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Wildlife Ecology and Management, Santa Rita Experimental Range (1903 to 2002)

Abstract: The Santa Rita Experimental Range (SRER), established in 1903, is a natural laboratory used to better understand desert grasslands. We reviewed the literature to summarize studies that have been conducted on wildlife at SRER from 1903 to 2002 and to provide recommendations on expanding contemporary research at SRER. Research related to wild vertebrates has been limited to a few studies of reptiles, avifauna, and mammals. Mammalian studies were dominated by rodent research. Peer-reviewed publications dominated the references (n = 45), followed by technical bulletins (n = 12), theses (n = 9) and dissertations (n = 9), conference proceedings (n = 3), reports (n = 3), and other (n = 3). Although research on wildlife has been limited (about 0.8 publications per year) from 1903 to 2002, several works were landmark studies that led the way for future work (for example, water requirement studies, life history studies of small mammals, studies of coyotes, and disease studies). There has not been a concentrated effort to continue wildlife research at SRER, and since 1983, only five manuscripts have been published. We recommend that land managers and administrators initiate inventory and monitoring of all vertebrates on SRER to gather new knowledge, to quantify abundance trends, and to assist with resource research and management.

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Introduction

The Santa Rita Experimental Range (SRER) was established in 1903 as a natural laboratory to better understand arid rangelands. It is the oldest research area maintained by the USDA Forest Service. Although it was established as a research site for range improvement in the Southwestern United States, only limited research has been directed toward wildlife. The history of SRER, location, and mission are outlined by Medina (1996). The purpose of our paper is to summarize the work that has been conducted at SRER on wild vertebrates, indicate the role those studies have on a better understanding of wildlife ecology and management, and make recommendations for the future.

We obtained information from the University of Arizona's digital archive (ag.arizona.edu/SRER), Medina's bibliography (1996), and literature searches conducted at the Science Library, University of Arizona. Most of the archival data supported the published material and was not referenced again.

Although the SRER was established in 1903, it was nearly 2 decades before the first manuscript related to wildlife was published (Vorhies and Taylor 1922). In the subsequent 5 decades there were approximately 10 publications per decade. In the eighth decade of SRER (1973 to 1982), the number of publications peaked at 25. Since 1983, only five publications have been produced and more than 5 are in press or in preparation. We are unaware of ongoing research on wildlife at SRER.

Although wildlife research has been limited (about 0.8 publications per year) at SRER over the past 100 years, much of the work published are landmark studies that created a framework for future studies, were classical works that are still used as

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reference sources, provided data that are applicable to wildlife in arid regions worldwide, or were part of larger studies to examine disease in desert mammals. Each of these appeared to be initiated by individuals who were aware of the SRER instead of any unified effort by SRER administrators to direct wildlife research. For example, the early life history studies were conducted by U.S. Biological Survey biologists; the water-balance work, most coyote and rodent studies, and disease studies were directed by scientists affiliated with universities. Because of the location of SRER to the University of Arizona, it would be valuable to begin a research program with more direction in the next 100 years to maximize our ability to learn and provide more and better information related to how wildlife influences grasslands grazed by livestock and vice versa. The wildlife research conducted over the past 100 years has been limited to a few studies of reptiles, avifauna, and mammals (dominated by rodents). Peer-reviewed publications dominated the references (n = 45), followed by technical bulletins (n = 12), theses (n = 9), dissertations (n = 9), conference proceedings (n = 3), reports (n = 3), and other (references in books, popular papers, and mimeographs) (n = 3). In addition, projects were conducted by mammalogy students from the University of Arizona as part of class requirements (Mammal Museum, University of Arizona, Tucson). The wildlife research is categorized as related to reptiles, avifauna, and mammals.

Reptiles

Reptiles received the least amount of attention by ecologists at SRER. A distribution of rattlesnakes was based on 40 records of diamondbacks (*Crotalus atrox* Baird and Girard), six records of tiger rattlesnakes (*C. tigris* Kennicott), seven records of Mohave rattlesnakes (*C. scutulatus* Kennicott), and nine records of blacktailed rattlesnakes (*C. molossus* Baird and Girard). Diamondbacks ranged from an elevation of 854 to 1,220 m. Mohave rattlesnakes ranged from an elevation of 854 to 1,373 m, and blacktails were found in canyons from 1,281 to 1,464 m. The distribution of tiger rattlesnakes overlapped the distribution of all the other rattlesnakes (Humphrey 1936).

