable biological goals and objectives, and then, if necessary, adjusting future conservation management actions according to what is learned.” In addition, incorporating adaptive management in HCPs should “allow for changes in the mitigation strategies that may be necessary to reach the long-term goals (or biological objectives) of the HCP, and to ensure the likelihood of survival and recovery of the species.” In the case of Pima County, changes in the mitigation strategy might include purchase or lease of community types or modeled covered species habitat that is not currently well represented.

Adaptive management typically takes one of two forms: passive and active (Walters and Holling 1990) and both types are recognized as useful for HCPs. *Passive adaptive management* uses observational data to infer causation based on observed patterns and *active adaptive management* is more powerful and involves applying management treatments as randomized experiments so that the results of these actions can be continuously assessed and refined to bring about the desired objective.

The application of adaptive management practices is best employed after monitoring data indicate that a covered species and/or its habitat shows significant decline (i.e., over or near to an established threshold) or because of the emergence of a threat. If one of the covered species, its habitat, or ecosystem properties exhibits significant and deleterious declines, a team of experts should be convened to evaluate active adaptive management options that may include measures such as re-introduction, removal of a threat (e.g., non-native species), or alteration of habitat. In some cases the cause of the observed change may be unknown, in which case resources should be marshaled to undertake a research effort to investigate possible causes of the change. In those instances where the risk of active adaptive management treatments pose too great a risk to species, then Pima County should work closely with the USFWS to determine the best course of action. In addition to exploring adaptive management for covered species and their habitat, a rigorous adaptive management program will be investigated for the broader SDCP monitoring effort, especially with regards to improving rangeland condition.

When adaptive management is undertaken, it should follow the basic steps in the adaptive management cycle by:

- Identifying uncertainties and the questions that need to be addressed to resolve the uncertainty;
- Develop alternative strategies and determine which experimental strategies to implement;
- Integrate the monitoring program to determine effectiveness; and
- Incorporate feedback loops that link implementation and monitoring to a decision-making process.

A notable exception to the discretionary use of adaptive management noted early is when the covered activities are thought to "pose a significant risk to the species at the time the permit is issued due to significant data or information gaps." Based on the amount of information that is known about listed species and the extraordinary conservation measures that have been conducted or are proposed to be implemented (through the conservation of the CLS and ongoing activities such as the acquisition program), it is unlikely that adaptive management would be required at the beginning of the permit process.

Bate (2008) provides an in-depth analysis of the issues and opportunities for adaptive management in the PCEMP.

6.2 Covered Species Information Database

The annual monitoring activities for the Pima County EMP will form the foundation of the program and will be used to determine permit compliance and effectiveness. Yet the program stands to benefit from the fact that Tucson is a regional center for ecological research and monitoring activities, much of which could contribute to an understanding of the distribution and abundance of covered species. To provide an effective means of collecting and summarizing this information, Pima County would investigate developing the Covered Species Information Database (CSID). Each year Pima County will query researchers and other governmental entities and non-governmental organizations regarding any data collected on covered species in the preceding year. Information would include a diverse range of information such as reports, sightings, or emergence of new threats. Information from these sources would be part of the annual report to the USFWS. Participating researchers and government and non-governmental entities would be encouraged to participate through public outreach activities, but the program would be on a voluntary basis. Pima County would be careful to that no sensitive information (e.g., locations of Threatened or Endangered species) be released without permission of the research entity and the relevant landowner. Data from this project will be stored using appropriate protocols that include metadata (see Powell 2008).

6.3 Development of Sonoran Desert Ecosystem Data Clearinghouse

The CSID will be the most immediate data management activity to develop. Yet the potential exists to expand that effort to include non-covered plants and animals and other environmental features such as soils, water, vegetation, etc. This information would provide a means for the County to put our monitoring information into a broader context by comparing trends in resources both on and off conservation lands. To accomplish this task, we will investigate the development of a host of tools that will allow for the collection and storage of reports and data (including raw data, database copies, locations of plots, and associated metadata) that are relevant to the resources of Pima County (i.e., research could in surrounding areas, if appropriate). Particular emphasis will be placed on research and monitoring projects focused on vertebrates and plants (e.g., Rosen and Caldwell 2004, Powell et al. 2006, Bodner et al. 2007, Powell et. al. 2007, Albrecht et. al. 2008) and threats (e.g., Bradley et al. 2002, Rogstad 2008). Our intention would be to compile these data into a database that would allow for the analysis of county-wide changes in the distribution of particular species or changes in species richness. Though we anticipate that this tool would provide only an assessment of gross changes in abundance or distribution of species, the combination of these tools with our broader measure of ecosystem changes (as derived from remote sensing and land-use indicators), this tool it would provide would be enormous benefit including refinement of species/habitat models, assessment of land-use practices, and evaluation of emerging threats. Though promising, this effort will require a significant investment of time and resources.

6.4 Other Activities

Also in Phase III, we will begin active engagement with the research community to encourage research on county-owned and leased lands, with particular emphasis on projects that might provide information on covered species. Because of the close proximity of many County properties to Tucson, there will likely be considerable support for this initiative.

Similarly, coordination of monitoring activities with other entities will be critical. The appropriate partners will likely be the National Park Service and Bureau of Land Management at

Las Cienegas National Conservation Area. In addition, the County should work closely with the Arizona Game and Fish Department (AZGFD) to draft an agreement for the possible re-introduction of covered species onto the County's reserve system. Though re-introductions are important for the success of the SDCP and are expressed in one of its biological objectives (See Section 3.1), such actions must be accomplished with the close cooperation of the AZGFD because of that agency has jurisdiction over the state's wildlife resources.

6.5 Peer Review of the Proposed Approach

The proposed approach identifies a mix of species-based monitoring with other types of monitoring such as habitat, ecosystem, and threats. Together they form the basis of an integrated program that has the best chance of detecting biologically meaningful changes. Many details remain to be finalized and therefore the ideas and approaches suggested in this document are subject to revision in the coming months. In addition to intra-county review, this document will also be shared with the USFWS and interested citizens to be sure that the proposed plan will meet with regulatory and citizen approval.

6. Literature Cited

Albrecht, E. W., E. L. Geiger, A. R. Litt, G. R. McPherson, and R. J. Steidl. 2008. Fire as a tool to restore biodiversity in ecosystems dominated by invasive grasses. Project 03-192. Department of Defense Legacy Resource Management Program.

Atkinson, A. J., P. C. Trenham, R. N. Fisher, S. A. Hathaway, B. S. Johnson, S. G. Torres, and Y. C. Moore. 2004. Designing monitoring programs in an adaptive management context for regional multiple species conservation plans. USGS Geological Survey Technical Report. USGS Western Ecological Research Center, Sacramento, CA.

Bate, J. 2008. Adaptive management of Habitat Conservation programs: a review of the literature and selected case studies for Pima County. Draft report to the Pima County Board of Supervisors, Tucson, Arizona

Belnap, J. 1998. Environmental auditing: Choosing indicators of natural resource condition: A case study in Arches National Park, Utah, USA. Environmental Management 22:635-642.

Bodner, G., J. Simms, and D. Gori. 2007. State of the Las Cienegas National Conservation Area: Gila topminnow population status and trends 1989-2005. The Nature Conservancy, Tucson, AZ.

Bradley, G. A., P. C. Rosen, M. J. Sredl, T. R. Jones, and J. E. Longcore. 2002. Chytridiomycosis in native Arizona frogs. Journal of Wildlife Diseases 38:206-212.

Buckland, S. T., D. R. Anderson, K. P. Burnham, J. L. Laake, D. L. Borchers, and L. Thomas. 2001. Introduction to distance sampling: Estimating abundance of biological populations. Oxford University Press, Oxford, England.

Bundrick, G., S. Anderson, L. Harvey, M. Brosseau, A. Loughner, and N. Connolly. 2000. Mountain parks, reserves, and biologically significant resource lands in Pima County, Arizona. Report to the Pima County Board of Supervisors for the Sonoran Desert Conservation Plan, Tucson, AZ.

Busch, D. E., and J. C. Trexler, editors. 2003. Monitoring ecosystems: Interdisciplinary approaches for evaluating ecoregional initiatives. Island Press, Washington, DC.

Canterbury, G. E., T. E. Martin, D. R. Petit, L. J. Petit, and D. F. Bradford. 2000. Bird communities and habitat as ecological indicators of forest condition in regional monitoring. Conservation Biology 14:544-558.

Carignan, V., and M. A. Villard. 2002. Selecting indicator species to monitor ecological integrity: A review. Environmental Monitoring and Assessment 78:45-61.

Cauglan, L., and K. L. Oakley. 2001. Cost considerations for long-term ecological monitoring. Ecological Indicators 1:123-134.

Christensen, N. L., A. M. Bartuska, J. H. Brown, S. Carpenter, C. D' Antonio, R. Francis, J. F. Franklin, J. A. Macmahon, R. F. Noss, D. J. Parsons, C. H. Peterson, M. G. Turner, and R. G. Woodmansee. 1996. The report of the Ecological Society of America Committee on the scientific basis for ecosystem management. Ecological Applications 6:665-691.

Diefenbach, D. R., D. W. Brauning, and J. A. Mattice. 2003. Variability in grassland bird counts related to observer differences and species detection rates. Auk 120:1168-1179.

Duchamp, J. E., M. Yates, R. M. Muzika, and R. K. Swihart. 2006. Estimating probabilities of detection for bat echolocation calls: An application of the double-observer method. Wildlife Society Bulletin 34:408-412.

Elzinga, C. L., D. W. Salzar, J. W. Willoughby, and J. P. Gibbs. 2001. Monitoring plant and animal populations. Blackwell Publishing, Malden, MA.

Ervin, J., and J. Parrish. 2006. Toward a framework for conducting ecoregional threats assessments. Pages 105-112. *In* C. Aguirre-Bravo, P. J. Pellicane, D. P. Burns, and S. Draggan, editors. Monitoring science and technology symposium: Unifying knowledge for sustainability in the western hemisphere. Proceedings RMRS-P-42CD. USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO.

Farnsworth, G. L., K. H. Pollock, J. D. Nichols, T. R. Simons, J. E. Hines, and J. R. Sauer. 2002. A removal model for estimating detection probabilities from point-count surveys. Auk 119:414-425.

Fleishman, E., and R. Mac Nally. 2003. Distinguishing between signal and noise in faunal responses to environmental change. Global Ecology and Biogeography 12:395-402.

Flesch, A. D. 2008. Population and community dynamics of lizards and rodents in Organ Pipe Cactus National Monument, 1989-2006, and implications for future monitoring. A report to the Organ Pipe Cactus National Monument, Ajo, Arizona.

Flesch, A. D., and R. J. Steidl. 2007. Detectability and response: Rates of ferruginous pygmy-owls. Journal of Wildlife Management 71:981-990.

Fonseca, J. 2008. Monitoring land cover change in Pima County, Arizona. A report to the Pima County Board of Supervisors. Tucson, Arizona.

Fonseca, J., and N. Connolly. 2002. Representation of vegetation communities and special elements in reserve design. Report to the Pima County Board of Supervisors for the Sonoran Desert Conservation Plan, Tucson, AZ.

Gerrodette, T. 1987. A power analysis for detecting trends. Ecology 68:1364-1372.

Gorresen, P. M., A. C. Miles, C. M. Todd, F. J. Bonaccorso, and T. J. Weller. 2008. Assessing bat detectability and occupancy with multiple automated echolocation detectors. Journal of Mammalogy **89**:11-17.

Graber, A. E., D. M. Weddle, H. C. English, S. D. Stump, H. E. Telle, and L. A. Ellis. 2007. Southwestern willow flycatcher 2006 survey and nest monitoring report. Technical Report 249. Arizona Game and Fish Department, Nongame and Endangered Wildlife Program, Phoenix, AZ.

Hall, L. S., P. R. Krausman, and M. L. Morrison. 1997. The habitat concept and a plea for standard terminology. Wildlife Society Bulletin 25:173-182.

Harding, E. K., E. E. Crone, B. D. Elderd, J. M. Hoekstra, A. J. Mckerrow, J. D. Perrine, J. Regetz, L. J. Rissler, A. G. Stanley, and E. L. Walters. 2001. The scientific foundations of Habitat Conservation Plans: A quantitative assessment. Conservation Biology 15:488-500.

Hayes, J. P. 1997. Temporal variation in activity of bats and the design of echolocation-monitoring studies. Journal of Mammalogy **78**:514-524.

Hinman, K. E., and T. K. Snow. 2003. Arizona Bat Conservation Strategic Plan. Nongame and Endangered Wildlife Program. Technical Report 213. Arizona Game and Fish Department, Phoenix, AZ.

Kepler, C. B., and J. M. Scott. 1981. Reducing bird count variability by training observers. Studies in Avian Biology 6:366-371.

Kincaid, T. M., D. P. Larsen, and N. S. Urquhart. 2004. The structure of variation and its influence on the estimation of status: Indicators of condition of lakes in the northeast, U.S.A. Environmental Monitoring and Assessment 98:1-21.

Kuenzi, A. J., and M. L. Morrison. 2003. Temporal patterns of bat activity in southern Arizona. Journal of Wildlife Management 67:52-64.

Larsen, D. P., T. M. Kincaid, S. E. Jacobs, and N. S. Urquhart. 2001. Designs for evaluating local and regional scale trends. BioScience 51:1069-1078.

Larsen, D. P., N. S. Urquhart, and D. L. Kugler. 1995. Regional scale trend monitoring of indicators of trophic condition of lakes. Water Resources Bulletin 31:117-140.

Lohr, S. 1999. Sampling: Design and analysis. Duxbury Press, Pacific Grove, CA.

Martin, J., W. M. Kitchens, and J. E. Hines. 2007. Importance of well-designed monitoring programs for the conservation of endangered species: Case study of the snail kite. Conservation Biology 21:472-481.

Morrison, M. L., W. M. Block, M. D. Strickland, and W. L. Kendall. 2001. Wildlife study design. Springer Press, New York, NY.

Morrison, M. L., B. G. Marcot, and R. W. Mannan. 1998. Wildlife-habitat relationships: Concepts and applications. The University of Wisconsin Press, Madison, WI.

National Biological Service. 1995. Organ Pipe Cactus National Monument ecological monitoring program monitoring protocol manual. Special Report 11. Cooperative Park Studies Unit, University of Arizona, Tucson, AZ.

Niemeijer, D., and R. S. de Groot. 2008. A conceptual framework for selecting environmental indicator sets. Ecological Indicators 8:14-25.

Noss, R. F. 1990. Indicators for monitoring biodiversity: A hierarchical approach. Conservation Biology 4:355-364.

O'Shea, T. J., M. A. Bogan, and L. E. Ellison. 2003. Monitoring trends in bat populations of the United States and Territories: Status of the science and recommendations for the future. Wildlife Society Bulletin 31:16-29.

Oakley, K. L., L. P. Thomas, and S. G. Fancy. 2003. Guidelines for long-term monitoring protocols. Wildlife Society Bulletin 31:1000-1003.

Olsen, A. R., J. Sedransk, D. Edwards, C. A. Gotway, W. Liggett, S. Rathbun, K. H. Reckhow, and L. J. Young. 1999. Statistical issues for monitoring ecological and natural resources in the United States. Environmental Monitoring and Assessment 54:1-45.

Palmer, C. J., and B. S. Mulder. 1999. Components of the effectiveness monitoring program. Pages 69-97. *In* B. S. Mulder, B. R. Noon, T. A. Spies, M. G. Raphael, C. J. Palmer, A. R. Olsen, G. H. Reeves, and H. H. Welsh Jr., editors. The strategy and design of the effectiveness monitoring program for the Northwest Forest plan. General Technical Report PNW-437. USDA Forest Service, Pacific Northwest Research Station, Portland, OR.

Parrish, J. D., D. P. Braun, and R. S. Unnasch. 2003. Are we conserving what we say we are? Measuring ecological integrity within protected areas. BioScience 53:851-860.

Pearson, G., and C. W. Conner. 2000. The Quitobaquito desert pupfish, an endangered species within Organ Pipe Cactus National Monument: Historical significance and management challenges. Natural Resources Journal 40:379-410.

Pima County. 2000a. Draft preliminary Sonoran Desert Conservation plan. Draft report to the Pima County Board of Supervisors for the Sonoran Desert Conservation Plan, Tucson, AZ.

Pima County. 2000b. Riparian protection, management and restoration: An element of the Sonoran Desert Conservation Plan. Report to the Pima County Board of Supervisors for the Sonoran Desert Conservation Plan, Tucson, AZ.

Pollock, K. H., J. D. Nichols, T. R. Simons, G. L. Farnsworth, L. L. Bailey, and J. R. Sauer. 2002. Large scale wildlife monitoring studies: Statistical methods for design and analysis. Environmetrics 13:105-119.

Powell, B. F. 2008. Draft data management plan for the Pima County Ecological Monitoring Program. Draft report to the Pima County Board of Supervisors, Tucson, Arizona

Powell, B. F., and A. D. Flesch. In prep. Determining sample sizes for landbird monitoring: an example from National Parks in the Desert Southwest, USA. To be submitted to the Journal of Field Ornithology.

Powell, B. F., W. L. Halvorson, and C. A. Schmidt. 2006. Vascular plant and vertebrate inventory of Saguaro National Park, Rincon Mountain District. Open-File Report 2006-1075. U.S. Geological Survey, Southwest Biological Science Center, Sonoran Desert Research Station, University of Arizona, Tucson, AZ.

Powell, B. F., W. L. Halvorson, and C. A. Schmidt. 2007. Vascular plant and vertebrate inventory of Saguaro National Park, Tucson Mountain District. Open-File Report 2007-1296. U.S. Geological Survey, Southwest Biological Science Center, Sonoran Desert Research Station, University of Arizona, Tucson, AZ.

Rahn, M. E., H. Doremus, and J. Diffendorfer. 2006. Species coverage in multispecies habitat conservation plans: Where's the science? BioScience 56:613-619.

RECON Environmental Inc. 2000a. Draft reserve design: Guidelines, goals, opportunities, and constraints. Report to the Pima County Board of Supervisors for the Sonoran Desert Conservation Plan, Tucson, AZ.

RECON Environmental Inc. 2000b. Priority vulnerable species: Habitat data analysis. Report to the Pima County Board of Supervisors for the Sonoran Desert Conservation Plan, Tucson, AZ.

RECON Environmental Inc. 2001. Reserve design process update. Report to the Pima County Board of Supervisors for the Sonoran Desert Conservation Plan, Tucson, AZ.

RECON Environmental Inc. 2006. Draft Pima County multi-species conservation plan. Report to the Pima County Board of Supervisors for the Sonoran Desert Conservation Plan, Tucson, AZ.

RECON Environmental Inc. 2007. Ecological effectiveness monitoring plan for Pima County: Phase 1 final report. Report to the Pima County Board of Supervisors for the Sonoran Desert Conservation Plan, Tucson, AZ.

Robbins, C. S., J. R. Sauer, R. S. Greenburg, and S. Droege. 1989. Population declines in North American birds that migrate to the Neotropics. Proceeding of the National Academy of Sciences, USA 86:7658-7662.

Rogstad, A., ed. 2008. Southern Arizona buffelgrass strategic plan. Buffelgrass Working Group, Tucson, AZ.

Rosen, P. C., and D. J. Caldwell. 2004. Aquatic and riparian herpetofauna of Las Cienegas National Conservation Area, Pima County, Arizona. Unpublished report to Pima County Board of Supervisors for the Sonoran Desert Conservation Plan, Tucson, AZ.

Salafsky, N., and R. Margoluis. 1999. Threat reduction assessment: a practical and cost-effective approach to evaluating conservation and development projects. Conservation Biology 13:830-841.

Salzer, D., and N. Salafsky. 2006. Allocating resources between taking action, assessing status, and measuring effectiveness of conservation actions. Natural Areas Journal 26:310-316.

Schwarz, C. J., and G. A. F. Seber. 1999. Estimating animal abundance: Review III. Statistical Science 14:427-456.

Scott, J. M., P. J. Hegland, M. L. Morrison, J. B. Haufler, M. G. Raphael, W. A. Wall, and F. B. Samson. 2002. Predicting species occurrence: issues of accuracy and scale. Island Press, Washington, DC.

Simms, J. R., K. M. Simms, and D. K. Duncan. 2006. An assessment of long-term aquatic habitat change and Gila Topminnow population trends for Cienega Creek, Pima County, Arizona. P. 75 *In* Borders, boundaries, and time scales. Extended abstracts from the Sixth Conference on Research and Resource Management in the Southwestern Deserts, May 2-5, Tucson, Arizona.

Sims, M., S. Wanless, M. P. Harris, P. I. Mitchell, and D. A. Elston. 2006. Evaluating the power of monitoring plot designs for detecting long-term trends in the numbers of common guillemots. Journal of Applied Ecology 43:537-546.

Slocombe, D. S. 1998. Defining goals and criteria for ecosystem-based management. Environmental Management 22:483-493.

Steidl, R. J., J. P. Hayes, and E. Schauber. 1997. Statistical power analysis in wildlife research. Journal of Wildlife Management 61:270-279.

Steidl, R. J., and L. Thomas. 2001. Power analysis and experimental design. *In* S. M. Scheiner and J. Gurevitch, editors. Design and analysis of ecological experiments. Oxford University Press, Oxford, NY.

Stromberg, J. C. 2001. Biotic integrity of *Platanus wrightii* riparian forests in Arizona: A first approximation. Forest Ecology and Management 142:251-266.

Tear, T. H., P. Kareiva, P. L. Angermeier, P. Comer, B. Czech, R. Kautz, L. Landon, D. Mehlman, K. Murphy, M. Ruckelshaus, J. M. Scott, and G. Wilhere. 2005. How much is enough? The recurrent problem of setting measurable objectives in conservation. BioScience 55:815-835.

Thomas, L., K. P. Burnham, and S. T. Buckland. 2004. Temporal inferences from distance sampling survey. Pages 71-105. *In* S. T. Buckland, D. R. Anderson, K. P. Burnham, J. L. Laake, D. L. Borshers, and L. Thomas, editors. Advanced distance sampling. Oxford University Press, New York, NY.

Thompson, S. K. 2002. Sampling. Second edition. John Wiley and Sons, New York, NY.

Thompson, S. K., and G. A. F. Seber. 1996. Adaptive sampling. John Wiley and Sons, New York, NY.

Thompson, W. L., G. C. White, and C. Gowan. 1998. Monitoring vertebrate populations. Academic Press, San Diego, CA.

Tibbitts, T. J., M. K. Sogge, and S. J. Sferra. 1994. A survey protocol for the Southwestern Willow Flycatcher (*Empidonax traillii extimus*). NRTR-94/04. U.S. Department of the Interior, National Park Service.

U.S. Environmental Protection Agency. 2007. Guidance for preparing standard operating procedures (SOPs). U.S. Environmental Protection Agency, Washington, DC.

U.S. Fish and Wildlife Service. 1996. Habitat conservation planning and incidental take permit processing handbook. Washington, D.C.

U.S. Fish and Wildlife Service.Fish and Wildlife Service, Ed. 2000. Final addendum to the Handbook for Habitat Conservation Planning and Incidental Take Permit. Washington, D.C.

Urquhart, N. S., and T. M. Kincaid. 1999. Designs for detecting trend from repeated surveys of ecological resources. Journal of Agricultural, Biological and Environmental Statistics 4:404-414.

Urquhart, N. S., S. G. Paulsen, and D. P. Larsen. 1998. Monitoring for policy-relevant regional trends over time. Ecological Applications 8:246-257.

Walker, B., and J. A. Meyers. 2004. Thresholds in ecological and social-ecological systems: A developing database. Ecology and Society 9: 15-23.

Wallace, E. J., D. E. Swann, and R. J. Steidl. 2006. Effects of wildland fire on lowland leopard frogs and their habitat at Saguaro National Park. Final report to Western National Park Association and Saguaro National Park, Tucson, Arizona.

White, G. C. 2005. Correcting wildlife counts using detection probabilities. Wildlife Research 32:211-216.

Wiens, J. A. 1985. Habitat selection in variable environments: Shrub-steppe birds. Pages 191-226. *In* M. L. Cody, editor. Habitat selection in birds. Academic Press, Orlando, FL.

Wiggens, D. 2005. Yellow-billed cuckoo (Coccyzus americanus): a technical convervation assessment. [Online]. USDA Forest Service, Rocky Mountain Region. Available: http://www.fs.fed.us/projects/scp/assessments/yellowbilledcuckoo.opdf. Accessed: August 11, 2008.

Wilhere, G. F. 2002. Adaptive management in habitat conservation plans. Conservation Biology 16:20-29.

Yoccoz, N. G., J. D. Nichols, and T. Boulinier. 2001. Monitoring of biological diversity in space and time. Trends in Ecology & Evolution 16:446-453.

Appendix A. List of species currently proposed for coverage und the forthcoming Section 10 permit application to the U.S. Fish and Wildlife Service.

Species Group	Common name	Scientific name
Plants	Pima pineapple cactus	*Coryphantha scheeri var. robustispina*
	Needle-spined pineapple cactus	*Echinomastus erectocentrus var. erectocentrus*
	Huachuca water umbel	*Lilaeopsis schaffneriana recurva*
	Tumamoc globeberry	*Tumamoca macdougalii*
Mammals	Mexican long-tongued bat	*Choeronycteris Mexicana*
	Allen's big-eared bat	*Idionycteris phyllotis*
	Southern yellow bat	*Lasiurus xanthinus*
	Western red bat	*Lasiurus blossevillii*
	Lesser long-nosed bat	*Leptonycteris curasoae yerbabuena*
	California leaf-nosed bat	*Macrotus californicus*
	Pale Townsend's big-eared bat	*Plecotus townsendii pallescens*
	Merriam's mouse	*Peromyscus merriami*
Birds	Burrowing owl	*Athene cunicularia hypugaea*
	Cactus ferruginous pygmy-owl	*Glaucidium brasilianum cactorum*
	Rufous-winged sparrow	*Aimophila carpalis*
	Swainson's hawk	*Buteo swainsoni*
	Western yellow-billed cuckoo	*Coccyzus americanus*
	Southwestern willow flycatcher	*Empidonax traillii extimus*
	Abert's towhee	*Pipilo aberti*
	Bell's vireo	*Vireo bellii*
Fishes	Longfin dace	*Agosia chrysogaster*
	Desert sucker	*Catostomus clarki*
	Sonora sucker	*Catostomus insignis*
	Desert pupfish	*Cyprinodon macularius*
	Gila chub	*Gila intermedia*
	Gila topminnow	*Poeciliopsis occidentalis occidentalis*
Amphibians	Chiricahua leopard frog	*Rana chiricahuensis*
	Lowland leopard frog	*Rana yavapaiensis*
Reptiles	Desert box turtle	*Terrapene ornate luteola*
	Sonoran desert tortoise	*Gopherus agassizii*
	Tucson shovel-nosed snake	*Chionactis occipitalis klauberi*
	Mexican garter snake	*Thamnophis eques megalops*
	Giant spotted whiptail	*Aspidoscelis burti stictogramma*
	Red-backed whiptail	*Aspidoscelis burti xanthonotus*
	Ground Snake (valley form)	*Sonora semiannulate*
Invertebrates	Arkenstone Cave pseudoscorpion	*Albiorix anopthalmus*

Appendix B. Cost estimate for the single day of field collection and the analysis, archiving, and administration of the data.

Estimating the cost of monitoring activities is an important component in the design process and allows for determining the feasibility of conducting monitoring and for comparing among competing methods. Often, cost considerations focus on the cost of collecting data, but other aspects in the "life cycle" of data (e.g., analyzing, reporting and storing data) are often not recognized, yet are critical to state explicitly (Cauglan and Oakley 2001).

As a starting place for estimating cost of monitoring individual species, I estimated the cost of sending a monitoring crew into the field for one day. These data were then used to calculate the cost of monitoring for individual species (Tables 2-5). This model is based on a two-person field day, which is typical in this type of work. For data collection, I used a modest wage of $13.00/hour for field technicians and included costs for vehicles, mileage, and equipment. I then used a formula for how much effort is needed for dealing with the data after it has been collected: administration (hiring, payroll, etc.), data entry, validation, and storage, analysis, and reporting. Based on past experience, these activities typically take 0.75 for every two-person field day. In these calculations, I estimate that office staff costs $90,000 per year.

Based on these calculations, I estimate it would cost $690 for each day (unit) of data collection (Table A1). Accounting for inflation, I estimate that by year 30, the cost of collecting, analyzing, archiving, and reporting a single field day worth of data is projected to cost $2,238 per day (using an annual inflation rate of 4%; cost = $690[1.04]^{30}$).

Savings can be realized throughout the data life cycle, such as in borrowing equipment, hiring less skilled workers for some tasks, and using existing resources (administrative staff). In some cases, data collection can be performed by other staff in the course of their other duties. Such efficiencies will be realized in a well-run monitoring program, yet this model represents a starting place for estimating costs.

Table A1. Summary of costs associated with the collection, reporting, and archiving, scaled by a typical day's worth of field collection (based on 2008 dollars).

Category	Item	Cost
Field	Personnel wages (two technicians @$13.00/hour, 8 hours/day)	208
	Personnel benefits and overhead (assume seasonal: 22% employee-related expense)	46
	Mileage: 65 miles/day round trip @ $0.50 mile	33
	Vehicle cost: $30/day	30
	Field and office equipment	20
Administration	Program management (data entry, data management, analysis, scheduling, purchasing, hiring, and report writing): 0.75 office days per field day @ $350/day	263
	Subtotal for Field and Administration costs	600
	Administrative overhead (15% of subtotal)	90
Total cost per field day		690

ADAPTIVE MANAGEMENT FOR HABITAT CONSERVATION PROGRAMS:

A Review of the Literature and Selected Case Studies for Pima County, Arizona

Report to the Pima County Board of Supervisors

August 2008

Joanna Bate
Office of Conservation Science

Pima County
Natural Resources,
Parks and Recreation

Tucson, Arizona

Figures and Tables…

Introduction

As stated in the Phase I report from the Ecological Effectiveness Monitoring Plan for Pima County, the monitoring program must include "dissemination of information to policy makers, land managers, and the general public (Woodward et al. 1999; Palmer and Mulder 1999; Harwell et al. 1999)." Furthermore, revisions to the Habitat Conservation Planning (HCP) handbook in 2000 included an explicit recommendation for the use of adaptive management in HCPs (Nelson, 2000; citation).

A review of the literature on adaptive ecosystem management processes and programs provides a set of elements important for designing an effective adaptive management program in an HCP. Lessons learned from this review will inform ways for Pima County to form their own framework for integrating adaptive management activities into the Pima County EMP. This work will lead to a solid foundation for future communication of monitoring information both within the county and ultimately to a wider set of stakeholders.

Literature Synthesis

Responsible stewardship requires a continual assessment of the state of the environment and the effects of human behavior (Noon 2003). Due to the lack of reliable scientific information on environmental conditions and trends, performance-based environmental policies are difficult to find (US GAO 2004). Decision-making based on science entails explicit consideration of risks and uncertainties associated with the effects of management actions (Kim and Bridges 2006). The traditional method has been trial-and-error learning, as opposed to systematic design, implementation, and evaluation of management strategies (Holling 1978).

Adaptive management provides a structured method for comparing alternative management strategies to address potential uncertainties within an HCP design (Nelson 2000). Wilhere (2002) defines adaptive management as "investing in reliable information to yield excellent returns in the sustainable use of natural resources." The U.S. Fish and Wildlife Service (FWS) proposes that adaptive management be used where there is uncertainty that cannot be addressed with small-scale research (FWS 2000, Kareiva et al. 1999). Adaptive management can focus on a general class of problems with similar types of decisions as they occur in different locations (Johnson 1999). Jensen et al. (1996) defines adaptive management as exploring explicit hypotheses about ecosystem structure and function, defined management goals and actions, and anticipated ecosystem responses. All of these definitions describe some aspect of the integrated, complex method of managing systematically that is adaptive management.

A review of the adaptive management literature provides a theoretical basis for best practices in communication and monitoring as part of an adaptive management program.

Ideal AM program

When is AM appropriate?

Adaptive management has often failed due to attempted applications of the theory to inappropriate contexts (Gregory et al. 2006). However, the literature describes some conditions that are amenable to adaptive management. First, there must be a mandate to take action, despite uncertainty (Lee 1993). Second, there must be institutional commitment to undertake and sustain a program (Lee 1993). This requires that an institution provide the resources necessary for long term monitoring and evaluation as part of an adaptive management program. Other insights about applying adaptive management include the requirement that a consensus about objectives exists and that monitoring can provide information that will reduce uncertainty (Williams et al. 2007). Thus, to prepare for a successful adaptive management program, one must consider each of these variables and the likelihood that the necessary conditions exist for adaptive management.

There is an area of the literature that is less conclusive about the appropriate settings for applying adaptive management: scale and complexity. While some authors believe the HCP handbook intended adaptive management for use in large, complex management programs (Nelson 2000), others suggest that large scale adaptive management might be unwieldy [citation].

Critical elements of an AM program

Planning process elements for natural resource management are described by several authors as a series of steps to be taken by those seeking to manage adaptively (Hockings et al. 2006; Stanley 1995; Walters 1986; Bormann et al. 1994) and for designing HCPs (Atkinson et al 2004).

[Figure 1. – flow of adaptive management]

The first two steps identified by Hockings et al. 2006, Atkinson, and Stanley (1995) are to set goals and/or objectives and identify context, in alternating order. In Walters (1986), these two are considered as one step: “bounding management problems and recognizing constraints”. Bounding management problems, according to Walters, involves posing questions that apply to management and setting goals (desired future conditions) for management. This means that we decide which factors we want to manage, at what detail, at what spatial and temporal scales. Recognizing constraints covers the process of gathering information about the management context.

The next step is to plan (Bormann et al. 1994), which Stanley and Walters identify as building models to demonstrate knowledge as hypotheses. The knowledge depicted in models concerns the predicted relationships between management actions or disturbance processes and natural system elements. Both authors characterize these models as living documents, calling them “dynamic” or “working”. Holling (1978) identifies adaptive management as an “iterative process”. Hence, the purpose of subsequent steps would be to document (monitor) environmental responses to management, and to update models with this new information. Walters, Atkinson and Hockings et al. 2006 suggest the intention of the planning stage should be to incorporate mechanisms for learning into management actions. Whether planners call adaptive management the use of working hypotheses or the design of actions to be learned from, the general idea is the same: management is an imperfect science that we can improve by documenting our assumptions and measuring the accuracy of our predictions.

A large body of literature exists about the rigor required for designing management and monitoring for learning. Part of the concern over reliable science includes the explicit description of uncertainties and inherent risks due to uncertainties. Atkinson et al. (2004) recognize the need to minimize risks to the ecosystem, while striving for rigorous and effective decision processes. Kim and Bridges (2006) also emphasize the risks and uncertainties involved in management, requiring explicit consideration in science-based decision making. Walters (1986) specifically emphasizes the consideration of uncertainty, through the use of alternate hypotheses or otherwise, setting this as an individual step in the adaptive management process.

Hockings et al. (2006) identifies two areas that need documentation – implementation (outputs) and natural element responses (outcomes). Stanley identifies the need to document social and environmental outcomes. Other authors simply identify the need for documentation and evaluation or analysis (Walters, Stanley, Bormann et al. 1994). Atkinson et al. (2004) and Hockings et al. (2006) recognize the need for rigor in analyzing the effectiveness of a management program. Atkinson et al. (2004) expresses the importance of tracking progress toward objectives and of demonstrating progress in a scientifically defensible way.

The final step recommended by Hockings et al. (2006) is making recommendations. Other authors (Walters, Bormann et al. 1994, Stanley) stop describing the AM process at the point of analysis, in one case (Walters) summarizing the next step as “learning”. Holling (1978) describes adaptive management as the use of management experiences to contribute to future policy development. Atkinson et al. (2004) describe two potential uses of monitoring information – adjusting management and adjusting the conservation strategy. Additionally, Atkinson et al. (2004) highlight the importance of finding cost-effective management strategies. Thus, recommendations based on analysis of monitoring results may guide management at multiple levels to be effective in terms of both outcomes and costs. These are some of the applications of “learning”, that commonly cited goal of adaptive management. Finally, Hockings et al. (2006) identifies the rewarding of good behavior as another contribution monitoring information and evaluation can make.

Each component of the adaptive management process deserves additional inquiry. The complexity of any real-world management situation outpaces the progress made by simply describing adaptive management program elements that may lead to learning. Thus, the steps named above – setting goals and objectives, considering the context, planning for management and monitoring, and using monitoring results for analysis and management guidance – each have important qualities that researchers have identified.

Setting goals and objectives

Lee (1999) suggests that a collaborative structure should be in place *before* an adaptive exploration of the landscape gets underway. Otherwise, basic disagreements about objectives will surface in light of obstacles or unexpected discoveries, stalling or even derailing the process. This collaborative structure will meet the need to identify common goals among stakeholders involved in planning and implementation (Margerum 1997). Specifically, stakeholders must define objectives and potential management actions based on their values.

