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Long-term avian research at the San Joaquin Experimental Range: Recommendations for monitoring and managing oak woodlands

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ABSTRACT

Experimental forests and ranges are living laboratories that provide opportunities for conducting scientific research and transferring research results to partners and stakeholders. They are invaluable for their long-term data and capacity to foster collaborative, interdisciplinary research. The San Joaquin Experimental Range (SJER) was established to develop appropriate land management practices on foothill rangelands in California. SJER has a long and rich history of avian research. Natural history observations recorded since 1935 demonstrate that oak woodlands are one of the most diverse habitat types in North America. Early avian studies focused on California quail (*Callipepla californica*) as a game species and led to insights on quail diet and habitat requirements. Starting in the late 1970s, the focus of avian research shifted to methods for detecting changes in wildlife populations over time and response to management practices. This research has led to important recommendations for implementing bird monitoring programs. Using data collected on bird numbers, in conjunction with monitoring reproductive success of all species, recent studies have examined life history strategies, source–sink dynamics, the effects of livestock grazing, and the impacts of an invasive species on native cavity-nesting species. We are currently in the process of examining population trends and predicting the effects of climate change using long-term data. SJER continues to provide unique opportunities for research and educational activities that increase our understanding of the foothill oak woodlands of California.

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1. Introduction

Experimental forests and ranges provide lands for conducting research that serve as a basis for the management of forests and rangelands. Of the 80 U.S. Forest Service Experimental Forests and Ranges (hereafter EFRs), the San Joaquin Experimental Range (hereafter SJER) is one of only four experimental ranges. In 1934, the Forest Service purchased private ranchlands in foothill woodlands of the western Sierra Nevada to create SJER. While originally conceived as an interdisciplinary research center to identify cost-effective methods of commercial livestock production while maintaining the integrity of the surrounding foothills, research interests have since expanded and diversified to include research on ecosystem patterns and processes.

SJER has a long and rich history of avian research leading to recommendations for managing both public and private land. The oak woodlands of SJER are extremely rich in animal species and provide breeding, wintering, and migratory stopover habitat for many bird species. Early investigations focused primarily on inventories of fauna and studies of game species and raptors. Natural history observations recorded since 1935 include a total of 201 (194 native and 7 introduced) bird species observed (Purcell et al., 2007). More recently, the focus of avian research has been on monitoring and management recommendations for oak woodlands, one of California's most diverse and threatened habitats. The National Forest Management Act of 1976, which charges the Forest Service with monitoring trends in populations of wildlife species to detect changes over time and responses to management practices, prompted research to evaluate techniques for estimating numbers of birds. The avian monitoring begun during that period formed a solid basis for work on life history strategies of oak woodland birds and the effects of anthropogenic-induced changes on the bird community. The goal of this paper is to describe avian research at SJER since its inception, highlight some of the major results of that research, provide recommendations based on those findings, and illustrate the value and opportunities of SJER as a research facility.

2. Study area

SJER is located near the geographic center of California in the foothills of the Sierra Nevada in Madera County (Fig. 1). Elevation across the 1875-ha site ranges from 210 to 520 m. The climate is

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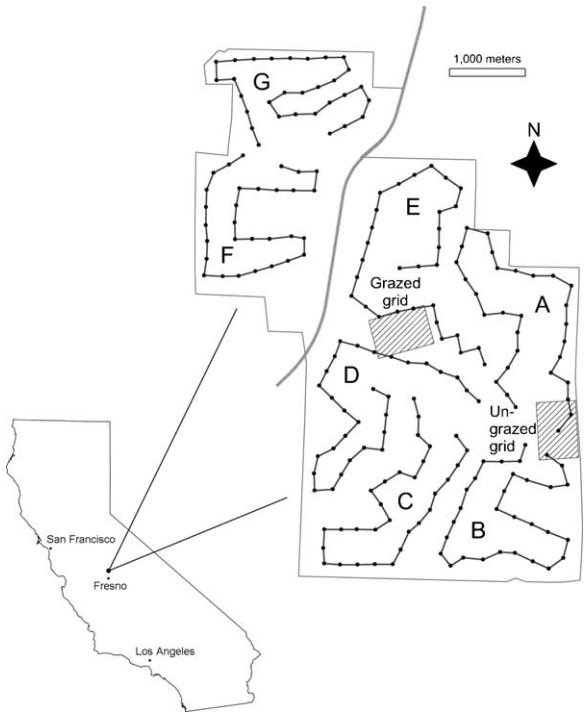

Fig. 1. Location of the San Joaquin Experimental Range, Madera County, CA. Inset shows locations of grazed and ungrazed study plots and 210 point-counting stations (7 lines of 30 points).