As mesquite was cleared from SRER in various treatments, the Sonora spotted whiptail (*Cnemidophorus sonorae* Lowe and Wright) was more abundant than in areas that contained undisturbed mesquite and mesquite with irregularly shaped clearings (Germano 1978; Germano and Hungerford 1981). The studies of Germano (1978) and Germano and Hungerford (1981) were pioneer studies in considering reptiles in landscape management plans in the Southwest.

Avifauna

Studies of birds at SRER were limited, and seven of the 13 published works were related to quail. The other six articles included short notes on the first record of the pectoral sandpiper (*Calidris melanotos* Vieillot) for Arizona (Vorhies 1932), the life history and diurnal activity of the roadrunner (*Geococcyx californianus* Lesson) (Calder 1968a,b), and diet and nesting data for 20 to 55 Sonoran Desert birds (Russell and Gould 1974; Russell and others1972, 1973) on a 20.3-ha study plot in SRER.

Studies of quail included water requirements, productivity, diets, and life history traits (Gorsuch 1934). Whether or not water supplied for wildlife influences populations has been debated for years (Grinnell 1927; Rosenstock and others 1999; Vorhies 1928). The controversy began over 50 years ago when biologists in Western States began to supply water for game birds (MacGregor 1953). The first studies to examine the response of Gambel's quail (*Callipepla gambelii gambelii* Gambel) to water sources provided as management activities were, in part, studied at SRER (Hungerford 1960a,b).

Water supplied by humans was not important, as quail maintained body moisture from succulent plants. Vitamin A was an important part of the life history, and during dry years quail did not store enough vitamin A in their liver for successful breeding. Rainfall, as it influenced vegetation, was the driving force for quail reproduction in southern Arizona, not water provided by humans (Hungerford 1960a,b, 1964). The importance of vitamin A was first proposed by Vorhies (1928) more than 30 years earlier based on his studies of lagomorphs on SRER. Diet and physiological studies (Hungerford 1960a,b, 1962, 1964) of quail supported Vorhies' observations.

Diets of scaled quail (*Callipepla squamata* Vigors) were studied at SRER (Medina 1988). The scaled quail also selected succulent food during dry seasons. Unfortunately, additional studies of avifauna have not been conducted at SRER.

Mammals

Scientists have concentrated mammalian studies at SRER on lagomorphs, rodents, coyotes (*Canis latrans* Say), collared peccaries (*Pecari tajacu* Linnaeus), and deer (*Odocoileus* spp). However, there are only limited data for each group, and no central theme prevails. Because SRER is primarily grassland, several studies examined influences of range management practices (for example, mesquite [*Prosopis* spp.] control) on wildlife. For example, the control of mesquite (15 to 100 trees per 0.41 ha) caused a subsequent reduction of use by mourning doves (*Zenaida macroura* Linnaeus), white-winged doves (*Zenaida asiatica* Linnaeus), Gambel's quail, scaled quail, and desert cottontails (*Sylvilagus audubonii* Baird). The abundance of antelope jackrabbits (*Lepus alleni* Mearns) and blacktailed jackrabbits (*L. californicus* Gray) did not change with mesquite removal (McCormick 1975). Other studies were very general and simply presented anecdotal sightings of animals (Martin 1966).

Lagomorphs

Some of the earliest studies of lagomorphs were conducted at SRER (Vorhies and Taylor 1933) with the use of treatment and control areas. These early wildlife biologists recognized the importance of examining species in their habitat and understanding their value and relationships with humans. The importance of considering human dimensions as a critical component of wildlife management was raised by Leopold (1933), and Vorhies and Taylor

(1933). Human dimensions have been a central aspect of wildlife management ever since. As stated by Vorhies and Taylor (1933: 579), “This is wild life management.” Their publication came out the same year Leopold (1933) published *Game Management*, and the monograph serves as a model for the scientific management Leopold (1933) advocated. Through their studies of lagomorphs, Vorhies and Taylor (1933) determined life history traits, distribution, interactions with livestock, forage consumption, diseases and parasites, censusing techniques, habitat relationships, predation, and management of antelope and blacktailed jackrabbits. Their monograph was one of the first in-depth studies of a game species conducted in the United States. Taylor and others (1935) also documented and demonstrated ways that jackrabbits influenced vegetation, and argued that wild animals should be considered in maintaining balanced rangelands.