Goals for a resource management program may need to be differentiated by human-inhabited areas and natural areas (Callicot et al. 1999 in Meffe). Some goals may be appropriate to apply to the whole area managed by an adaptive management program, but for some lands, detailed objectives need to be set according to the particular natural context in that place.

Many authors have defined what they deem to be appropriate goals for managed ecosystems. Ecosystem resilience is a concept cited by Meffe et al. (2002), involving the maintenance of the natural variability that provides a buffer for ecosystem-dependent species against disturbances. Walters (1986) describes the goal of maximizing risk-averse utility, the method where managers attempt to measure the risks of degradation posed by maintaining status quo versus the risks of changing current management practices and choose the highest payoff with the least risk, as described by Raiffa (1968) and Keeney (1977). Ecosystem health, a concept defined by Costanza et al, involves protection of the intact, autonomous, self-integrative processes of nature. Other goals suggested for managed ecosystems include biodiversity conservation, species viability or recovery, and biotic integrity.

In a synthesis involving at least 12 leading conservation biologists, Tear et al. (2005) describe principles and standards for use in conservation objective-setting. Tear et al. (2005) recognize the importance of goal-setting by consensus, but the authors also recommend the clarification of temporal and spatial bounds for goals, as well as the goals for species and habitat conditions. Once goals have been set, measurable objectives must be described along with performance measures to determine shorter-term progress towards achieving goals (Tear et al. 2005). Rogers (1998) recommends that practitioners limit goals to those that can be monitored through indicators and achievement audited within the resource constraints of the institutions involved.

Identify context

The success of any sustainability initiative will ultimately depend on its structural coupling with the context in which it is applied (Manuel-Navarrete et al 2006). Atkinson et al. (2004) describe the second step in adaptive management as identifying the context of the monitoring program. This involves setting bounds on the lands to be monitored, the constraints on management on those lands, the intended users of the monitoring information, and relevant spatial and temporal scales for reporting and decision-making. These elements are critical characteristics of the local situation that will influence the success of a monitoring program at meeting its objectives.

Planning monitoring for adaptive management

In 2004, Andrea Atkinson and others published a report that reviewed literature on designing monitoring programs in an adaptive management context. Several steps in the process for adaptive management involved the preparation of information, structures, and strategies for monitoring and evaluation. Early on, managers should strategically divide the system and prioritize system components for monitoring program development. Next, managers should develop simple management-oriented conceptual models. Then, they need to identify monitoring recommendations and critical uncertainties. Finally, they must determine a strategy for implementing monitoring, analysis, and reporting in such a way as to ensure effective feedback to decision-making.

Firstly, the long term security of monitoring programs and the compatibility of data with larger efforts are top priorities (Trexler and Busch 2003). Adaptive management will falter without long-term data sets and commitments from institutions to responding to indications of the need for change.

To connect the results of monitoring to future decisions, managers must set out to answer management questions or questions about management impacts/successes. The "bounding of monitoring questions" means managers must ask questions about the factors they want to manage, at some level of detail, at some spatial and temporal scale (Walters 1986). Then, they choose variables that might be impacted by management and monitor variables at the scale of management. They can match monitoring to ongoing management activities, as a form of passive adaptive management. This might include linking monitoring questions to the decisions routinely made in ongoing decision processes (Cort 1996). Scientists designing monitoring must communicate with managers to identify management questions, to identify ongoing management actions and potential changes in management, to commit to or negotiate potential responses to specific monitoring results, and to bring them information quickly enough that they can act while it is timely.

Depending on goals and objectives, managers may seek different goals for evaluating monitoring information. Thus, managers need to plan both monitoring and evaluation based on the purposes they deem appropriate for their use. In cases where decision makers want to identify changes in natural elements or early stages of decline, monitoring and evaluation efforts would focus on different elements than where the concern is demonstrating implementation of management actions and compliance with regulations. Where little information is available about the current condition of the managed system, managers may want to focus on gathering data indicative of natural element trends. This type of information can motivate intervention before environmental losses are irreversible (Noon 2003). Where managers must demonstrate compliance with management actions or regulatory standards, monitoring programs should include tracking of management activities and regulated indicators.

Frequently, adaptive management activities include making predictions of system states or setting objectives for management outcomes, which can be compared against monitoring results. These evaluations may provide information about the need to change management actions or update conceptual models of the system.

Measuring the effectiveness of management actions, so as to inform decisions about adjusting future management policies, requires monitoring both the implementation of management activities and the natural element outcomes. To truly identify the effects that are caused by a management action, it is necessary to identify the natural range of variability before management implementation (Meffe et al. 2002). This will require discovering the scales at which natural variation is occurring in addition to measuring trends over time (Trexler and Busch 2003).

The ideal adaptive management program would seek to evaluate whether management actions are effective in meeting objectives (Nelson 2000; citation). This process has been called management as experimentation in which management processes are the "hypotheses being tested" (Trexler and Busch). Predictions for use in evaluation of management policies should include a description of the management activity to be performed and the expected natural system response.

Management policies can be applied as experimental treatments through active adaptive management, or management actions from the past can be considered retrospectively to answer monitoring questions (Trexler and Busch). Where management is already being applied, some assumptions about its effectiveness have already been made. Documentation of these assumptions in a conceptual model or set of hypotheses allows comparison of future monitoring results with predictions (Nyberg 1998; Walters and Holling). Managers can design management actions for future experimentation, a process often called active adaptive management. This allows true experimentation with management policies, by varying methods over time to allow for comparison of results (Walters et al. 1997).

Known elements in a system can be used to test hypotheses for credibility (Walters and Holling). Existing knowledge, created through research and other monitoring efforts, is useful to help refine conceptual models and management hypotheses (Nyberg 1998). Existing monitoring programs also provide the potential for learning from monitoring results, as results can be compared across larger scales and with varying management treatments. This requires some coordination of monitoring across jurisdictions or programs, perhaps including setting standards for data collection and reporting, to make multiple datasets useful for system-wide analysis. Scientists and those designing evaluation plans should develop clear protocols including 1) triggers (thresholds or results that initiate a change, often tied to objectives) and 2) management responses in the event that a threshold is triggered (Noon 2003; Bisbal et al. 2001; Gregory et al. 2006).

In places where multiple management "treatments" cannot be applied, managers can make passive adaptive management more powerful by drawing on retrospective studies/past actions and responses, descriptive studies, process research, responses from natural disturbances, and local knowledge. The initial stage of gathering information provides a long-term data set for use in developing a smaller set of hypotheses/models.

Next, managers can create a set of alternative models used to predict outcomes, then given estimated outcomes from monitoring data, identify most successful models/set credibility measures or weights to models.

Monitoring can set limits on what can be evaluated and therefore achieved (Trexler and Busch 2003). Many authors identify the importance of describing current levels and locations of uncertainty before attempting to make predictions about causal relationships (Wilhere 2002). More importantly, Schreiber et al (2004) recognizes the need to explore existing sources of uncertainty within monitoring methods before attempting to utilize the methods for comparing the results of various management scenarios. As part of understanding natural system elements, managers should seek to identify the range of natural variation using historical data and long term monitoring (Meffe et al 2002). Because natural variation exceeds human capacity for control (Holling 1995), we must incorporate natural variation into our adaptive management processes.

To learn from the adaptive management approach, it is necessary to incorporate mechanisms for learning into management actions (Walters, Atkinson and Hockings et al. 2006). Monitoring natural system responses, a key component of a monitoring program, is only informative about the effects of management if natural variability is understood and all stressors defined. Measurement of management activities is critical for determining causal relationships between these activities and observed ecosystem responses. The use of predictions and conceptual models in setting monitoring priorities provides a foundation for future evaluation of monitoring results for use in adaptive management.

Application of adaptive management principles may occur within a program or as a comprehensive approach that considers the cumulative ongoing activities and their impacts and communicates across programs (Margerum 1997). Need to consider each one on its own and in tandem (transdisciplinary regulatory approach). For HCPs this is a shift away from applying one concept of the system in perpetuity and towards reevaluating assumptions of the reserve design with monitoring information on an ongoing basis.

Learning from monitoring results

The preparation of monitoring results for use in decision making can involve various methods of evaluation. Many authors have recognized the necessity of scientific rigor in evaluating results and the importance of documenting the program objectives, monitoring results, and revisions to models (Hamann and Ankerson 1995; Schreiber et al. 2004; Hockings et al. 2006). However, the use of several methods for evaluation has been proposed in the literature; no clear consensus has yet emerged.

The importance of rigor in designing monitoring has been identified, and the necessity of reliable science in evaluation of monitoring results is equally as important (US GAO 2004; Wilhere 2002). This applies not only to the level of documentation of evaluation methods and monitoring results, but the choice of evaluation methods as well (Steidl 2001).

Many authors suggest that AM programs must be built around building of models, which makes a simple process sound more complicated than it needs to be. By using a concept of the history and current knowledge of management activities and their levels and intensities, one can try to figure out what general relationships exist between management actions and natural mechanisms. Where these concepts are unclear, or disagreements exist, managers can draw out the possible scenarios. Managers should seek to find indicators or outcomes that represent each mechanism/scenario and then refer to this when results come in.

Each monitoring and evaluation project provides an opportunity to document each step of the process, so that future managers and scientists can learn from the experience. Results should be interpreted based on documented objectives, documented management plans, and documented revisions to plans and explicit models (Hockings et al. 2006). To ensure continual learning, managers should create a long term schedule and plan for monitoring and evaluation and assign tasks and responsibilities (Hockings et al. 2006). As the monitoring program provides new information, managers can describe innovative understanding of mechanisms and new knowledge about causal relationships.

In an ideal adaptive management program, managers would analyze observed outcomes in relation to applied management strategies. Also, where unexpected disturbances occur, results provide opportunities to understand impacts (NSTC 1997). For this analysis, both applied management actions or disturbances and outcomes must be documented and evaluated. New information about natural and/or human-caused variability within the natural system should be incorporated into models between sampling periods (Steidl 2001). Both social and environmental outcomes are informative to analyzing management effectiveness.

The analysis required for assessing effectiveness of management actions includes documentation of progress towards measurable objectives, variation from natural range of variability, and/or maintenance of acceptable standards. Various methods can be used for these types of analyses: comparison against set standards (goals, thresholds, natural variation) or statistical analyses to find trends (Haney and power 1996; Legg and Nagy 2006). Additionally, sensitive measurements of species dynamics, such as measurements of reproduction or mortality, can contribute to early detection of negative trends (Legg and Nagy 2006). Managers can integrate data at various scales about various attributes using GIS (Haney and power 1996). Indicator values viewed as a whole across the assessment region can provide a more accurate view of the true condition in relation to a standard or threshold (Noon 2003). However, extrapolation of data beyond its initial context may cause problems with conflating effects, unless sufficient replication is provided and the relevant natural processes are understood (Walters and Holling 1990; Legg and Nagy 2006).

To identify causal relationships, monitoring information must help eliminate alternative mechanisms to explain observed patterns. Haney and Power (1996) recommend ordination techniques to evaluate community shifts in response to treatments.

Additionally, a before-after/control (BACI) design can help identify possible links between management actions and system responses (Legg and Nagy 2006).

The results of monitoring are also only as good as their reporting. Monitoring program staff must communicate the scientific relevance of findings to other scientists (Noon 2003). Staff must also communicate the uncertainty of results so it can be addressed in the decision making process (Noon 2003). The use of monitoring information in selecting future management actions requires explicit descriptions of tradeoffs and risks involved in each management alternative.

Use of science in decision making

Decision-makers want to know effects of past actions on ecosystems (trends after implementation) and potential effects of future management actions (based on models of ecosystem), according to NSTC (1997). Ad hoc information can be useful in setting targets for the future. Results can be used to adapt plans and policies, adjust resource allocation, and affirm good work (Hockings et al. 2006).

Monitoring and evaluation results can assist in adjusting management at small and large scales (Hockings et al. 2006). Monitoring information can be useful in adjusting the overall conservation strategy, as suggested by Atkinson et al. (2004). Identifying effective and cost-effective strategies assists in rewarding good work and highlighting areas needing a change in management (Hockings et al. 2006).

Walters 1986 indicates the importance of using monitoring results to describe tradeoffs of alternative management strategies. Walters and Holling (1990) temper the potential concern about introducing more information about risks and uncertainty into decision-making by sharing their finding that uncertainty can be high as long as acceptability is high. Thus, where stakeholders are informed about tradeoffs and uncertainty, they may continue to support management activity if the end-goal is of value to them.

Finally, a discussion of the applicability of monitoring science to decision-making must include a review of various methods of communication. Among scientists, findings from adaptive management are often presented in peer-reviewed literature, conferences, or through publication of gray literature. Where monitoring scientists can provide recommendations, their reports will demonstrate the utility of monitoring in guiding decisions. However, findings and recommendations should be tied to timing and needs of managers (Margerum 1997). Early results that indicate failures of current management to meet objectives should be given to decision-makers as soon as they are available (Hockings et al. 2006). Venues for bringing monitoring results to decision processes involve offering consultation with managers (Margerum 1997), participating in management decisions as a board or committee member (Margerum 1997, Broberg 2003), review of management plans (Margerum 1997, Broberg 2003, Hockings et al. 2006), testifying at public hearings (Broberg 2003), and education of staff and planning boards (Broberg 2003).

Applications of adaptive management to program areas

Adaptive management can be applied to each area of management to discern the impacts on natural elements. Adaptive management as applied to land use planning, grazing management, floodplain delineation, or recreation areas will have different objectives, information constraints, possible activities, impacts, and relationships. Monitoring designers can tailor an adaptive management program to each program area, considering these constraints and what each program area truly needs in terms of geographic scale of data, coarseness of information, and possible management actions. For example, in which program areas might active adaptive management be possible and what might it look like?

Recommendations for HCPs

Habitat Conservation Plans (HCPs) involve a somewhat predictable set of goals, objectives, constraints, and management actions. Goals for HCPs often include recovery or viability of species and intact functioning of ecosystems (ecosystem health). Common measures to minimize and mitigate the effects of take include acquisition of habitat (procurement of conservation easements, land acquisition at other sites) and management of habitat (translocation of animals off-site, habitat restoration, removal of exotic species, and provision of funds to support research on the species).

For many HCPs, insufficient data are available to support the actions recommended in the plans. James (1999) suggests that unless substantial flexibility is built into an HCP, a permit issuance would be inappropriate before the necessary data are procured. However, given the importance of identifying uncertainty and risk in adaptive management processes, flexibility may not as applicable as is precaution. When information important to the design of the HCP does not exist, higher levels of mitigation might be required. Management and monitoring in HCPs should be designed to provide new information that can be used to inform future management decisions. Flexibility in mitigation designs allows managers to be responsive to results of monitoring.

Quantitative estimates of proposed take are what allow subsequent evaluations of the HCP in terms of actual take, the effects of take on the focal population, and whether the HCP's implementation did in fact reduce prospects for the recovery of species. FWS 1999 addendum to HCP handbook requires the linking of the monitoring program to an adaptive management strategy in cases where mitigation methods have not been thoroughly tested. Thus, HCP managers must improve linkages between monitoring and the evaluation of success of HCP (James, 1999). This challenge will require consideration of all of the aforementioned elements.

Challenges

Scientific

Tear et al. (2005) include in their discussion about setting conservation objectives a comment on the current gaps in knowledge that limit our ability to set effective management objectives. The authors identify two gaps in ecological knowledge: information about species distributions and understanding of large-scale, long-term ecosystem dynamics, which are critical for setting conservation objectives. By starting with limited information about system components, large-scale questions that encompass multiple species and habitats are difficult to address (Trexler and Busch 2003). Natural variability and management induced changes are difficult to separate (Jassby 1998). Instead, a piecemeal approach is often required to build a basic knowledge of ecosystem interactions.

Survey design must be capable of detecting an impact on the system with adequate statistical power (Legg and Nagy 2006). However, monitoring information is often unable to meet stated project objectives, since it is difficult to detect ecologically significant changes.

While monitoring and management of ecosystems should take place at large scales so as to incorporate a wider extent of variability, scale presents its own set of management issues. When information is aggregated from across large scales, processes at larger or smaller scales than that of the monitoring sample may lead to conflated effects (Walters and Holling 1990; Schreiber et al. 2004). Temporal variability is also an important factor when evaluating results from a large-scale management experiment. Time-treatment interactions can conflate causality, in addition to response lags that are often inherent in natural processes (Holling 1986; Walters and Holling 1990). Thus, while many authors praise the benefits of large-scale management, significant challenges remain for evaluating data from large-scale monitoring efforts.

Institutional

Adaptive management has been more influential in theory than in practice (Lee 1999). Lee (1999) suggests that the lack of collaborative structures in place before experimentation with management often leads to irretractable conflicts. When creating structure for the long term, consider how to maintain experimentation and information flow, as well as how to continue the integration of findings with management actions (Walters and Holling 1990). Hockings et al. (2006) report identified the need for commitments by landowners to change management in support of integrating monitoring with management. Furthermore, inherent rigidity in management institutions often limits the management flexibility required for successful adaptive management. Often, decision-makers rely on the status quo to avoid conflicts that come with trying to make a change, despite the fact that the uncertainty of status quo outcomes may lead to future failure (Walters et al. 1997).

The cost of maintaining a long-term adaptive management program can be prohibitive, especially when decision-makers and the public are not well informed about the values of long-term monitoring and evaluation (Walters et al. 1997). Scientists may pursue research that is intriguing or intellectually difficult, rather than focusing on management needs (Cullen 1990). Often, adaptive management requires high-cost sampling methods, which are difficult to maintain (Walters and Holling 1990). Additionally, adaptive management findings can only influence management where management capacity exists (i.e. knowledge, skills, money, time, and equipment; Hockings et al. 2006).

The issue of scale in managing information from across large scales applies to institutional settings as well as scientific processes. The scales of management decision-making will dictate the usefulness of data in adaptive management processes (Haney and Power 1996). Where data is unavailable at large enough or small enough scales, recommendations may not be applicable to existing decision processes.

Case studies

What follows is a synthesis of lessons learned from case studies from around the U.S. that have employed adaptive management methods. Lessons learned from this review will inform ways for Pima County to form their own framework for integrating adaptive management activities into the Pima County EMP. This work will lead to a solid foundation for future communication of monitoring information both within the county and ultimately to a wider set of stakeholders.

The programs analyzed vary in size, scope, and levels of success in implementing adaptive management approaches. The first section provides brief summaries of single management areas using an adaptive management approach. This is followed by summaries of the surveyed regional ecosystem management programs attempting adaptive management, and a synthesis of findings from both.

Adaptive Monitoring

The Northwest Forest Plan forced regional mangers to look at the northern spotted owl, old-growth forests, and watershed effects on fishes at a larger scale than previous single-agency management plans had (Ringold et al 1999). Regional ecological objectives were set in a linked hierarchy of goals set at different management levels, and monitoring, reporting, and evaluation were envisioned to occur at a regional extent. The design of the monitoring and evaluation was to assist in observing and managing features on a regional scale.

Lessons learned: Monitoring design is an adaptive process, to be changed with increasing understanding of system. This provides opportunities for feedback between managers (information users) and the monitoring program (information producers) to identify what information is truly useful. Successful programs will define a monitoring program in terms of large elements through goal-setting and then refine objectives to be quantitative and about particular features to be measured. Refinement of objectives means translating policy goals and thus must include some interaction between scientists and public policy process. Objectives need to be compared with management priorities iteratively.

The challenges of an integrated regional monitoring approach include a lack of consistent measurement methods (making integration of data challenging) and a lack of information about the variability of environmental features and measurement error. While there are needs to obtain information about both local level and regional level natural processes, information from one scale cannot easily be extrapolated to the other. Thus, a tradeoff emerged between supporting local monitoring, which would provide information about project effects, versus pursuing regional monitoring, which can provide information about aggregate effects of multiple actions across the system.

Grazing management as adaptive management

[las Cienegas discussion]

River restoration as adaptive management

O'Donnell and Galat (2008) assessed river enhancement projects (project-level) for adaptive management criteria, including setting of goals, monitoring, evaluation of monitoring data, and data dissemination. The researchers used a survey method, selecting a sample of projects to survey from a pre-gathered database of enhancement projects, to gather more information than is available in published project documents. Some projects set goals, using success criteria based on the expected results from management actions. While implementation monitoring shows that project activities were completed, it does not demonstrate success or effectiveness. Funding cycles often restrict long-term planning and require an advocate that keeps objectives in mind. A lack of decision support systems and historic reference data or just a general lack of technical expertise may limit managers choices of explicit objectives (see Kondolf and Micheli 1995; Reeve et al 2006). Many projects did not set biologic criteria but monitored biological elements, and then had no basis for determining success. Also, when projects do not determine inherent variability in ecosystem through use of reference or control and before and after monitoring (BACI), project managers can only determine post-project trends and not assess effects of management on biologic communities.

Hughes et al (2005) and Rogers and Biggs (1999) provide additional support for methods needed when assessing project effectiveness. These authors recommend setting up a control site or sites, but warn managers that a true control site must reflect similar sources of change or degradation as project sites. If managers monitor community elements, but not the biological community, they may miss the inherent biological variability (Hilderbrand et al 2005). A lack of project documentation and accessible reports inhibits adaptive management. Hypothesis testing requires systematically planned projects, where managers quantify the expected effects that indicate success, and implement appropriate monitoring plans to evaluate such effects.

Land use planning as adaptive management

Several authors have considered the use of existing biodiversity data in guiding land use policies. Washington State's critical area ordinance policy guides a scientific review of peer reviewed literature, local monitoring, agency literature, and expert opinion for use in designating critical areas (Francis et al 2005). Larger jurisdictions were more likely to do a literature review, while medium jurisdictions were guided more by policy review than science. Small towns tended to rely on the state models, which incorporated several types of information. Where limited funding and/or limited scientific expertise existed, planners relied on state-provided information. Where planners had limited familiarity with agency data or peer-reviewed literature, they tended to rely on local data and be guided by the political process.

Cort (1996) reviewed the use of Natural Heritage data in land use planning in over 30 states in the U.S. The author found that state-mandated use of biodiversity data in comprehensive plans and state-funded natural areas inventories can lead to more frequent use of biodiversity data in local land-use planning. Among surveyed states, biodiversity data was used most often for state environmental reviews of proposed projects or state land-management planning. However, biodiversity data is used least often in local government comprehensive planning. The authors state two causes for this observation: 1) state comprehensive planning systems often lack requirements for biodiversity conservation, and 2) biodiversity data are used more frequently for local review of proposed projects than for comprehensive planning. Providing natural element data in Geographic Information Systems (GIS) was cited as a step to ensuring more effective data use in local planning. While these studies help inform managers about the regulatory and political context involved in applying biodiversity information to planning processes, a question remains about how the policies and strategies of land-use planning can be measured for effectiveness at meeting conservation goals.

Where they exist, monitoring programs set up by land managers are rarely robust, often ignoring whole subsets of management actions and ecosystem responses. Land use practices and policies can be considered a set of management hypotheses, which can be tested with the use of monitoring information and geographic information systems (GIS). Through an adaptive management approach, planners can facilitate collective learning about causal relationships between human activities and impacts to ecosystems and determine whether current policies are effective at achieving management goals. Using the foundational information from monitoring data and GIS systems, planners can adopt an adaptive approach to analyzing historical land use patterns, making current development decisions, and planning for the future.

Applying these elements to land use planning requires defining the elements in terms of urbanization and development regulations. Land use activities have widely varying impacts on rural and natural landscapes (Theobald et al., 2005). Land use activities primarily impact natural resources at the urban fringe, where urban areas and natural landscapes meet. Theobald et al. (2005) describes both the traditional regulatory practices of land use planning, such as zoning and land use ordinances, and incentive-based land use tools, such as easements, transfer of development rights, and cluster developments as potential subjects for evaluation regarding their ecological consequences. These management strategies are the hypotheses that can be tested in their real-world applications by establishing a set of goals and criteria and collecting monitoring information. Goals can be associated with relevant, measurable criteria for development footprints, landscape condition, context, and quantities of land in open space. Additionally, criteria for the pace of development or indices describing the proportion of an area recently developed could inform planners about the disturbance impacts occurring in their region.

If a planner identifies the need for changes in management strategies, there exist several venues in which to apply new policies. In land use planning, policies and practices are considered on an individual basis when new development is proposed (development review) and on a comprehensive basis when plan revisions are made in the master planning process (Duerkson et al., 1997; Theobald et al., 2000). Traditional land use planning policies can be considered in comparison with innovative approaches from sustainable development. For the purpose of considering alternative management strategies at both site-specific and landscape scales of review, simulation forecasting may be useful. Simulation forecasting involves the evaluation of the future effects of a set of management regulations and environmental and social conditions. This provides a planner with a method for considering the hypothetical outcomes of multiple strategies. This approach has been used in several instances to consider the future impacts of potential land use policies on biodiversity and natural processes over time (Hulse et al., 2004; Merelender et al., 2005).

As part of a larger adaptive management program, monitoring information should be collected about a suite of management actions and natural system responses. Once information about relationships between management actions and landscape indicators has been gleaned, managers can incorporate the information back into the land use planning processes to complete the adaptive management loop. First, analysts could complete a historical review of management practices, development patterns and indicators over time (Odell et al, 2003). This can help determine recent trends in the various criteria. If results indicate a particular area is approaching a threshold, current land use policies could be reconsidered. For example, if past traditional site level guidelines have aggregated to produce a negative landscape scale pattern, the site level guidelines could be revised and reconsidered in an alternative futures exercise. Second, planners could be given tools to review potential projects as they come up for rezonings. During development review, a planner could use GIS to assess the current status of an indicator and a new development's contribution to meeting the criteria for achieving the stated goals. Then, if the development will not lead to diminished status of the indicator, the planner might recommend it for approval. Finally, as part of preparations for future plan revisions, innovative land use management strategies can be assessed as part of an alternative futures analysis.

Large-scale species management as adaptive management

Implementation of an adaptive management framework for the waterfowl harvest management in North America began in 1995 (Johnson and Williams 1999). Annual harvest policies are developed using a decision process that explicitly accounts for natural variation, harvest actions, and waterfowl population dynamics. These policies are adopted as hunting regulations by U.S. states. This management program uses a model of waterfowl population dynamics that includes not only population variability, but the impacts of management activities as well. While there remains great uncertainty in this model, because it applies to a continental range of migrating animals, biologists are equipped with a statistical decision process that provides them an opportunity to learn from each decision. Biologists collect data about the harvest activities and the population characteristics of each year. Using information from previous years as a baseline, they attempt to determine causal relationships between management and population responses. The knowledge gained through iterative model-building is shared with decision-makers, who incorporate it into their political decision process.

The benefit of applying adaptive management to this system is the extensive funding support that comes in from the booming hunting industry. Additionally, after more than

70 years of management, this process has emerged. Thus, the common limitations of funding and of institutional knowledge do not constrain waterfowl biologists.

Regional ecosystem management as adaptive management

Case study of CA Natural Community Conservation Planning Act and Program: Regional conservation efforts are hindered by limited conflict-resolution capacity in local governments and large number of private landowners. Focusing on the community-level conservation needs (as opposed to species-specific efforts), this program seeks to use state and federal coordination of planning, guidelines for conservation plans, smaller subregion planning efforts, and a scientific review panel to augment the basic conservation planning process. Though it is a voluntary process, pairing of the program with federal ES protection provided an incentive for participation. Guidelines establish objectives and serve as a basis within which local actions can be reviewed and modified, while providing some flexibility for various approaches. Guidelines incorporate concerns about depletion of the diversity of habitats, need for connectivity, the need for ongoing research to understand remaining habitat. Guidelines include preservation goals for existing habitat due to lack of information about minimal habitat requirements for target species. Discuss methods of managing the planning processes across a region, during the time when information is limited (e.g. interim loss limit) and as more information is gained. Authors recognize the great need for scientific information as a foundation for regional planning. Reid and Murphy 1995 Bioscience

The ecosystem management programs analyzed here include the San Diego MultiSpecies Conservation Program (SDMSCP), Clark County Multiple Species Habitat Conservation Program (CCMSHCP), Travis County's Balcones Canyonlands Conservation Program (BCCP), and the Lake Tahoe Regional Planning Agency (LTRPA). Each program has a particular set of goals and activities, but managers in every program are faced with a legal mandate of maintaining and protecting ecosystem components in regions of intense human activity. Three of the programs comply with Endangered Species Act (ESA) requirements (Section 10a) and one is the product of a congressional mandate and interstate compact to address degraded ecosystem health. The programs were investigated through review of program management plans, program reports, peer-reviewed studies, and interviews with program managers.

Methods

These programs were chosen because they were being implemented at the county level, involved endangered species concerns, and monitoring had been going on for more than 5 years. Also, the MSCPs were chosen as opposed to single species plans for concurrence with the Pima County monitoring and adaptive management situation.

A series of questions was developed based on the elements identified in the literature synthesis and based on issues of importance for Pima County managers. The refined survey questions included open-ended and closed-ended questions about program details, the design of the monitoring and adaptive management program, the evaluation of monitoring results, and the use of monitoring information. Surveys were recorded and entered into a database for summary and evaluation. The results of the analysis are as follows.

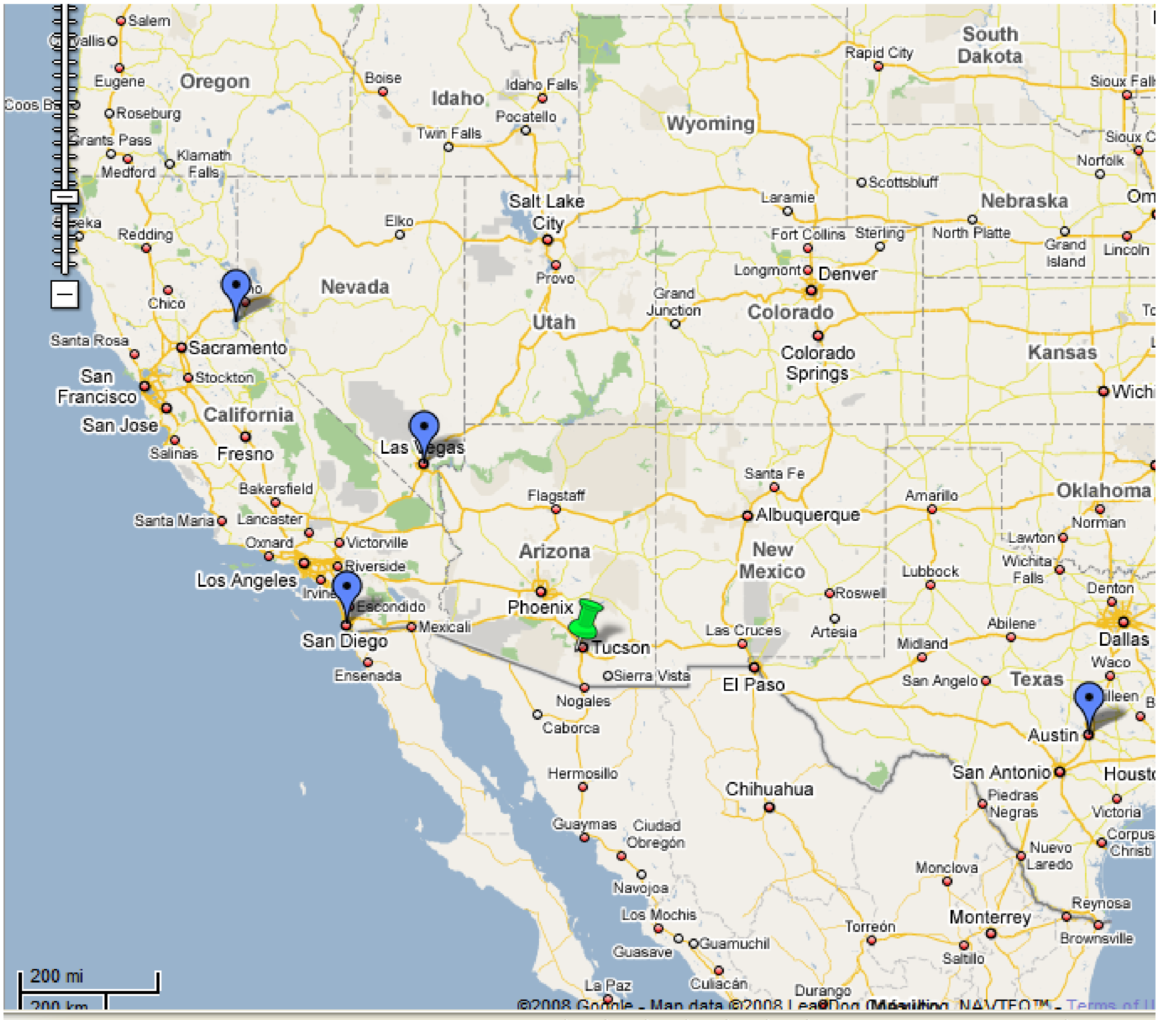

Figure 2. Case study locations.

I. Balcones Canyonlands – Plan goals; Plan administration

The Balcones Canyonlands Conservation Plan (BCCP) is a 30 year regional permit (approved in 1996) that allows for incidental take outside of proposed preserve lands, and provides mitigation for new public schools, roads and infrastructure projects of the participating agencies (Travis County, the City of Austin, and the Lower Colorado River Authority). The 30,428 acre BCCP preserve system is to be managed to permanently conserve and facilitate the recovery of the populations of target endangered species. The objective of the Plan is to improve target species habitat with preserve management activities, while protecting preserves against degradation caused by urbanization and recreation usage.

The preserve consists of private, county, and city lands, with most private lands being eligible for an ITP under the permit. County and city staff perform monitoring and management activities on the preserve lands. Annual costs for the county preserve management program range between $561,000 and $637,500, which supports 8 FTE.

Funding for the program management activities is provided by a $22M bond issue, by the purchase of participation certificates by private landholders, who receive sub-permittee status in return, and by federal, state and local grants.

Intro Summary

The BCCP plan provides a foundation for assessing covered species status and trend, which serves the short-term Plan goals and site-level preserve management and land acquisition strategies. However, the lack of requirements in the Plan for assessing management activities or details about monitoring population viability have left managers to fend for themselves. After a decade of monitoring, managers shared their data with university researchers, who identified a series of gaps in their monitoring strategy that left them unable to determine causal relationships between management and monitoring observations. Thus, instead of addressing program goals from the beginning, or having a structure in place for implementing more-complex monitoring in later years, the Plan elements left the work of adaptive management up to future managers. Unfortunately, given the limited funding of the management program, this has led them to rely heavily on university researchers to assist them in developing appropriate monitoring strategies.

Goals for monitoring and AM; Plan for AM

The goal of monitoring for the BCCP is to determine the status of each listed endangered species; the long-term goal is monitoring for endangered species viability. According to the Plan, data is to be analyzed to show the extent and condition of covered species and identify causal relationships between human activities and indicators. Land management activities are to be documented in annual reports.

Managers were involved in design of monitoring by posing questions during consultation with biological advisory team (1992-1996). Monitoring is planned for natural communities, plants, springs, birds, and cave invertebrates to identify baseline conditions. Future monitoring is intended to inform managers about the status of each species or habitat.

Species population viability estimates were made for the reserve lands based on initial species models used in reserve design. Predictions of land disturbance (habitat loss) were also made in the initial Plan. Baseline data has been collected on all lands, and previous studies on preserve lands were compiled to define existing knowledge.

On county preserve lands, public access is limited due to the recognition that the limited staff resources cannot manage the impacts associated with access.

Analysis of AM elements in Plans

Monitoring guidelines in the initial Plan are broad, with measurable objectives well-linked to species population viability, but lacking detailed guidelines for assessing effects of the management program. In the subsequent land management plans, species-specific monitoring methods are identified and linked to general management questions. Potential management responses are identified as management guidelines in the Plan and in land management plan guidelines, but are not linked to any analysis methods or standards for evaluating monitoring results. The conceptual models of species distribution used in designing the preserve do not currently incorporate management pressures. Since management activities are not included in monitoring and evaluation of management effectiveness is not detailed, important elements of effectiveness monitoring are missing. Thus, progress towards the goal of identifying causal relationships cannot be measured based on planned monitoring elements.

Methods for analyzing data are not explicitly detailed in the Plan, but the BCP land management plan emphasizes the collection of baseline data for understanding existing population status. This provides a foundation for the short-term and long-term goals of the monitoring program.

Management guidelines in the Plan focus on the potential conflicts between management activities for the two covered bird species, such as prescribed fire activities that create habitat for one species resulting in take of habitat for the other species. The management guidelines are not prioritized in any way within the Plan or the land management plan guidelines.

The Plan identifies a somewhat precautionary approach for managing public access, wherein demonstration of effective management strategies on a preserve may result in increased public access. However, due to the emphasis within the plans on monitoring objectives and methods for assessing population status, managers have little guidance for meeting other monitoring goals: determining species population viability or effectiveness of management actions. Thus, efforts to provide reliable evidence in support of increased access will be inherently limited.