Mediterranean, with cool wet winters and hot dry summers. Most precipitation occurs as rain, with an annual average of 46 cm.

Vegetation consists of an open woodland dominated by blue oak (*Quercus douglasii*), interior live oak (*Q. wislizenii*) and foothill pine (*Pinus sabiniana*). Shrubs grow as scattered individuals or clumps, and annual grasslands form a mosaic across gentle slopes where the overstory is lacking. Dominant shrub species include wedgeleaf ceanothus (*Ceanothus cuneatus*), chaparral whitethorn (*C. leucodermis*) and Mariposa manzanita (*Arctostaphylos viscida mariposa*). In a few areas the overstory is primarily blue oak with a relatively open understory. SJER is grazed by livestock year-round through a cooperative agreement with California State University, Fresno. A 29-ha Research Natural Area (RNA) has remained ungrazed since 1934 along with a few other exclosures, mostly small.

Two 20-ha spot mapping grids were established in 1980, one in the RNA and one in grazed pastures, matched for total canopy cover (Fig. 1). Both plots were gridded at 30-m intervals to assist with mapping locations of birds and nests. These grids were expanded to 30 ha in 1985.

In 1984, an array of 210 point count stations consisting of seven lines of 30 count stations each was established (Fig. 1). Three to seven observers have completed counts at all stations each year since 1985. Count protocols were highly standardized. Counting began at 10 min after local sunrise. Counts were 5 min in duration, with 5 min to cover the 200 m between stations, so that all observers counted at the same time on the same day each year.

3. Historical work

The importance of California quail as a game species triggered studies on diet, habitat requirements, and the effects of grazing and hunting on population size and health that formed a basis for quail management in California (Glading, 1938, 1941; Glading et al., 1940; Herman and Chattin, 1943; Glading and Saarni, 1944; Duncan, 1968; Duncan and Shields, 1966; Shields and Duncan, 1966). Glading developed the artificial water storage devices for quail known as gallinaceous guzzlers SJER (Glading, 1943) and Leopold's book on California quail relies heavily on work done at SJER (Leopold, 1977). Important early work on raptors was done by Fitch (Fitch, 1940; Fitch et al., 1946a,b).

4. Avian monitoring recommendations

Abundance is a fundamental characteristic of populations that provides information on distribution, habitat relationships, response to management activities, and population trends. Estimating abundance is therefore a key parameter in many ornithological field investigations, yet many common survey methods are based on untested assumptions that may significantly affect their effectiveness and precision. Work done at SJER on avian monitoring techniques has formed the basis for recommendations on implementing techniques for determining bird abundance and density, enumerated limitations and advantages of specific methods and led to recommendations for coping with sources of variability. This was some of the first rigorous and critical examination of monitoring techniques and many widely cited publications have arisen from this work (e.g., Verner, 1985; Verner and Ritter, 1985, 1986; Verner and Milne, 1989). This work foreshadowed the recent controversy surrounding bird censusing methods in recent years (Rosenstock et al., 2002; Anderson, 2003; Ellingson and Lukacs, 2003; Hutto and Young, 2003; Johnson, 2008), yet it still represents the state of our knowledge in many aspects of this field. Results and recommendations from this work are broadly relevant and applicable to monitoring in any habitat where these methods are used.

The selection of the most appropriate avian monitoring method depends on the study objectives. Density estimates, while essential in providing answers to some ecological and management questions, are not needed to answer many questions (Verner, 1985). It is important to recognize that most techniques provide indices of abundance rather than absolute abundance or true density, and that simple unadjusted counts from a well-designed study can be used to track annual trends in populations. The fundamental mantra involved in all techniques is simply *standardization* (Verner, 1985). It is essential to control for as many sources of variability as possible through appropriate standardization of the study design.

4.1. Spot mapping

Spot mapping, also known as territory mapping, is considered the "gold standard" for establishing the number of bird territories on a plot, short of intensive color-banding studies and nest searches (Robbins, 1970; Verner and Milne, 1990). Spot mapping involves plotting the locations of individual birds on maps of gridded areas during each of several visits to a plot, transferring the locations to separate maps for each species, and identifying clusters of locations assumed to represent territories (Verner, 1985).