Two studies followed Vorhies and Taylor (1933) that expanded on their work. Forage consumed by jackrabbits was determined from experimental trials (Arnold 1942: 46–69); jackrabbits consume as much as a 454-kg range cow consumes. Arnold and others (1943) also explored ways to estimate lagomorph numbers with counts of fecal pellets.

The second study examined the growth, development, and forage requirements of young California jackrabbits (Haskell and Reynolds 1947). These studies were conducted in a scientific manner, and the data are still useful today (Brown and Krausman 2003), primarily due to the scientific approach adopted by early wildlife biologists. Lagomorphs on SRER were also used as a model to study water balance and water requirements.

Early observations correlated moist diets as one mechanism to reduce dependency on free-standing water for the kangaroo rat (*Dipodomys spectabilis* Merriam), wood rat (*Neotama albigula* Hartley), round-tailed ground squirrel (*Spermophilus tereticaudus* Baird), and jackrabbits (Vorhies 1945). Later, more detailed studies of the physiology of jackrabbits were conducted, which determined that jackrabbits reduced their dependency on free water in other ways: seeking shade, the insulation properties of their fur, use of a clear sky as a radiation heat sink during midafternoon (when solar and reflected radiation are reduced), high blood flow in the ears to permit heat loss, and development of a high lethal body temperature (45.4 °C) (Schmidt-Nielsen and others 1966). The survival techniques described by Schmidt-Nielsen and others (1966) were further applied to and studied for cottontails and jackrabbits (Hinds 1970). The study by Hinds (1970) only used animals captured at SRER; experimentation was conducted at the University of Arizona, Tucson.

Rodents

More work has been conducted on rodents at SRER than any other group of mammals. The studies ranged from notes to studies on ecology and life history traits.

Notes—The note (Taylor and Vorhies 1923) that was published described the capture of a pair of kangaroo rats. This was a time in the evolution of natural history writing where unusual observations were published regularly.

Abundance Indices—The Standard Minimum Method was a reliable technique to estimate small, nocturnal rodents at SRER, except it required large, homogeneous sample areas (7.3 ha) and large grids in addition to the assumptions that accommodate the technique. These drawbacks are time consuming (Olding 1976; Olding and Cockrum 1977), which preclude the method as a rapid technique suitable for estimating small rodents.

Breeding population density (per 2.6 km^2) was tabulated for SRER for selected species by Leopold (1933: 233). Data for rodents were from Taylor (1930), but estimates for other species were subjectively estimated.

Physiology—Most of the physiological studies of rodents on SRER were related to water. Some heteromyid rodents conserve water through excretion of concentrated urine. Their maximum excretory ability (1,200 mN for electrolytes and 900 mN for chlorides) exceeds the limits for other mammals (K. Schmidt-Nielsen and others 1948). Other rodents such as white-throated woodrats cannot survive on dry food only, but solved the water problem by consuming succulent plants (B. Schmidt-Nielsen and others 1948).

Further studies demonstrated the importance of the humidity in rodent burrows to survival. The humidity in burrows of kangaroo rats was higher than outside humidity and significant for their water balance (Schmidt-Nielsen and Schmidt-Nielsen 1950a,b, 1951). These studies were some of the first that examined the water balance of desert mammals and are still widely cited.

More recent studies have examined the survival of small mammals from which blood was collected (Swann and others 1997). The survival of most rodents was not influenced due to anesthetization and bleeding through the orbital sinus. Pocket mice (*Chaetodipus* spp.) were the exception, and those that were bled had significantly lower survival rates compared to controls (Swann and others 1997).

Range Relations—Because of the economic value of SRER and its representation of desert grasslands in general, managers were interested in animals that competed with livestock for forage. One of the earliest studies was to determine how much forage kangaroo rats consumed (Vorhies and Taylor 1922). Unfortunately, they miscalculated and later revised their figures (Vorhies and Taylor 1924). Kangaroo rats consumed forage equivalent to 28 steers per year. However, because resources are often limited prior to summer rains, the forage destroyed by kangaroo rats would support 336 cattle in one month during this critical period (Vorhies and Taylor 1924). Because rodents have such an impact on range resources, it is important for managers to know how much they consume before establishing carrying capacity for livestock. Numerous methods to determine rodent pressure on rangelands were established, but how rodents interact with other aspects of rangeland ecology are unknown and need further research (for example, pressure on soil, relationship between rodents and insects) (Taylor 1930). Only limited research occurred in the past.