Monitoring results

Monitoring results are reported annually through annual reports, available on the website and provided specifically to FWS scientists, and to public officials in the form of executive summary. Annual reports as defined in the Plan are to track measures of compliance with land management plans and summaries of monitoring efforts. The baseline data is used for evaluating monitoring data for each plot or site to determine general trends. Monitoring results have showed stable or positive trends for most species.

A Coordinating Committee has been convened semi-quarterly with representatives from the city, county, and FWS. This committee reviews results and considers management activities in response. The Scientific Advisory Committee and Citizens Advisory Committees support the Coordinating Committee. The land management subcommittee meets periodically to discuss management activities, share results, and update the BCP Land management Plan.

Monitoring results have led to increases in local knowledge as it relates to preserve management. Managers learned through analysis of monitoring results that birds move into the preserve when neighboring land is developed. This evidence supports the assessment of adjacent development as an important threat to species viability.

Other monitoring information has been useful in preserve management, adaptive monitoring, and land acquisition. Oak wilt monitoring has aided in early detection of disease. Land condition trend analysis has identified invasions by exotic species. Karst biological indicators showed declines, which were then investigated to determine the cause. Habitat monitoring has been used to identify successful restoration and protection techniques. Ten years of monitoring data were used to evaluate and revise monitoring protocols. Distribution information was useful in guiding land acquisition efforts.

Analysis of AM elements in evaluation of results

Processes

A coordinating committee of managers from the covered entities meets to discuss results and review management tactics. No formal process is used to evaluate management priorities or connect monitoring results with next steps, which interviewees attribute to limited staff availability for management and monitoring. The interview subject suggested that they would benefit from having a senior biologist on staff or contracted to review and interpret the data.

Evaluation Elements

Reports on species status and trend are provided annually to the coordinating committee and advisory committees. Monitoring information has not been used to track management effectiveness or measure species viability, both goals defined in the Plan. This level of evaluation has been constrained by a lack of monitoring activity to provide information about management implementation. Also, methods for identifying species viability were not identified in the initial Plan, leaving managers to address this gap.

Case-by-case application of monitoring data to decision making has been the most common evaluation method. The interview subject reported that due to the data collection methods, information can not be clearly extrapolated to other sites.

Bird banding studies have contributed some information to understanding of population viability. However, given the goal of managing for population viability, the lack of methods for assessing viability within the monitoring program has led managers to fall short in tracking effectiveness in this area.

Analysis of AM elements in use of results

Processes

While the interview subject reported that the coordinating committees were useful in sharing information and revising land management plans, no formal decision process was described that would give the participants regulatory authority over one another.

Use of results

A formal decision approach has not been followed to select management responses, as far as can be determined from published documents and interview responses. However, preserve management activities were reported as influenced and guided by monitoring information. Oak wilt monitoring aided in early detection of disease for use in preserve management. Identification of invasive species locations led to invasive species removal efforts. Habitat monitoring was used to identify successful restoration and protection techniques. Thus, in the area of restoration, lessons learned at one site could be applied elsewhere.

Species distribution information and anecdotal evidence of impacts have been useful in guiding land acquisition processes.

Causal relationships were identified with the use of monitoring data, but not through rigorous monitoring of management and natural elements. Karst monitoring data indicated biological declines, the cause of which turned out to be development water interception and raccoon prevalence. This led to development regulations and revised flood management techniques.

Trail impacts were discovered through the analysis of prime plot data (nest territories), and have led to limits on trail access in past. The city is currently struggling to maintain sufficient protection for covered species from recreation impacts, due to increasing pressure for public access onto preserves. This departs from the intent of the original Plan to allow access only where management has been effective.

Bird data confirms use of habitat (updates to species models) and is being expanded to determine whether original population estimates are appropriate management objectives. Ten years of monitoring data have been used by university researchers to evaluate and revise monitoring protocols for the city and county. Updates to monitoring design may include methods for assessing management effectiveness. Additionally, implementation of point-transects concurrently with existing monitoring methods is intended to help identify the most efficient and informative monitoring strategy. Review of a decade of data revealed that most plot data was insufficient for extrapolation across the range. However, interviewees indicated that an earlier trend analysis (after 5 years) might have resolved some monitoring inefficiencies sooner, and allowed managers to make better decisions about allocation of resources between monitoring and management.

Lessons learned

The BCCP program managers cited several areas of their monitoring program that are being updated, and several lessons learned from attempting adaptive management in a very species-specific management program. The County program manager recommended that managers in other programs should identify management questions to be answered through monitoring and research. They also recommended that other programs complete a review of the appropriateness of monitoring methods after a few years of data have been collected to determine whether methods are efficient and/or informative. Given the outcome of their monitoring review, the managers surveyed indicated that their monitoring results had occasionally been used for purposes other than that which they were intended, leading them to wonder about the credibility of management decisions based on such information. The program manager recommended the use of university/scientists to read published literature, design studies, and inform managers about the meaning of monitoring results. The manager also indicated that their program barely had enough funds to do the minimum required monitoring and management. Finally, they suggested that managers in other programs should coordinate monitoring data collection with land management partners, to standardize data collection forms and equipment. This would make summarizing results across the management area more straightforward.

II. Clark County summary – Plan goals; Plan administration

The Clark County Multiple Species Habitat Conservation Plan (MSHCP) is a 30 year regional permit (approved in 2001) that allows for incidental take on private and county lands, while providing mitigation on 2,961,538 acres of federal and state lands and county and private easements. The habitat goal of the Clark County Multiple Species Habitat Conservation Plan (MSHCP) for each covered species is no net unmitigated loss or fragmentation of habitat, within the plan's conservation reserve, which consists primarily of Federal and State lands. In addition, the MSHCP has a general species-oriented goal of stable or increasing populations of covered species.

County control over implementation of the Clark County MSHCP is limited by the small extent of county lands available for mitigation. While the MSHCP covers 5,000,000 acres of Clark County, the MSHCP reserve design is primarily comprised of federal and state lands, which have diverse mandates and are managed according to each agency's management plans. The MSHCP reserve defines management areas that will provide core habitat (Intensively Managed Areas) and corridors/connectivity (Less Intensively Managed Areas and Multiple Use Management Areas) deemed consistent with the needs of species conservation. Monitoring and implementation are accomplished through contracts with individual federal and state land managers, wherein Clark County sets the basic requirements for monitoring and management activities necessary to meet the goals of the MSHCP. Funding from development impact fees ($550/acre) has been sufficient to support program administration, resulting in a minimum of $2,000,000 annually.

Intro Summary

The Clark County Multiple Species Habitat Conservation program is in the stage of pilot testing long-term monitoring and resolving mgt uncertainties. Little quantitative evaluation or adaptive management has occurred. Monitoring results have been reported since 1999, but as monitoring has been targeted at specific issues, little ecosystem-wide data was gathered. This may be due to the fact that the plan for monitoring and adaptive management in guiding documents was vague and did not link monitoring activities with analysis and evaluation tasks necessary to define progress towards goals.

Progress towards the first goal, net habitat loss, has not been documented. Monitoring information about populations (the second goal) has been poorly-described and has shown some decreasing trends, e.g. desert tortoise. Additionally, the County has had limited access to detailed information about monitoring methods or, until 2007, raw data or results. Generally, monitoring results reported to the county have described animal and plant population trends, habitat condition and total habitat losses. These results have been used to improve preserve management through measures of restoration effectiveness, but have been limited in their applicability of habitat trends system-wide and overall program effectiveness.

Goals for monitoring and AM; Plan for AM

Adaptive management goals set forth in the MSHCP include tracking habitat loss by ecosystem, tracking the balance of take and conservation, tracking population trends and ecosystem health, and evaluating effectiveness of conservation strategies (management actions). Additionally, the Adaptive Management Program (AMP) is to evaluate the effectiveness of inventory, monitoring, and research based on results. To accomplish these tasks, the AMP is directed in the Plan to set quantifiable objectives, identify stressors, construct conceptual models incorporating natural variation, identify indicator species, develop sampling design, and set thresholds to trigger management responses. Additionally, an adaptive management decision making framework is described.

Analysis of AM elements in Plans

While the Plan does identify many of the important steps in creating an effective adaptive management program, monitoring guidelines in the initial plan and in implementing agreement agency contracts are broad, lacking measurable objectives, detailed guidelines for assessing ecosystem health, or standards for reporting.

Specific measurable objectives have since been identified in several site- or species group-specific management plans, created in the last 2 years. The MSHCP did not include any ecological thresholds or descriptions of natural variation for species populations or habitat values for use in evaluation of monitoring results. The initial Plan and subsequent management plans only provide broad goals for monitoring and predictions of habitat loss due to land disturbance over the extent of the permit.

While the MSHCP document lists potential conservation actions to respond to threats and stressors, these actions are general and require additional refinement in order to be implemented. The county program manager indicated that in her opinion no management responses had been defined.

Baseline data has been collected for some monitoring elements, starting as early as 1999. Uncertainty is recognized in one plan, but not quantified. Conceptual models were developed to identify species distribution in early stages of the MSHCP process, but these have not been linked to management questions and do not incorporate possible management pressures.

Use of management questions and priorities in monitoring design

The ability of Clark County to do adaptive management has also been limited by a lack of early preparation and groundwork for a holistic monitoring and evaluation program. The Plan did not set management priorities based on covered species, but identified ongoing implementing agency actions to support and monitor as part of the MSHCP. This led to the formation of site- and issue-specific monitoring and management programs that have not been easy to conglomerate into an overall assessment of ecosystem health. As described by the program manager, “Our funding process as described in the plan starts with implementing agreement agency proposals, rather than clear articulation of current MSHCP priorities.”

Monitoring results

Rare plants, sediment transport, disease, restoration project implementation, and habitat loss and disturbance have all been monitored. To date, only species population distribution and habitat trends have been reported. The most recent adaptive management report (2006) identified next steps for information gathering and development of evaluation methods for addressing adaptive management tasks.

Some covered species populations, e.g. desert tortoise, have shown declining trends. The interview subject indicated that results of species population monitoring had been compared with baseline species data, and species population trends had been described and extrapolated distribution-wide.

While county staff has little information about the certainty of status and trend information (due to lack of metadata reporting), plant and animal distribution status has been useful to the county to direct weed management, habitat and disturbance restoration, law enforcement, public education, tortoise fencing and inform other county departments. Other county departments have used the species distribution information in review of land designations, land uses, comprehensive plans/zoning, and in public meetings or NEPA comments.

Recent sampling of long term monitoring plots in retired grazing areas managed by BLM indicated no major change had occurred, which the subject indicated was a common feature of desert restoration projects.

Results have indicated that land disturbance/development is happening at a somewhat faster pace than anticipated in the initial Plan. Disease monitoring results were used in mesquite restoration activities, funded by Section 10 grants. Discovery of natural resources, such as springs, has led to exclosure fencing.

Recommendations based on monitoring results have been general (e.g., suggesting the need for weed control or habitat restoration) or have been utilized within partner agencies without reporting either to the county or to the public.

Research studies and monitoring results have informed federal land managers about the effectiveness of restoration and conservation techniques. Implementation of restoration actions has been tracked according to acres restored from recreation or fire disturbances. Informal assessments of biological conditions of previously restored sites provided information to BLM and NPS managers about the most effective recreation management actions, which are then applied elsewhere. Additionally, research studies on NPS restoration sites indicate the importance of soils on a site to determine the potential of site recovery.

Other research studies, e.g. on gypsum-associated vegetation community pollinators, have indicated that non-covered lands and neighboring vegetation types are critical for preserving important ecotones and habitats.

Analysis of AM elements in evaluation of results

Processes

A lack of decision structure for evaluating results has led to informal evaluations of weed invasions, restoration effectiveness, and other management strategies. While some research has been done in these areas, most of the described activities have been ad hoc and poorly documented. Additionally, distribution information from monitoring data has been used in many processes, despite the lack of metadata about monitoring results.

Evaluation elements

Monitoring information has not been formally used to track habitat loss by ecosystem, assess ecosystem health, or track conservation effectiveness due to various limitations. The ability of Clark County to do adaptive management has been partly limited by their minimal control over lands and their limited access to details about monitoring methods and spatial results. Despite receiving annual summary reports, the county has had little confidence doing evaluations of results as they do not have information about standard error of the results or the natural variability of the natural system. The lack of access to spatial data has prevented the county from performing analyses of geographical priorities or objectives. The county AM program manager related that monitoring and evaluation was done on a case-by-case, issue-by-issue basis, and thus had been inadequate for use in evaluating overall program effectiveness or assessing ecosystem health. Studies funded by federal agencies have helped increase knowledge about the system.

The AMP has been unable to complete most of its assigned adaptive management tasks to date. Due to the lack of spatial information, county managers have been unable to track habitat loss by ecosystem. Results reported from land disturbance monitoring were not compared with predictions of land disturbance (take) from the original Plan in any recent reports. The broad goal of ecosystem health was never clearly defined, thus limiting the ability of reporting agencies to describe its current condition or trend. Since no reports have been issued since the recent establishment of measurable objectives, future reporting will demonstrate the utility of recently-defined objectives in evaluating monitoring data.

Implementing agencies have performed some restoration effectiveness monitoring, which has assisted them in finding the most effective disturbance restoration strategies (e.g. burned area rehabilitation) and prioritizing potential restoration areas. NPS subject indicated that due to lack of control sites, their knowledge about restoration techniques is truly through trial-and-error. However, research efforts have been done on restoration monitoring results from other lands to identify the most effective techniques.

Because of problems with the plan for evaluating effectiveness and the lack of standards for reporting, effectiveness monitoring and evaluation has not occurred. Management activities beyond restoration actions are not currently monitored and reported spatially, leaving little room for linking observed patterns with management inputs. Due to the lack of system-wide effectiveness monitoring, there is no current information about how much mitigation has been successful, according to the 2006 AM report. Thus progress towards the goal of balancing take and conservation cannot be assessed.

Reporting of results from contractors

Due to the reliance on contracted monitoring projects to identify progress towards program goals, the program manager identified a need for standardization in data collection and reporting, to enable her to assess conditions system-wide. The need to conglomerate results across system is being addressed in current revisions being made to the monitoring and reporting program. This process addresses the Plan requirement that the AMP be made more efficient and effective as the program progresses.

Level of detail in plan for evaluation in monitoring design

The MSHCP and supporting area-specific documents include a number of basic features necessary for setting up and implementing adaptive management, such as setting biological goals, identifying evaluation tasks, and even creating measurable objectives in recent plans. Many important elements of AM were identified in the Plan for later development and implementation. However, much of the detail needed for measurable threshold setting was not done in the MSHCP development. Specific measurable objectives or thresholds were poorly developed, no linkages were made between objectives and potential management responses, and species conceptual models lacked information about management hypotheses in early documents. These things have limited use of monitoring results in identifying the effectiveness of management activities beyond restoration actions. The AMP is just now beginning to flesh out these important processes for analyses, due to a lot of time spent "searching for indicator species and assisting FWS with improvements to monitoring methods."

As part of studies done in partnership with universities and with NPS, the County has modified rare plant monitoring, and the new monitoring design will be intended to resolve uncertainties in the conceptual models that predict species distribution. Bird monitoring designs will also be reconsidered this year to identify more effective methods.

Additionally, the lack of standards for reporting and standardizing data from the various management agencies has limited their ability to meet even basic program goals, such as tracking habitat loss by ecosystem. Thus, a very large program, with many lands to manage, has found itself unable to meet some of the most basic requirements of documentation and evaluation.

Analysis of AM elements in use of results

Processes

The Clark County program manager did not identify any formal collaborative processes used to share information or coordinate activities.

Use of results

Plant and animal distribution status has been useful to the county in preserve management activities. Species distribution information has also been used in planning processes both at the site level and county-wide. In addition, the county program manager indicated that providing reports of monies spent on implementation has been useful in demonstrating activity and garnering support for future actions.

While management activities on state and federal lands have been modified due to monitoring results, the county program manager was unable to report these outcomes due to a lack of awareness of internal decisions and processes within the federal agencies. Conversations with Bureau of Land Management (BLM) staff revealed that restoration effectiveness monitoring had been used to select the most successful recreation management techniques, and ecological site inventory monitoring assisted with range management. While some recreation disturbance restoration activities were completed, the need for law enforcement to manage disturbances is ill-met with current funding.

Monitoring has been useful to the National Park Service (NPS) to reaffirm their commitment to ORV management and funding. Also, NPS has used monitoring of impacts to increase public awareness. Additionally, the knowledge of plant and animal species distribution helped managers minimize and avoid impacts by directing activities (e.g. ORV) to low density or low value habitat.

Lessons learned

The first lesson that can be gleaned from a review of Clark County's MSHCP program is that planning for adaptive management means more than identifying the important elements. In particular, plans should set up predictions over time of habitat loss, species populations, or other elements for comparison against monitoring results. This, in combination with measurable objectives and/or well-defined goals, will lead to a program more capable of evaluating its effectiveness.

While conservation actions are reported on in terms of status of implementation, there is little information regarding the extent of implementation, and little spatial data is submitted, despite availability. Recent area-specific planning documents have emphasized the importance of the management and monitoring reports to, in the future, increase the detail included in update reports so that managing agencies may track the extent of implementation and spatial locations of current conservation efforts.

An important element of success in the Clark County program has been commitment from managers early and for the long term. Program managers also identified the importance of well defined adaptive management tasks and processes in planning documents, which should be prioritized based on what areas of management are most uncertain and need adaptive management. This would include specifying management questions and prioritizing actions based on things over which managers truly have control. The county manager recommended the use of models if possible to demonstrate inherent system variability (they recently made models a requirement of funding). Finally, plans should link thresholds or objectives to management responses. As suggested by a federal program manager, programs will do well if they prepare processes for addressing unforeseen circumstances

Managers recommended that other programs begin by setting up monitoring studies (with the help of scientists) to reduce Type I and Type II errors.

Surveyed managers emphasized the need to set out roles and responsibilities early on. This would include clear roles and responsibilities for each manager (e.g., HCP manager sets goals and defines needs; implementing partner agencies manage contributing actions).

To measure management effectiveness as a group of diverse managers, start with standardizing monitoring and reporting to meet effectiveness assessment needs. Then, as you identify management weaknesses, you can discuss ways to make change together. Additionally, partnerships are useful to identify uncertainties and document knowledge through collaborative discussion and documentation. This foundation can lead to ideas for research and management projects. Kickoff meetings should include discussion of reporting expectations

In settings where managers don't know much about ecosystem processes, they can't know which habitat components to protect. Thus, protection of the whole biotic community is necessary until more information is obtained, to achieve protection of "function". In other words, preserve connectivity while it still exists!

Managers need to manage entire habitat, not specific species (don't get obsessed with counting). Surveyed managers suggested programs should start with inventory, start looking at connections, and then do habitat management.

III. Lake Tahoe RPA Summary – Plan goals; Plan administration

Lake Tahoe Regional Plan covers 501 square miles of private, city, county, state, and federal FS lands, which includes 191 square miles of Lake Tahoe. Lake Tahoe is the dominant natural feature of the Basin, and lake clarity is the focal issue that initiated the environmental regulations in the Lake Tahoe Region. The lake is a stationary resource, which enables not only constituents to track it informally, but it allows tracking of causation from regional actions to lake conditions. The planning documents state, "everything we do to the land in the Lake Tahoe Basin can positively or adversely affect lake water clarity."

The Regional Plan is a continuation of the process initiated by the Compact, which identified the need to preserve and enhance the many values of the Basin. To address this need, the Tahoe Regional Planning Agency was created to establish and work toward the achievement of environmental thresholds within the context of a regional plan and corresponding code of ordinances.

The goal of the Plan is to achieve and maintain adopted environmental threshold carrying capacities while providing for orderly growth and development consistent with such capacities. Thresholds set the environmental standards for the Region and indirectly define the capacity of the Region to accommodate additional development. Environmental thresholds (carrying capacities) were identified before the Regional Plan, and serve as a basis and rationale for the Plan's regulations. Thresholds have been set for 9 categories of concern (Water Quality, Soil Conservation, Air Quality, Vegetation, Wildlife, Fisheries, Scenic Resources, Noise, Recreation), with quantitative (numerical standards) and/or qualitative (management standards) objectives set for each indicator. Environmental indicators are not directly linked to management activities, but the land use, transportation, conservation, recreation, and facilities elements in the Plan identify goals policies intended to attain and maintain the environmental thresholds.

The first Regional Plan was adopted in 1987, and monitoring has been conducted on the thresholds since 1986. Regional plans are to be revised every five years if needed, in the following areas: annual residential and commercial project allocations, development priorities, capital improvement program, enforcement, or funding. The TRPA has been updating the Plan with amendments since 1987, and this year marks the beginning of the first comprehensive revision to the Plan. The TRPA coordinates activities with state, county, and federal managers.

The TRPA monitoring and evaluation program is funded by USGS and a dedicated fund, as well as through other funding sources. Overall, annual funding for the program varies between $400,000 and $900,000.

Intro Summary

The Lake Tahoe Regional Planning Agency oversees a large monitoring and evaluation program that measures attainment of threshold standards for a wide variety of environmental and social variables. While the planning documents for this program identified critical environmental thresholds for important indicators to be monitored and evaluated regularly, they provided little description of the potential linkages between observed trends and management policies.

The existing program of reporting and analysis has enabled review of the overall ecosystem condition. Additionally, monitoring data has supported changes to regulations and funding in order to address potential management issues. However, overall program review based on monitoring information has been difficult due to lack of knowledge about causal connections between management and trends.

Goals for monitoring and AM; Plan for AM

The official goals and policies document states three goals for the RPA monitoring program: Evaluate progress toward attaining and maintaining the environmental thresholds. Improve understanding of cause-effect relationships for Lake Tahoe and the Lake Tahoe Region. Evaluate the environmental thresholds, the effectiveness of the regional plan, and the implementing ordinances and programs.

Monitoring is planned to occur for the threshold standards in each category, with individual protocols developed for each status indicator. Stressor indicators and environmental response indicators are both included in monitoring.

The goals and policies document identifies the fact that there is uncertainty about cause-effect relationships for various environmental components and suggests future study aimed to reduce uncertainty. The Plan also suggests that study results will help adjust reasonable progress lines. Furthermore, the Governing Body set standards for amending the pertinent environmental threshold standards where the scientific evidence and technical information support a change to make them more efficient and useful.

In the Plan, implementation reports are required every year or semi-annually. According to the Plan, the monitoring program will evaluate the results of its monitoring at least every five years.

Analysis of AM elements in Plans

The focal point of the plan and management is lake clarity. The initial documents identify the carrying capacities (or thresholds) for the region, and builds goals and policies from those. The objectives/thresholds are not explicitly set for particular lands, but rather are used as benchmarks for assessing indicator status across the Basin (or where it occurs). Setting quantitative thresholds is an important foundational method for evaluating achievement of overall goals. The wide range of threshold categories helps to characterize the social and environmental values in the Basin.

The Plan identifies management strategies (policies) thought to be effective in attaining thresholds, but does not generally provide explicit reasoning of the conceptual links between the selected management policy and indicator status. Thus, assumptions about management strategies are not used as hypotheses to be tested.

Conceptual models were formulated, but did not link management stressors to indicators, limiting the ability to predict effectiveness of future actions. However, causal relationships are identified for analysis. For example, studies of sediment transport mechanisms are intended to lead to an understanding of activities that cause sediment and nutrient delivery to the lake. Thresholds and reasonable progress lines were to be set for each indicator, and supplemental management measures (potential management responses) were identified for use as possible responses to monitoring results. The interview subjects were not present for monitoring design processes, and could not confirm the role of management questions within the design. However, without links between thresholds and particular management responses, adaptive management participants must either define appropriate linkages as they go or work through this part of the evaluation plan in advance.

While management concerns (recreation and land use impacts) led to initiation of the program, specific management questions are not posed in the Plan. While reasonable progress lines are identified as a useful tool in measuring the future status of indicators, many objectives are general or qualitative in nature. Also, where non-degradation standards are set in the Plan without a reference condition to measure divergence from the desired state, they are meaningless.

Threshold standards are not explicitly tied to potential management responses, but potential management responses are identified. Uncertainty is identified as an important component of the monitoring and management program, but it is not quantified.

Despite many important AM elements contained in the Regional Plan, including setting a goal for evaluating effectiveness of the management program, the current program manager wishes for more guidance within the plans about *how* to evaluate effectiveness of management actions in meeting threshold targets.

Monitoring results

A threshold evaluation report is completed every 5 years. This report compares each indicator with its threshold and assesses a trend. Indicators measured include plant diversity, forest structure, habitat extents, animal/plant population distribution, stream habitat extent, water and air quality, soil stability, social values, management actions for erosion and restoration, and disturbances. Additionally, the trend of all the indicators is summarized and evaluated to identify overall program effectiveness. Annually, managers provide annual status and trend data for lake clarity. Results are also disseminated through their website, newspaper reports, and public hearings.

Management actions are monitored to some extent within the threshold indicator monitoring and as part of the Environmental Improvement program, where they are catalogued based on status.

Through the ongoing research efforts described in the threshold evaluation report, uncertainty about some indicators has been discovered and the appropriateness of some threshold standards reconsidered given changing conditions and changing knowledge. Also, some causal connections are being explored through external research to identify links between management actions and indicators.

Management recommendations for each indicator are made in each evaluation report and then incorporated into the Regional Plan. These recommendations have included new regulations for water quality, land development, stormwater management, and noise management, as well as restoration and acquisition projects.

Many decisions of varying types are influenced by monitoring results. The Lake Tahoe program manager says that locations of special status species or hotspots of diversity data are requested most often by county planners, land managers, consultants, and the public, often for use in project design.

The program manager feels that all of the indicators are useful. In particular, he reported that VMT, recreation surveys, and water quality are most often used in decision processes. Site level project design is influenced by locations of species, and TRPA staff comments on site-review of development proposals. FS grazing permits are constructed in response to monitoring information.

Regional plan revisions involve revisions to land designations, community design strategies, BMPs, land acquisition strategies, recreation management, roadway construction (through CIP), and floodplain management. New regulations have been created based on feedback from monitoring information, applying to water quality, land development codes, stormwater management, and noise management. Monitoring results have also led to additional funding for the Capital Improvement Program (CIP) and regulation implementation activities.

The monitoring program is being revised based on review of results, to include an adaptive monitoring component, reference or control sites, conceptual models that include management stressors, and revision of targets for environmental quality based on natural system requirements.

Analysis of AM elements in evaluation of results

Processes

Evaluation information is shared and reviewed in the Advisory Planning Commission (APC), a group of agency planners and managers who provide monthly peer review of results and recommendations. The APC makes recommendations to the governing board, which includes county, state, and federal agency representatives and can direct the TRPA activities in response to recommendations. This formal structure is probably effective in promulgating regulations and revised plans at the higher levels, and for coordinating activities at the lower levels.

The 5-year evaluations are useful for application to regional plan revisions and overall management priorities, but do not provide any early detection for use in project-level adaptive management.

Evaluation Elements

Comparisons of baselines and thresholds with current status allows for quantitative assessment of progress and achievement of goals. Also, tracking of indicators over time demonstrates variability within indicator values and progress.

Cataloguing of management projects is useful for program management, and in the most recent threshold evaluation report, this implementation tracking led to a recommendation for accelerated project implementation. Tracking the implementation of management projects does not, however, provide sufficient basis for linking observed trends to implemented management activities (ie. evaluating effectiveness).

The 2006 report summarizes general attainment of or progress toward goals for all indicators, reporting positive trends in the majority of indicators. However, overall program review based on monitoring information has been difficult due to lack of knowledge about causal connections between management and trends. Thus, ecosystem-wide status and trend information is useful, but management responses cannot be well-defined without causal links between observed trends and management impacts.

Analysis of AM elements in use of results

The monthly group meeting is essential for distributing information quickly between managers. The regulatory body of the Governing Council helps to ensure implementation of recommendations.

Site-level preserve management actions have relied mostly on population status and distribution information to aid in project design for land management and restoration. For example, grazing management has changed due to past inventories of land condition.

Information about water quality and disturbance processes has led to new regulations on roadway construction, boats in the lake, and community design.

Regional plan revisions driven by evaluation results create specific land use policies and regulations for designated geographic areas. These include limits on land coverage within an area, on density, and on annual allocation of development permits. Additionally, Regional Plan Code of Ordinances includes water and air quality mitigation programs and resource management guidelines.

Good data on certain elements has drawn additional funding. The water clarity indicator, reported annually, has resulted in a lot of funding into basin to improve water quality. Funding for the CIP also has improved based on monitoring data. Despite some funding support, other management actions have limited funding, which limits implementation of recommendations and ordinances. Where funding is not an issue, an occasional lack of regulatory flexibility or limits on acceptability of recommendations has hindered effective changes in management.

Lessons learned

Program managers at Lake Tahoe emphasized the importance of connecting indicators with management actions to learn what is driving the system. Particularly, they advocate the use of management-oriented conceptual models, and monitoring stressors and indicators over time to identify key stressors and response variables.

To institutionalize an adaptive management program, the surveyed manager recommended clarifying roles and responsibilities of team members. Additionally, he advocated standardized M&E plans (including protocols, data management, evaluation procedures, and communication processes).

Decision makers often assume no impacts from human activities, while managers are cautionary in the face of uncertainty. Experiments on land concern people who think lands need to be preserved as is. However, in reaction to hot issues, some actions go on the ground quickly, such as recent fuels treatment planned in response to fire.

According to the adaptive management manager at TRPA, the scale of AM must be small enough to manage and not take on too many indicators or issues at once, unless you have unlimited staff and resources. Furthermore, monitoring should be guided by what can be managed. Project or program level adaptive management is the most useful, especially in situations where there is high uncertainty, high risk, high financial investment or public interest.

Information generated must be used to inform policy, regulate, and choose management actions and expenditures. The program manager identified the importance of engaging with partners, decision makers, staff and the public, partly by being transparent (i.e. publish monitoring plan). When people understand why indicator is being measured, they can assist in supporting monitoring and management programs.

IV. San Diego summary – Plan goals; Plan administration

The San Diego Multi Species Conservation Plan (MSCP) covers 900 sq mi in San Diego County, including private, city, county, state, and federally-owned lands. The overall goal of the MSCP is to maintain and enhance biological diversity in the region and conserve viable populations of endangered, threatened, and key sensitive species and their habitats, thereby preventing local extirpation and ultimate extinction, and minimizing the need for future listings, while enabling economic growth in the region. The MSCP biological goal is to maintain ecosystem functions and persistence of extant populations of covered species by preserving a network of habitat and open space. Objectives are set in the MSCP for conservation of specified proportions of vegetation communities, which are intended to preserve the covered species. The MSCP allows for development outside preserve mitigated by conservation inside the preserve, as well as allowing some development within the preserve if developed according to mitigation ordinances. Because much of the MHPA is comprised of small habitat patches adjacent to development, habitat management techniques intended to minimize edge effects are included in the MSCP, subarea plans and habitat management plans.

The City of San Diego subarea plan encompasses 206,124 acres within the MSCP study area, with 52,012 acres in the MHPA (Multihabitat Planning Area). The City's MHPA preserves 77% of the core biological resources areas and habitat linkages within the subarea. On some MHPA lands, 100% of the land will be preserved for biological purposes; on private lands, at least 75% of the parcel will be preserved. [ownership, protection] The City of San Diego relies primarily on grants from CDFG and USFWS to fund their management activities. Their annual costs for land management are approximately $3,125,000.

The San Diego South County subarea plan covers 252,132 acres, with 98,379 acres anticipated for conservation. San Diego County has funding from the BOS and a regional transportation tax for the monitoring and adaptive management program, which supports the MSCP program manager (contracting and in-house implementation) and the CEQA/NEPA program manager (monitoring county parks activities, other jurisdiction's activities and development impacts on preserves). Their annual costs for land management and operations are approximately $4,700,000.

Intro Summary

San Diego County and the City of San Diego monitor a wide variety of species, habitat, and disturbance indicators on their preserve lands. However, given the lack of documentation of monitoring evaluations or adaptive management decision processes, whatever adaptive management that has occurred cannot be easily identified. Determination of the need for change or evaluation of indirect impacts from off-site development and construction has not been documented, although it may be discussed and evaluated in more informal settings.

The City of SD and SD County evaluate implementation (tracking of take vs. conservation, acres of each vegetation type) and follow population trends, but are not able to evaluate the effectiveness of design or management strategies. This is partly due to lack of standards in reporting and problems with getting monitoring results from constantly growing preserve lands.

Goals for monitoring and AM; Plan for AM

Monitoring goals for the MSCP as specified in the Plan are to document ecological trends; evaluate effectiveness of mgt activities; provide data on species populations and movement; evaluate indirect impacts of land uses and construction (i.e. edge effects), and identify the need for change. The SD County Framework Management Plan (FMP) identifies the purpose of monitoring as informing preserve managers of the general trends of wildlife use and species preservation, while indicating areas where management focus is needed. The Ogden (1996) biological monitoring plan identified potential analysis tasks for each monitoring component (habitat, plant, and animals) to identify condition and trend. “The objective of habitat monitoring is to detect changes over time, as measured against baseline conditions rather than any pre-set "success criteria."” (Ogden 1996).

The Multi-Habitat Planning Area (MHPA) is defined by mapped boundaries, conservation criteria, and by quantitative targets for conservation of vegetation communities in the MSCP. Predictions are made in the MSCP for all subareas, for acres of vegetation communities that will be conserved and the associated species population numbers. The MSCP requires annual reports tracking acres, type, and location of habitat conserved and destroyed and biological monitoring reports (every 3 years) to determine whether the preserve is meeting conservation goals for species and habitats.

Vegetation composition, plant populations, animal populations and movement, and disturbance processes such as climate, erosion, development, and fires are monitored on the preserves. No objectives are set in any of the plans for habitat condition (e.g., structure), although habitat value is monitored. A baseline survey is collected on each new parcel as it is acquired.

Land conservation, habitat condition, or quantitative species thresholds are not linked to management actions. Conceptual models are being built for species distribution and risk, but these models are not management oriented. Thus, observations of natural system elements will not be easily linked to the effectiveness of management actions. Beyond those identified in the Ogden adaptive management section, the SD City FMP does not include specific management responses in the event that monitoring data demonstrates the need for change. Rather, it provides management guidelines for ongoing use in addressing management objectives.

The SD County and SD City FMPs outline their Adaptive Management Programs to involve monitoring resources to identify a need for change and modifying management actions based on that knowledge. The FMPs list general management guidelines and specific management guidelines for each segment of the preserve. The general management guidelines include potential directives for recreation management, monitoring (identifying the locations of critical populations and all covered species populations), adjacent land use management, flood control, fire management, grazing management, enforcement, and cultural resources management. Area Specific Management Directives have been developed for five county areas and are being developed for the other areas over the next few years. Resource Management Plans have been developed for at least two city preserves. Recommended management activities for each management area, such as habitat restoration, invasive species control, and recreation management, stem from baseline surveys.

Analysis of AM elements in Plans

The goals and objectives within the Plan make sense to MSCP managers; the San Diego County FMP management objectives make sense with MSCP goals, but no definitions of effectiveness are provided for use in analysis. In particular, the Plan makes no direct linkage between indicators and objectives. Furthermore, thresholds were not linked to potential management actions, leaving managers to make subjective determinations of the need for change.

Managers and management questions were not involved in monitoring design. Methods for analyzing particular monitoring parameters are identified, and have been revised in light of new information. However, methods for assessing overall program or site-specific management effectiveness are not defined. And yet, monitoring of vegetation communities for habitat value and of selected species is intended to indicate the need for implementation and/or prioritization of management actions.

Reporting requirements and methods for assessing compliance of balanced take with conservation are clearly identified. Reporting and processes for deciding on management actions based on monitoring results are vague. However, the preparation of baseline data and its use in evaluation does provide some foundation for analyzing trends.

Uncertainty is not quantified or explicitly identified within the Plan. Managers expect to wait for monitoring to alert them of a problem, and they intend to target management areas based on existing knowledge.

Monitoring results

The subareas report habitat loss and gain by vegetation community within MHPA boundaries and compare progress towards preservation goal in annual reports. Also, these reports evaluate whether take and conservation are in rough step, based on a comparison with the Plan. Monitoring is performed on species, habitats, disturbance processes, and development on all preserve lands.

The City of SD reports on completed and ongoing monitoring and management activities annually through the annual report and a public workshop. City managers provide annual reports to CDFG, USFWS, and preserve managers. The County reports at a BOS hearing and public workshops. The San Diego South County subarea annual report (2007) describes species population size from current yearly monitoring, but includes no interpretation of results, such as comparison to a baseline or a threshold, other than a description of population condition over past years.

Through informal partnerships and working groups at monthly meetings with representatives from all partnering agencies, the city and county evaluate data, share information, and coordinate management activities.

Species-specific data is available through the CAL BIOS system hosted at the DFG website. Monitoring data about covered species distribution, fire occurrences, and invasive species is available on the CA Dept of Fish and Game on their BIOS online map system. Species monitoring results are used in updating distribution models.

The Plan identifies the responsibility of the wildlife agencies to prepare biological monitoring reports every 3 years, but these have not been shared with San Diego managers. The County and City staff are now taking on this role through the preparation of area-specific management directives (ASMDs). Perhaps in lieu of reports, the county manager also indicated that wildlife agencies set regional management priorities, which the county is required to incorporate into their activities.