While spot mapping is generally considered the most accurate method for estimating densities of breeding birds, various factors are known to affect the accuracy of the method. Territories not entirely contained within the plot boundaries, known as boundary clusters, are difficult to quantify and can lead to bias (Verner, 1985). The territories drawn may not reflect reality, but they do result in an index of the number of territories. A fairly large effort is required to achieve even a sample size of one, with no measure of variability (Verner, 1981).

Some species are reliably censused with spot mapping. These include species with fairly small territories that are densely packed so that most available habitat is used, and species that sing regularly and loudly, providing contemporary contacts that allow territories to be delineated. Spot mapping is not well suited for species that do

not defend non-overlapping, all-purpose territories (e.g., California quail), species that do not sing frequently (e.g., western bluebird, *Sialia mexicana*), species that do not have distinct songs sung by the male (e.g., bushtit, *Psaltriparus minimus*), species that have helpers at the nest, species with floater populations (e.g., western scrub-jay, *Aphelocoma californica*), polygamous species (e.g., house wren, *Troglodytes aedon*), species with large territories (e.g., California thrasher, *Toxostoma redivivum*, and raptors), and nocturnal species.

Recommendations for spot mapping start with adequate training of observers. Observer variability, including analyst variability, is the greatest source of error (Verner and Milne, 1990). Verner (1985) recommended using only the most skilled observers with demonstrated ability to identify all target species by sight and sound. The foremost assumption of all methods is that all birds are correctly identified. A 2-week training period prior to the start of the censusing period, using standardized terminology and symbols, and having all observers' hearing tested is recommended. Plot size and shape are important, with larger and rounder plots generally better (Verner, 1981, 1985). The number of visits is important to consider, as the number of territories has been found to be somewhat dependent on the number of visits. More visits leads to more registrations and the ability to draw more territories. The timing of visits is also important. Visits should be timed to coincide with the peak singing period for most species. Emphasis of contemporary contacts is of primary importance in drawing territory boundaries. These are observations of individuals detected simultaneously, particularly countersinging and boundary disputes, which differentiate adjacent territories. Finally, finding nests can help tremendously in delineating territories.

4.2. Point counts

Recommendations for point counting again begin with training and using only the most skilled observers. Verner and Milne (1989) recommended using several observers and reusing observers over as many years as possible, or until their hearing starts to decline. For techniques where distances must be estimated, training observers to estimate distances is important and can improve estimates markedly (Verner, 1985). It is important to consider carefully the duration of counts to avoid missing or double-counting individuals (Verner, 1988) and to standardize the timing of sampling for both time of day and time of year (Verner, 1985; Verner and Milne, 1989). The number of counting stations is important, with more stations important for detecting uncommon species (Purcell et al., 2005). But for most species, and for a given level of effort, more visits are better than more stations. The number of sampling years has an especially large effect on power. Ten years of sampling were insufficient to detect a decline in abundance of 30% (Purcell et al., 2005). Fifteen to 20 years are needed to detect trends in abundance with adequate effect size and power, depending on relative abundance and other design considerations such as number of visits and count stations (Purcell et al., 2005). Similarly, Verner et al. (1996) found that 11–22 years were needed to account for annual variability and establish baseline estimates of abundance for 34 species with at least 10 detections per year. Compared to spot mapping, point counting is best for large-scale projects within fairly homogeneous habitat.

4.3. Transect counts

Another technique studied at SJER is the use of line transects for monitoring bird populations (Verner and Ritter, 1985, 1988). Recommendations for transect sampling are similar to those for point counting, including using only experienced observers and standardizing for time of day and year. The rate of movement of the observer along the transect should be carefully standardized. The rate must be slow enough to allow detection of birds and avoid repelling birds by the movement of the observer, yet not so slow as to risk counting birds more than once (Verner, 1985). The length should be sufficient to allow location of at least 40 individuals of a species, although results showed continued improvement with samples of 80 or more records per species (Verner and Ritter, 1988). Transects are not recommended for rough terrain, where observers will be distracted by obstacles that hinder movement.

Assuming estimates of density from spot mapping are more accurate than those from transects, Verner and Ritter (1988) found that density estimates from transects converged on those from spot mapping as sample sizes increased. Results suggested a minimum sample of 100 detections per species as an appropriate standard, limiting analysis to only the most abundant species (Verner and Ritter, 1988).