Merriam kangaroo rats were identified as an agent of mesquite propagation. When harvested, many seeds were buried that germinated and developed away from the parent tree. The result was an increase of mesquite at the expense of grasslands (Reynolds and Glendening 1949).

Some researchers recommended a reduction in kangaroo rats, along with livestock management to manage forage (Reynolds 1950; Reynolds and Glendening 1949). Merriam kangaroo rats consume large-seeded perennial grasses and other large seeds. When rangelands are in poor condition, rodents eat most seeds, which prevents rangeland restoration (Reynolds 1950). However, because other mammals also perpetuate an increase in mesquite and a decrease in grassland, removing kangaroo rats only would not increase grassland landscapes (Reynolds 1954). Additional forage studies of heteromyid rodents were conducted by Price (1977), and effects of woody removal on nocturnal rodents was examined by Vaughan (1976). Overall, as woody vegetation was removed, rodents were not effected, with few exceptions: kangaroo rats decreased and silky pocket mice (*Perognathus flavus* Baird) increased, as did others. Manipulation of vegetation for any reason needs to address how it will influence overall biodiversity.

The early studies on rodents were directed at basic traits and interactions with the grasslands. However, they also served to guide future research questions.

Ecology and Natural History—There was not a constant theme identified for the broad area of ecology and natural history. Studies conducted ranged from soils to disease and included abundance related to rainfall, dispersal and movements, behavior, life history, and habitat.

Despite the importance of rainfall to rodent populations, only two studies examined rodent abundance in relation to rainfall. Rainfall from 1942 to 1972 was correlated to the density of 10 rodents. Rodent fluctuation was predicted based on the amount of rainfall during the previous year (Turkowski and Vahle 1977). Petryszyn (1982) was able to correlate extreme rodent population fluctuations at SRER with certain El Niño events. Heteromyid rodent numbers increased over sixfold in just a few months in 1973. This pattern was repeated in 1979. Biomass of the Arizona pocket mouse (*Perognathus amplus* Benson) increased from less than 100 g per ha in May 1973 to over 1,100 g per ha by September 1973. The timing and amplitude of these increases varied among the rodent species. Petryszyn (University of Arizona, unpublished data) continued monitoring rodent populations at SRER until 1994, thus providing a 24-year record of rodent population fluctuations.

Rodent movements were contrasted in a control area and areas cleared of woody vegetation. Shifts in home range from clearing vegetation were made by adults primarily. However, the difference in movements or numbers of individual rodents (kangaroo rats, *Perognathus penicillatus*, southern grasshopper mouse [*Onychomys torridus* Coves]) on disturbed and undisturbed areas was minor (Vaughan 1972). A short removal study (to determine how trapping affected rodents) most frequently captured the same three rodent species. Results were inconclusive (Courtney 1971). Additional removal studies were conducted (Courtney 1983), but removal did not influence home range size or physiology of kangaroo rats.

Studies on behavior were also limited. One dissertation was conducted on predatory behavior of the southern grasshopper mouse (Langley 1978). The southern grasshopper mouse learned how to kill different prey (for example, crickets, stink beetles, scorpions) based on their defenses (Langley 1981).

Because so little was known about the life history of many rodents, some of the earlier studies at SRER concentrated on establishing a basis of knowledge for several rodents. Early researchers were also interested in how rodents influenced rangelands.

Classical life history accounts (for example, status, taxonomy, range, periods of activity, breeding, habitat, diet, predation, economics, management) were provided for woodrats (Vorhies and Taylor 1940), Sonoran Desert pocket mouse (*Chaetodipus penicillatus pricei* Allen), Bailey's pocket mouse (*C. baileye baileyi* Merriam), and Merriam's kangaroo rats (Reynolds 1958, 1960). There was no impact to rangelands from pocket mice or woodrats. Merriam's kangaroo rats were more abundant on rangelands grazed by livestock, and they are likely beneficial by burying seeds. However, they also bury mesquite and cactus seeds, which is not always favorable to range management objectives (Reynolds 1958).