Management recommendations are made as ASMDs and RMPs are developed, using analyses of past data. ASMDs have not been in place more than one or two years so far.

The City program manager said that data about vernal pool species, cactus wren, and burrowing owl is most often requested and used by land managers, water managers, and interest groups. Cactus wren data has led to alterations of development regulations in Southern California. The City program manager also noted that GIS maps of species distribution and photo points over time showing habitat value are most useful to preserve management (i.e. trails siting, erosion control, invasive species removal, and fencing and signs), writing fire management plans, and in identifying priorities for grant proposals and land acquisition. The long term annual data has been most useful to the City in applying for grants to perform management activities.

Requests for city management actions often come from non-profit interest groups who are concerned about a specific issue or species.

County management areas including public works (DPW), preserve management, and land use (DPLU) use monitoring info. The DPW has designed wildlife crossings in response to monitoring information about undercrossings. Preserve management activities guided by monitoring information have included fire management (restoration and revegetation), grazing management (removal or fencing), invasive plant removals, and recreation management (trails plans). The DPLU has developed development regulations in response to increased knowledge about cactus wren habitat requirements.

The County manager says that monitoring information on vegetation community distribution, species distribution, and species population trends has been useful in preparing ASMDs and RMPs. Management activities recommended in RMPs include recreation management (trails siting, access rules), invasive species removal, stormwater management/erosion control, fire management (thinning). These actions are dependent upon funding availability, but the interview subject says that preserve managers are required to respond to ASMDs and that funding has been sufficient.

DFG and SDSU have been involved in reviews of monitoring plans and protocols based on a past decade of monitoring results. Thresholds and management-oriented conceptual models are being developed for rare plant and animal monitoring as part of a monitoring program review completed in 2005 by SDSU. Thresholds will be based on literature synthesis of animal population viability. Additionally, the review recommended construction of a single database for storage and analysis of monitoring data. Finally, updates have stressed documentation of causes of observed trends.

Analysis of AM elements in evaluation of results

The City of SD and SD County evaluate implementation (tracking of take vs. conservation, acres of each vegetation type) and follow population trends, but are not able to evaluate the effectiveness of design or management strategies. Future monitoring of disturbance processes may help support revision and refinement of conceptual models.

Despite the existence of baseline information in several areas, it has rarely been used. Given the recent acquisition of many properties, some areas of the county are only in the initial stage of collecting a baseline inventory, and therefore are not able to demonstrate adaptive management approaches. Additional evaluation of monitoring data may help in assessing linkages between management activities and identifying ecosystem trends.

The failure of San Diego to identify effective management strategies is related partly to the Plan's inability to tie monitoring results to hypotheses to evaluate effectiveness of management. Not only do more management activities need to be monitored, but managers need to be able to link monitoring to management goals for the species or the site.

The region has no formal integrated system for coordination of monitoring and adaptive management (CBI 2006). The challenge of rigorously analyzing status and trends in species populations and ecosystem threats has been due to a lack of assimilation of data, which thus limited the application of data to guide regional management decisions (CBI 2006). The informal working group does coordinate actions based on available monitoring data, but the decision processes involved in these actions have not been documented.

Analysis of AM elements in use of results

In San Diego County, there has been little regional priority-setting for management and little strategic implementation of management objectives (CBI 2006). Overall, San Diego has demonstrated very case-by-case, ad hoc management as opposed to adaptive management. The rare plant monitoring review (2006) identified the current lack and yet the great potential for use of local experts in collaborative planning. While ASMDs have presumably been developed based on monitoring information, no clear decision framework was documented, indicating a somewhat lacking level of transparency.

Informal working groups that review data and collaborate about management decisions have been the most effective method for adaptive management in San Diego thus far. However, uneven participation in monitoring and reporting across jurisdictions has made it difficult to determine true habitat and population conditions.

Public workshops have been an important method for communication with the public. However, annual reports are clearly intended to meet standards set by the permit, and they are very limited in their levels of evaluation or effectiveness as an education tool.

Lessons learned

Program managers recommend that other programs involve local experts in workshops to document knowledge and ask monitoring questions. While the managers recognized that many programs use consultants, they thought it best if managers and scientists can observe data for themselves.

San Diego's situation provides a neat lesson in funding, when one compares the situation of San Diego County with the City of San Diego. Where jurisdictions funded a monitoring and adaptive management program up front, the program was able to leverage to get more in the form of federal grants, for example. Limited program funding led the City program managers to use monitoring information to get grants for management activities.

Program managers also recommend that monitoring efforts get started as soon as possible, by getting protocols standardized across jurisdictions and doing surveys quickly after program conception.

The County program manager emphasized that public access on the preserves has led to increased future public support for the program.

Finally, the San Diego program managers suggested that an oversight group can ensure that roles and responsibilities are fulfilled throughout a regional management program.

Case study synthesis

This analysis attempts to discern opportunities for and constraints to success when implementing an integrated, long-term effort to maintain ecosystems and endangered species amidst ongoing human activities. In particular, I examine the processes used to communicate with managers within the agency and work through an adaptive management approach, the most effective products created from monitoring data for use in adaptive management, and the constraints to/elements of success for implementing an adaptive management approach.

Ecosystem management as adaptive management

Program goals

Monitoring and evaluation programs are designed around various program strategies and objectives. Goals for endangered species programs vary from conservation and recovery of target species populations (BCCP) or preservation of habitat and populations of covered species (CCMSHCP, SDMSCP) to achievement and maintenance of environmental threshold carrying capacities (LTRPA). *Species:* The San Diego MSCP incorporates the concept of population viability for covered species into its goals, whereas the Clark County MSHCP sets a goal of stable or increasing populations of covered species. The Lake Tahoe Regional Plan requires maintenance of a minimum number of population sites to meet the threshold standard. The BCCP identified long term and short term goals. Long term goals included managing for population viability and identifying causal relationships between management actions and covered species responses. *Habitats:* The BCCP reserve design is the foundational element in the Plan for meeting the species goals. The San Diego MSCP goals include conservation of key sensitive species habitats, which is specifically defined within the plan objectives. The Clark County MSHCP sets a goal of no net loss or fragmentation of habitat within the Plan's conservation reserve. The Lake Tahoe Regional Plan identifies one habitat association – riparian – to be maintained or enhanced (measured in acres) across the planning area.

Program context

Management context/Program lands

Each surveyed ecosystem management program is responsible for monitoring and managing a suite of lands within its region. Additionally, in the MSCPs, each management program has a direct relationship with the regulation of activities outside managed lands. In three out of four surveyed cases, the managed lands provide mitigation for permitted incidental take (degradation or harm?) on other lands. The combination of managed lands and permitted take lands are referred to in this document as covered lands. Thus, regulations or management guidelines may apply to mitigation (managed) lands, non-mitigation lands, or all covered lands. While the Lake Tahoe RPA does not have mitigation requirements, the LTRPA does use land designations to identify different management levels for the lands in the Lake Tahoe Basin. Their land designations refer to "conservation lands", which are non-urban areas with value as natural areas with strong environmental limitations on use. . In this document, mitigation lands are referred to as conserved lands, to connote their similarity with the LTRPA land designation for conserved lands.

Table 1. Extent of covered lands and conserved lands by program.

	San Diego MSCP – city	San Diego MSCP – county	Lake Tahoe Regional Plan	Balcones Conservation Plan	Clark County MSHCP
Covered Area (acres)	206,124	252,132	197,887	647,680	5,000,000
Conserved Area (acres)	52,012 (goal) 34,474 (2008)	98,379 (goal) 77,460 (2008)	128,048	30,428	2,961,538

Conserved lands for habitat conservation programs can include private, city, county, state, and/or federal lands designated as part of a preserve. Generally, each landowner is responsible for management and monitoring on its conserved lands. However, in the case of Clark County, the entity managing the permit has few conserved land to manage, and thus relies on contracts and cooperation with other (in this case federal) landowners to implement the management activities that have direct relationships with the permitted activities on private, city, and county lands. In San Diego, the County implements the MSCP on County lands and on BLM-owned conserved lands through a cooperative agreement. In Travis County, the Balcones Canyonlands Preserve (BCP) is managed in part by the city and part by the county. In Lake Tahoe, the conserved lands span all jurisdictions – private, city, county, state, and federal lands, and the Lake Tahoe RPA regulates and implements with the help of partnering agencies the Code of Ordinances on all conserved lands.

Management activities

All of the surveyed programs fulfill specific management roles within their regions. The San Diego MSCP preserves a network of habitat and open space through acquisition and regulation and manages, maintains, and monitors plant and animal life on the preserve lands. Clark County's MSHCP achieves mitigation for take on covered lands by funding other, larger land manager efforts that minimize, mitigate or monitor the impacts of take. The BCCP manages and maintains a preserve that provides mitigation for incidental take outside of preserve lands. The Lake Tahoe Regional Planning Agency designs and implements a Regional Plan and a Code of Ordinances that apply to all covered lands.

Monitoring and Research activities

Each program includes monitoring and research activities, according to their planning documents or interviews. All four programs are intended to identify the current status of covered species, although they all define status monitoring in different ways. All the programs monitor status and trends of covered animal and plant species.

Three programs, all except for the BCCP, state the goal of assessing the effectiveness of program management activities in their planning documents. Three programs, all except for the Clark County MSHCP, state the goal of identifying causal relationships between management and natural system elements in their planning documents, and interviews with Clark County program managers revealed that research studies done on NPS lands have sought to identify causal relationships between covered species and habitat components (pollinators for bear poppy rely on other vegetation communities).

Table 2. Elements monitored by program.

	San Diego MSCP – city	**San Diego MSCP – county**	**Lake Tahoe Regional Plan**	**Balcones Conservation Plan**	**Clark County MSHCP**
Animal/Plant Species distr.	X	X	X	X	X
Animal/Plant population trends	X	X	X	X	X
Environmental Values			X		
Habitat values	Qualitative	Qualitative	X	X	X
Mgt activities			X	X	X
Disturbance	X	X	X		X – cattle
Social indicators			X		

[Detail about monitoring elements/differences
disturbances: San Diego monitors climate, development, erosion, and fires in its disturbance monitoring. Lake Tahoe monitors development as a function of land coverage, VMT, and noise. Clark County monitors cattle trespass, ORV impacts.]

Most programs partner with local universities to review and revise monitoring program methods throughout the course of program implementation. In Travis County, the BCCP had a decade of monitoring data reviewed by a university science team. Findings from this review indicated that current methods were not effectively producing information that could be extrapolated range-wide. Thus, a new set of protocols is being implemented on the BCCP reserve lands alongside existing protocols, with the hope that the most efficient method can be used in the future. In Clark County, the MSHCP has recently embarked on a project to detail some of the general adaptive management tasks outlined in the original Plan. This will include development of conceptual models, documenting thresholds and management responses, and identifying appropriate measures to evaluate ecosystem health. Also, information about species has not been updated for more than 5 years, and existing monitoring information will be compiled to provide a current summary of species status. The Lake Tahoe RPA is also performing a review of current indicators, which is required in their Plan, but in this instance they are also adding explicit linkages between indicators and management project implementation. In San Diego, modifications have been made to their rare plant monitoring based on a decade of monitoring, species models have been updated using past monitoring information, and additional evaluation elements, such as triggers and management responses are being developed.

Some programs take a more active approach to adaptive management. The passive approach involves waiting for need for change to emerge or learning from natural/ongoing disturbances. An active approach involves applying management as a hypothesis. Clark County specifically says in their 2006 AM report that they seek to take a more active adaptive management approach, where the design, review and implementation of effectiveness monitoring and management decision oriented species and threats monitoring are adequately funded. They characterize their past efforts as “passive” and “learning by doing”. In some ways, the BCCP program has incorporated uncertainty into their management strategies, by limiting public access until monitoring identified areas that would not be harmed by public access. However, their trend monitoring of karst species in particular identified a negative trend, which then signaled a need for more analysis to determine causation. In San Diego, the program design included reference to comparing results against a baseline, to identify the need for change. This is inherently a passive adaptive management approach.

Processes of Adaptive Management/Information Sharing

The administrative responsibilities of the surveyed agencies determine their communication and decision-making methods.

Information users/audience

In the three programs mandated by the ESA, information about monitoring and management activities is provided to the U.S. Fish and Wildlife Service (FWS) as required by the permit. In the TRPA, information is shared with land management agencies, universities, public officials, and the public, all of whom are affected by subsequent regulations propagated by the TRPA Regional Plans.

Additional information sharing occurs in each program according to their specific circumstances. In the Clark County program, information is provided by federal and state land managers who have been contracted by the county managers, who then distribute the information to county staff, to university scientists, local decision makers, and the public. In BCCP, information is formally shared in a committee that includes a single representative from each management agency involved in the permit.

Communication of monitoring findings among scientists and managers occurs in all surveyed programs, albeit with varying levels of detail. University researchers are involved in evaluating monitoring information in all surveyed programs. In San Diego and Clark County, state wildlife agencies are also involved in evaluating monitoring information.

In most programs, a land manager from each management agency that holds conserved lands is informed about monitoring results from other partnering agencies. Public officials are provided with monitoring results through public hearings, executive summaries, or copies of annual reports in all programs.

Outreach methods

All surveyed programs have requirements to annually report on at least a portion of their management and monitoring activities. Most programs use a website to interpret their program activities and provide an electronic version of their reports. Balcones Canyonlands CP does not provide electronic versions of the annual reports from monitoring on its website because of their size. Lake Tahoe prepares a system-wide evaluation every three years and reports on the status of a select group of indicators, including water quality, in its annual reports.

Report contents vary considerably both across programs and over the years within programs.

Table 3. Content of Reports by program?

The Clark County MSHCP biennial adaptive management report from 2006 provides general information on implementation of conservation actions, current acres of habitat lost, new or ongoing stressor activities, and recommendations for the program. While the 2006 report does not characterize any species trends, the 2004 report does include information about species population trends. This is related to the administrative situation in Clark County. The Clark County MSHCP manager receives summary reports from contracts with other entities. Until 2007, these reports provided only a general summary of activities completed and general findings. As of 2007, Clark County negotiated new reporting requirements with the contracting land managers and now receives raw data and metadata in addition to general summaries. The 2006 AM report indicates that given new reporting requirements, species status updates will be provided in future reports.

[BCCP annual report]

The Lake Tahoe RPA Threshold Evaluation Reports, produced every three years, provide detailed monitoring results, where the status of each indicator is reported and compared against previous years' data and against threshold standards for that indicator. For the wildlife threshold categories, the TRPA reports on the status of riparian habitats and the number of population sites provided for Special Interest Species. Environmental improvement projects are catalogued according to project completion status. Additionally, the LTRPA Threshold Evaluation Report includes an overview of Basin-wide progress towards meeting all threshold standards as well as proposed follow-up activities for each threshold category.

San Diego's annual reports are produced by each entity and track management, disturbance and conservation activities within their subarea. Monitoring activities are summarized according to implementation in both city and county reports, and the county provides the most recent species population counts from individual monitoring sites, with little or no analysis of monitoring findings. For the city's monitoring efforts, species population counts are reported on the entity's website or can be viewed spatially by using the CAL BIOS online map system.
[SUMMARIZE!!]

Most surveyed programs (all except Clark County) reported hearings with public officials to report their management and monitoring activities. San Diego holds public workshops as well as hearings with public officials. The LTRPA interview subject indicated that results are communicated to the public through newspaper reports as well as being made available online.

Decision processes

Several of the management programs utilize new decision forums that were initiated as part of program implementation. These collaborative groups can provide a forum for sharing information and making decisions about responses to the information produced from monitoring while considering local circumstances. Decision groups identified by surveyed respondents have varying levels of formality and authority. At the most formal, the TRPA program Governing Board is comprised of county state and federal decision makers who use an established voting structure to implement regulations and direct TRPA program actions. On the other end, the San Diego and Balcones Canyonlands programs utilize coordinating committees that have little authority, where participants can share results of monitoring and management activities and work to coordinate activities between the city, the county and wildlife agencies. The Clark County program manager did not identify any formal collaborative processes used to share information or coordinate activities.

Meetings that allow peer review and information sharing are useful to allow participants to learn from each other's efforts, even if they do not result in the coordination of activities. As part of the formal TRPA governance structure, a set of subcommittees exist in addition to the governing board, one of which provides a monthly forum for agency planners and land managers to receive monitoring results and make recommendations to the Governing Board for action. The San Diego management group also meets monthly to compare results and coordinate activities, and the Balcones Canyonlands Coordinating Committee meets quarterly at most.

Finally, informal agency to agency relationships among managers were identified as a common coordination method by the interview subjects in the Clark County and San Diego programs. In San Diego, these "good working relationships" were named by interviewees as important for getting information and implementing management actions across jurisdictions. In Clark County, coordination between federal agencies and county program managers has been limited in the past, but the county program manager cited recent efforts at documenting knowledge and improving reporting between the agencies as major program successes.

In San Diego, ASMDs and RMPs are developed based on monitoring information, according to the interviewees, but the decision process is not documented or clearly transparent.

Use of Monitoring Information

In surveyed programs, the monitoring information requested most by managers, planners, interest groups, and the public is the distribution of special status species. Additionally, locally important natural elements, like the vernal pools in the San Diego area and the lake clarity of Lake Tahoe, garner public interest in monitoring information.

Monitoring results inform and influence various levels of decision making, ranging from ad hoc management actions to program-wide reviews of the overall conservation strategy. The Lake Tahoe RPA, which monitors a wider variety of environmental and social variables than the MSCPs, reported the widest variety of uses of monitoring information in decision making.

Table 4. Applications of monitoring info used in decision levels

	Project design	**Land acquisition**	**Regulations**	**Preserve Management Plan**	**Comprehensive Plan/Land Use**	**Program Review**
Animal/Plant Species distr.	SD, LT, BC, CC	SD, BC, LT	SD, CC	SD, BC	LT, CC	
Animal/Plant population trends	BC, LT		SD	SD, BC	LT	LT
Environmental Variables		LT	LT		LT	LT
Habitat value/ Photo pts	SD, CC	SD	LT			
Mgt activities	BC, CC					
Disturbance	SD, CC, LT		LT	SD, CC	LT	
Social indicators				LT		
# Programs cited	4	3	3	4	2	1

While data on the number of decisions influenced by monitoring information across the surveyed programs was not available, the most commonly reported area of decision making influenced by the most types of monitoring information was site- or issue-specific preserve management actions. These include preserve management activities, grazing management, forest management, fire management, recreation management, and invasive species removal. Additionally, monitoring information was used in all four surveyed programs to update and prepare preserve management plans.

Restoration effectiveness evaluation has generally demonstrated a successful adaptive management capability within surveyed projects. Managers from three projects applied knowledge from past monitoring of restoration treatments to upcoming projects: BCCP (forest restoration), CC (desert restoration), and San Diego, although San Diego's program didn't explicitly describe restoration treatment monitoring as included in their monitoring activities. Lake Tahoe program managers surveyed restoration in their indicators, but only in terms of acres restored, as they were not able to identify effectiveness.

In some cases, programs outside of preserve management, such as site-specific development or construction designs and land acquisition decisions, were influenced by monitoring information. In San Diego, the Department of Public Works receives monitoring data about wildlife movement from the County to determine appropriate sites to construct wildlife crossings. Also, acquisition priorities are driven by information from monitoring about species distribution (available on GIS). The Lake Tahoe monitoring data assisted with CIP funding decisions and provided program staff a basis upon which to review proposed development designs.

In addition to modifying site management, monitoring information was reported as leading to the development or modification of regulations on recreation and development/land use. In Lake Tahoe and in Clark County, limits were placed on recreation activities in response to negative trends in environmental or species variables.

In Clark County and in the BCCP, recreation plans were created to guide activities away from known distribution sites.

Other decision levels using monitoring information included revision processes for land designations or land use plans (Clark County, Lake Tahoe) and grant prioritizing (San Diego).

Program Success

Program effectiveness

None of the programs surveyed were successful in performing systematic evaluations of overall management program effectiveness. The Lake Tahoe program provides an evaluation report for all quantitative indicators, which summarizes program progress towards thresholds, but this analysis does not link progress with program management actions. While every plan reviewed requires the evaluation of management effectiveness, local constraints within monitoring and evaluation program elements have kept managers from performing this analysis. However, in all surveyed programs except San Diego, managers identified a wish to perform this analysis and identified current measures being taken to provide a foundation for effectiveness evaluation. San Diego is making revisions to its monitoring and management program that will facilitate effectiveness evaluation.

In the BCCP, managers provided the past decade of data to university scientists to review protocols for effectiveness. While this is perhaps a long time to wait, this pattern was seen in all the surveyed programs…

Adjustments have been made to management at the scale of individual preserves or lower. In most cases, these adjustments have been poorly documented, and conservations with managers revealed the extent of management informed by monitoring. It is important to mention that management adjustments on preserves have often been strictly based on avoidance or minimization of impacts to known species populations or important habitats. In some cases, restoration techniques have been monitored and evaluated for effectiveness, but generally effectiveness of individual management strategies has not been explicitly evaluated. Additionally, many respondents indicated that identifying successful conservation or management strategies was not completed for various reasons.

Most programs (all of the MSCPs) were required to provide evaluations of take and conservation. These evaluations provide a measure of progress towards program objectives at a very coarse scale. Evaluations of take vs. conservation often relied on tabulations of acres of approved land use activities and land designation changes. Habitat condition and species population trends were generally measured on a sample of conserved lands, and results of this analysis were extrapolated distribution-wide. This level of evaluation cannot support program-wide decision making, as described by one respondent.

Information about the timing and location of management was rarely used to evaluate monitoring data and discern causal relationships, most often because it was not available.

Monitoring did not include monitoring of management actions beyond restoration actions in any of the surveyed programs. Disturbance processes were monitored in three out of four surveyed programs, but each program monitored different processes.

Restoration effectiveness monitoring and evaluation was being done in three of four surveyed programs. The level of rigor in analyzing data and applying the lessons from this analysis varies. Generally, they each monitored pre- and post-treatment condition and compared results between types of restoration treatments. In the case of CC and BCCP, this included the discovery of the most effective recreation management techniques (e.g. fencing, signs) to protect natural elements.

Development regulations improved as a result of monitoring information in San Diego and in Lake Tahoe. The many anecdotal management adjustments that are informed by monitoring information, while they contribute somewhat to the process of adaptive management, do not address the concerns about risks to the ecosystems. Where rigor is not applied in evaluation and application of monitoring information to decision-making, risks are not quantified and therefore may not be appropriately managed.

Program progress

Atkinson et al. (2004) describes three stages of monitoring and adaptive management programs. The stages are (1) inventorying resources and identifying relationships; (2) pilot testing of long-term monitoring and resolving management uncertainties; (3) implementing long-term monitoring and adaptive management. All programs except for Clark County reported that, depending on the site, they were in all three phases of monitoring programs. In San Diego, for example, the intention to compare results against a baseline to identify the need for change reflects the preliminary level at which they are able to manage. Since they are in the early stages of an adaptive management program, they are not yet able to set thresholds or identify natural variation within which to guide management and evaluate monitoring results. All programs look, after 5-10 years, like they are still in the design phase, where they inventory resources and identify relationships.

Constraints/ Elements of Success

AM components in plan

Monitoring guidelines in the plans are often broad, lacking measurable objectives, guidelines for assessing stated goals with monitoring data, or descriptions of decision processes to use for acting in response to results. Measurable objectives, while recommended by authors like Tear et al. (2005), are difficult to assemble without extensive literature or local data. As observed in the river restoration projects study, problems in evaluating project success often stem from limited data to support objective-setting, leaving the critical foundation upon which to evaluate success unsteady.

Most interviewees suggested that the lack of details in the plans to guide evaluation and decision making has slowed down their progress in doing adaptive management. In particular, the Lake Tahoe program manager criticized the guiding documents' lack of details for directing effectiveness evaluation. In Lake Tahoe, the plan identified management actions and thresholds, but never provided a link between them to identify casual relationships or guide future decision-making. Objectives that are not explicitly defined or methods for evaluation that are not explicitly described in planning documents are hard for programs to manage.

Several programs found the lack of management involvement in planning monitoring made their monitoring programs unable to provide useful data to managers. In the BCCP, monitoring was not designed to answer management questions, despite the many management questions that have arisen for BCCP preserve managers. The BCCP program managers overlooked some other lacking elements that left them unable to meet stated monitoring goals, but they bemoaned the fact that they were still working through monitoring techniques after a decade of implementation to make them relevant to managers. In Clark County and in Lake Tahoe, monitoring programs were designed as offshoots of existing programs, and were not designed with manager input or for manager use. In San Diego, while program managers thought that monitoring was designed with the help of local managers, the planning documents explicitly guide management to be reactive to trends revealed by monitoring.

Decision frameworks were often not described well in plans, despite being a critical element of the adaptive management process. Clark County program managers identified the importance of setting up a structured process to deal with future changing circumstances and unforeseen results. San Diego planning documents recommended a general format for decision-making, but interview responses indicated that this methodology was preempted by local level, informal decision-making.

An important element of success in programs attempting to do adaptive management has been well-defined adaptive management tasks and processes included in planning documents. Program managers in Lake Tahoe and Clark County suggest that adaptive management should be prioritized based on what areas of management are most uncertain and need adaptive management. This would include specifying management questions and prioritizing actions based on things over which managers truly have control. Specifically, the Lake Tahoe manager recommended against doing large-scale adaptive management, unless you have unlimited funding or personnel. He found it most applicable where there is high uncertainty, high risk, high financial investment or public interest in a given issue.

AM components in evaluation

The success observed in Lake Tahoe's planning program appears to be largely due to the use of thresholds against which to identify progress across the ecosystem, which was not done in any other of the programs. Due to the limited level of monitoring reporting about management actions, not enough cohesive information exists to extrapolate system-wide for a program effectiveness evaluation. This problem plagued BCCP as well, but only after a university review of their monitoring data revealed the deficiencies. In the meantime, data was applied to management situations beyond its intended use. In Clark County, distribution data has been used within land management agencies to direct preserve management activities, but has not been available in a standardized format for system-wide effectiveness evaluation.

Where data is not quickly available for use by managers, the lack of a quick evaluation leads to limitations on information usefulness. In Lake Tahoe, the preparation of 5 year detailed evaluations was helpful only to higher level budgeting processes and development of regulations. Preserve management activities require a more expedient process of communicating results. Informal decision processes provide the advantage of a forum for sharing results more quickly, but they often lack rigorous analysis and decision support methods. Thus, while information can come into these processes more efficiently, decisions may not reflect the systematic character so important to science-based adaptive management.

The lack of connections between management actions and observed results in evaluation limits the application of new data to increase knowledge of system connections. In Lake Tahoe and in Clark County, little information regarding the extent of implementation, and little spatial data is submitted, despite availability. These data limitations cause managers to avoid attempting to evaluate causal relationships or effectiveness. In addition, where spatial data is not relevant to the scales of decision making, the lack of spatial data limits evaluation of priorities within a management area.

The emphasis of endangered species management has formerly been on species status, a concept that many managers seem unwilling to amend. However, Clark County program managers recommend starting with an inventory of management actions and ecosystem status that will provide a basis for starting to identify linkages, on the basis of which one might try out management changes. In their situation, several years of monitoring research and development focusing on counting single species is now considered wasted time. Additionally, most programs surveyed reported the usefulness of species status data above other data types. While species distribution data is widely used in preserve management, creation of regulations, and restoration effectiveness assessment, it is inherently limited in its usefulness in evaluating overall program effectiveness (see Table). However, given the innate lack of foundational elements for assessing habitat values with monitoring and the lack of linkages between management actions and observed conditions, the emphasis on species data seems to be all that is left to use.

Funding

Table 5. Funding for preserve management, monitoring, and administration by program

	San Diego MSCP –	SD MSCP county	LTRP	Balcones	Clark County
Annual costs (total)	$3,400,000-$3,625,000	$4,700,000	$400,000-$900,000		
Monitoring/ Administration	$200,000-$500,000	$585,000-$1,230,000	$400,000-$900,000	$560,000-$638,000	$10,000,000
Management	$3,125,000	$4,600,000	0		

Despite similarities in terms of the amount of lands they must manage, the BCCP managers and the San Diego managers have very different funding situations. Funding for management and monitoring does not appear to be directly related to the scope of management responsibilities. For example, BCCP managers report that they spend $110-125/acre to manage their preserve lands. San Diego cites a similar figure: $125/acre cost for managing their preserve. However, BCCP managers report that they do not have enough funding to monitor, manage, and adaptively manage, especially without a staff scientist. The BCCP funds cover not only monitoring and administration, but implementation of management as well. When the BCCP funding situation is compared with the San Diego funding situation, the discrepancy becomes clear. In addition to the amount that the BCCP has for all of its programs, San Diego has an additional $3-4 million to use in implementing management on their preserve lands.

The San Diego County program manager indicates that management guidance from the monitoring team has resulted in management activities on preserve lands, because preserve managers have sufficient ongoing funding for management. In contrast, the City of San Diego program manager indicated that due to limited funding from local sources, they have had to solicit grant funding based on monitoring information to support their management activities.

The Lake Tahoe program manager reported that funding for some management areas in Lake Tahoe has been insufficient. However, monitoring results have led to increased funding for construction projects (CIP) and implementation of Best management Practices. Lake Tahoe's program managers do not seem to be responsible for funding the implementation of recommended management, relieving them of a burden that other surveyed programs must carry. Finally, Clark County does not report problems with funding, given the recent amount of revenue generated by development impact fees. Clark County's funding is distributed to other managers for management and monitoring implementation.

Landscape scale vs. scale of monitoring and management

In the BCCP, San Diego, and Clark County programs, the splintering of management and monitoring duties over several agencies, a result of the splintered land ownership patterns, has made coordination of monitoring protocols difficult. Hence, the program managers identified the need to coordination data collection by standardizing data forms and equipment, so that data could be aggregated for larger scale analysis. In Lake Tahoe, the central management and collection of data seems to have facilitated system-wide analysis.

External constraints

Pressure for public access on preserves in the BCCP led managers to provide access, despite insufficient data to ensure protection of sensitive species. In comparison, in San Diego County, the program manager believes that public access builds support.

Institutional

Commitment from managers early and for the long term has been important in successfully doing adaptive management (ie. sharing monitoring and management results and coordinating future efforts) both in Lake Tahoe and in Clark County. While these programs both need more development of adaptive management processes within their regions, the commitment of partners enables them to explore the weaknesses and strengths of various monitoring and management methods over time.

The success in the Lake Tahoe program is a result of a combination of factors; however, one element demands particular attention. The existence of an oversight body with the power to require implementation of best management practices, new regulations, and a Regional Plan provides a critical element for adaptive management. The mandates and funding that come from the Governing Council ensure application of the LTRPA monitoring and evaluation to a wide variety of management areas and decision levels. As demonstrated in the land use case study (Cort 1996), where states mandate or fund the use of biodiversity data in comprehensive planning, it is most frequently used and used well. While many programs found uses for their monitoring and evaluation results, only the Lake Tahoe program was able to apply their information through all decision levels.

Considerations from case studies

Information from the surveyed programs revealed the importance of understanding the system one is trying to manage and the importance of designing monitoring and management processes that systematically seek to increase one's knowledge of the managed system. Only once programs had 5-10 years of monitoring data did they begin to build truly adaptive monitoring and management programs. Thus, gathering existing knowledge to build models and predictions is a critical element in the design of an adaptive management program.

Other considerations include:

- Setting appropriate (i.e. measurable) and detailed goals for monitoring and evaluation
- Development of evaluation methods and decision processes to address program goals and goals for monitoring
- Considering ongoing and proposed management activities as hypotheses
- Incorporating uncertainty about impacts of management activities into models and overall conservation strategy
- Recognition of program scope, constraints, and level of coordination necessary to implementation of monitoring and management
- Selecting appropriate programs for adaptive management based on level of risk, level of uncertainty, and level of support for science-based learning and management modification.

References

Atkinson, A.J., P.C. Trenham, R.N. Fisher, S.A. Hathaway, B.S. Johnson, S.G. Torres, and Y.C. Moore. 2004. Designing monitoring programs in an adaptive management context for regional multiple species conservation plans. U.S. Geological Survey Technical Report, USGS Western Ecological Research Center, Sacramento, CA.

Bisbal, G.A. 2001. Conceptual design of monitoring and evaluation for fish and wildlife in the Columbia River Ecosystem. Environmental Management 28:433-453.

Bormann, B.T., P.G. Cunningham, M.H. Brookes, V.W. Manning and M.W. Collopy. 1994. Adaptive Ecosystem Management in the Pacific Northwest. Pacific Northwest Research Station, General Technical Report PNW-GTR-341. USDA Forest Service.

Broberg, L. 2003. Conserving ecosystems locally: A role for ecologists in land-use planning. *BioScience* 53:670–673.

Callicott, J. B., L. B. Crowder, K. Mumford. 1999. Current Normative Concepts in Conservation. *Conservation Biology*, 13(1): 22-35.

Cort, Cheryl A. 1996. A survey of the use of natural heritage data in local land-use planning. Conservation Biology. 10(2): 632-637.

Costanza, R. Haskell, B.D. & Norton, B.G. *Ecosystem health : new goals for environmental management.*Washington, D.C. : Island Press, 1992.

Cullen, P. 1990. The turbulent boundary between water science and water management. Freshwater Biology: 201-209.

Francis, T., K. Whittaker, V. Shandas, A. V. Mills, and J. K. Graybill. 2005. Incorporating science into the environmental policy process: a case study from Washington State. *Ecology and Society* 10(1):35.

Fish and Wildlife Service. 2000. Notice of availability of a final addendum to the Handbook for Habitat Conservation Planning and Incidental Take Permit Process. Habitat conservation planning and incidental take permit processing handbook. Fish and Wildlife Service.

Gregory, R., L. Failing and P. Higgins (2006). 'Adaptive Management and Environmental Decision Making: A Case Study Application to Water Use Planning,' *Ecological Economics* 58(2) pgs. 434-447.

Hamann R, Ankerson T. 1995. Ecosystem management and the Everglades: a legal and institutional analysis. Gainesville (FL): Center for Governmental Responsibility, University of Florida School of Law.

Haney, A., and R. Power. 1996. Adaptive management for sound ecosystem management. Environmental Management 20: 879–886.

Harwell, Mark A., Victoria Myers, Terry Young, Ann Bartuska, Nancy Gassman, John H. Gentile, Christine C. Harwell, Stuart Appelbaum, John Barko, Billy Causey, Christine Johnson, Agnes McLean, Ron Smola, Paul Templet, Stephen Tosini. 1999. A framework for an ecosystem integrity report card. *BioScience* 49(7):543-556.

Hilderbrand, R. H., A. C. Watts, and A. M.Randle. 2005. The myths of restoration ecology.Ecology and Society 10(1): 19.

Hockings, M., S. Stolton, F. Leverington, N. Dudley and J. Courrau. 2006. Evaluating Effectiveness: A framework for assessing management effectiveness of protected areas, 2nd Edition. Queensland, Australia: World Commission on Protected Areas. 136 pp.

Holling, C. S., editor. 1978. Adaptive environmental assessment and management. John Wiley, New York, New York, USA.

Holling, C.S. 1986. The resilience of terrestrial ecosystems; local surprise and global change. In: W.C. Clark and R.E. Munn (eds.). Sustainable Development of the Biosphere. Cambridge University Press, Cambridge, U.K. Chap. 10: 292-317.

Holling, C.S. 1995. What barriers? What bridges? Pages 3-36 in L. H. Gunderson, C. S. Holling, and S. S. Light, editors. Barriers and bridges to the renewal of ecosystems and institutions. Columbia University Press, New York, New York, USA.

Hughes, F. M. R., A. Colston, and J. Owen Mountford. 2005. Restoring riparian ecosystems: the challenge of accommodating variability and designing restoration trajectories. Ecology and Society 10(1):12.

James, F.C. 1999. "Lessons Learned from a Study of Habitat Conservation Planning". BioScience, Vol. 49, No. 11, 871-874.

Jassby, A. D. 1998. interannual variability at three inland water sites: implications for sentinel ecosystems. Ecological Applications 8(2):277-287.

Jensen, M. E., P. Bourgeron, R. Everett, and I. Goodman. 1996. Ecosystem management: a landscape ecology perspective. Water Resources Bulletin 32(2):203-216.

Johnson, B. L. 1999. Introduction to the special feature: adaptive management - scientifically sound, socially challenged? Conservation Ecology 3(1): 10.

Johnson, F. and Williams, K. Protocol and Practice in the Adaptive Management of Waterfowl Harvests. Conservation Ecology 3(1): 8.

Kareiva, P, Andelman, Sandy J.; Doak, Daniel F.; Elderd, Bret D.; Groom, Martha ; Hoekstra, Jonathan ; Hood, Laura ; James, Frances C.; Lamoreux, John ; LeBuhn, Gretchen ; McCulloch, Charles E.; Regetz, Jim ; Savage, Lisa T.; Ruckelshaus, Mary ; Skelly, David K.; Wilbur, Henry M.; Zamudio, Kelly. 1999. Using Science in Habitat Conservation Plans. Santa Barbara (CA): National Center for Ecological Analysis and Synthesis, and Washington (DC): American Institute of Biological Sciences. Printed version available from AIBS, 1444 ISt., NW, Suite 200, Washington, DC 20005.