5. Long-term population trends and climate

A primary use of long-term point count data is to examine population trends and investigate the reasons underlying the observed trends. Long-term datasets that encompass the large range of variability found in both bird abundances and climate are lacking. Based on 13 years of count data, Verner and Purcell (1999) found that house wrens were sensitive to multi-year measures of precipitation while Bewick's wrens (*Thryomanes bewickii*) decreased following a severe winter. The large swings in abundance found in these two species caution against inferences about long-term population trends based on short-term studies.

Long-term datasets can provide more realistic predictions of the effects of climate change on bird species than predictions based on modeling alone. Using 16 years of point count data collected at 210 count stations, we examined relations among abundances of 16 bird species, temperature and precipitation variables, and El Niño Southern Oscillation events (ENSO) to predict bird species responses to climate change (Purcell, unpublished data). We used nonparametric Poisson regression models as a subset of generalized additive models (GAM) with Loess smoothing (S-Plus, 1999) as an exploratory approach to examine relations between avian abundance and the independent variables and to determine the functional shapes of the link function. Parametric shapes considered included polynomial, logarithmic, or other parametric functions suggest by GAM results. We then used Poisson regression models as a subclass of generalized linear models (GLM; SAS Institute, Inc., 2000), employing the functional shapes for the explanatory variables suggested by the nonparametric analyses for the parametric analysis to further explore relationships between avian abundance and the independent variables.

Results revealed that a majority of the species examined decreased in abundance following hot summers (Table 1). These species would likely decline in abundance in California oak woodlands with increases in mean or extreme temperatures. Response to precipitation varied among species, with some increasing in or following wet years and others following dry years (Table 1). Nearly all species were more abundant in or following warm, wet El Niño years, while no species appeared to benefit from cold, dry La Niña conditions (Table 1).

6. Life history of cavity-nesting birds in oak woodlands

Oak woodlands are extremely rich in biodiversity and they face many threats including residential and commercial development, conversion to agricultural uses, woodcutting, invasive species, and Sudden Oak Death. The lack of recruitment for some oak species, where natural regeneration does not appear to be adequate to sustain local populations, has created concern over the long-term

Table 1
Response of 16 bird species at the San Joaquin Experimental Range to weather and climate from 1985 through 2000. See Table 2 for scientific names unless otherwise noted. Percent deviance explained by the parametric overdispersed Poisson regression models for each species: California quail—59.4; mourning dove—41.1; Anna's hummingbird—33.6; acorn woodpecker—62.8; Nuttall's woodpecker—41.4; ash-throated flycatcher—82.7; common raven—70.3; bushtit—39.9; oak titmouse—58.4; white-breasted nuthatch—49.3; house wren—76.8; European starling—48.9; rufous-crowned sparrow—48.9; house finch—62.4; lesser goldfinch—43.4.

	Decreased following warmer than average summers	Decreased following colder than average winters	Increased when precipitation in the current year or preceding years was low	Increased when precipitation in the current year or preceding years was high	Increased following warm, wet El Niño winters
California quail (*Callipepla californica*)			X		X
Mourning dove		X	X		X
Anna's hummingbird			X		X
Acorn woodpecker	X	X	X		X
Nuttall's woodpecker	X			X	X
Ash-throated flycatcher				X	
Western scrub-jay	X		X		X
Common raven (*Corvus corax*)				X	
Bushtit		X		X	X
Oak titmouse	X		X		X
White-breasted nuthatch	X				
House wren	X	X			X
European starling	X			X	X
Rufous-crowned sparrow (*Aimophila ruficeps*)	X		X		X
House finch			X		X
Lesser goldfinch (*Carduelis psaltria*)	X				X

viability of oak woodlands. Because oaks and oak woodlands are so important to bird populations, it is important to understand the life history requirements of the species that depend on them.

We used data on reproductive success to examine life history strategies of oak woodland birds. Cavity-nesting birds are generally believed to have higher reproductive success than open-cup nesting birds, but most of what we know about cavity nesters comes from studies using nest boxes. If birds experience a benefit from nesting in nest boxes, the assumed relationship could be spurious. Nests of all species were located and monitored from 1988 through 1994. A variety of tree climbing methods was used to access nests in trees. Cavity nests were viewed using a fiber optic scope (Purcell, 1997). Nesting success was calculated using Mayfield estimates (Mayfield, 1961), with variances calculated following Hensler and Nichols (1981). Differences in daily survival rates were tested using Program Contrast (Hines and Sauer, 1989). A nest that fledged at least one young was considered successful.