Studies of habitat have been limited. Competition was examined as a mechanism for rodents to use different microhabitats for foraging (Price 1976, 1978). Similar results (for example, habitat selection as an important factor in species coexistence) were reported by Wondolleck (1975, 1978). Price and others (1984) also demonstrated that rodents spent less time in open areas on moonlit nights than on dark nights. Langley (1980) described habitat (such as burroweed, a few grasses, and bare soil) for southern grasshopper mice at SRER. More recently, the habitat use and abundance of rodents at SRER was documented. These data revealed temporal and age-related differences in habitat use by rodents, which are of use in fine-scale planning for restoration of desert plant communities (Morrison and others 2002). Gottesman (2002) studied the habitat use and movement patterns of rodents in riparian vegetation and concluded that most animals made only short-distance movements. Although the papers on habitat were limited, they ranged from basic habitat requirements to brief discussions of habitat alteration and restoration.

Three studies addressed the response of soils to animal activity at SRER: Greene and Murphy (1932); Greene and Reynard (1932); and Taylor (1935). All were very general but pointed to the importance of physical and chemical changes animals caused in the soil. No other studies were found that addressed the influence of wildlife on soil.

Some of the more recent work with rodents at SRER has examined Sin Nombre virus prevalence. Thirteen species were captured and examined, but only mice in the genus *Peromyscus* were seropositive for the virus. There was a suggested correlation between population size and hantavirus-antibody prevalence (Kuenzi and others 1999).

Predators

In the 1970s and early 1980s a series of studies on coyotes was conducted at SRER. Home ranges (54 to 77 km^2 for juveniles), abundance, and behavior were documented (Danner 1976; Danner and Smith 1980). During these studies Danner and Fisher (1977) were the first to document homing by a marked coyote.

More detailed studies of coyotes were conducted at SRER by Drewek (1980) and Fisher (1980). Drewek (1980) examined home ranges, activity patterns, and age distribution.

Fisher (1980) examined how an abundant food source (such as carrion) influenced density, age distribution, weights, ovulation rates, and litter sizes of coyotes in three study areas (no differences). Other diet studies were also conducted (Short 1979).

Ungulates

Collared peccaries and deer received some attention at SRER. Collared peccary diets were examined and were found not to be competitive for forage with livestock (Eddy 1959, 1961). General life history data were also presented (Knipe 1957). Home ranges and movements of five mule deer were examined (Rodgers 1977; Rodgers and others 1978). These researchers concluded that disturbances by humans influenced breeding activity and normal movement patterns.

Feeding trials for Coues white-tailed deer (*Odocoileus virginianus* Coues) were conducted at SRER (Nichol 1936, 1938). Nichol (1938) also examined parasites, disease, water and salt consumption, reproductive patterns, and hybridization of mule deer and white-tailed deer. The study was initiated because the U.S. Forest Service was interested in appropriate allocation for livestock and wildlife, a controversy that still continues in Arizona. This was one of the first studies addressing these topics in Arizona, and the work is still used as a reference.

Despite the importance of deer to Arizona, including hunting, no studies were found that examined harvests in SRER. Some summary data were provided in a memo (Yeager and Martin 1965; not seen, cited in Medina (1996) (hunt success) for the 1964 deer season.

This array of research has been instrumental in establishing SRER as the natural laboratory it was designed to be. However, scientists and administrators could be more efficient with a directed approach for long-term research that include inventory and monitoring. To our knowledge, the U.S. Department of Agriculture's Forest Service or the University of Arizona administrators have not allocated funds or a central mission in which continuous studies of wildlife could be conducted. Unless a central theme or funding level is established, wildlife research at SRER will continue to be based on individual efforts.

Inventory and Monitoring

Inventory and monitoring are the most frequently conducted type of wildlife studies (Morrison and others 2002). They are done to gather new knowledge about an area, quantify trends in some animal or resource of interest, and to assist with resource management. The goal of an inventory is to quantify the current composition, distribution, and perhaps abundance of a species of interest in an area. Monitoring is simply conducting repeated inventories to quantify changes in composition, distribution, and abundance over time. In addition to the general pursuit of knowledge, inventory and especially monitoring are often mandated by legislation, such as by the National Forest Management Act (1976) and the Endangered Species Act (1973). Unfortunately, both initial inventories and followup monitoring are seldom conducted with sufficient rigor to precisely estimate the parameters of interest (Morrison and Marcot 1995; Morrison and others 2002).