Keeney, R. 1977. A utility function for examining policy affecting salmon in the Skeena River. Journal of Fish Research Board Canada 34: 49-63.

Kim, J. B. and Bridges, T. S. (2006) "Risk, uncertainty, and decision analysis applied to the management of aquatic nuisance species," ERDC/TN ANSRP-06-1, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Kondolf, G.M., and E.M. Micheli. 1995. Evaluating stream restoration projects. *Environmental Management* 19:1-15.

Lee, K. N. 1999. Appraising adaptive management. Conservation Ecology **3**(2): 3.

Lee, K. N. 1993. Compass and gyroscope. Island Press, Washington, D.C., USA.

Legg, C. J. & Nagy, L. 2006. Why most conservation monitoring is, but need not be, a waste of time. Journal of Environmental Management 78, 194-199.

Manuel-Navarrete, D., S. Slocombe, B. Mitchell. 2006. Science for Place-based Socioecological Management: Lessons from the Maya Forest (Chiapas and Petén), Ecology and Society, 11(1):8.

Margerum, Richard D. 1997. “Integrated approaches to environmental management and planning.” Journal of Planning Literature. 11, 4: 459-475.

Meffe, G.K., R.L. Knight, L.A. Nielsen, D.A. Schenborn. 2002. Ecosystem Management: Adaptive, Community-Based Conservation. Island Press. Washington, D.C., USA.

Nelson, Marj. 2000. The Changing Face of HCPs. *Endangered Species Bulletin.* 25 (4): 4-7.

Noon, B. R. 2003. Conceptual issues in monitoring ecological resources. In Monitoring Ecosystems: Interdisciplinary Approaches for Evaluating Ecoregional Initiatives, edited by D.E. Busch and J.C. Trexler, 27-72. Island Press.

National Science and Technology Council (NSTC). 1997. Integrating the Nation's Environmental Monitoring and Research Networks and Programs: A Proposed Framework. Final Report of the Committee on Environment and NaturalResources, Environmental Monitoring Team, Washington, DC. 101 pp.

Nyberg J. B. 1999. An Introductory Guide to Adaptive Management for Project Leaders and Participants.

O'Donnell, T. K., and D. L. Galat. 2008. Evaluation of success criteria and project monitoring in river enhancement within an adaptive management framework. Environmental Management 41 (1): 90-105.

Palmer, C. J. and B. S. Mulder (1999). Components of the effectiveness monitoring program. The strategy and design of the effectiveness monitoring program for the Northwest Forest plan. General Technical Report PNW-437. B. S. Mulder, B. R. Noon, T. A. Spieset al. Portland, OR, USDA Forest Service, Pacific Northwest Research Station: 69-97.

Raiffa, H., 1968. Decision Analysis: Introductory Lectures on Choices Under Uncertainty. Addison-Wesley, Reading,. MA.

Reeve, T., J. Lichatowich, W. Towey, and A. Duncan. 2006. Building science and accountability into community-based restoration: can a new funding approach facilitate effective and accountable restoration? Fisheries 31(1): 17-24.

Reid, T.S., and Murphy, D.D., 1995. Providing a Regional Context for Local Conservation Action: A natural community conservation plan for the southern California coastal sage scrub. BioScience Supplement 1995: 84-90.

Ringold, P. L., J. Alegria, R. L. Czaplewski, R. S. Mulder, T. Tolle and K. Burnett, 1999. Establishing a regional monitoring strategy: The Pacific Northwest Forest Plan. Environmental Management 23: 179-192.

Rogers, K. 1998. Managing science/management partnerships: a challenge of adaptive management. Conservation Ecology 2(2): R1.

Rogers, K.; Biggs, H. 1999. Integrating indicators, endpoints and value systems in strategic management of the rivers of the Kruger National Park. Freshwater Biology Vol. 41, p439-451.

Schreiber, E.S.G, A.R. Bearlin, S.J. Nicol, and C.R. Todd. 2004. Adaptive management: a synthesis of current understanding and effective application. Ecological Management & Restoration Vol. 5 Issue 3, p177-182.

Stanley, T. R. Jr. 1995. Ecosystem management and the arrogance of humanism. Conservation Biology 9:255-262.

Steidl, R. J. 2001. Practical and statistical considerations for designing population monitoring programs. Pages 284-288 in R. Field, R. J. Warren, H. Okarma, and P. R. Sievert, editors. Wildlife, land and people: priorities for the 21st century. Proceedings of the Second International Wildlife Management Congress The Wildlife Society, Bethesda, Maryland, USA.

Tear, T. H., P. Kareiva, P. L. Angermeier, P. Comer, B. Czech, R. Kautz, L. Landon, D. Mehlman, K. Murphy, M. Ruckelshaus, J. M. Scott, and G. Wilhere. 2005. How much is enough? The recurrent problem of setting measurable objectives in conservation. Bioscience 55: 835-849.

Trexler, J.C. & Busch, D.E. 2003. Monitoring, Assessment, and Ecoregional Initiatives: A Synthesis. En: Busch, D.E. & Trexler, J.C. Monitoring ecosystems: interdisciplinary approaches for evaluating ecoregional initiatives. (pp. 405-424. Island Press, Washington DC, USA.

U.S. Government Accountability Office. 2004. Environmental Disclosure: SEC Should Explore Ways to Improve Tracking and Transparency, GAO 04-0808.

Walters, C. J. 1986. Adaptive management of renewable resources. Macmillan, New York City, New York.

Walters, C. 1997. Challenges in adaptive management of riparian and coastal ecosystems. Conservation Ecology 1(2):1.

Walters, C. J., and C. S. Holling. 1990. Large-scale management experiments and learning by doing. Ecology 71:2060-2068.

Wilhere. G.F. 2002. Adaptive management In Habitat conservation plans. Conservation Biology. 16 (1) 20-29.

Williams, B.K., Szaro, R.C., and C.D. Shapiro. 2007. Adaptive Management: The U.S. Department of the Interior Technical Guide. Adaptive Management Working Group, U.S. Department of the Interior, Washington, D.C., USA.

Woodward, A., K.J. Jenkins, and E.G. Schreiner.1999.The role of ecological theory in long-term ecological monitoring: Report on a workshop. *Natural Areas Journal* 19:223-233.

Remote Sensing to Monitor Land Cover Change
Pima County, Arizona

Report to the Pima County Board of Supervisors

August 2008

Julia Fonseca
Office of Conservation Science

Pima County
Natural Resources,
Parks and Recreation

Tucson, Arizona

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Cover: Oblique aerial photograph of the Bullock fire in the Catalina Mountains, courtesy of NASA.

Abstract

Pima County will use a variety of information sources to monitor changes in ecosystems at different time intervals and scales of resolution. The National Land Cover Dataset, derived from Landsat satellite images, will provide inexpensive and valuable data for detecting gross changes in vegetation and urban development throughout Pima County every five years, thereby meeting one of the monitoring objectives established by the Science Technical Advisory Team. This will be supplemented with in-house review of high-resolution digital aerial imagery, obtained by the Pima Association of Governments (PAG) every three years. The PAG imagery would be used to detect land use changes in and around urban reserves, where edge effects may be most pronounced, thereby providing a leading indicator of ecosystem change. These two sources of information, coupled with analyses using Pima County's tax assessor database, PAG land use, and locations of building permits, roads and sewers, will support Pima County's efforts to adapt its activities toward meeting the goals of the Sonoran Desert Conservation Plan (SDCP).

Introduction

Pima County spans two primary eco-regions in Arizona: the Sonoran Desert and the Apache Highlands (Figure 1). The natural vegetation of the Sonoran ecoregion in Pima County is dominated by vast tracts of somewhat sparse desert scrub with narrow linear patches of denser scrub and woodland along ephemeral stream channels. Varying soils and geological substrates, as well as diverse hydrological conditions, contribute to the landscape complexity of the Sonoran desert. The natural vegetation of the Apacherian ecoregion is even more varied: a mixture of desert scrub and grasslands, studded by montane "sky islands" harboring a rich mix of evergreen and deciduous forests and woodlands. The sky islands are part of a larger ecoregion that extends from the Mogollon Rim south into the Mexican states of Sonora and Chihuahua (Marshall et al., 2004).

Pima County has adopted a plan to conserve the natural and cultural heritage of the area. The biological goal of the Sonoran Desert Conservation Plan (SDCP) places emphasis on the retention of native biodiversity through maintaining

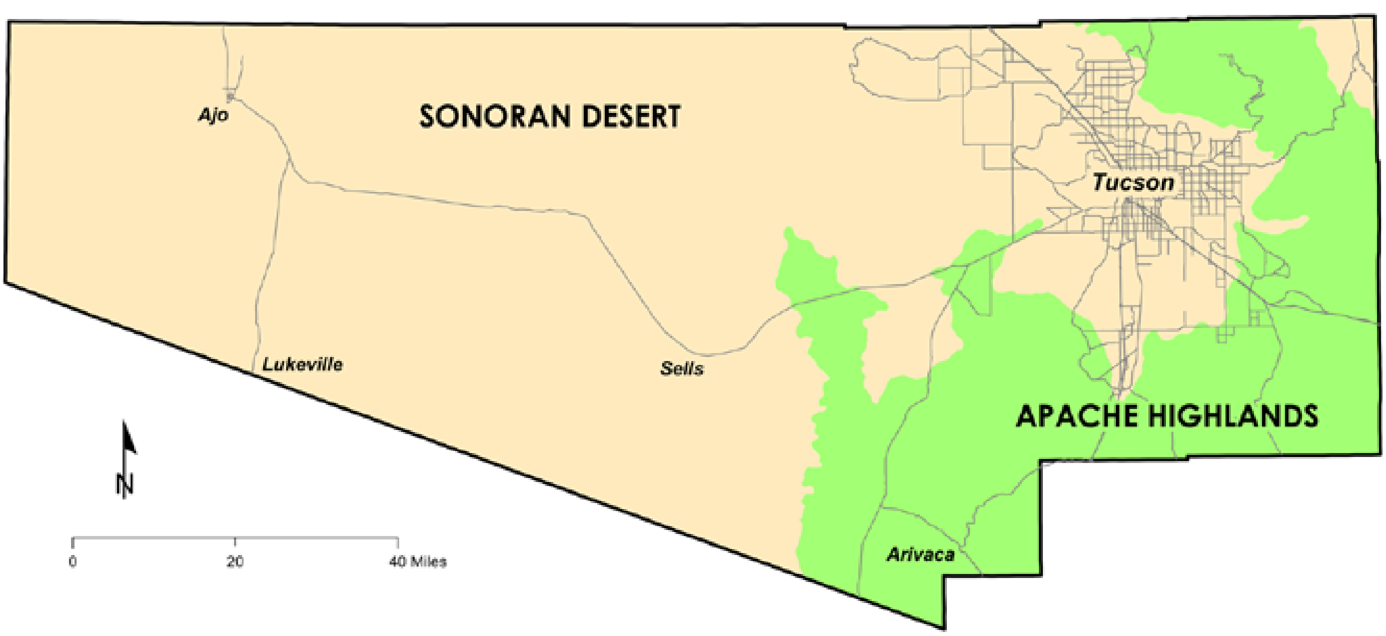


Figure 1. Ecoregional setting for Pima County

or improving ecosystem structure and function, rather than managing individual species. Our objective in developing the Pima County Ecological Monitoring Plan is to detect and quantify changes that can tell us whether Pima County is achieving the SDCP goal, and provide the County with information to direct land management actions including open space acquisitions, land and water resource management, infrastructure development and land use planning. The scope of Pima County's activities affects a wide and diverse area, ranging from high elevation forest lands in the Santa Catalina Mountains to low deserts near Ajo and Lukeville. Because of the diverse scope of Pima County's jurisdiction and actions, a broad view of landscape-scale ecosystem change is important.

The purpose of this report is to recommend appropriate types of ecosystem-level monitoring for the Pima County Ecological Monitoring Program. In 2006, the Science Technical Advisory Team (STAT) for the SDCP recommended that the scope of inference of the monitoring plan should be broad, not confined to the permit area or the committed lands alone (Appendix 1). Recognizing that resources for monitoring are and will be limited, the STAT proposed that remote sensing be used to monitor land cover as a means of tracking the loss of habitat on a gross scale due to land conversion. Furthermore, they recommended that the monitoring program should be phased: after an initial period of five years, all elements of the monitoring program will be assessed and modified to increase efficiency and effectiveness.

In accordance with STAT's guidance, this report will be focused on remote sensing techniques which can be used in the initial five-year monitoring period. Remote sensing of the landscape is an obvious tool to consider for a landscape as large and diverse as Pima County. Because the County's reserve system is highly fragmented and spatially distributed in various locations, remote sensing offers the promise of providing a broader context in which to view the forces operating upon reserves. A future report will address potential monitoring of vegetation using ground-based techniques.

Repeated measurements of *land cover* can be used to track changes in ecosystem structure and function, and measure direct impacts of development upon the land. Land cover refers to the biophysical aspects of the earth's surface or its immediate subsurface (McConnell and Moran 2000). Land cover is typically delineated into major categories such as types of natural vegetation (e.g., forest, shrubland, grassland) and the built environment such as urban development, agricultural fields, mine sites, and roads. Common measures of land cover include areal extent, the pattern of connectedness, or the diversity of cover types.

Land use encompasses both the activities on the land and the intent of the use (Turner et al. 1995). Figure 2 illustrates the difference between land cover and land use. For instance, the land cover classification of an area may be desert scrub, but the land use there could vary from park to active ranchland, and each could have very different and important conservation implications such as the potential for future subdivi-

Figure 2. Land cover types vary from left to right: Forest, barren, urban commercial, scrub. Land use types from left to right are all urban. More specifically, urban low-density residential, urban vacant, urban commercial, urban open space.

sion or mining. Typical measures of land use might include areal extent, length of linear infrastructure, or the number of points representing where particular land use activities occur. Mapping distinctions in the intent to conserve natural land cover is most important for our purposes.

Land use can be an excellent leading indicator of environmental condition and a major determinant of land cover (Meyer and Turner 1994). Further, the type, distribution, and extent of major land uses can foreshadow changes to the distribution and abundance of plant and animal species (Blair 1999; Hope et al. 2003; Hansen et al. 2005) or other parameters such as water quality (Soranno et al. 1996) that have important implications for maintenance of biodiversity and ecological health (Hansen et al. 1993) in Pima County (RECON 2007).

Changes in land use and land cover can reflect fundamental changes in the natural and built environments used by people and other animals. Runoff is particularly affected by change in land cover. Land cover metrics are useful because they respond quickly to change, such as fire and land conversion. At a global level, changes in land cover are used to detect patterns and extent of human disturbance, including habitat fragmentation. Watershed goals and species management goals sometimes have land cover standards to achieve for conservation. At a local level, changes in land use and landcover are also used for describing and analyzing purely social phenomena, such as urban land use trends or the effectiveness of land use policies.

FUNDAMENTALS OF IMAGERY ANALYSIS

Pima County will rely primarily on imagery obtained from aircraft and satellites to understand ecosystem changes across the breadth of our landscape. The spatial resolution of this imagery will vary from as high (fine) as 0.3 meters to as low (coarse) as 30 meters (approximately 100 feet), depending on the source. Figure 3 shows how resolution affects the ability to detect differences in land cover. Digital imagery is composed of a matrix of square cells called picture elements, or pixels, and its spatial resolution corresponds to the pixel size. High-resolution imagery will allow for smaller features to be distinguished than low-resolution imagery, but the increased data density generally imposes higher costs for analyzing the data.

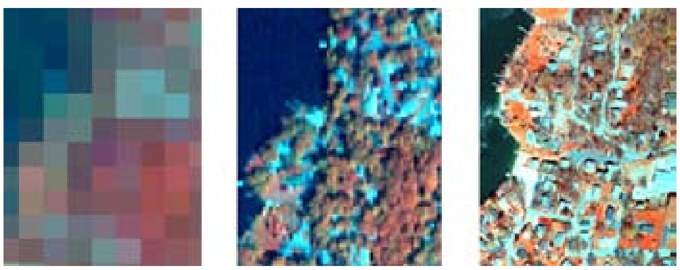


Figure 3. Image resolution affects detection of land features. This is the same image displayed at three different spatial resolutions. Left to right: Landsat resolution is based on 30-meter pixels; Ikonos has 4-meter resolution; airborne ADAR has 0.5-meter resolution. See http://clear.uconn.edu/projects/landscape/measuring/intro.htm for a good primer on remotely sensed imagery.

Imagery is created using sensors which detect light reflected from soil, vegetation or other material covering the earth. Each pixel contains a set of numbers representing the intensity of light (or other electromagnetic energy) reflected from the land surface in different wavelengths. The sensor determines the part of the spectrum which will be sampled. Sensors can detect not only visible light but also additional wavelengths not visible to the human eye. For instance, your digital camera uses sensors to record light in a range of wavelengths visible to humans. Different wavelengths appear as different colors. Satellite-derived land cover images typically also include information about wavelengths which are not visible to the human eye, particularly longer wavelengths from near-infrared to thermal-infrared (heat) energy. Near-infrared (NIR) wavelengths are especially useful for ecological monitoring, to discriminate among different types of cover, because reflectance in this range is so sensitive to the chlorophyll content of vegetation. Green plants reflect most of the NIR radiation striking them, while other objects reflect relatively little. Thermal infrared (TIR) reflectance can be used to examine variations in soil moisture content or study "heat island" effects in urban areas.

Widely available imagery sources provide specific combinations of spatial resolution and spectral characteristics. Some common imagery sources are listed in Table 1. The last one listed is the imagery funded by local governments through a contract with the Pima Association of Governments (PAG). This is the only type of imagery that is regularly acquired by local government or land managing agencies in our region. It is discussed in greater detail under land use.

After an image is acquired, there are a number of additional steps which must be taken to process and analyze the image.

Type of Imagery	Spatial Resolution	Wavelengths	Cost
AVHRR	1090 m	6 bands Visible-TIR	Free, or nominal
Landsat	30 m	7 bands Visible-TIR	Free, or nominal
Ikonos MSS	4 m	4 bands Visible and NIR	$25.20 / sq. km
Panchromatic	1 m	Visible only	
Quickbird MSS	2.44 m	4 bands Visible and NIR	$28 / sq. km
Panchromatic	0.6 m	Visible only	
PAG Aerials	0.3 m (1 ft)	(3 bands?) Visible	$77.22 / sq. km

Table 1. Imagery Characteristics. Costs cited are for new imagery (Jennifer Psillas, Pima County Natural Resources, Parks and Recreation; Sam Drake, Office of Arid Lands Studies)

These steps take additional time, money and considerable training to execute. For these reasons, the cost of utilizing remotely sensed imagery can be high, especially for Pima County's geographically dispersed reserve system, which spans a great variety of climatic and topographic settings.

The steps to make imagery useful often include:

1. Radiometric and/or geometric corrections to remove systematic errors
2. Georeferencing or orthorectification
3. Atmospheric correction
4. Image data processing for specific applications
5. Developing a classification system
6. Applying a classification system to the processed image
7. Accuracy assessment of the imagery classification
8. Change detection analysis using imagery from at least two different time periods

Step 1 is usually done by the data vendor, and step 2 may be done at additional cost. Steps 3-6 are usually done by the user, or by a separate vendor with those specialized skills. In some cases, steps 4, 5 and 6 are iterative, so that the classification accuracy can be improved. Fieldwork may be needed for step 7, unless higher resolution imagery or other source data are available to test and improve the accuracy of the classification. Step 8 occurs when a time series of imagery from the same location is available, and is sometimes performed by a different set of people than the other steps.

LAND COVER IN PIMA COUNTY

There have been many separate efforts at characterizing Pima County's land cover (Fonseca, 1999). A consortium of federal agencies mapped Arizona in 1992 using various Landsat images and the Anderson Level 2 classification (Table 2). The Anderson classification (Anderson 1976) is widely used for land cover studies and primarily on the physiognomy (structure) of the vegetation and the distinction between urban, agricultural and industrial land uses in the built environment.

Connolly et al. (2000) used a combination of 1992 Landsat imagery and local land cover maps to estimate that approximately 355,605 acres in Pima County had been converted (lost) to urban, agriculture, or mining uses, with most losses occurring in the Tucson and Avra basins. The 1992 Landsat data were used to estimate the extent of urban, agricultural and mining land cover.

The environmental consulting firm RECON prepared a composite land cover map for the Sonoran Desert Conservation Plan (RECON 2000). It used the most accurate information that Pima County could compile at that time. The source data included site-specific investigations spanning many decades. Because the composite vegetation map was derived from various time periods, it cannot provide a suitable baseline for monitoring land cover change over time. Since then, new federal efforts have provided representations of land cover at the national scale.

National Land Cover Database

The National Land Cover Database is the current system used to describe land cover in the US (Horner et al. 2004) and serves as a basis for monitoring land cover change. Figure 4 shows the NLCD 2001 for Pima County. The processed, analyzed data for 2001 are available at no cost from the Multi-Resolution Land Characteristics Consortium (MRLC). Data is acquired at a resolution of 30 meters every 5 to 10 years and change can be resolved at a minimum of 1 acre (http://www.mrlc.gov/changeproduct.php). However, because of long processing times, results are not delivered back to users for years after the date of imagery acquisition.

The 2006 land cover data are being analyzed by MLRC, but have not yet been released. MRLC will compare imagery from 2001 and 2006 spectrally. Areas identified as changed

1. Urban or Built Up Land
11. Residential
11A. High Intensity Residential
11B. Low Intensity Residential
12. Commercial
13. Industrial
14. Transportation, Comm, Util
15. Indust/Commercial Complexes
16. Mixed Urban or Built-up Land
17. Other Urban or Built-up Land
17A. Urban/Recr'l Grasses
2. Agricultural Land
21. Cropland & Pasture
21A. Crops
21B. Pasture
21C. Fallow
22. Orchards, Vineyards, etc.
23. Confined Feeding Operations
24. Other Agriculture
3. Rangeland
31. Herbaceous Rangeland
32. Shrub/Brush
33. Mixed Rangeland
4. Forest
41. Deciduous Forest
42. Evergreen Forest
43. Mixed Forest
5. Water
51. Streams/canals
52. Lakes
53. Reservoirs
54. Bays/estuaries
6. Wetland
61. Forested (woody) wetland
62. Nonforest (herbaceous) wetland
7. Barren Land
72. Beaches
73. Other sand
74. Bare exposed rock
75. Strip mines/quarries/gravel pits
76. Transitional areas
77. Mixed barren lands

Table 2. Anderson Classification. Level 1 (shaded, single digit) and Level 2 (double digit) classes. Classes with letters are supplemented from the National Land Cover Database. From a National Park Service classification protocol (Townsend, 2006)

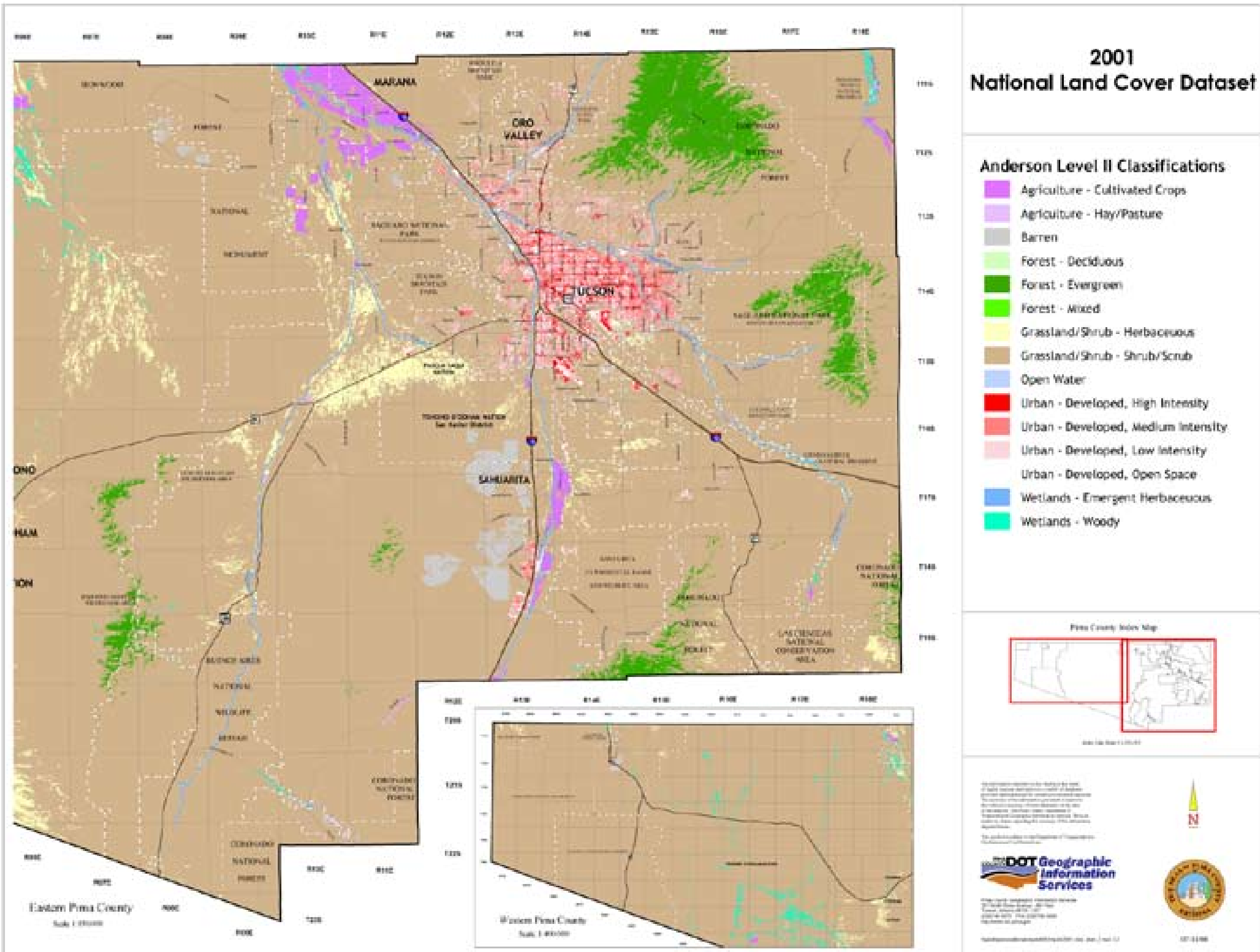


Figure 4. National Land Cover Dataset for eastern and western Pima County, displayed at Anderson Level 2.

will be extracted from the image sets and classified according to NLCD 2001 methods at Anderson Level 2. The 2001-2006 change detection, land analyses will be released to the public at no cost, however a timeline for completion is not yet available.

Pima County and its partners can use the NLCD to detect conversion of natural cover to urban and mining land uses, and to observe changes in the distribution and extent of bare soil, deciduous and evergreen forest, grassland/shrub and riparian "wetlands" (primarily mesquite bosques, broadleaf deciduous forests, and herbaceous seasonal wetlands combined).

The NLCD can provide unique information on the conversion of natural land to urban development at the local, state and national level. There is no local program to detect or report acres of land cover altered by mining, agriculture or tribal activities. Therefore, NLCD's change detection product can provide a periodic, cumulative assessment of landscape changes for the Sonoran Desert Conservation Plan that is not otherwise available. NLCD data can also provide a metric for direct urban impacts upon land cover by each jurisdiction, independent of local agency development tracking methods discussed later in the report.

One of the most important drawbacks to using the NLCD are the long time lags between satellite acquisition and release of the processed data to the public, which can exceed two years. These time lags mean that Pima County's can only use these data as a retrospective tools for landscape change—change that may no longer be occurring at the same rate or location. Such time lags may not be so vexing to the interpretation of landscape-level changes as it might seem at first glance. Changes in species and their habitat features may be apparent more quickly, but also change significantly from year-to-year, thereby making long-term trend detection difficult, except over longer time periods (see treatise on this subject in Powell 2008, in prep). The significance of trends in species or habitat will be informed by the history of land cover change. In addition, some ecosystem shifts are, by nature, slow, subtle, and often uni-directional such as the re-growth of forests or the incursion of shrubs into grasslands.

Pima County Geographic Information Systems (GIS) has analyzed change detected by the NLCD between 1992 and 2001 as a trial to test what types of change can be detected by this source of information. The results will be described more fully in an upcoming report (Fonseca et al., in preparation). Using GIS, Pima County can assess where change is occurring relative to various administrative and natural boundaries. Most land cover change during this time period occurred on private lands in eastern Pima County, primarily due to urbanization. By contrast, on federal lands most of the change was between forest and grassland/scrub, primarily due to forest fires, with little net loss of cover. NLCD data also shows trends in riparian forest cover that parallel those detected in other regions (Fonseca et al., in prep.) These types of changes in land cover may exert powerful influences upon ecosystem structure and function.

NLCD Strengths:
- nationally consisent monitoring
- detects removal of land cover
- detects gross change in vegetation structure
- change detection product available at no cost
- independent source

NLCD Weaknesses:
- imagery analyzed at infrequent intervals
- may not detect scrub-grassland shifts
- low-density ex-urban residential may be underestimated
- unreliable detection of agricultural change

Our analysis also shows that there are limitations, of course, to the usefulness of NLCD for detecting some land cover changes likely to occur in Pima County in the future. NLCD Level 1 cover types are very broad and relate primarily to gross changes in the vegetation structure and urbanization. It remains to be seen whether the Level 2 NLCD analyses for 2001 to 2006 will be able to detect natural conversions between desert scrub and grassland in our region, a vegetation shift that is of interest for understanding habitat suitability change. NLCD will not detect invasions by non-native grasses. NLCD data are also unreliable for detecting changes in the agricultural category, at least in a way that might be most meaningful for our project. The accuracy assessment is not complete, but is reported to range from 70% to 98% (USEPA, 2007).

In the eastern United States, the 30-meter resolution has proven to be unreliable for detecting low-density residential (LDR) development of one dwelling per one-half acre or less (Irwin and Bockstael, 2007). Low-density residential makes up a high proportion of total development in unincorporated Pima County. There is ample evidence to suggest indicate that low-density ex-urban development can greatly affect ecosystem structure and function as well as species richness (Maestas, et al, 2003; Lenth, et al. 2006). Detecting land cover change associated with this development is therefore important to the PCEMP. Our inspection of NLCD imagery indicates that many of the changes associated with LDR may go undetected at the 30-meter pixel resolution, such as partial removal or intensification of vegetation. However, the acreage of many of the direct impacts of roads associated with LDR upon land cover may be quantified with NLCD 2001 in Pima County due to lack of obscuring tree canopy (Figure 5). This idea would need further analysis to demonstrate feasibility.

The Anderson classification system used by NLCD is relatively stable. In general, however, land cover monitoring continues to evolve, and future changes in the classification algorithms and sensors can make year-to-year comparisons less accurate. The results should be examined for artifacts generated from changes in methods of detection rather than just actual changes on the ground. Any change detection product

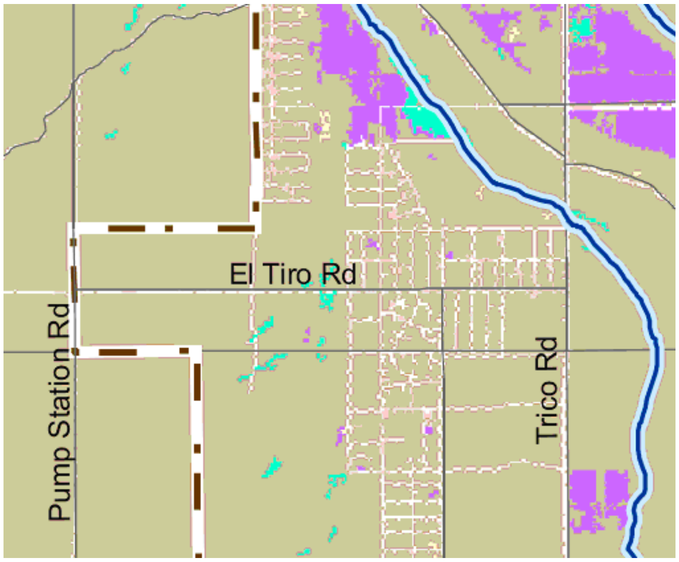


Figure 5. An area of low density residential ex-urban development as shown on NLCD 2001. Roads (called transportation corridors in the Level 2 classification) are white, low density residential is light pink. Actual residential footprint is more scattered than shown here, but the roadway network is largely accurate. Agriculture is purple, brown is shrub/scrub, and teal areas are woody wetlands. This area is bounded by Los Robles Wash (blue line) on the east and Ironwood Forest National Monument (white and brown dashed line).

released by NLCD should be reviewed against higher-resolution imagery or other Pima County GIS data sources to understand systemic biases.

GAP Vegetation and Other Land Cover Sources

Another federal effort is the Gap Analysis Program (GAP), which provides periodic assessments of the conservation status of native vertebrates and their habitats. Gap analysis itself is a scientific means for assessing to what extent native animals and their habitats are being protected. GAP has produced the new, regional land-cover maps, such as the Southwest Regional GAP land cover, (cite) as one tool for habitat analysis. The maps use the National Vegetation Classification System (NVCS) and landform information (e.g., elevation, slope, aspect) to classify natural and semi-natural ecological communities. Like the Anderson classification scheme, NVCS has a hierarchical structure, with the upper levels of the NVCS hierarchy being based primarily on vegetation structure (e.g. forest versus savanna and grassland)—such that these can be related ("crosswalked") to Anderson levels 1 and 2 in the NLCD. At the lower levels, the NVCS hierarchy relies on floristic characteristics, thus providing a finer scale understanding of the distribution of vegetation cover types than NLCD can offer. Agriculture and urban land cover types for GAP are derived and generalized from the NCLD. Recently burned areas are differentiated on the basis of Landsat imagery interpretation.

Updates to GAP vegetation maps could be used to detect large changes in the patterns and distribution of the natural vegetation cover types in Pima County if data analysis techniques are not greatly altered between iteration. GAP vegetation mapping cannot be relied upon for detecting shifts among several grassland and scrubland types in the Chihuahuan ecoregion, because a number of types are similar in terms of their spectral reflectance Lowry et al., in prep. And while GAP does define vegetation classification does include cover dominated by non-native plants, very little was actually captured for our area.

U.S. Geological Survey's Center for Earth Resources Observation and Science (EROS) is studying the types, rates and causes of land cover change using Landsat imagery at the ecoregional level during the time period 1973-2000. Their studies use Landsat and other sources to interpret land cover change at sample sites. Their study for our region is not yet available, and will not report information at the county level or constitute a monitoring program per se.

Burned areas have been mentioned as a potential type of land cover change worthy of monitoring (RECON, 2007). In Phase 1 of the Ecological Monitoring Plan development, participants did not rate fire or burned area monitoring as a high priority. Changes in land cover that result from fire are of more interest than the aerial extent of fire itself. While fire may not cause a land cover change, like floods, they represent an explanatory process. Various federal agencies compile fire histories for our area, and their data can be used, if necessary, to interpret land cover change detected by other means.

In conclusion, the NLCD can provide a regional context for monitoring changes in ecosystem structure in Pima County; it can detect some changes in vegetation structure that would be costly and time-consuming to obtain, such as changes in distribution of forest cover and wet floodplain vegetation. However, because there will be long lag times between when the data are collected, analyzed, and reported in both NLCD and GAP, and there are inherent limitations in the reliability of the data, Pima County should not rely solely upon these federal sources to detect change in land cover. In particular, Pima County should seek other means to monitor loss of land cover and other effects associated with low-density development which is disconnected from the urban center, and small-scale changes within its reserve system. Suggestions for acquiring these data are highlighted in the next section.

Opportunities for Monitoring Land Use

The Pima County GIS Library includes over 1,100 GIS layers. GIS information is made available to the public and other agencies through the Internet at www.dot.pima.gov. Aside from the GIS library, users can also display and superimpose GIS layers via a MapGuide viewer, or download GIS information via FTP site.

The largest and most complex of the GIS Division's datasets is the Parcel layer, also called the Landbase. This data layer contains over 429,000 polygons representing property boundaries. Each one of those parcels has 73 attributes, including land ownership and a use code which can be related to land uses. Parcel use codes are updated every year for tax assessment purposes, but are often "blind" of land use information for parcels owned by authorities which are not taxed. Parcel boundaries are updated whenever parcels are split or legally subdivided, and thereby provide an indication of areas where land use intensity is likely to change. However, parcels may be split years or even decades before construction.

From a practical standpoint, one of the most important land-use attributes that Pima County should monitor is the protection afforded to natural cover by various state, federal and local measures. The formal name for this attribute is land stewardship. Changes on federal and state land stewardship are tracked by the GAP program mentioned earlier in this report. The GAP land stewardship classification recognizes differences between areas which have a biological conservation mandate, and those that do not. In addition, the security of the protective designation is used to classify stewardship. GAP's land stewardship coverage for Pima County was reviewed for this project and found insufficient for local use. GAP's land stewardship data is out of date and incomplete compared to local records for our area.