Comparing nesting success, timing of laying, and number of young fledged, some species clearly benefitted from nesting in nest boxes while others showed no apparent benefit (Purcell et al., 1997). Western bluebirds nesting in nest boxes laid earlier, had higher nesting success, and fledged more young compared to birds nesting in tree cavities. House wrens initiated laying earlier, laid larger clutches, and fledged more young from nests in boxes and oak titmice fledged more young from nest boxes. Ash-throated flycatchers (*Myiarchus cinerascens*), on the other hand, did not differ in any metric examined and experienced no apparent benefits from nesting in boxes.

Consistent with the existing paradigm, cavity nesters nesting in tree cavities did have significantly higher nesting success than open nesters, but there were interesting differences between primary and secondary cavity nesters (Table 2). Primary cavity nesters, species that excavate their own cavities, had higher nesting success than secondary cavity nesters, which nest in cavities excavated by primary cavity nesters and natural cavities (Purcell, 1995). Differences between primary and secondary cavity nesters may be related to other life history attributes and differing selection pressures. Secondary cavity nesters fledged more young per attempt, had shorter nestling periods, and made fewer nesting attempts (Table 2), which may be related to their dependence on existing cavities, which are generally considered limited in availability (Purcell, 1995). Another potential factor for differing selection pressures on primary and secondary cavity nesters is related to parasitism by Protocalliphorid blowflies, which were commonly found in nesting material of secondary cavity nesters using nest boxes (Purcell, unpublished data). High parasitism rates could favor shorter nestling periods to limit exposure to blood-sucking larvae. Woodpeckers nest in cavities with no added nesting material and are rarely parasitized (Mason, 1944).

Secondary cavity-nesting species comprise a surprisingly large proportion of birds at SJER, both in terms of numbers of species and numbers of individuals (Verner et al., 1997). Eight common species of secondary cavity nesters occur at SJER, generating questions about the potential for interspecific competition and ecological factors that permit species coexistence. Nesting cavities are generally assumed to be limiting. We measured attributes of nest sites and nesting habitat of the eight species and found that they differed in habitat selection, but that considerable overlap occurred among some species (Purcell and Verner, 2008). We found overlap among European starlings, western bluebirds, violet–green swallows (*Tachycineta bicolor*) and white-breasted nuthatches (*Sitta carolinensis*). Because to a large extent they provide the cavities needed by secondary cavity nesters, the primary cavity nesters—acorn woodpeckers (*Melanerpes formicivorus*) and Nuttall's woodpeckers (*Picoides nuttallii*)—are keystone species in this ecosystem. They have an influence on the associated bird community that is out of proportion to their abundance or biomass (Purcell, 1995; Verner et al., 1997).

7. Native cavity-nesting species and impacts of European starlings, an avian invader

The European Starling (*Sturnus vulgaris*) is one of the world's most numerous and successful birds. Starlings were introduced to North American in 1890 and rapidly spread throughout North America. They were first documented in California in 1942 (Jewett, 1942) and are now likely the most abundant bird species in the

Table 2
Percent nest success, clutch size, number fledged, length of the nesting period, and number of broods for species nesting at the San Joaquin Experimental Range. Data for secondary cavity nesters are from tree cavities and do not include data from nest boxes.