There are numerous reasons why establishing an organized and rigorous inventory and monitoring program would benefit an education and research mission at SRER. First, resource managers need to have reliable data upon which decisions can be based. Only a comprehensive monitoring program that involves all taxa can hope to provide an understanding of the interactions between management decisions and wildlife responses. Second, there is the need to provide students and potential researchers with a complete list of species composition, relative abundances, and distribution to assist with teaching and research planning. Third, the University of Arizona and the Forest Service should have an interest in monitoring the influence of local, regional, and global changes in climate, air quality, human population impacts, and other factors on wildlife populations over time.

Simply establishing a series of repeated sampling locations (regardless of the specific methodologies used) is insufficient, however, to address any questions regarding wildlife at SRER in a meaningful way. Specific and quantifiable objectives must be established before successful monitoring can be accomplished; these objectives then drive the sampling design, intensity of sampling, and statistical analyses. A typical goal of monitoring is to identify trends in a resource of interest. Trends represent the sustained patterns in count data that occur independently of cycles, seasonal variations, and irregular fluctuations in counts. A common problem in trend detection, however, is that sources of "noise" in counts obscure the "signal" associated with ongoing trends. The probability that a monitoring program will detect a trend in sample counts when the trend is occurring, despite the "noise" in the count data, represents its statistical power. Although statistical power is central to every monitoring effort, it is rarely assessed. Consequences of ignoring it include collection of count data insufficient to make reliable inferences about population trends, and collection of data in excess of what is needed (Gibbs 1995).

The statistical power of population monitoring programs must be estimated relative to (1) the number of plots monitored, (2) the magnitude of counts per plot, (3) count variation, (4) plot weighting schemes, (5) the duration of monitoring, (6) the interval of monitoring, (7) the magnitude and nature of ongoing population trends, and (8) the significance level associated with trend detection (Gibbs 1995). Because these factors interact in complex ways to determine the capacity of a monitoring program to detect trends in populations, such basic questions of "how many plots should I monitor" or "how often should I conduct surveys" rarely have intuitive answers. Programs such as **MONITOR** (Gibbs 1995) are designed to explore interactions among the many components of monitoring programs and to evaluate how each component influences the monitoring program's power to detect trends.

In general and certainly applicable to SRER, broad objectives for conducting monitoring are (Spellerberg 1991) to:

1. Provide guidance to wildlife management and conservation.
2. Better integrate wildlife conservation and management with other land uses.
3. Advance basic knowledge in addition to applied knowledge.

4. Track potential problems before they become real problems.

These objectives are often addressed by conducting monitoring studies (Gray and others 1996; Miller 1996) to:

1. Determine wildlife use of a particular resources or area.
2. Evaluate effects of land use on populations or habitats.
3. Measure changes in population parameters.
4. Evaluate success of predictive models.
5. Assess faunal changes over time.

Monitoring Elements

Key components of a monitoring program at SRER should include the:

1. Ability to link past, current, and any future research activities with a systematic grid system (in other words, to be able to locate relative to base monitoring sampling frame).
2. Sampling frame developed around an attribute-based GIS vegetation system.
3. Sampling protocol for rare species, such as adaptive cluster sampling, to be instituted in addition to the basic sampling frame.

For example, a 500- by 500-m grid coordinate system could be established across SRER. This spacing would be applicable for implementing a standard point-count methodology for birds because most counting protocols require an interpoint spacing of greater than or equal to 300 m. The actual spacing of grid points is actually irrelevant because the system would only exist as coordinates in a GIS layer and not physically exist on the ground. Using the 500- by 500-m spacing and beginning at a random starting point in one corner of SRER, points would be systematically spread across the area. Additional points would also be randomly placed within each currently recognized vegetation type, while ensuring that adequate sampling occurred in rare types. For example, additional (nongrid) points would need to be established in linear (for example, riparian) and relatively small (for example, hackberry [*Celtis reticulata*] woodland) types. A systematic placement of grid points is recommended because there is no assurance that a currently recognized classification of vegetation would be of adequate refinement for many applications, or that the classification would be stable into the future. It is likely, however, that certain vegetation classifications (for example, riparian, the major plant associations currently recognized) will remain adequate upon which to base the general allocation of points. The value of points is that they are readily locatable using GPS, even if they serve as the starting point of a transect.