Pima County GIS maintains a "preserves" coverage that includes GAP classification as an attribute. This allows our local data on land stewardship to be displayed using the national classification system at a much finer, parcel-level, resolution, with much greater accuracy regarding the potential for future development. Protection levels are in a state of flux due to ongoing land acquisitions, exchanges, Congressional legislation, and state ballot measures. Pima County staff should continue to monitor changes in land stewardship and report changes to this attribute in its "preserves" GIS coverage. This information will be used in annual land use updates prepared by Pima Association of Governments (K. Zimmerman, personal communication.)

PAG Land Use Monitoring

Pima Association of Government (PAG) characterizes urban land use for metropolitan jurisdictions. The methodology and categorization system was tested in 2005 and 2006; the 2007 dataset is the first complete dataset. Their protocol is attached as Appendix 2, and relies upon the parcel base as only one source of information. Their land use representation is updated annually to support the PAG travel and land use models. The primary strength of their system is that they classify land use for federal and institutional categories (and other categories) for which the parcel use codes are unreliable or absent. PAG land-use data can supplement the County parcel data to help classify remotely sensed data more accurately into urban density categories or to verify certain other man-made land cover modifications.

The removal of natural land cover by many other types of urban development is not tracked by local governments. Building permits can however be used to understand the distribution of development on a yearly basis. PAG compiles all of the building permit information for local government on an annual basis. Building permit locations are point locations: the total acreages of land affected by the permit cannot be derived from this source, nor from grading permits issued by individual jurisdictions. The building permit attributes include distinctions between single-family and multi-family dwellings, and between housing types, such as mobile homes versus townhomes. Building permits can be used to identify the location of development on an annual or cumulative basis. Figure 6 shows the data from 2007. Permits are issued for modification of existing structures, not just new construction. For the ecological monitoring plan, plots of building permits relative to county reserves might help identify "hot-spot" areas where indirect impacts are likely to intensify in the near-future.

PAG combines building permits with census information to establish residential densities, which could be useful for understanding indirect impacts of population growth on habitat. Census data are used to establish an estimate of the

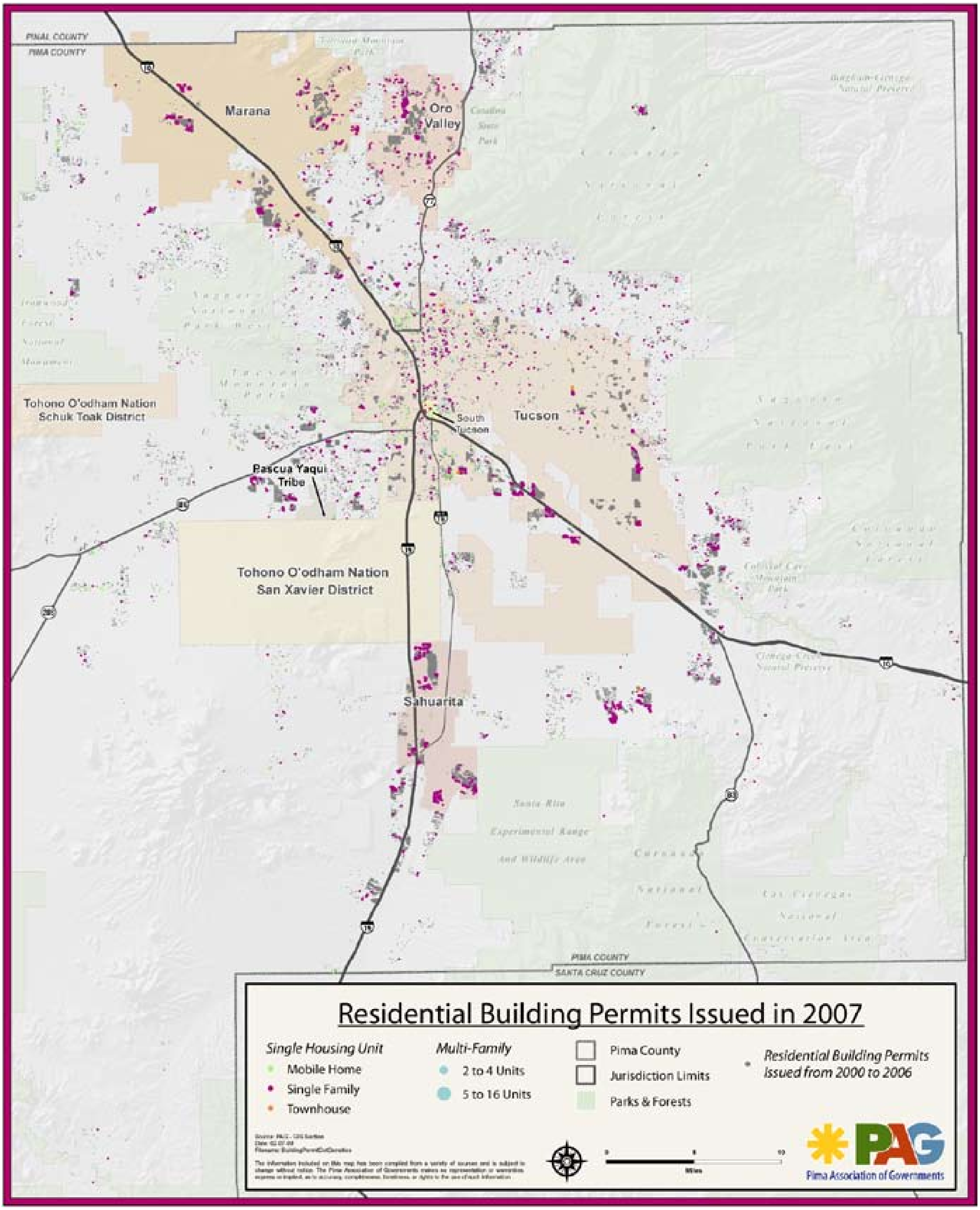


Figure 6. Development permits issued in 2007. Pima Association of Governments map. Colors represent types of housing permits.

number of housing units in 2000 per PAG residential land use polygon. Then, PAG adds the address-level building permits to estimate the number of housing units in the run year (e.g, 2007, 2008, etc.) per residential polygon (Kristin Zimmerman, personal communication, 2008). The polygon geometry and the land use codes do not change from year to year, just the attribute data associated with them. In essence, this process aggregates contiguous parcels with the same assessor use code together, and assigns these 'neighborhoods' a 2000 housing unit count and a current year housing unit count. Users can then derive neighborhood level densities from the count estimates.

PAG coordinates natural color aerial imagery acquisition for metropolitan Tucson. Imagery is acquired at approximately three-year intervals (2002, 2005, 2008). Figure 7 shows that the extent of the 2005 imagery. PAG 2005 imagery encompasses over 81,000 acres of Pima County's mountain parks, and the Cienega Creek Natural Preserve, Saguaro National Park West, Catalina State Park, and many of the small urban reserves. Around 118,000 acres of County reserves, primarily in the Rancho Seco, A7, Diamond Bell and Six Bar ranches, lie outside the 2005 imagery boundaries (Jennifer Psilla, personal communication).

At the 2-foot resolution of 2005 imagery, individual trees can be discerned, as well as wash bottoms, houses and trails (Figure 8). Future imagery acquisitions will be at 1 foot or better resolution. Because the primary purpose of the imagery acquisition is for planning and engineering urban infrastructure, PAG members have sought increasingly high horizontal and vertical accuracy, a trend which is increasing the unit cost and leading to decreases in aereal extent of coverage.

It is currently infeasible to obtain this imagery for all of the permit area, or even all of the County reserve system, each year. The three-year interval between imagery acquisition dates represents a compromise in terms of balancing the cost, accuracy and processing time. PAG imagery acquisition can be expanded beyond the metropolitan area. Increasing the spatial extent costs Pima County about $200 per square

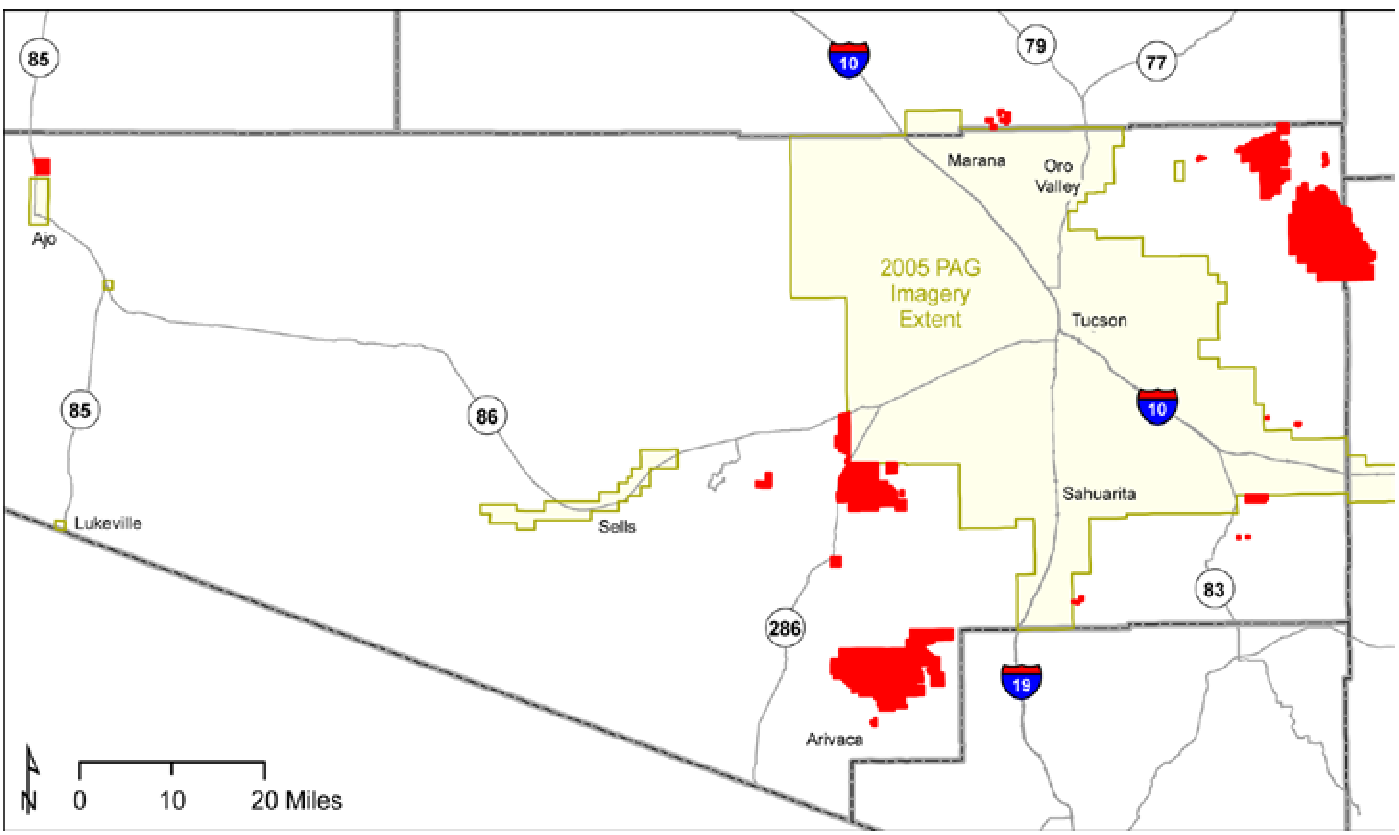


Figure 7. Extent of 2005 PAG imagery is outlined in beige, County reserves outside the photographic extent are shown in red.

Figure 8. Trees, shrubs, roads, houses, small washes, and social trails can be distinguished in this high-resolution PAG 2005 color aerial available to the public at Pima County's Mapguide system. Black lines represent parcel boundaries. Pima County could use these digital images for change detection.

mile. In other words, around $40,000 per year would be needed to cover all of the reserves currently outside the 2005 baseline extent, for any given year. Additional funding was provided to PAG by Pima County to acquire 2008 imagery acquisition for A7 and Bar V Ranches. With additional funding, or a decrease in resolution, the extent could be enlarged in 2011 to cover these and other new acquisitions, but this course of action should be weighed against obtaining multispectral imagery from other vendors. For instance, it would be cheaper to acquire Quickbird multispectral images at $73 per square mile (Sam Drake, personal communication); for this investment, ecologists would receive both visible color and the near-infrared bandwidths. Infrared spectra, which would be useful for land cover/land use classification and urban heat-island studies, are collected by PAG's vendor, but PAG jurisdictions have not purchased these data. To process the PAG imagery for infrared would cost an additional $75,000, and would provide us with a very good sense of what portion of the land is occupied by the built environment. No monies were available to do this for the 2008 flight.

PAG imagery provides an unparalleled resolution, but any imagery would require classification or analysis to become information useful to monitoring land use. At present, Pima County has limited capacity to process remote sensing imagery. To fund a graduate student at University of Arizona to process and classify imagery might cost $20,000 (excluding software costs) and take a year to return meaningful results.

Until such time as the budget can fund multispectral image acquisition and analysis, interpreting the high-resolution PAG imagery to detect removal of natural land cover in County reserves would be one way to track habitat condition. County-managed lands should be foci for monitoring because they are where Pima County's ability to respond to ecosystem change is the greatest. Reserve management is part of the county's mitigation for habitat take elsewhere. The 2005 and 2008 PAG color imagery are suitable for examining change on small preserves located in urban and suburban settings, where edge effects would likely affect a greater proportion of the area. While natural land cover removal from County projects should be minimal within a preserve, it could occur through various approved or illegal activities: off-road vehicles, utilities, mines, vegetation manipulation by adjacent homeowners, trailhead development, and social trails. The resolution of the NLCD is too coarse to pick up some of these land-use effects. The 2005 and 2008 PAG imagery could be compared to detect land-use changes and loss of natural cover in and around the periphery of reserves.

County Parks staff could use the 2005/2008 photographic series detect change in within their areas of familiarity. This would take advantage of the human eye and brain, and could be effective in mapping human disturbances accurately than automated classification systems. Detecting land cover change in and around the periphery of a preserve could provide an information feed-back loop to land managers. A protocol for sampling and reviewing the imagery, and cataloguing and reporting the changes by different observers in a systematic way would be essential. "Virtual transects" could be established for review during successive years. Potentially, other free aerial photographic sources could also be pressed into service, if resolution was consistent. Initially, free ArcReader plug-ins, jpgs or Adobe pdfs could be used to record annotations by land managers. Jpgs or PDFs would require digitizing by GIS staff to transfer annotations to ArcGIS. Pima County GIS is exploring various options to conduct this type of analysis.

Fragmentation Analyses

Conversion of natural land cover can be regarded as a direct measure of wildlife habitat loss. Dispersed patterns of residential and commercial growth in the United States have raised ecological concerns about indirect impacts caused by fragmentation (breaking up wildlife habitat into smaller areas), and the spread of invasive exotic species (Theobald, 2001).

Pima County should apply some simple metrics of natural land cover unit size, configuration, and connectivity deemed relevant to a wide range of species, to examine the indirect effects of landscape fragmentation using the NLCD. Protocols are being formulated for fragmentation analyses by the National Park Service's Inventory and Monitoring Program, but these are mainly for forested areas outside the Sonoran Desert. Pima County will coordinate with NPS and others regarding protocols for fragmentation analyses.

Fragmentation by roads and sewers is also of interest due to its connection to the scope of County activities. Sewers facilitate intensification of land uses. Roads are of interest as a form of direct habitat loss, but more particularly roadways are associated with many indirect and cumulative effects upon habitat (Forman 2003). The 2001 NLCD transportation corridors cover type will be used as a baseline to measure direct habitat impacts. acres of change over time. Successive versions of NLCD will be used to detect direct impacts across all jurisdictions, regardless of whether the transportation corridor is legal or illegal. In addition, Pima County will report extensions of County roads and sewer systems into the Conservation Lands System as a measure of the degree to which County infrastructure has fragmented the Conservation Lands System. The baseline for this will be July 2006 data. Pima County regularly updates its GIS to reflect sewer extensions and additions of County-maintained roadways.

In response to habitat considerations and other needs, some land use jurisdictions, including Pima County, have adopted "smart growth" approaches that tend to cluster development and encourage infill and redevelopment of urban areas (Pima County, 2001). Metrics relating to spatial configuration of regulated development types could be used to test the effectiveness of smart growth techniques or regulations, possibly using grant funding to support the work. This could be viewed as the inverse of examining habitat fragmentation, because here the growth patterns are the focus of investigation. While not central to our initial program development, studies of growth patterns could be an important complement to ecosystem monitoring, providing information useful to future land-use planning.

Proposed Land Cover and Land-use Monitoring Program

Existing staff with the Office of Conservation Science (OCS), within Pima County Natural Resources, Park and Recreation Department, would direct analyses of land use and land cover data for ecological monitoring. The Pima County Geographic Information System Division would be the primary data analyst. It is also possible that Pima County might choose to contract with individuals or agencies for supplemental analyses. Information and metadata is and would continue to be stored in the existing Geographic Data Library. Data collected by PAG and the federal government at no charge to Pima County would be used to supplement Pima County's information.

Figure 9 summarizes recommendations for the EMP. At the annual time scale, analysis would focus on detecting short-term change in land use at a high spatial resolution. At five-year intervals, determined by the availability of NLCD products, OCS would analyze regional change in land cover. Episodically, OCS would utilize land use projections to predict land cover change into the future. By looking forward as well as back, we would hope to produce information to inform urban land use planning, not just land management of the reserve system.

On an annual basis, Pima County GIS and PAG would maintain and update land use databases in preparation for later regional analyses. OCS would report changes to the GAP status due to land acquisitions, and report road and sewer basin extensions and major land use changes annually. OCS could look for land cover changes in and around the reserves

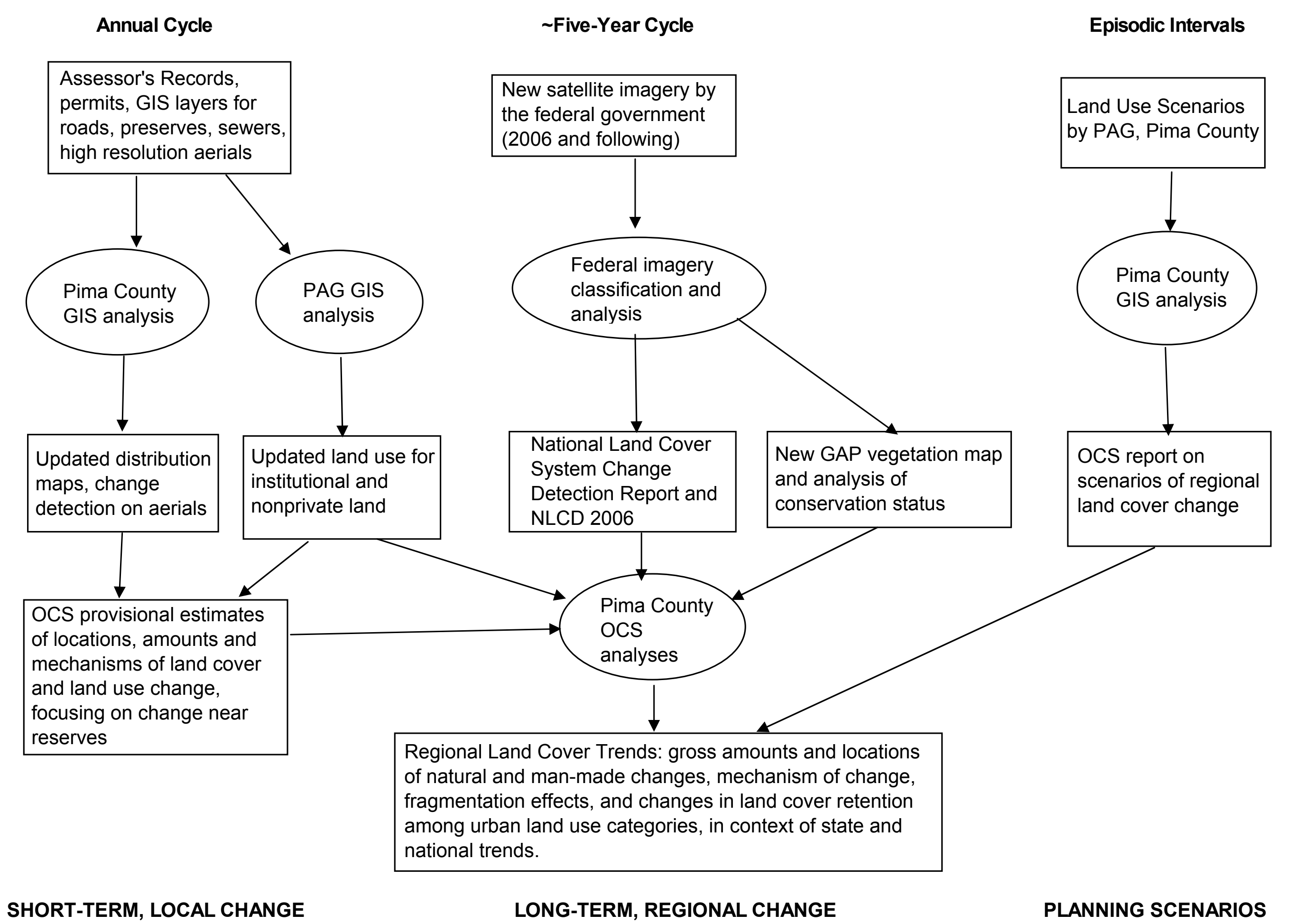


Figure 9. Proposed land monitoring program cycles and products would span temporal and spatial scales to give a complete picture of land cover change in Pima County.

using high-resolution aerial imagery. Depending on the success of investigations now ongoing, use of high-resolution aerial imagery to detect change might be limited to a few reserves each year, or if a more efficient and automated protocol could be developed, then the entire PAG imagery set could be analyzed. New imagery is available about every three years. Analyses would be limited by the geographic extent of the available high-resolution imagery, unless a specific funding source is provided.

As NLCD change detection products are released by MRLC, Pima County GIS would analyze gains and losses in land cover types throughout Pima County and the OCS would attempt to explain why the changes occurred in the context of available research and ancillary data by others. More specifically, Pima County's integrated GIS enables a much better understanding of changes detected by the National Land Cover Datasets than is afforded in most other jurisdictions of the country. By utilizing a combination of Landsat and high-resolution imagery, coupled with unique GIS datasets already tracked by Pima County, the ecological monitoring program (EMP) could understand changes occurring multiple scales of analysis.

An advantage of utilizing the NLCD would be to enable the OCS to put county-level observations within a state and national context. If warranted, the NLCD could be particularly valuable when investigating declines of Priority Vulnerable Species by looking at fragmentation of species' habitat due to changes in regional land cover. Changes in land cover retention within built-out areas could be examined to detect post-construction trends. Progress toward conserving plant communities and species habitat would be reported by OCS.

Periodically OCS would like to examine scenarios for future land cover change that involve different development assumptions This would probably be done in conjunction with land use planning needs, either for County Comprehensive Plan updates or other purposes. In all likelihood, these analyses would be restricted to eastern Pima County, where most of the land cover change relative to Pima County operations occurs.

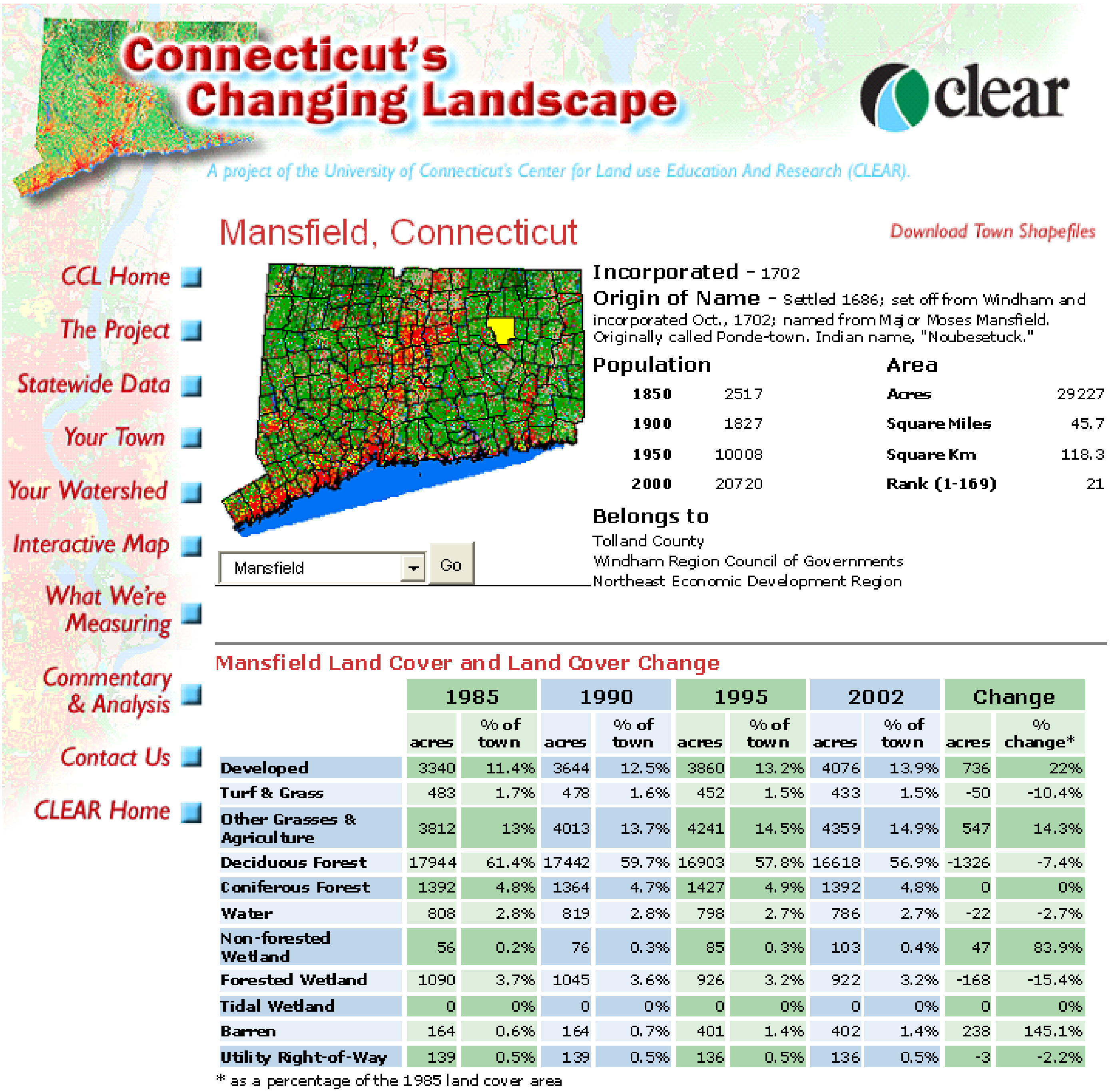
Products

The final product would be a report called Regional Land Cover Trends, which would integrate analyses of local and federal data on land cover change with a prognosis for potential future land cover change based on at least one short-term (5- to 10-year) scenario of private, state, and federal land use change. This report would be geared toward identifying issues relevant to adapting the scope of Pima County operations to meet SDCP biological goals.

The proposed land cover and land use monitoring could address questions of interest to those outside the County reserve management system. Some ancillary uses of land cover/land use data might include answering questions such as:

1. How does Pima County's land utilization for residential subdivision development compare with national trends?
2. What percentage of a given watershed is impervious cover versus forest cover versus desert scrub, and how has this changed over time?
3. Are abandoned agricultural fields and sand bars in major watercourses revegetating naturally?
4. How many acres of mined lands are in Pima County and where has revegetation succeeded?
5. What is the long-term consequence of forest fire on regional land cover?
6. What is the overall acreage of roadways in a given jurisdiction?
7. Does the pattern of Pima County's urban expansion fit a given model?
8. Was a particular ordinance effective in altering the configuration of new development?

Ultimately, it would be desirable to provide information about Pima County's changing landscape in a user-friendly manner to the public and other SDCP land-managing partners via the Internet. One model might be University of Connecticut's land cover change project, which reports land cover and population change by township and watershed boundaries (Figure 10). Pima County and Connecticut are similar in scale.



	1985		1990		1995		2002		Change	
	acres	% of town	acres	% of town	acres	% of town	acres	% of town	acres	% change*
Developed	3340	11.4%	3644	12.5%	3860	13.2%	4076	13.9%	736	22%
Turf & Grass	483	1.7%	478	1.6%	452	1.5%	433	1.5%	-50	-10.4%
Other Grasses & Agriculture	3812	13%	4013	13.7%	4241	14.5%	4359	14.9%	547	14.3%
Deciduous Forest	17944	61.4%	17442	59.7%	16903	57.8%	16618	56.9%	-1326	-7.4%
Coniferous Forest	1392	4.8%	1364	4.7%	1427	4.9%	1392	4.8%	0	0%
Water	808	2.8%	819	2.8%	798	2.7%	786	2.7%	-22	-2.7%
Non-forested Wetland	56	0.2%	76	0.3%	85	0.3%	103	0.4%	47	83.9%
Forested Wetland	1090	3.7%	1045	3.6%	926	3.2%	922	3.2%	-168	-15.4%
Tidal Wetland	0	0%	0	0%	0	0%	0	0%	0	0%
Barren	164	0.6%	164	0.7%	401	1.4%	402	1.4%	238	145.1%
Utility Right-of-Way	139	0.5%	139	0.5%	136	0.5%	136	0.5%	-3	-2.2%

* as a percentage of the 1985 land cover area

Figure 10. Screen print of a web-accessible data report for land cover monitoring. Such an application would be desirable for Pima County by informing residents of land-cover changes by jurisdiction or watershed.

Summary Recommendations

1. The NLCD 2001 should be used as a regional baseline for monitoring land cover change across jurisdictions in Pima County, realizing that other datasets may be better for applications at finer scales.

2. Pima County should prepare a sample report based on the 1992-2001 NLCD to develop the protocols for using the NLCD 2001-2006 change detection product (when it is available) to analyze and report land cover change.

3. The NLCD 2001-2006 change detection product should be examined (when available) to determine its usefulness for detecting shrub-grass conversions.

4. Pima County should develop methods to detect changes in the distribution and intensity of low-density residential exurban development using a combination of building permits, NLCD and roadway data.

5. Pima County should explore and compare methods for detecting land-cover change within its urban reserves, and develop a sampling plan. Initially, this will consist of in-house experiments using visual review by County staff and trials of supervised classification of PAG high-resolution imagery for selected reserves.

6. Pima County should monitor and report changes in land use, ownership, and the extensions of County roads and sewers as leading indicators of land cover change.

7. Pima County should continue maintaining the "preserves" layer and monitoring changes in GAP land stewardship status in the entire area.

8. Pima County should explain land cover data in reports and if possible, provide simple change-analysis tools on Pima County's Internet site that report changes by geographic areas meaningful to the public (see below)

This report outlines products and procedures for assessing land cover change and provides suggestions for combining this information with land-use and fragmentation metrics for a complete picture of landscape change in eastern Pima County. This information will form a critical foundation for the Pima County EMP. Like all broad-scale change detection, the effects of land cover change will also be expressed as changes in other landscape elements that are important for the structure and function of the Sonoran Desert ecoregion, most importantly water resources, soils, plants, animals, etc. The choice of these elements is currently underway and will be the subject of future reports.

An effective land cover monitoring program would utilize both remotely-sensed information and ground-based measures. This report covers only remote sensing. Remote sensing alone would be insufficient for detecting change in certain fine-scale ecological processes or habitat features of significance to Pima County's ecological monitoring plan. Monitoring for land cover and land use change will be complemented by ground-based methods for detecting changes in vegetation and other habitat features. This will be the subject of future reports.

Literature Cited

Anderson, J. R. 1976. A land use and land cover classification system for use with remote sensor data. U. S. Geological Survey Prof. Paper 964. 41 pp.

Blair, R. B. 1999. Birds and butterflies along an urban gradient: Surrogate taxa for assessing biodiversity? Ecological Applications 9 (1): 164-170.

Connolly, N., et al. 2000. Land stewardship in Pima County. Report to the Pima County Board of Supervisors for the Sonoran Desert Conservation Plan. Tucson, AZ.

Fonseca, J. 1999. An Evaluation of Previous Vegetation Mapping Efforts for the Sonoran Desert Conservation Plan. Memorandum to the Science and Technical Advisory Team, June 1999.

Fonseca, J., J. Regan, C. Jones, M. List, and M. Probstfeld, in preparation. Land Cover Change in Pima County, Arizona, 1992-2001.

Forman, R. T., Daniel Sperling, John A. Bissonette, Kevin Heanue. 2003. Road Ecology: Science and Solutions Island Press. 481 pp.

Hansen, A. J., et al. 2005. Effects of exurban development on biodiversity: Patterns, mechanisms, and research needs. Ecological Applications 15 (6): 1893-1905.

Hope, D., et al. 2003. Socioeconomics drive urban plant diversity. Proceedings of the National Academy of Sciences of the United States of America 100 (15): 8788-8792.

Homer, C. C. Huang, L. Yang, B. Wylie and M. Coan. 2004. *Development of a 2001 National Landcover Database for the United States. Photogrammetric Engineering and Remote Sensing*, Vol. 70, No. 7, July 2004, pp. 829-840.

Jordan, D., 2006. Remote Sensing Tools for a Regional perspective. In Southwest Hydrology. 4 (3):16-18.

Lenth, B. A., R. L. Knight, and W. C. Gilgert. 2006. Conservation Value of Clustered Housing Developments. Conservation Biology 20:1445-1456.

Lowry , J. H. Jr., R. D. Ramsey, K. Boykin, D. Bradford, p. Comer, S. Falzarano, w. Kepner, J. Kirby, L. Langs, J. Prior-Magee, G. Manis, L. O'Brien, T. Sajwag, K. A. Thomas, W. Rieth, S. Schrader, D. Schrupp, K Schulz, B. Thompson, C. Velasquez, C. Wallance, E. Waller and B. Wold. 2005. Southwest Regional Gap Analysis Project: Final Report on Land cover Methods, RS/GIS Laboratory, Utah State University, Logan, Utah. http://ftp.nr.usu.edu/swgap/swregap_landcover_report.pdf

Maestas, J. D., R. L. Knight, and W. C. Gilgert. 2003. Biodiversity across a rural land-use gradient. Conservation Biology 17:1425-1434.

Marshall, R., et al., 2004. An Ecological Analysis of Conservation Priorities in the Apache Highlands Ecoregion: 152

McConnell, W. J. and E. F. Moran. 2000. Meeting in the middle: The challenge of meso-level integration. An international workshop. October 17-20, 2000, Ispra, Italy. Anthropological Center for Training and Research on Global Environmental Change, Indiana University, Bloominton, IN.

Meyer, W. B. and B. L. Turner II. 1994. Changes in land use and land cover: A global perspective. Cambridge University Press, Cambridge, UK.

Pima County 2001. Comprehensive Plan Update. Report to the Pima County Board of Supervisors, Tucson, AZ.

Powell, B. F. In prep. Recommended monitoring approach for Pima County's Multiple Species Conservation Plan. Report to the Pima County Board of Supervisors, Tucson, AZ.

RECON Environmental, Inc. 2000. Land cover data assessment in Pima County. A report to the Pima County Board of Supervisors for the Sonoran Desert Conservation Plan, Tucson, AZ.

RECON, 2007. Ecological Effectiveness Monitoring Plan for Pima County: Phase 1 Final Report. A report to the Pima County Administrator's Office, Tucson, AZ.

Soranno, P. A., et al. 1996. Phosphorus loads to surface waters: A simple model to account for spatial pattern of land use. Ecological Applications 6 (3): 865-878.

Townsend, et al, 2006. Classification of remotely sensed imagery into land cover maps. Standard Operating Procedure #3, Version 3.1. National Park Service.

Turner, B. L., et al. 1995. Land use and land cover change science/research plan. IHDP Report No. 7. International Geosphere-Biosphere Programme, International Council of Scientific Unions, Stockholm, Sweden.

USEPA, 2007. Completion of the 2001 National Land Cover Database for the Conterminous United States. Accessed at http://www.epa.gov/mrlc/pdf/april-07-highlight.pdf on June 26, 2008.

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Appendix 1. Science Technical Advisory Team Memorandum [Excerpted]

Date: February 21, 2006

To: C. H. Huckelberry, Pima County Administrator

From: William Shaw, Chair, Science Technical Advisory Team

Subject: Biological Monitoring Program (Adopted by STAT on February 17, 2006)

PURPOSE & CONTEXT:

This memo is intended to serve as the work plan and guidance document on how Pima County will develop the biological ("effectiveness") Monitoring Plan for both the Pima County Multi-Species Conservation Plan (MSCP) and Sonoran Desert Conservation Plan (SDCP). Biological monitoring will support the Adaptive Management Plan of the MSCP and will inform the community about the County's progress in meeting the goals of the SDCP.