	Percent nest success[a] (n)	Clutch size (n)	Number fledged (n)	Duration of nesting period[b]	Number of broods[c]
Primary cavity nesters					
Acorn woodpecker (*Melanerpes*	70.9	5.41	2.80	49	2.0
formicivorus	(115)	(56)	(51)		
Nuttall's woodpecker	77.1	5.00	2.90	44	1.0
Picoides nuttallii	(22)	(9)	(10)		
Secondary cavity nesters					
Ash-throated flycatcher	55.8	4.04	3.33	34	1.1
Myiarchus cinerascens	(52)	(26)	(27)		
Western bluebird	31.5	4.64	3.15	40	1.5
Sialia mexicana	(39)	(14)	(13)		
European starling	74.6	4.16	2.73	34	1.7
Sturnus vulgaris	(115)	(38)	(48)		
White-breasted nuthatch	51.8	6.52	3.89	45	1.0
Sitta carolinensis	(45)	(27)	(18)		
House wren	62.6	6.59	4.64	37	1.3
Troglodytes aedon	(47)	(27)	(14)		
Bewick's wren	91.2	5.40	3.36	33	1.3
Thryomanes bewickii	(22)	(10)	(11)		
Oak titmouse	60.0	5.81	4.20	41	1.0
Baeolophus inornatus	(171)	(59)	(85)		
Violet–green swallow	64.8	4.55	3.30	40	1.0
Tachycineta bicolor	(26)	(11)	(20)		
Enclosed nesters					
Bushtit	58.3	6.38	5.08	36	1.5
Psaltriparus minimus	(120)	(40)	(26)		
Open nesters					
Anna's hummingbird	36.9	2.11	1.78	41	1.5
Calypte anna	(37)	(9)	(9)		
Mourning dove	7.4	2.00	1.73	29	1.3
Zenaida macroura	(71)	(42)	(11)		
Western kingbird	34.6	3.42	2.86	34	1.0
Tyrannus verticalis	(21)	(14)	(11)		
Western scrub-jay	32.9	3.53	2.36	41	1.0
Aphelocoma californica	(127)	(95)	(44)		
House finch	44.1	4.47	3.23	33	1.7
Carpodacus mexicanus	(44)	(30)	(13)		
California towhee	31.3	3.72	2.82	25	1.0
Pipilo crissalis	(80)	(50)	(22)		

[a] Mayfield estimates.
[b] Duration of the nesting period includes the laying, incubation, and nestling periods and is based on our data rather than published values, as incubation and nestling periods tended to be longer in our study area than those reported in the literature.
[c] Number of broods is the average number of successful broods attempted per year and was based on the following categories: 1.0—no evidence of any second broods, 1.1—rarely renest, 1.3—occasionally renest, 1.5—often renest, 1.7—usually renest, 2.0—almost always renest.

state (Small, 1994). Starlings were first documented at SJER in the late 1960s and by 1970 SJER was home to several nesting pairs. Presently, they are widespread and abundant breeders throughout SJER and the foothill oak woodlands. Starlings are known to compete for and usurp nest sites from other cavity-nesting birds, whose nest sites are commonly limiting. Starlings use nest cavities similar in size and shape to those used by native species (Purcell, 1995), raising questions about nest site availability for these species with increases in starling numbers. The successful invasion of starlings into foothill oak-pine woodlands is likely to negatively impact cavity nesters. Using long-term data from SJER, we have documented the increase in the numbers of starlings in the last 35 years and examined factors affecting the abundance of European starlings at SJER (Purcell et al., 2002).

Because previous work showing niche overlap provided only weak evidence of competition, we used behavioral experiments to evaluate competition for nest sites and the extent to which European starlings are seen as a threat by native cavity nesters at SJER. Using a life-like model of a starling placed near the entrance of nests, Olsen et al. (2008) showed that acorn woodpeckers, ash-throated flycatchers, western bluebirds, and oak titmice clearly recognized starlings as threats to their nests and provided convincing evidence for nest-site competition. Response was correlated with mass, with response of oak titmice limited to constant scolding, response of western bluebirds and ash-throated flycatchers included aggressive flights and attacks, and response of acorn woodpeckers included continuous alarm calls and attacks by all members of the group.

Putting up nest boxes can help reduce competition with native species for nest sites. Entrance diameters of nest boxes should be <3.97 cm (< 1 9/16 in.) (Lehmann, 1997). At SJER we have not observed use of nest boxes with entrance holes of 3.81 cm (1 ½ in.) by starlings (Purcell, unpublished data). We recommend monitoring nest boxes regularly to ensure that entrances are not enlarged by woodpeckers, making them available for starlings. Consider the target species when constructing and placing nest boxes, including factors such as nest box height and diameter and shape of the entrance hole. Because starlings are well adapted to coexist with humans, plugging holes in buildings and other crevices where starlings may nest may help reduce their numbers.

8. Source–sink dynamics on a disturbance-dependent bird species

Most bird species occur over a range of habitats that may differ in parameters such as rates of survival and reproduction. In sink habitats, reproductive output is inadequate to maintain local population levels and populations are maintained only through emigration

from nearby source populations (Pulliam, 1988). Models of habitat selection commonly assume that higher-quality source habitats will be occupied at higher densities than sink habitats (Fretwell and Lucas, 1970). Van Horne (1983) warned that density may not be a good indicator of habitat quality, yet habitat relationship models used by resource managers generally assume that habitats where birds are abundant are also optimal. When abundance and reproductive success are negatively correlated, the maladaptive habitat selection results in an ecological trap (Dwernychuk and Boag, 1972). Identifying ecological traps and understanding their causes is vital to conserving species.