The number of points to be sampled should be based on power analysis using the best available estimates of variance associated with each parameter of interest. It is important to recognize that power analysis only provides an initial estimate of sample size. The final sampling effort must be based on an iterative process that updates the number of required samples as data are gathered. Power analysis requires that a magnitude of biological effect be established. That is, what magnitude of change must be quantified with what level of certainty? For example, is it sufficient for SRER resource managers to be able to identify a 5 percent annual change in abundance of a species in 3 years, or can they wait to identify this change over 5 years? The answer will vary depending on the species in question. Note that allowing for a 5 percent decline in abundance over 5 years results in a cumulative loss of 29 percent—a substantial decline for any species.

Unfortunately, very little general guidance is in the literature regarding appropriate initial sample sizes for a large-scale, multispecies monitoring program. This is due, in part, to the rather recent general interest in statistical rigor being shown among many wildlife professionals. However, many computer statistical packages are now available that allow easy access to power analyses. Because there are so many potential criteria that can appropriately be used for establishing monitoring parameters, and because the rarer species will require specialized sampling efforts, we cannot provide a cookbook answer for necessary sample sizes. Some studies on monitoring relatively common bird species have shown, however, that 30 to 50 points (usually counted 3 times each per season, most often in the breeding season) are adequate to detect a 5 percent annual change in abundance within a 5-year period. At SRER, however, it will not be possible to place that many points within relatively rare vegetative types or plant associations. In such situations, it becomes necessary to increase sampling intensity, and conduct a more intensive type of monitoring, to rigorously quantify change. With birds, for example, researchers often supplement point counts with more intensive spot mapping procedures.

Rare Species

Management recommendations are sometimes made for rare species based on data from common species, although rare species are excluded from analyses due to small sample sizes. In many cases, threatened or endangered species are "rare." If a species only occurs in a very specialized habitat, it would be rare in that its only detections occur within spatially clumped areas. Alternatively, if a species has a large geographic range it may be considered rare because it is only detected during a community assessment as it wanders through a study area. Lastly, species are considered rare when local populations are composed of a few individuals per unit area, as is the case with most threatened and endangered species (Queheillalt and others 2002).

Due to the great number of "rare" species in plant and animal communities, these communities are known to adhere to lognormal species abundance distributions, in which a small number of species are common, only a few species reside in intermediate to low numbers, and most are uncommon (Harte and others 1999; Maina and Howe 2000; Rosenberg and others 1995; Van Auken 1997). Frequently used sampling designs, such as simple random sampling, stratified random sampling, and systematic random sampling, are ineffective when applied to infrequently encountered species, and such sampling designs return numerous zero counts and decrease the accuracy of the studies using these designs (Thompson 1992; Thompson and others 1998).

The exclusion of species due to low detection rates leads to the erroneous inflation of relative abundance and density calculations of included species. In instances of special status species (for example, legally threatened or endangered), elevated density estimates may lead to the biological notion that a species is prevalent in sufficient numbers when in fact its actual density is low. Also, if the object of the study is to compare relative abundances over successive years, trends may appear for a species, which are due to the number of species excluded from abundance calculations rather than true biological trends.

Because rare species are often spatially clumped, we recommend using one of the forms of adaptive sampling methods—adaptive cluster sampling design, strip adaptive cluster sampling, or stratified adaptive cluster sampling—as described by Thompson (1992) to supplement the systematic arrangement of sampling points described above. Adaptive cluster sampling is a two-stage sampling design in which initial sampling plots are randomly selected and monitored. Any of the initial plots containing animals are selected to have all adjacent plots monitored as well. This process continues until adjacent plots no longer contain animals of interest (Krebs 1999; Morrison and others 2001; Thompson 1992). This method increases the probability of encountering clumped species, and thus often increases sample sizes.

Statistical analyses with small sample sizes can be problematic. When samples are from highly variable populations, statistical analyses often have low power. Although beyond the scope of this paper, there are options for statistical analyses with small sample sizes. Contingent upon the specific situation and type of data being used, nonparametric tests can be employed or data transformed to allow the use of parametric tests when working with small sample sizes.

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