We propose the basic three steps of the biological monitoring program are:

1. Developing the Work Plan (this memo). This establishes the fundamental goals and objectives, and guides the development of the Monitoring Plan.
2. Developing the Monitoring Plan. This establishes the process and monitoring protocols that will be followed.
3. Implementing the Monitoring Plan. This is the actual measurement of selected parameters, using the protocols established in step 2.

While acknowledging that the monitoring program will be adaptive in order to best respond to circumstances, needs and new knowledge, we nevertheless stress the need for fundamental, guiding principles as described herein.

As a point of clarification, monitoring as discussed in this memo refers to biological (i.e., "effectiveness") monitoring and not to compliance monitoring. Compliance monitoring is also a requirement of Permit issuance, and will serve to demonstrate that the legally defined terms and conditions of the Section 10 Permit are being met. As such, compliance monitoring is in essence an accounting exercise, whereas biological monitoring seeks to determine if the HCP is successfully achieving its goals. The compliance-monitoring program will be developed in a separate forum.

GOAL AND OBJECTIVES FOR MONITORING BIOLOGICAL ELEMENTS OF THE SONORAN DESERT CONSERVATION PLAN

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.*

BIOLOGICAL MONITORING GOAL: *To determine if the biological goal is being accomplished.*

The biological monitoring program will be designed to accomplish these objectives:

- Provide reliable information on the status and trends of natural resources in Pima County, with a focus on measuring the most relevant, powerful, and cost-effective parameters; and to

- Detect and quantify changes in ecosystem structure and function in order to inform adaptive management, by monitoring changes over time in a hierarchical manner. Monitoring will occur on three basic levels or scales, each of which will use different tools and measures, appropriate to the scale, and will provide different types of information:

1. **Regional Landscape Level:** Monitor land cover changes on a landscape scale (i.e., County-wide) using remote sensing imagery.

2. **Ecosystem Level:** Monitor key parameters of vegetation communities (i.e., structure, composition, distribution) and riparian and water resources to detect changes that affect components of the ecosystem.

3. **Species Level:** Monitor selected species, suites of species, such as land birds, or aquatic species where they are efficient indicators of change at a higher hierarchical level (e.g. community structure and function) or where the status and trend of individual species require specific attention.

CRITICAL BIOLOGICAL MONITORING ELEMENTS:

Our recommendation is that the scope of inference should be broad, not confined to the permit area or the committed lands alone. Because of the scope and complexity of the biological elements of the SDCP, the potential parameters that could be monitored are nearly infinite. Recognizing that resources for monitoring are and will be limited, we propose the monitoring plan be structured around the following four elements, with their supporting questions and basic importance:

Top Four Biological Monitoring Elements:
Land Cover: Question: How is land cover changing and what are the implications for biodiversity in Pima County? Importance: To track the loss of habitat on a gross scale due to conversion from natural cover to urban, agriculture or mining uses. Monitoring should be based on remote sensing data to track the magnitude and spatial distribution of change in the major land-cover types throughout Pima County.
Vegetation composition: Question: How are vegetation communities changing and what are the implications for biodiversity in Pima County? Importance: To detect change in the structure (e.g., conversion of grasslands to shrublands) and composition of vegetation communities, including invasive plant distribution. Utilize ground-based monitoring in key plant communities. Include semi-desert grasslands and saguaro-mixed cactus associations because of their national and local significance.
Riparian and Water Resources Question: How are riparian systems and groundwater levels changing and what are the implications for biodiversity in Pima County? Importance: Most of the vulnerable species in Pima County are aquatic or have riparian associations and urbanization, agriculture, and mining are associated with increased water use and changes in hydrology. Also, this monitoring will assist in determining whether or not restoration efforts are meeting success criteria. Detect change in springs, streams and shallow ground water areas, riparian vegetation, and gross changes in hydrologic patterns. Utilize measures such as groundwater levels, stream flows; spring flows, and aerial extent of riparian vegetation.

Land birds, Aquatic Vertebrates, and selected species.
Question: How are bird and aquatic vertebrate and invertebrate populations changing, and what are the implications for biodiversity in Pima County?
Importance: As a measure of environmental health, monitor distribution and abundance of selected species known to track environmental changes closely. Detect invasions of non-native vertebrates (fish, frogs) and invertebrates (e.g., crayfish, snails) thought to be detrimental to populations of native species. Note: Species specific monitoring may be performed to inform ecosystem structure and function elements of the monitoring plan.

PHASING:

We intend for the monitoring program to be phased, beginning with an emphasis on broad, powerful, and cost-efficient parameters that establish robust baselines for assessments that can be repeated indefinitely over time. After an initial period of 5 years, all elements of the monitoring program will be assessed and modified to increase efficiency and effectiveness for conservation of vulnerable species.

[end of excerpt]

Appendix 2. Land Use Mapping Protocol for Pima Association of Governments

Summary

The PAG 2008 existing land use shapefile represents July 1 land uses and residential densities in Pima County. There are approximately 50,000 polygons in this dataset. It builds on the USE code collected by the Pima County Assessor's office, aggregates geographically continuous parcels with the same land use code (e.g., individual residential lots are aggregated into one 'neighborhood'), removes gaps in the parcel base by 'growing' surrounding land uses, and estimates mid-year residential density using address level building permits issued by Pima County, the City of Tucson, the City of South Tucson, the Town of Oro Valley, the Town of Marana, and the Town of Sahuarita and Census 2000 data.

Methodology

Geocode Residential Building Permits

1. Create Address Locator using adcounty downloaded at same date of paregion (e.g., ~July 1, 2008).
2. Create Address Locator using adparcel downloaded at same date of paregion.
3. Add unique ID field to original permit table and make a copy of it.
4. Delete all fields except unique ID and address if necessary.
5. Geocode to adcounty
6. Select and export all features with Score >74. Name file with adcounty.
7. Switch Selection.
8. Export selection to dbf.
9. Geocode dbf to adparcel.
10. Export all features with Score > 74. Name file with adparcel.
11. Switch selection to see if record count of un-geocoded addresses is acceptable. If not geocode to paregion either with an address locator or manually. If it's a limited number sometime it's easier by hand.
12. Merge adcounty and adparcel exports. Add addresses that matched paregion if applicable.
13. Join back to original table.
14. Check for duplicate IDs and compare totals to original table.

Note: Do not geocode to stnetall or any other feature that would create points in the right of way. This is too inaccurate and does not allow location selection of paregion for the purposes of recalculating PAGLUCODE to work properly.

All residential building permits should fall within a parcel.

Prep Input Shapefiles

All input shapefiles are current as of July 1, 2008.

paregion

Part I

1. Use the same **exact** file for land use inventories, update in model.
2. Remove unnecessary fields from paregion. This is most easily done by turning the unwanted fields off and exporting to a new file. Designate and keep this file unchanged and in a safe place because it is the same file to be used for the land use inventories, update in model.
3. Join the PAGLUCODE table to the exported paregion based on the USE field. The PAGLUCODE field must be an integer type. Note: this table can change over time. No USE value is equal to PAGLUCODE 999

Part II

* Some building permits fall into parcels that do not have a residential PAGLUCODE. This occurs because of paregion update lag (see important note). This code must be changed to account for these new building activities.

1. Add EXLU with the final Residential building permits to ArcMap.

2. Select and create 2 layers from permit points by PAGTYPE = MF and PAGTYPE = (SFR, MH, TWN). Name layers accordingly.

3. Select by location EXLU that contain MF. Create layer from EXLU selection.

4. Select all non-residential PAGLUCODE values and recalculate PAGLUCODE to 165

5. Repeat process for SFR,MH, TWN and convert PAGLUCODE to 101

Important Note: The selection tool is finicky with large datasets. Make sure areas of 10-15 acres which are obviously non-residential features are not selected when recalculating PAGLUCODEs. Bad selections are also due to paregion update lag on new subdivisions. Do not over-write code on National Parks Forest, Monuments, rights of way, etc. This is why it is important to use the same exact paregion file.

pima_all

1. Add field PAGLUCODE and calculate field = 617

PAG major roads inventory

1. Add field GRIDCODE that is equivalent to PAGLUCODE

PAG land use inventories

1. Put in a file geodatabase in a feature dataset called Input.

2. Create two other feature datasets called Output and Intermediate.

Build the Current Year EXLU Features (using ArcGIS Model Builder)

This first step creates a single feature class of all the land use inventories. They must be added in a particular order so more detailed coverages do not over-write less detailed coverages. For example casinos should be updated after Indian Reservations because they are on reservations. The Update tool does not create overlapping topology. It performs erases and appends in one step.

1. Use the Update tool (required ArcInfo license) to "merge or append" the below listed inventories in order from A to AA. Name the output with its associated letter for convenience and save under feature dataset Output.

A) ASLD Grazing

B) Indian Reservations

C) Military

D) Open Space

E) Post High School schools

F) Airports

G) MTLUS industrial

H) MTLUS office

I) MTLUS streetside commercial

J) MTLUS shopping centers

K) Casinos

L) Hospitals

M) Lodging facilities

N) K-12 schools

O) Active landfills

P) Eldercare facilities

Q) Prisons

R) Dedicated government

S) Special events

T) Transit centers

U) Mines

V) Utilities

W) RV/Mobile Home parks

X) Multifamily residential

Y) Washes

Z) CAP

AA) Railroads

BB) Paregion (same as used for inventories)

CC) pima_all

(Note: See Attachment A for inventory description and detailed methodology on how each inventory dataset was constructed.)

6. Make sure there are no features without a PAGLUCODE. If there is, populate it with correct code or delete it if appropriate.
7. Clip CC to pima_all and name EXLU
8. Input EXLU into ET Geowizards tool: Explode Multi Part Features, name as EXLU_2008

Create new model of raster tools. Spatial Analyst is needed for this step.

9. Convert EXLU to grid with the Feature to Raster tool. Field is PAGLUCODE. Name output GRID and put in working geodatabase. Output cell size is 10.
10. Use the Shrink tool on GRID. Name output SHRINK and put in working geodatabase. Number of cells is 75. Zone values are 617 and 999.
11. Weird but necessary step. Use the Resample tool to create SHRINK2 that has a cell size of 5.
12. Convert SHRINK2 to polygon using Raster to Polygon tool. Check the simplify polygons box. Name output EXLU_YEAR (ex: EXLU_2008) in Output feature dataset.
13. Run Update tool on EXLU_YEAR with major roads inventory.
14. Run Check Geometry tool.
15. Run Repair Geometry tool if necessary.
16. Add field LUCode that is equivalent to the GRIDCODE field.

Sweet, the Existing Land Use layer is ready!!

Attribute the Current Year EXLU Features with Current Year Residential Density (using two Python Scripts)

Part I

This tool is used to assign dwelling units (DUs), households (HHs), and household population to a land use theme for the BASE YEAR, typically the year 2000 for which a census block group databases is available. The tool does NOT affect the input land use theme -- all results will appear in the COPY, which is written to the same directory as the source. The tool REQUIRES there to be an input existing land use theme containing polygons with appropriate land use codes AND a census block group theme source. The tool will overlay the two creating an identity theme so that we know for each census block group which residential polygons are resident in it. The tool then assigns census data to those polygons, apportioning on the basis of area. However, the method also attempts to assign DUs and HHs to each residential polygon in a way so as to prevent very large residential polygons from absorbing everything in the block group at the expense of other small residential polys.

Part II

This tool will UPDATE residential data in a land use shape file that you have already created with census 2000 base data, using a point file of lagged residential building permits as a source. The update can be applied periodically over time and as needed to keep the land use database current. DUs appearing in the permits file are added to those already in the land use theme. HHs and population are then estimated for them, using occupancy rates and household size averages that appear in the census block shape file.

ATTACHMENT A. LAND USE INVENTORY CONSTRUCTION METHODOLOGY

Land Use Inventories Used in 2008 Existing Land Use Dataset

(Note: Every attempt was made to update and accurately portray the actual physical extent of each feature and the PAGLUCODE attribute. Other attribute data are less reliable.)

LAYER	DESCRIPTION	SOURCE	FEATURE CREATION METHOD NOTES
Airports	Publicly accessible airports (TIA, Ryan, Marana)	previous year's inventory plus any new	select paregion that "have their centroid in" old inventory, create centroid from old inventory; join selection to centroid to populate name & address; merge individual shapes then explode
ASLD Grazing	AZ State trust owned lands that are leased for grazing	Most recently available AGIC datasets: "alott" and "own"	own is CATEGORY = State Trust; project datasets to match paregion; select parcels and copy, paste and trim to appropriate boundaries to create paregion rectified boundaries, PAGLUCODE = 750 for Agriculture and Ranching; dissolve by PAGLUCODE; explode multi part features
Dedicated Gov't	Lands owned by local, state, and federal governments	PCLIS bldg_gov, firestat, library, police, postoffi, cotparc, parcpima, related websites	combine bldg_gov, firestat, library, police, postoffi tables to create one large table to geocode to adcounty; make sure records have correct PAGLUCODE, name address, check cotparc, parcpima and websites to find new records to add, or update cot with parc then update with new combined final shape; attribute with new PAGLUCODE; dissolve by PAGLUCODE then explode OR do select by location paregion "that have their centroid in" old inventory and find new records to add from datasets and websites
Indian Reservations	Lands held in trust by the Pascua Yaqui and TON Tribes	PCLIS limjuris	select paregion that "have their centroid in" exported Indian boundaries from limjuris, copy paste and trim remaining parcels for complete coverage; dissolve, explode; PAGLUCODE = 821
Landfills	Active landfills	previous year's inventory, PCLIS lfil_ex	select paregion that "have their centroid in" old inventory, create centroid from old inventory; join selection with centroid to populate name & address; merge individual shapes then explode, check jurisdiction websites, and lfil_ex "status = open" for additional records
Mines	Active mineral and sand/gravel mines	previous year's inventory, PCLIS mines and mines and mines_act	select paregion that "have their centroid in" old inventory, create centroid from old inventory; join selection with centroid to populate name & address; copy, paste and trim for complete coverage, check for new records in updated county datasets merge individual shapes then explode,
Open Space	Lands dedicated to active and passive open space	PCLIS preserve, park_all, golf	select paregion that "have their centroid in" old inventory, create centroid from old inventory; join selection with centroid to populate name & address; copy, paste and trim for complete coverage, check for new records in updated county datasets, merge individual shapes then explode, attribute PAGLUCODE by dataset
Prisons	Detention facilities (all ages)	previous year's inventory	select paregion that "have their centroid in" old inventory, create centroid from old inventory; join selection with centroid to populate name & address; copy, paste and trim for complete coverage, check for possible new records, merge individual shapes then explode, attribute PAGLUCODE
Special Events	Special events and tourist destinations (e.g., TCC, Rodeo Grounds)	previous year's inventory, county and tucson websites, metro atlas Downtown (Map C)	select paregion that "have their centroid in" old inventory, create centroid from old inventory; join selection with centroid to populate name & address; copy, paste and trim for complete coverage, check for possible new records, merge individual shapes then explode, attribute PAGLUCODE
Transit Centers	SunTran transit centers (Rondstat, Tohono T'dai, Laos)	previous year's inventory	select paregion that "have their centroid in" old inventory, create centroid from old inventory; join selection with centroid to populate name & address; copy, paste and trim for complete coverage, check for possible new records, merge individual shapes then explode, attribute PAGLUCODE
Multifamily Residential	attached dwelling units (dpx, tpx, qpx, twn, condo, apt, assisted living, boarding house)	previous year's inventory, plus any new (sources for new include building permits, MTLUS, appropriate pargion use code)	select paregion that "have their centroid in" old inventory, create centroid from old inventory; join selection with centroid to populate table; copy, paste and trim for complete coverage, check for possible new records, merge individual shapes then explode, attribute PAGLUCODE = 165

LAYER	DESCRIPTION	SOURCE	FEATURE CREATION METHOD NOTES
Lodging	hotels, motels, bed/breakfast, resorts	previous year's inventory, plus any new (sources for new include building permits, MTLUS, appropriate pargion use code)	select paregion that "have their centroid in" old inventory, create centroid from old inventory; join selection with centroid to populate table; copy, paste and trim for complete coverage, check for possible new records, merge individual shapes then explode, attribute PAGLUCODE
Major Roads	estimated width of major roads	PCLIS stnetgdb	Query out major roads (MAJOR ROAD = Y), calculate total number of lanes per record (if Direction_of_travel = "Both Directions", total number of lanes = 2*LANE_CAT, if DIRECTION_OF_TRAVEL = 'One Way' or 'One-way reverse', total number of lanes = LANE_CAT. Buffer each feature accordin to number of lanes. (2 lanes= 26 ft buffer, 3 lanes = 32 ft buffer, 4 lanes = 38 ft buffer, 6 lanes = 68 ft buffer). Dissolve on STREET_NAME. PAGLCODE = 616, except I-10, I-19, State Roads =615. Clean topology (overlaps), dissolve again, clean gaps including highway interchanges, dissolve again.
RV/MH Parks	Recreational vehicle/mobile home parks	previous year's inventory, plus any new (sources fo new include appropriate paregion use code)	select paregion that "have their centroid in" old inventory, create centroid from old inventory; join selection with centroid to populate table; copy, paste and trim for complete coverage, check for possible new records, merge individual shapes then explode, attribute PAGLUCODE = 161
Major Washes	major water courses	PCLIS wash_maj	delete all records where WASH_NAME = null. PAGLUCODE = 730.
K-12 Schools	private, charter, and public k-12 schools	previous year's inventory, plus any new (sources for new include Tucson Book of Lists, AZ Daily Star school survey, AZ Dept of Education enrollment report, PCLIS schools)	select paregion that "have their centroid in" old inventory, create centroid from old inventory; join selection with centroid to populate table; copy, paste and trim for complete coverage, check for possible new records, merge individual shapes then explode
MTLUS_IND	MTLUS Industrial facilities, >5000 sq ft	MTLUS 3Q report, Table 6.1A	select paregion that "have their centroid in" old inventory, create centroid from old inventory; join selection with centroid to populate table; copy, paste and trim for complete coverage, check for possible new records, update vacancy/occupancy attributes, merge individual shapes then explode
MTLUS_STSIDECOM	MTLUS Strip commercial located along selected corridors	MTLUS, original source date was 2006.	select paregion that "have their centroid in" old inventory, create centroid from old inventory; join selection with centroid to populate table; copy, paste and trim for complete coverage, check for possible new records (if updated list is obtained), update vacancy/occupancy attributes, merge individual shapes then explode
MTLUS_OFFICE	MTLUS Office facilities, >5000 sq ft	MTLUS 3Q report, Table 5.1a	select paregion that "have their centroid in" old inventory, create centroid from old inventory; join selection with centroid to populate table; copy, paste and trim for complete coverage, check for possible new records, update vacancy/occupancy attributes, merge individual shapes then explode
MTLUS_SHOPCTR	MTLUS Shopping centers, >25,000 sqft	MTLUS 2Q report, Table 8.1	select paregion that "have their centroid in" old inventory, create centroid from old inventory; join selection with centroid to populate table; copy, paste and trim for complete coverage, check for possible new records, update vacancy/occupancy attributes, merge individual shapes then explode
Cap Canal	Above ground Central AZ Project Canal	PCLIS cap	Digitized physical extent of canal based on PCLIS cap feature overlaid on orthophoto. Geometry does not change from year to year.
Casinos	Actively operated casinos	Tribal/casino websites	Digitized physical extent of casino boundary based on orthophoto. Add/edit as changes occur.
Railroad Lines	Major railroads and spurs	PCLIS railroad	Digitized physical extent of lines based on PCLIS railroad feature overlaid on orthophoto. Geometry does not change from year to year.

Data Management Plan for the Pima County Ecological Monitoring Program

Report to the Pima County Board of Supervisors

August 2008

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Pima County
Natural Resources,
Parks and Recreation

Tucson, Arizona

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EXECUTIVE SUMMARY

Ecological monitoring is one of the most critical endeavors in natural resource science and management. If done properly, monitoring data can provide an objective view of ecosystem change and put management actions into a formal assessment framework that leads to progressively better decisions. The foundation of trend assessments and management actions is the data itself, but rarely is the management of data given sufficient attention in long-term monitoring programs. Staff turnover, new field methods, and constantly changing technology and just a few of the compelling reasons for adopting a formal data management structure.

The Pima County Ecological Monitoring Program (PCEMP) is now in the Phase II planning stage, namely to determine what indicators have the best chance of detecting changes in ecosystem structure and function for the Pima County Multiple Species Conservation Plan. As part of this design effort, it was deemed important to develop a data management plan that would identify the standards of data collection, storage, and dissemination for the program once implementation begins in 2009. The need for clear and concise data management procedures is increasingly important as the number of tools used in data collection increase and the applications to management also increases. More importantly, once a program begins data collection, the long-term success of the program then rests on ensuring consistent data collection and the long-term availability of the data.

The PCEMP Data Management Plan presents the overarching strategy for ensuring that data are documented, secure, accessible, and useful for decades by future managers and members of the public. The data management plan is based on a set of core principles:

- **Quality:** Ensure that appropriate quality assurance measures are taken during all phases of data development: acquisition, processing, summary and analysis, reporting, documenting, and archiving.
- **Interpretability:** Ensure that complete documentation accompanies each data set so that users will be aware of its context, applicability, and limitations.
- **Security:** Ensure that both digital and analog data are maintained and archived in a secure environment that provides appropriate levels of access to project leaders, technicians, network staff, and other users.
- **Longevity:** Ensure that data sets are maintained in an accessible and interpretable format, accompanied by sufficient documentation.
- **Availability:** Ensure that the data are made available and easily accessible to managers and other users.

Once the PCEMP is implemented there are a variety of roles and responsibilities that will need to be filled. Depending on the size of the program (i.e., how many parameters will be monitored), it will likely be necessary to employ at least one full-time data manager to coordinate the production, analysis, management, and/or end use of the data. Though these functions will benefit greatly from the many GIS and IT software application and infrastructure already in place within various Pima County departments, there will still be a need for a focused effort on the collection and integration of monitoring field data. More specifically, the data management position will require understanding and determining program and project requirements, creating and maintaining data management infrastructure and standards, and communicating and working with all responsible individuals. In addition to the data manager, the program manager also assists the data management effort by ensuring that all project personnel meet timelines for data entry, verification, validation, summarization/analysis, and reporting.

A modern information management infrastructure (e.g., staffing, hardware, software) represents the foundation upon which the program's information system is built. Systems architecture refers to the applications, database systems, repositories, and software tools that make up the framework of the data management enterprise. One important element of a data management system is a reliable, secure network of computers and servers. Fortunately, Pima County has significant capacity in this regard and future development of data archiving will involve an investigation as to if additional redundancy is needed in archiving program data.

The development and maintenance of databases for the entry and storage of field data is yet another key aspect of data management. Individual project (i.e., parameter) databases will be developed, maintained, and archived separately, but common themes among databases (such as collocation of plots) will be emphasized, where appropriate. Regardless of the structure, project database standards ensure compatibility among data sets, which is vital given the often unpredictable ways in which data sets will be aggregated and summarized. Well-thought-out standards also encourage sound database design and facilitate interpretability of data sets. To the extent possible, the PCEMP will follow the standards for database objects used by National Park Service Inventory and Monitoring Program.

Most data acquired by the Program will be collected as field data or discovered through data mining initiatives such as legacy or existing data. Methods of field data collection, such as paper field data forms, field computers, automated data loggers, and GPS units, will be specified in individual monitoring protocols and study plans. Field crew members will closely follow the established standard operating procedures (SOPs) in the project protocol. These and other activities will be part of quality assurance (QA) and quality control (QC) procedure that will identify and reduce the frequency and significance of errors at all stages in the data life cycle.

Before data are ready to be analyzed, the final step in the data management process is for complete, thorough, and accurate documentation of the data. Data documentation refers to the development of metadata, which at the most basic level can be defined as "data about data." Additionally, standardized metadata provide a means to catalog data sets within intranet and internet systems, thus making these data sets available to a broad range of potential users. Without metadata, potential users of a data set have little or no information regarding the quality, completeness, or manipulations performed on a particular 'copy' of a data set. Such ambiguity results in lost productivity as the user must invest time in tracking down information, or, worst case scenario, renders the data set useless because answers to these and other critical questions cannot be found. As such, data documentation must include an upfront investment in planning and organization.

One of the most important goals of the Pima County PCEMP is to integrate natural resource monitoring information into Pima County's planning, management, and decision-making processes. To accomplish this goal, the program will use a variety of distribution methods to make data and information collected and developed as part of the Program available to a wide community of users, including County staff, other researchers and scientists, and the public. This communications plan will be developed during the implementation phase of the program.

The importance of proper data management necessitates that resources be budgeted early in the program's design. Using the model of the National Park Service Inventory and Monitoring Program, it is anticipated that 25-30% of the program's budget be allocated for data management.

The standards outlined in this report represent a new approach to data management, particularly for Natural Resources, Parks and Recreation Department, the host department within Pima County. These standards will not be realized unless there is a clear understanding of the benefits of a robust data management program and a long-term commitment to realizing those benefits.

Introduction

"Data and information are the basic products of scientific research. In ecological research, where field experiments and data collections can rarely be replicated under identical conditions, data represent a valuable and, often, irreplaceable resource . . . In long-term ecological studies, retention and documentation of high quality data are the foundation upon which the success of the overall project rests"
Brunt 2000

Background and Setting

The Pima County Board of Supervisors initiated the Sonoran Desert Conservation Plan (SDCP) in 1998. The intent of the SDCP was to help ensure that impacts of human population growth complied with the regulatory requirements of the Endangered Species Act (ESA). The ESA prohibits "take" of threatened or endangered species that is defined by actions that harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect listed species. Section 10(a)(1)(B) of the act allows incidental take of listed species provided that a Habitat Conservation Plan (HCP) is in place. The SDCP was a first step in creating a HCP for Pima County and at its heart it has a 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.
(Pima County 2000)

Implementation of the SDCP has begun through land acquisition as part of the Conservation Land System and bond initiatives, development guidelines as provided for by Comprehensive Land-use Plan policies, and Pima County departmental policies and requirements. To satisfy the requirements of a permit application, Pima County developed a Multi-species Conservation Plan (MSCP) that embodies the scientific principles of the SDCP biological goal and specifies mechanisms for addressing legal requirements of the ESA (RECON Environmental 2006).

As part of the permit application, Pima County is required by the USFWS to establish a monitoring program. Given this requirement and the much broader goal of the SDCP, Pima County is proposing to expand the level of monitoring beyond individual species monitoring to assess trends in a wide range of natural resources in Pima County (RECON Environmental 2007). Expanding the scope of the monitoring program will both enhance its overall effectiveness and continue the diverse base of community support that has been the hallmark of the SDCP planning process.

The Pima County Ecological Monitoring Program (PCEMP) draft Data Management Plan presents a strategy for ensuring that program data are documented, secure, accessible, and useful into the future. The plan also refers to the need to develop other standards and steps for achieving data management goals. Because the program is now in the design phase, it provides an ideal opportunity to articulate the level of detail and tools that will be employed once the program is implemented. Therefore, this plan acts as a foundation upon which to build as new protocols are developed and advances in technology are adopted.

This data management plan describes how the Program will:

- Support PCEMP objectives
- Acquire and process data
- Assure data quality
- Document, analyze, and summarize data and information
- Integrate with other regional data management systems
- Disseminate data and information
- Maintain, store, and archive data

This data management plan will be finalized in late 2009/2010, after the list of monitoring parameters are decided on and protocols are developed. Revisions to this plan and associated data management documents (guidelines and procedures) will be made as needed, and the overall plan will be reviewed and revised as necessary every 3-5 years.

Data and Data Management: An Overview

The collection of scientifically credible, natural resource data is a critical step toward understanding and conserving natural resources. Though data are a set of discrete, objective facts, if they are to be meaningful or useful, they must be processed or transformed into information by adding context and appropriate interpretation. Thus, data management is more than simply inputting values into a table or spreadsheet or filing away data sheets. Rather, if the data management goals of the PCEMP are to be achieved, a modern information management infrastructure (i.e., staffing, hardware, software) must be developed. In addition, procedures must be established to ensure that relevant natural resource data collected by PCEMP staff, cooperators, researchers, and others are entered, quality checked, analyzed, reported, archived, documented, cataloged, and made available to others for management decision making, research and education. This endeavor requires planning.

Any good set of data must be accompanied by enough explanatory documentation (e.g., how and why it was collected) so that any trained personnel (now or in the future) can understand and use it with confidence. Therefore, any data management system cannot simply attend to the tables, fields, and values that make up a data set. It must also provide a process for developing, preserving, and integrating the context that makes data interpretable and valuable. Although thoroughly documenting a data set is time-intensive, it results in clear preservation and presentation of the data.

The term 'data' has many meanings, and they fall into five general categories:

- **Raw data:** GPS rover files, raw field forms and notebooks, photographs and sound/video recordings, telemetry or remote-sensed data files, biological voucher specimens;
- **Compiled/derived data:** Relational databases, tabular data files, GIS layers, maps, species checklists;
- **Documentation:** Data collection protocols, data processing/analysis protocols, record of protocol changes, data dictionary, metadata, data design documentation, quality assurance report, catalog of specimens and photographs;
- **Reports:** Annual progress reports, final reports (technical or general audience), periodic trend analysis reports, publications
- **Administrative records:** Contracts and agreements, study plans, research permits/applications, other critical administrative correspondence

Sources of Natural Resource Data

There are many potential sources of important data and information about the condition of natural resources, including inventories, monitoring, and research projects. Because the PCEMP focuses on long-term monitoring, our first priority is to produce and curate high-quality, well-documented data for that effort. However, a applying a set of data management standards, procedures, and infrastructure to other natural resource data should be a long-term goal of Pima County. As time and resources permit, we will work toward raising the level of data management for current projects, legacy data, and data originating from outside the program. These categories encompass one or more of the following data formats:

- Hard-copy documents (e.g., reports, field notes, survey forms, maps, references, administrative documents)
- Objects (e.g., specimens, samples, photographs, slides) Electronic files (e.g., Word files, email, websites, digital images)
- Electronic tabular data (e.g., databases, spreadsheets, tables, delimited files)
- Spatial data (e.g., shapefiles, coverages, geodatabases, remote-sensing data). (Pima County already has an excellent system for spatial data produced by the GIS team).

Data Management Goals and Objectives

The long-term programmatic goals of the PCEMP are 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 2007)

The data management activities for the program will provide scientifically and statistically sound data to support this goal. The data management objectives will be refined in the future, but will be guided by five principles:

- **Quality:** ensure that appropriate quality assurance measures are taken during all phases of data development: acquisition, processing, summary and analysis, reporting, documenting, and archiving.
- **Interpretability:** ensure that complete documentation accompanies each data set so that users will be aware of its context, applicability, and limitations.
- **Security:** ensure that both digital and analog data are maintained and archived in a secure environment that provides appropriate levels of access to project leaders, technicians, network staff, and other users.
- **Longevity:** ensure that data sets are maintained in an accessible and interpretable format, accompanied by sufficient documentation.
- **Availability:** ensure that the data and information from our activities are made available and easily accessible to managers and other users.

The PCEMP Data Management Plan outlines how we intend to implement and maintain a system that will adhere to these principles. This plan reflects the program's commitment to the acquisition, maintenance, documentation, accessibility, and long-term availability of high-quality data and information.

Data Management Resources: Infrastructure and Systems Architecture

Pima County has expended considerable resources toward computer resource architecture (applications, database systems, repositories, and software tools) and this infrastructure is an important foundation for the program. The PCEMP will rely on existing IT personnel and resources to maintain its computer resource infrastructure. These resources include, but are not limited to, hardware replacement, software installation and support, security updates, virus-protection, telecommunications networking, and backups of servers. This chapter will describe the infrastructure that is likely to be needed and which is often central to data management activities.

Computer Resources Infrastructure

An important element of a data management program is a reliable, secure network of computers and servers. The current system of county servers is administered by the Information Technology group in downtown Tucson, and the local IT specialist in the NRPR building. All project data will be stored on the secure servers administered by the Information Technology group. Because of the recent service transfer from NRPR to the IT group, it may be necessary to invest in an additional (redundant) data backup system.

Among the types of data that will need backup include:

- **Master project databases:** compiled data sets for monitoring projects and other multi-year efforts.
- **Common lookup tables:** e.g., projects, personnel, species
- **Program digital library:** repository for finished versions of products from program projects (e.g., reports, methods documentation, data files, metadata, etc.)
- **GIS files**: base spatial data, imagery, project-specific themes
- **Working files:** working databases, draft geospatial themes, drafts of reports, administrative records

Maintaining Digital Files

The PCEMP local area network (LAN) will be set up to accommodate a hierarchical directory structures for storing digital files. This is critical to establish and maintain early in the program's development because the large number of files that can quickly accumulate. Below are six categories of directory structure sections in which digital files will be maintained:

- **Admin:** documents related to program administration.
- **Databases:** all lookup tables, and back-end databases.
- **Libraries:** read-only storage of cataloged photographs and other reference documents.
- **Working:** workspace where groups and individuals can maintain draft material and other files as arranged by projects. The layout of folders and subfolders is more flexible here than elsewhere, but these areas must be cleaned out once per year to maintain order.
- **GIS:** base spatial data, imagery, and project-specific themes. Later in the program we will develop a system for separating those GIS files that are created by the Geographic Information Services group (Pima County Public Works), those created by the GIS specialist in NRPR, and those created by PCEMP staff.
- **Project Archive:** read-only storage of finished project products.

In general, this file management strategy has a number of advantages. First, working files are kept separate from finished products, the latter are typically read-only. Further, standards such as naming conventions and hierarchical filing will be enforced within the Libraries, Project Archive, Database, and GIS sections.

National Park Service Inventory and Monitoring Program Applications

The National Park Service (NPS) has devoted considerable resources to data management and as a result have developed many database applications that will be valuable to our effort. The PCEMP has a close working relationship with the Sonoran Desert Network I&M program, based in Tucson. They have committed to provide the PCEMP with databases and related products. Among those that might be useful for our efforts include databases for landbirds and an integrated aquatics database for plants, geomorphology, and water quantity and quality.

For those protocols that will differ from those collected by the Sonoran Desert Network, Pima County will have full access to the Vital Signs Monitoring Protocol Database (i.e., Protocol Database), a web-based clearinghouse of sampling protocols used in other National Parks to monitor the condition of selected natural resources. The database provides allows the user to download a digital copy of sampling protocols that have been developed by the prototype monitoring parks or other well-established protocols used in National Parks. The Protocol Database also makes it possible to download database components (e.g., tables, queries, data entry forms) consistent with the Natural Resource Database Template (see below) that have been developed for a particular protocol in MS Access.

The Natural Resource Database Template (NRDT) is a flexible, relational database in MS Access developed by the NPS I&M program for storing inventory and monitoring data (including raw data collected during field studies). This relational database can be used as a standalone database or in conjunction with GIS software (e.g., ArcView or ArcGIS) to enter, store, retrieve, and otherwise manage natural resource information. The template has a core database structure that can be modified and extended based on the needs of the PCEMP. The NRDT includes separate modules detailing different aspects of monitoring project implementation, from sampling design to data analysis and reporting, and include data management components that describe database table structure, data entry forms, and quality checking routines. Approved monitoring protocols, including the databases that are based on the Database template, are made available through a web-based protocol clearinghouse (see above).

Other National-Level Information Management and GIS Applications

STORET is an interagency water-quality database developed and supported by the Environmental Protection Agency (EPA) to house local, state, and federal water-quality data collected in support of managing the nation's water resources under the Clean Water Act. STORET is currently used by Pima Association of Governments for data collected at Cienega Creek Preserve.

Other Related County Databases

Some departments and programs within Pima County have Pima County is also developing an open space database that would store information critical to open space management. This database would relate the "Preserves" GIS layer to tabular data about property rights, management plans, buildings, wells, and other infrastructure located on County open space parcels. As in the current Mapguide system, users would view preserve lands in relation to various reference layers, but custom applications would be developed so that departments could update information.

PCEMP Systems Architecture

Rather than developing a single, integrated database system for all parameters in the monitoring program, it will be best to develop modular, stand-alone project databases that share design standards and links to centralized data tables. This way, individual project databases are developed, maintained, and archived separately. There are numerous advantages to this strategy. First, because data sets are modular in format, they allow greater flexibility in accommodating the needs of each project area. Individual project databases and protocols can be developed at different rates without a significant cost to data integration. In addition, one project database can be modified without affecting the functionality of other project databases. Also, by working up from modular data sets, a large initial investment in a centralized database can be avoided.