Spot mapping data showed that California towhees (*Pipilo crissalis*) were more abundant in the ungrazed site but had higher nesting success in grazed areas (Fig. 2; Purcell and Verner, 1998). Population models suggested that reproduction on the ungrazed site was insufficient to maintain population size without immigration from outside, resulting in sink habitat. Because towhees were more abundant in the sink habitat, ungrazed habitat appears to represent an ecological trap and may be detrimental to their population persistence. The dense understory foliage of the ungrazed area was perceived as suitable habitat, perhaps due to the abundance of nest sites, foraging sites, and cover. The high density of birds, and therefore nests, in the ungrazed area may have led to density-dependent predation. Bird banding data from SJER showed that towhees were sedentary with high site tenacity that does not appear to be affected by persistent nest loss. The benefits of territory ownership and increased survival may outweigh the potential advantage of moving to more productive habitat.

Alternatively, the causes of the mismatch in habitat selection and suitability may be related to changes resulting from fire suppression. Fire was once an important part of the disturbance regime of oak woodlands, but fires have been suppressed since the middle of the twentieth century, resulting in changes in vegetation structure (Purcell and Stephens, 2005). Habitat similar to the ungrazed area may once have been fairly rare and patchy in distribution. Fire suppression, combined with the lack of grazing, would result in increased shrub cover and habitat that would appear suitable to towhees.

9. Effects of livestock grazing

California's oak woodlands are 76% privately owned (Waddell and Barrett, 2005) and are under severe development pressure. Oak woodlands currently provide the majority of the forage used by the state's range livestock, but as ranches are converted to residential and agricultural uses, habitat quality for wildlife decreases. Large ranches are clearly preferable to subdivisions, but livestock grazing should be compatible with wildlife uses. Because livestock grazing has the potential to alter ecosystem dynamics, knowledge of impacts is key to managing oak woodlands. We studied the effects of moderate, year-round grazing at SJER.

We used paired *t*-tests, with Bonferroni adjustments to control for multiple tests, to examine differences in the numbers of territories of birds in the grazed and ungrazed plots based on 9 years of spot mapping (Verner et al., 1997). Effects of livestock grazing on vegetation were evident, with total shrub cover on the ungrazed plot more than three times that of the grazed plot. Despite clear changes in habitat related to grazing, few differences in numbers of territories were found. The average number of territories of Bullock's orioles (*Icterus bullockii*) and California towhees were greater on the ungrazed plot, while house wrens averaged more territories on the grazed plot. Four species differed in nesting success between grazed and ungrazed sites (Purcell, unpublished data). House wrens and bushtits had higher nesting success on the ungrazed site; mourning doves (*Zenaida macroura*) and California towhees had higher nesting success in grazed areas (Fig. 3).

Similar to fire, the most obvious change resulting from livestock grazing was a decrease in shrub cover (Purcell and Verner, 1998). Because the primary effects of fire and grazing appear analogous, the question arises to what extent livestock grazing creates habitat similar to that created by historical fire (Purcell and Stephens, 2005). Grazing and fire both reduce fuels and fire hazard, but we know little about how other aspects of grazing may differ from fire. These differences remain unstudied.

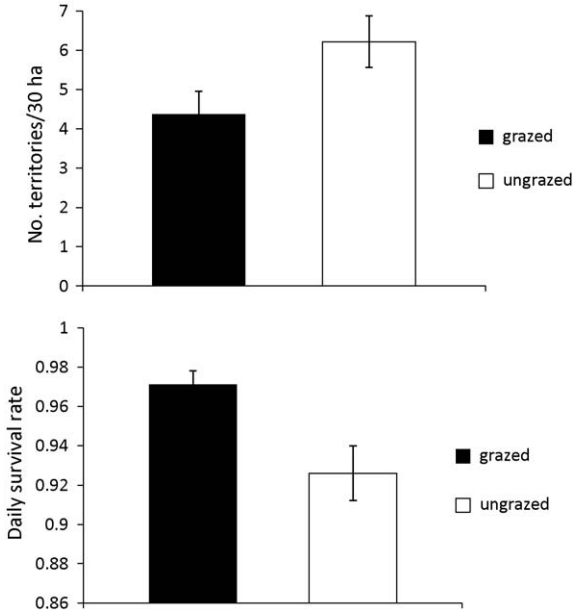

Fig. 2. Relative abundance (number of territories per 30 ha) and daily nest survival rate of California towhees (*Pipilo crissalis*) in grazed and ungrazed areas at the San Joaquin Experimental Range, CA. Error bars represent 1 standard error. Data on abundance are from 9 years of spot mapping. Number of nests was 45 for grazed and 30 for ungrazed areas.