Project Database Standards

Project database standards are necessary for ensuring compatibility among data sets, which is vital given the often unpredictable ways in which data sets will be aggregated and summarized. When well thought out, standards also help to encourage sound database design and facilitate interpretability of data sets. As much as possible, network standards for fields, tables, and other database objects will mirror those conveyed through the Natural Resource Database Template. In addition, documentation and database tools (e.g., queries that rename or reformat data) will be developed to ensure that data exports for integration are in a format compatible with current national standards. Databases for the PCEMP should all contain the following main components:

- **Common lookup tables:** links to entire tables that reside in a centralized database, rather than storing redundant information in each database. These tables typically contain information that is not project-specific (e.g., lists of reserves, personnel, and species).
- **Core tables and fields based on templates:** these tables and fields are used to manage the information describing the 'who, where and when' of project data. Core tables are distinguished from common lookup tables in that they reside in each individual project database and are populated locally. These core tables contain critical data fields that are standardized with regard to data types, field names, and domain ranges.
- **Project-specific fields and tables:** the remainder of database objects can be considered project-specific, although there will typically be a large amount of overlap among projects. This is true even among projects that may not seem logically related. For example, a temperature field will require similar data types and domain values.

Certain key information is not only common to multiple data sets, but to the organization as a whole – lists of contacts, projects, reserves, and species that are often complex and dynamic. It is a good strategy to centralize this information so that users have access to the most updated versions in a single, known place. Centralizing also avoids redundancy and versioning issues among multiple copies. Centralized information is maintained in database tables that can be linked or referred to from several distinct project databases. Program applications for project tracking, administrative reporting, or budget management can also link to the same tables so that all users in the Network have instantaneous access to edits made by other users.

The three types of database objects also correspond to three acknowledged levels of data standards. Because common lookup tables are stored in one place and are referred to by multiple databases, they represent the highest level of data standard because they are implemented identically among data sets. The second level of standards is implied by the core template fields and tables, which are standardized where possible, but project-specific objectives and needs could lead to varied implementations among projects.

Data Management Process and Work Flow

This section considers the general work flow characteristics of PCEMP projects that produce natural resource data, and then gives an overview of how natural resource data are generated, processed, finalized, and made available. Data management activities that relate to the various stages of a project are highlighted. By describing the progressive stages of a project and the life cycle of the resulting data, one can more easily communicate the overall objectives and specific steps of the data management process. In addition, this awareness helps manage staffing resources needed to produce, maintain, and deliver quality data and information. More details about data acquisition, quality assurance, documentation, dissemination, and maintenance can be found in later sections of this plan. In the next phase of this plan, tasks will be assigned to specific individuals, but because staff structure has not been finalized, it is too early in the program to assign such tasks.

Project Work Flow

Projects can be divided into five primary stages:

1. **Planning and Approval.** During the initial phase of the program, many of the preliminary decisions regarding project scope and objectives are made, and funding sources, permits, and compliance are all addressed.

2. **Design and Testing.** All of the details are worked out regarding how data will be acquired, processed, analyzed, reported, and made available to others. An important part of this phase is the development of the data design and data dictionary, where the specifics of database implementation and parameters that will be collected are defined in detail. Devoting adequate attention to this aspect of a project is possibly the single most important part of assuring the quality, integrity, and usability of the resulting data. Once the project methods, data design, and data dictionary have been developed and documented, a database can be constructed to meet project requirements.

3. **Implementation.** In this phase, data are acquired, processed, error-checked, and documented. This is also when products such as reports, maps, GIS themes, and others are developed and delivered. Throughout this phase, data management personnel function primarily as facilitators by providing training and support for database applications, GIS, GPS, and other data processing applications; facilitation of data summarization, validation, and analysis; and assistance with the technical aspects of documentation and product development. Toward the end of this phase, project staff members work to develop and finalize the products that were identified in the project planning documents (i.e., protocol, study plan, contract, agreement, or permit).

4. **Product Integration.** During this phase, data and other products are integrated into national databases (if appropriate), metadata records are finalized, and products are distributed or otherwise made available to their intended audience. Certain projects may also have additional integration needs, such as when working jointly with other agencies for a common database.

5. **Evaluation and Closure.** For long-term monitoring and other cyclic projects, this phase occurs at the end of each field season and leads to an annual review of the project. For non-cyclic projects, this phase represents the completion of the project. After products are cataloged and made available, staff should work together to assess how well the project met its objectives and to determine what might be done to improve various aspects of the methodology, implementation, and formats of the resulting information. For monitoring protocols, careful documentation of all changes is required. Changes to methods, SOPs, and other procedures are maintained in a tracking table associated with each document. Major revisions may require additional peer review.

Data Life Cycle

During various phases of a project, data take on different forms and are maintained in different places as they are acquired, processed, documented, and archived. This data life cycle is characterized by a sequence of events that we can model to facilitate communication. These events involve interactions with the following objects:

- **Raw data:** analog data recorded by hand on hard-copy forms and digital files from handheld computers, GPS receivers, automated data loggers, etc.
- **Working database:** a project-specific database for entering and processing data for the current season (or other logical period of time). This might be the only database for short-term projects where there is no need to distinguish working data for the current season from the full set of validated project data.
- **Certified data and metadata:** completed data and documentation for short-term projects, or one season of completed data for long-term monitoring projects. Certification is a confirmation by the project leader that the data have passed all quality assurance requirements and are complete and ready for distribution. Metadata records include the detailed information about project data needed for their proper use and interpretation.
- **Master database:** project-specific database for storing the full project data set, used for viewing, summarizing, and analysis; only used to store data that have passed all quality assurance steps.
- **Reports and data products:** information that is derived from certified project data.
- **Edit log:** a means of tracking changes to certified data.
- **Outside databases and repositories:** applications and repositories maintained by other entities. Also for sharing information with cooperators and the public.
- **Local archives and digital library:** local storage of copies of data, metadata, and other products generated by projects. Archives are for hard-copy items and off-line storage media, whereas the digital library is maintained live on a server.

Although the data life cycle may vary depending on specific project needs and objectives, the typical life cycle for Network projects proceeds as follows:

1. **Acquire data:** for data recorded by hand in the field, data forms should be reviewed regularly (at least daily) for completeness, legibility, and validity in order to capture errors as close to their origin as possible.
2. **Archive raw data:** copies of all raw data files are archived intact. Digital files are copied to the raw data folder for the project; hard copy forms are either scanned and placed in the active projects folder or are copied and placed in the archives. Archival or scanning of hard copy data forms may occur at the end of a season as a means of retaining all marks and edits made during the verification and validation steps.
3. **Data entry/import:** analog data are entered manually; digital data files are uploaded to the working database.
4. **Verification, processing, and validation:** verify accurate transcription of raw data; process data to correct data entry errors and remove missing values and other data flaws; validate data using database queries and other methods to capture missing data, out-of-range values, and logic errors.
5. **Documentation and certification:** develop or update project metadata and certify the data set. Certification is a confirmation that the data have passed all quality assurance requirements and are complete and documented. It also means that data and metadata are ready to be posted and delivered.
6. **Archive versioned data set:** copies of the certified data and metadata are placed in the project archive folder. This can be accomplished by storing a compressed copy of the working database or by exporting data to a more software-independent format (e.g., ASCII text).
7. **Post data and update national databases:** to make data available to others, certified data and metadata are posted to PCEMP repository. Note that data and data products may not be posted on public sites if they contain protected information about the nature or location of rare, commercially valuable, threatened or endangered species, or other natural resources of management concern (see Section 8.2.3).
8. **Upload data:** certified data are uploaded from the working database to the master project database. This step might be skipped for short-term projects where

there is no need to distinguish working data for the current season from the full set of certified project data.

9. **Reporting and analysis:** certified data are used to generate data products, analyses, and reports, including semi-automated annual summary reports for monitoring projects. Depending on project needs, data might be exported for analysis or summarized within the database.

10. **Store products:** reports and other data products are stored according to format and likely demand – either in the digital library, on off-line media, or in the document archives.

11. **Post products and update national databases:** to make data available to others, reports and other products are posted to appropriate repositories.

12. **Distribute data and information:** data, metadata, reports, and other products can be shared and distributed in a variety of ways – via the web-based repositories, by FTP or mailing in response to specific requests, or by providing direct access to project records to cooperators. Some limitations will be established to protect information about sensitive resources.

13. **Track changes:** all subsequent changes to certified data are documented in an edit log, which accompanies project data and metadata upon distribution. Significant edits will trigger reposting of the data and products to national databases and repositories.

This sequence of events occurs in an iterative fashion for long-term monitoring projects, whereas the sequence is followed only once for short-term projects. For projects spanning multiple years, decision points include whether or not a separate working database is desirable and the extent to which product development and delivery is repeated year after year.

Integrating and Sharing Data Products

Once project data and derived products have been finalized, they need to be secured in long-term storage and made available to others. In future versions of this plan we will develop an appropriate system to accomplish this function. In addition, a process will be developed for the distribution of the data.

Data Acquisition and Processing

The PCEMP is being developed to help reach the SDCP goal. To accomplish this task, the program plans to both collect our own data as well as acquire data from other sources. This chapter describes steps to accomplish both tasks.

Program Activities

Biological monitoring projects will be the focus of PCEMP activities, but other endeavors will also be used including shorter-term research and inventory projects. Regardless of the type of activity, there are a range of tools that might be used for collecting data. For each there are opportunities and constraints to their use.

- **Paper field data forms** are the most common method of recording field data. Although inexpensive, more opportunities for errors exist during the data collection/data entry process. They also require neat, legible handwriting and very rigorous QA/QC.
- **Field computers** increase data collection and data entry efficiency. Data can be downloaded directly from field computers to office desktops, thereby eliminating manual data entry. Fewer chances for error exist as QA/QC checks can be built into the database, but these devices may not be the optimal choice if copious amounts of notes or comments must be recorded in the field. In addition, these portable units are subject to environmental constraints such as heat, dust, and moisture. When handheld computers are used for data entry in the field, the data should be downloaded daily to avoid potential loss of information. The use of a memory card that will store the data in case of damage to the unit or battery failure can prevent accidental loss of data.
- **Handheld computers or Personal Digital Assistants (PDAs)**. The small size and relative low cost of these devices make them attractive options for collecting data in the field. Although they work well for small field projects, they are not powerful enough for large, data intensive field projects. PDAs can be customized to withstand a range of adverse environmental conditions fairly easily and inexpensively. Most run either Windows CE or Palm operating systems, which may require additional processing/programming to transfer/create the database structure in the field units.
- **Tablet PCs** have the same properties as most laptops and provide the user with the convenience of a touch screen interface. They are bulkier, more expensive, and harder to customize for fieldwork than the PDAs but are more powerful. They work well for field projects that are very data intensive. Because these units run Windows XP (Tablet Edition), the project database can be directly transferred from desktop units to field units without additional programming steps.
- **Automated data loggers** are mainly used to collect ambient information such as weather data or water-quality information. Data loggers are an efficient method for recording continuous sensor data, but routine inspections are necessary, and environmental constraints, as well as power (i.e., sufficient battery charge) and maintenance requirements, are potential pitfalls when using these instruments. Regular downloads should be required since physical memory is usually limited. Proper calibration is important.
- **Permanently deployed devices** are often very expensive, and data must be retrieved and batteries changed on a regular basis.
- **Portable hand-held devices** are deployed for sampling only during site visits. They are generally less expensive than permanently-deployed field units.

GPS receivers are often used during fieldwork in network parks to collect location information. There are two main types of hand-held units and the choice of the two will depend on the accuracy of information required:

- **Handheld recreation-grade GPS units** are relatively inexpensive and are good for collecting general position information, but they are not recommended for obtaining high-accuracy location information.
- **Mapping-grade GPS receivers** are good for collecting highly accurate (sub-meter) location information, but they are more expensive than recreation-grade units, and more training is required to use these units correctly.

Non-Programmatic PCEMP Data

PCEMP will leverage resources by collecting and integrating information collected by other entities. Data collected by others falls into two types: those collected by other within the current County reserve network and those collected in other areas of Pima County or the surrounding region. Emphasis will be placed on gathering data collected within the existing County reserve system, particularly natural resource inventory data (e.g., species lists) as well as historic photographs, maps, and voucher specimens. Programs of interest to the PCEMP are listed in Appendix A. The agencies or organizations that compile these data may not have the expertise to apply proper quality control procedures and the capability to function as a repository and clearinghouse for the validated data. When the data are not kept in-house, data may be acquired via downloads from online databases or requests for data on CD, DVD, or other media.

Data Processing and Data Mining

Unlike data from PCEMP sources, much of the data collected from external sources must undergo some degree of processing to meet the standards of the PCEMP; however some of the basic processing steps are very similar.

- All GIS data obtained from other entities will be stored in the proper format and include accurate spatial reference information and FGDC-compliant metadata.
- All biodiversity data received from other entities, such as Breeding Bird Survey data sets, should be entered into a species database (yet to be created). In addition, if the data were taken from a report or published document, the reference must be entered into the monitoring EndNote database (as of August 2008 it contains >1800 citations).
- Particular emphasis will be placed on collecting information on the species that will be covered under the Section 10 permit. Known as the Covered Species Information Database (CSID), each year Pima County will query researchers and other governmental entities and non-governmental organizations regarding any data collected on covered species in the preceding year. These data would be entered into a separate database.

Certain data sets will require more than the basic processing steps than described above. The level of data processing and mining required for external data sets will vary based on the source. Specific protocols might need to be developed that outline the necessary data processing requirements.

Remote sensing data sets (e.g., satellite imagery or aerial photography) may require geospatial or spectral processing, depending upon the formats in which they are received. Ideally, all spatial data sets will be received in a geo-referenced format and may require only geographic transformations.

Data mining will be particularly important at the beginning of Phase III as protocols are being developed. Data sources that will be queried include bibliographic/literature searches, geographic data, and biological/natural resources data. Much of these data are accessible via the Internet, but some can only be accessed through visits to local libraries, academic institutions, museums, and other land management agencies. All information collected during the data discovery process is maintained either electronically or in hard copy format, depending on how it was collected. Any geographic data sets collected during this process should be accompanied by FGDC-compliant metadata.

Data Quality Assurance/Quality Control

Data collected by the PCEMP is an invaluable resource that must be preserved over the long-term, but the long-term utility can be compromised by poor data. In particular, data of inconsistent or poor quality can result in loss of sensitivity and lead to incorrect interpretations and conclusions. The potential for problems with data quality increases dramatically with the size and complexity of the data set (Chapal & Edwards 1994).

Palmer (2003) defines *Quality Assurance* (QA) as "an integrated system of management activities involving planning, implementation, documentation, assessment, reporting, and quality improvement to ensure that a process, item, or service is of the type and quality needed and expected by the consumer." He defines *Quality Control* (QC) as "a system of technical activities to measure the attributes and performance of a process, item, or service relative to defined standards." QA procedures maintain quality throughout all stages of data development; QC procedures monitor or evaluate the resulting data products.

This section presents the procedures the PCEMP will employ to ensure that projects are of the highest possible quality. In short, we will establish and document protocols for the identification and reduction of error at all stages in the data life cycle, with the goal of attaining 95%-100% accuracy.

Not long ago, maintaining data meant filling filing cabinets full of notebooks and paper. Now we are more likely to use computer hardware and software – technology that changes rapidly. If we expect our current data to be useful to future users, the data must survive changes in technology. We can promote data longevity through high-quality documentation and maintenance during all phases of data management. Well-documented data sets are especially important when sharing data.

Quality Assurance and Quality Control Mechanisms

QA/QC mechanisms are designed to prevent data contamination, which occurs when a process or event other than the one of interest affects the value of a variable. Contamination introduces two fundamental types of errors into a data set (1) *Errors of commission* include those caused by data entry and transcription errors or malfunctioning equipment. They are common, fairly easy to identify, and can be effectively reduced upfront with appropriate QA mechanisms built into the data acquisition process, as well as QC procedures applied after the data have been acquired. (2) *Errors of omission* often include insufficient documentation of legitimate data values, which may affect the interpretation of those values. These errors may be harder to detect and correct, but many of these errors should be revealed by rigorous QC procedures.

QA/QC procedures applied to ecological data include four procedural areas (or activities), ranging from simple to sophisticated, inexpensive to costly:

1. Defining and enforcing standards for electronic formats, locally defined codes, measurement units, and metadata
2. Checking for unusual or unreasonable patterns in data
3. Checking for comparability of values between data sets
4. Assessing overall data quality

Much QA/QC work involves the first activity (defining and enforcing standards), which begins with data design and continues through acquisition, entry, metadata development, and archiving. The progression from raw data to verified data to validated data implies increasing confidence in the quality of the data through time (Figure 6.1).

Data Collection

Careful, accurate recording of field observations in the data collection phase of a project will help reduce the incidence of invalid data in the resulting data set. All field sheets and field data recording procedures must be reviewed and documented in the protocol. Field crews understand the procedures and closely follow them in the field and this should reinforced with proper training. Field crew members will be expected to understand the data collection forms, know how to take measurements, and follow the established procedures. Whatever the method of data collection, there must be procedures in place to reduce errors such as using project-specific data sheets (i.e., not field notebook). These

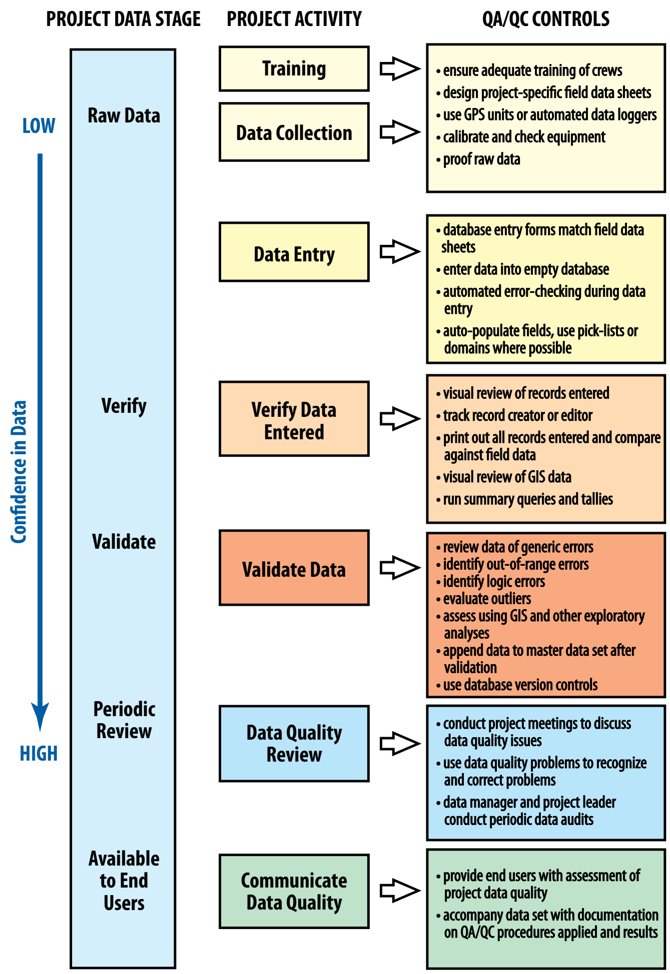


Figure 6.1. Quality assurance (QA) and quality control (QC) activities and pathways to ensure data integrity.

will be highlighted in the specific protocols that are developed. After data have been collected, the must be entered into the appropriate database will the goal of 100% accuracy. This can be achieved by having the technician collecting data enter it into the database, but have a separate technician check all data against the original data sheet. Prior to data entry, the database should be structured so that the entry forms are efficient and easy-to-use (i.e., they look like the original datasheet) and that automatic error checking is built into the database, through use of auto-filled fields, range limits, pick lists, and constraints).

Verification and Validation Procedures

Data quality is ensured by applying verification and validation procedures as part of the quality control process. *Data verification* checks that the digitized data match the source data, while *data validation* checks that the data make sense. It is essential to validate all data as accurate and not misrepresent the circumstances and limitations of their collection. Although data entry and data verification can be handled by personnel who are less familiar with the data, validation requires in-depth knowledge about the data.

Data verification immediately follows data entry and involves checking the accuracy of the computerized records against the original source, usually hard copy field records, and identifying and correcting any errors. When data have been verified, the original data can be archived. Among the tasks involved in data verification are: visual review at and after data entry, duplicate data entry, and simple summary statistics.

Data Quality Review and Communication

The PCEMP should require QA/QC review prior to communicating/disseminating data and information, and only data and information that adhere to the outlined quality standards should be released.

Data Documentation

Thorough, complete, and accurate documentation is critical during every stage of processing in the life cycle of a data set. At times, data sets appear to take on "lives of their own"; some are often found on multiple hard drives, servers, and other storage media. Others become hidden in outdated digital formats or in forgotten file drawers. In addition, once data are discovered, a potential user is often left with little or no information regarding the quality, completeness, or manipulations performed on a particular 'copy' of a data set. Such ambiguity results in lost productivity as the user must invest time in tracking down information or, worst case scenario, renders the data set useless because answers to these and other critical questions cannot be found. Therefore, data documentation must include an upfront investment in planning and organization.

Complete, thorough, and accurate documentation should be of the highest priority for long-term studies, and since long-term data sets are continually changing, this documentation must remain up-to-date. Data documentation involves the development of *metadata*, which at the most basic level can be defined as 'data about data,' or more specifically as information about the content, context, structure, quality, and other characteristics of a data set. Metadata provide the information necessary to relate the raw data to the underlying theoretical or conceptual model(s) for appropriate use and interpretation (Michener 2000). Additionally, standardized metadata provide a means to catalog data sets within Intranet and Internet systems, thus making these data sets available to a broad range of potential users.

Past efforts to standardize metadata content and format have focused primarily on geospatial data sets. Therefore, the term 'metadata' is often associated with documentation compliant with formal Federal Geographic Data Committee (FGDC) standards. However, in this plan, the term 'metadata' encompasses all forms of data documentation, including those for spatial and non-spatial tabular data, as well as project-level documentation.

The details of what products to use for compiling metadata will be more clearly articulated in the next phase of this data management plan. However, a number of products and procedures are worth noting and will likely be adopted by the PCEMP. In particular, ArcCatalog is a management tool for GIS files contained within the ArcGIS Desktop suite of applications. With ArcCatalog, users can browse, manage, create, and organize tabular and GIS data. In addition, ArcCatalog comes with support for several popular metadata standards that allow one to create, edit, and view information about the data. There are editors to enter metadata, a storage schema, and property sheets to view the data. Users can view GIS data holdings, preview geographic information, view and edit metadata, work with tables, and define the schema structure for GIS data layers. Metadata within ArcCatalog are stored exclusively as Extensible Markup Language (XML) files.

Regardless of the product used, all products will be FGDC-compliant. Databases, in particular will have the following information:

- Description of the project
- Location of the project study plan and work plan
- Project leader's name and contact information
- Principal investigator's name and contact information
- Data set contact's name and contact information
- Description of the database model (entity-relationship diagram and data dictionary)
- Sensitive data issues, if appropriate
- Description of data verification/validation methods and results (data quality report)
- Certification of the data set
- Additional comments/documentation references, where appropriate
- Description of the database model
- Entity-relationship diagram
- Data dictionary
- Data quality report
- Sensitive data report
- Certification of the data set

Data Analysis, Reporting and Dissemination

Data Analysis and Reporting

The success of the PCEMP depends upon providing information managers and other decision makers to empower them to make science-based decisions, as well as disseminating this information to a wider audience of other agency personnel, external scientists, and the general public. Data analyses are the means by which we transform data into this essential information. For long-term monitoring, data should be summarized at least annually and fully analyzed at three-to-five-year intervals (or as specified in the monitoring protocols) in order to detect trends in resource conditions. The information derived from data analyses will be conveyed through a variety of written reports and presentations. Project leaders are ultimately responsible for analyzing data and reporting the results, but this section discusses how data management activities can facilitate those activities through automated data summaries and reports.

Each project will have a schedule for data analysis and reporting requirements specified in the monitoring protocol, study plan, cooperative agreement, or contract. However, in general, the PCEMP will complete data analysis and reporting within one year of seasonal data collection or the end of the project. Yearly project reports will be required for all long-term projects. Annual reports should convey the past year's network monitoring activities with audience being agency personnel, USFWS and AZGF cooperators and other interested scientists and member of the public. Relevant information may include numbers of samples and from what areas, data management activities, any changes made to the protocols, and the status of resources. Annual reports will be written as part of a yet-to-be created monitoring report series produced by Natural Resources, Parks, and Recreation Department. A summary of each annual report that highlights key points will also be produced in a 'brochure' format for distribution to a wider audience, including Board of Supervisors and the general public. Findings from project-specific reports will be "rolled up" into annual 'state of the County' reports describing the current trends and conditions of County resources.

Comprehensive reports incorporating detailed data analyses, syntheses, and descriptions of trends in resource conditions for each parameter will be produced every 3-5 years or according to the individual monitoring protocol requirements. As with annual reports, these will be produced as part of the technical report series.

Technical reports are critical to providing periodic syntheses of relevant data and for ensuring that monitoring activities are accepted by the scientific community. Yet solely relying on producing technical reports would miss constituents that would be interested in program's findings, such as decision makers and the general public. To identify these key constituents and taylor products to them, the PCEMP will undertake a communications plan during Phase III. By highlighting opportunities to disseminate data to non-technical audiences, it will help ensure the long-term relevance and success of the program.

Data Ownership

Pima County defines conditions for the ownership and sharing of collections, data, and results based on research funded by the County. All cooperative and interagency agreements, as well as contracts, should include clear provisions for data ownership and sharing as defined by the Pima County:

- All data and materials collected or generated using Pima County personnel and funds become the property of the Pima County.
- Any important findings from research and educational activities should be promptly submitted for publication. Authorship must accurately reflect the contributions of those involved.
- Program personnel should share collections, data, results, and supporting materials with other researchers whenever possible. In exceptional cases, where collections or data are sensitive or fragile, access may be limited.

Guidelines will be developed for collaborative agreements regarding data ownership and timeframes and formats for submittal of data from outside cooperators. Products or deliverables would include, but are not limited to, field notebooks, photographs (hardcopy and digital), specimens, raw data, and reports. Details on formatting and media types that will be required for final submission will also be highlighted in the next phase of this report.

Data Distribution

One of the most important goals of the PCEMP is to integrate natural resource inventory and monitoring information into Pima County planning, management, and decision making. To accomplish this goal, procedures must be developed to ensure that relevant natural resource data collected by PCEMP staff, cooperators, researchers, and the public are entered, quality-checked, analyzed, documented, cataloged, archived, and made available for management decision-making, research, and education. Providing well-documented data in a timely manner to managers is especially important to the success of the program. The PCEMP will make certain that:

- Data are easily discoverable and obtainable.
- Distributed data are accompanied by complete metadata that clearly establish the data as products of the PCEMP.
- Sensitive data are identified and protected from unauthorized access and inappropriate use (criteria will be developed later).
- A complete record of data distribution/dissemination is maintained.

Data distribution mechanisms will likely be the Internet, which will allow the data and information to reach a broad community of users. It is anticipated that the PCEMP will have our own website and this will be the primary outreach and dissemination portal for the monitoring information. This website should be linked to the Pima County Mapguide for the visual display of plot locations and access to data products. For this, the Santa Rita Experimental Range is a model for this approach (http://ag.arizona.edu/srer/).

Data Feedback Mechanisms

The PCEMP website should be developed to provide an opportunity for cooperators and the public to provide feedback on data and information gathered as part of the PCEMP. A 'comments and questions' link should be provided on the main page of the PCEMP site for this purpose.

Long-term Archiving of Data

Relationship with statutes regarding records….and what ensures longer-term and interagency use? USGS data storage.

FUTURE DIRECTIONS

The PCEMP is now in the early design phase and as such many additional tasks lay ahead, including future development and implementation of the concept and guidelines that are introduced in this draft plan.

Staffing

Data management is about people and organizations as much as it is about information technology, database design, and applications. Therefore, an important aspect of the program will be for each member of the program team to have sets of roles and responsibilities. Because of the early stage of the PCEMP, it is premature to assign such roles until the structure of the program has been articulated and funding acquired. This will likely happen in early 2009. Once underway, the key to implementation of this data management plan will be hiring a data manager, who, as the title implies, will be the data stewardship leader and will be responsible for most of the data management activities. The role of the data manager and all other program staff will be articulated in the next phase of this data management plan.

Budgeting

The principles and guidelines outlined in this document demonstrate the level of detail that must be directed to data management. The level of detail may seem unreasonable or "overkill", but it can not be stressed enough that the foundation of any long-term endeavor, such as being proposed by the PCEMP, rests on the data. With staff turnover, rapid advances in technology, and new methods, data quality can be jeopardized and therefore resources wasted. But even more important than resources, the greatest loss resulting from poor data management would include not identifying trends that occurred or for managers and decision makers to make haphazard or inappropriate decisions because of a lack of data.

Because of the importance of data management, approximately 25-30% of a program's resources should be directed to this effort. Fortunately for the PCEMP, some of the elements of good data management are already part of the Pima County system including proper archiving of weather and GIS data, and system backup infrastructure.

ACKNOWLEDGMENTS

Much of the material in this data management plan was developed by a team of data managers from the National Park Service's (NPS) Inventory and Monitoring Program. In particular, gratitude is owed to Deborah Angell at the Sonoran Desert Network in Tucson, Arizona. We are indebted to the work by Ms. Angell and other NPS personnel for their commitment to natural resource data management and in doing so made many of us realize its importance in any long-term monitoring program. I am also grateful to Ms. Angell for encouraging the use her materials; this type of sharing and cooperation provides yet additional evidence that a southern Arizona regional monitoring partnership is now becoming a reality.

LITERATURE CITED

Brunt, J. W. 2000. Data management principles, implementation and administration. Pages 25-47 in W. K. Michener and J. W. Brunt, editors. Ecological data: Design, management and processing. Blackwell Science Inc., Malden, MA.

Chapal, S. E., and D. Edwards. 1994. Automated smoothing techniques for visualization and quality control of long-term environmental data. Pages 141-158 in W. K. Michener, and J. W. Brunt, and Susan G. Stafford, editors. Environmental information management and analysis: Ecosystem to global scales. Taylor & Francis Ltd., London.

Michener, W. K. 2000. Metadata. Pages 92-116 in W. K. Michener and J. W. Brunt, editors. Ecological data: Design, management and processing. Blackwell Science Inc., Malden, MA.

Palmer, C. J. 2003. Approaches to quality assurance and information management for regional ecological monitoring programs. Pages 211-225 in D. E. Busch and J. C. Trexler, editors. Monitoring ecosystems: interdisciplinary approaches for evaluating ecoregional initiatives. Island Press, Washington, DC.

Pima County. 2000. Draft preliminary Sonoran Desert Conservation plan. Draft report to the Pima County Board of Supervisors for the Sonoran Desert Conservation Plan, Tucson, AZ.

RECON Environmental Inc. 2006. Draft Pima County multi-species conservation plan. Report to the Pima County Board of Supervisors for the Sonoran Desert Conservation Plan, Tucson, AZ.

RECON Environmental Inc. 2007. Ecological effectiveness monitoring plan for Pima County: Phase 1 final report. Report to the Pima County Board of Supervisors for the Sonoran Desert Conservation Plan, Tucson, AZ.

Appendix A. Existing Monitoring-related Activities Carried Out by Other Entities 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); Fish (relative abundance) and aquatic habitat monitoring (LCNCA); Ecological site models and upland vegetation monitoring (LCNCA); 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.
	NPS, SODN	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.
Federal Government (cont.)	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.
	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;

PARTNER GROUP	PARTNER	MONITORING-RELATED ACTIVITIES AND EXPERTISE
Federal Government (cont.)	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	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;
	Arizona Department of Water Resources	Regional groundwater monitoring; Protocols for aquatic macroinvertebrate and water-quality monitoring;
	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; Citizen-science bird monitoring (Tucson Bird Count) 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 Flood Control District	Precipitation monitoring at 65 self-reporting sites; Climate monitoring- 4 weather stations; Streamflow gauges (A.L.E.R.T. system).

PARTNER GROUP	PARTNER	MONITORING-RELATED ACTIVITIES AND EXPERTISE
County and Local Governments, Cont	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.
	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

Pima County Ecological Monitoring Program Update

August 2008

Brian Powell

Overview

1) Review SDCP and MSCP:
   - Background and progress to date
2) Proposed MSCP monitoring approach:
   - Single-species
   - Other parameters: habitat, ecosystem, and threats

Rapid Growth & Development in Eastern Pima County

Ecological change: Riparian areas

1904

"A" Mountain

1982

Non-native Species: Threats to Native Species and Ecosystem Function

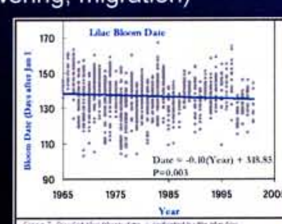
Crayfish

American Bullfrog

Buffelgrass

Climate Change: Organisms

- Species distributions changes
- Phenological events (timing of breeding, flowering, migration)



Sonoran Desert Conservation Plan Goal

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.

Pima County Multi-species Conservation Plan (MSCP)

- Permit under the Endangered Species Act (Issued by U.S. Fish and Wildlife Service)
- MSCP must anticipate and account for impacts to affected (covered) species
- Most recent addition: RECON (2006)

Covered Species = Priority Vulnerable Species

8 mammals (mostly bats)
8 birds
7 reptiles
2 frogs
6 fish
1 invertebrate
4 plants

Most species associated with riparian environments

Pima County's MSCP Monitoring Approach

1. Monitor subset of covered species for abundance, occupancy, presence OR support existing efforts
2. Monitor additional features:
   - Habitat
   - Ecosystem structure
   - Threats

Single-species Monitoring

MSCP Monitoring Challenges

Most MSCP monitoring plans attempt to monitor populations of many covered species with limited success because:

- Species are following indicators
- Often ambiguous response to changing conditions
- Lack of link to management actions
- Variable populations
- High cost

Direct Monitoring of Spatially Restricted Species

Huachuca water umbel	Presence
Southwest willow flycatcher	Abundance
Yellow-billed cuckoo	Abundance
Gila chub	Abundance
Gila topminnow	Abundance
Longfin dace	Abundance
Lowland leopard frog	Occupancy
Mexican garter snake	Occupancy
Giant spotted whiptail	??
Arkenstone cave pseudoscorpion	Occupancy

T&E Species Monitoring

Cooperative Monitoring:

- Lesser-long nosed bat
- Cactus-ferruginous pygmy owl
- Desert pupfish
- Chiricahua leopard frog

Monitoring underway:

- Pima Pineapple cactus

Monitor Re-introduction Efforts

- Desert sucker
- Sonora sucker
- Chiricahua leopard frog
- Others?

Other Monitoring Parameters

Beyond Single-species Monitoring: UA Planning Effort

Goal: Identify other monitoring parameters (habitat, ecosystem, and threats) that have the best chance of informing the SDCP and MSCP goals and provide opportunities for early change detection and adaptive management

PVS Shortfalls

- PVS provided planning tool, BUT
- Chosen based on anticipated threats and therefore have highest possibility of listing
- Poor representation for some species groups
- Little regard for monitoring issues or ability to inform broader management goals

Modeling Approach

Vertebrates chosen because of focus in SDCP and MSCP

Species chosen for modeling:

- Native to Pima County
- Breeds in Pima County
- Occurs primarily below the oak-woodland belt
- Sufficient information exists for the species

Modeled Species

103 species to represent range of vegetation communities, trophic levels, body sizes:

8	Amphibians
26	Reptiles
2	Fish
45	Birds
30	Mammals

Plus 36 PVS

Habitat Modeling

Identification and scoring of *specific* environmental features that each species uses including:

- Vegetation features
- Water resources
- Soils
- Human resources (e.g., buildings)

Threats Assessment

Identified 150+ threats in Pima County categorized by:

- Habitat conversion
- Transportation infrastructure
- Consumption: Abiotic resources
- Consumption: Biological resources
- Non-consumptive biological resource use
- Pollution
- Non-native species

Threats Assessment cont.

Scored threats for:

- Spatial extent
- Permanence
- Severity
- Cost/feasibility of abatement
- Possibility of abatement

Link to Environmental Features

Natural Processes

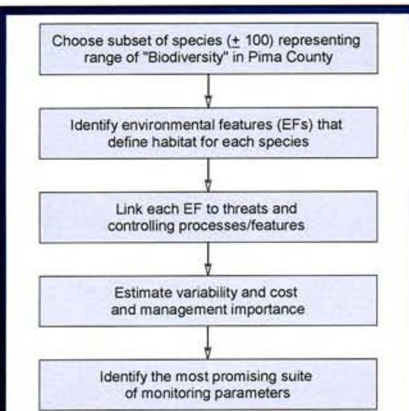
- Net primary productivity
- Nutrient cycling
- Fire cycle
- Succession
- Groundwater recharge
- Soil erosion/deposition

Project Matrix

	EF	Threats	Processes
Species	X	X	X
EF		X	X
Threats			X

Final Filters

- Matrix = Ecological Relevance
- Cost/variability
- Management Significance
  - Relationship to management goals
  - Management can influence undesirable trends



Timeline

- Species-level monitoring recommendations: Public review starts next week
- Ecosystem, threats and habitat work ongoing
  - To be completed Spring 2009
- Phase III implementation: summer 2009

Upcoming Reports

- Proposed species-level monitoring
  - Begins public review
- Land-cover monitoring report (J. Fonseca)
- Adaptive management report (J. Bate)
- Draft data management plan