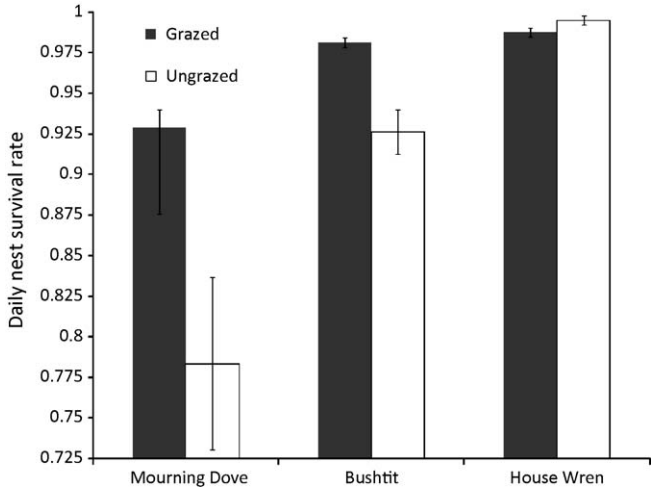

Fig. 3. Daily nest survival rates in grazed and ungrazed areas for mourning doves (*Zenaida macroura*), bushtits (*Psaltriparus minimus*), and house wrens (*Troglodytes aedon*). Error bars represent 1 standard error. Number of grazed and ungrazed nests was 55 and 16, respectively, for mourning doves, 80 and 40 for bushtits, and 57 and 26 for house wrens.

10. Conclusions

Experimental ranges and forests are ideally suited for long-term, multidisciplinary research exploring biotic responses to changing environmental conditions. Benefits of working at EFRs include the availability of long-term datasets and logistical assistance. Some of the resources available at SJER include long-term climate data, an herbarium, bird and mammal study skin collections, a plant checklist (Larson et al., 1985), an annotated checklist of all vertebrate species based on 75 years of observations (Purcell et al., 2007), long-term information on grazing intensity by pasture, a complete inventory of cultural sites, soil surveys, and annual acorn surveys. The bird point count monitoring is continuing and this dataset becomes more valuable with each passing year.

Additional opportunities provide frameworks upon which to build research. SJER was selected as 1 of 10 locations for the International Biome Project (IBP), representing the annual grassland biome. It has also been designated as a managed biological reserve under the Man and the Biosphere Program to serve as a demonstration area for cooperation between human activities and the conservation of ecosystems and biological diversity. Recently, SJER was selected as the candidate core site for the Pacific Southwest domain of the National Ecological Observatory Network (NEON). NEON is a proposed continental-scale research platform for gathering long-term data on ecological responses of the biosphere to changes in land use and climate.

Long-term records are particularly valuable in providing early warnings of undesirable environmental change. Long-term monitoring can provide information on expected population changes resulting from climatic change, as demonstrated by research done at SJER. Another example of the advantage of long-term data has been our ability to document the arrival and increase in abundance of European starlings. Starlings were first observed in the late 1960s, with both numbers and distribution of starlings increasing dramatically in the ensuing years. Other than outright habitat loss due to conversion of oak woodlands, starlings may be the biggest threat to native cavity-nesting birds.

Our understanding of the role of European starlings in the foothill ecosystem is still far from adequate. Starlings avoid ungrazed areas and areas with deep plant litter (Verner et al., 1997; Purcell et al., 2002), but research is needed on the foraging behavior of starlings, including distances traveled between nesting and foraging areas and the habitat and soil characteristics of foraging areas. Ongoing research on starlings is examining their response to grass height and litter through behavioral experiments testing responses of starlings to cut and raked grass. Results from this research will lead to recommendations for grazing and mowing that can help reduce starling numbers and their impacts on native species.

Keystone species are those that influence other species out of proportion to their abundance. Identification of keystone species is important, but even more importantly, we need to monitor the abundance and population health of keystone species, as a decrease in their numbers will have consequences for the entire bird community. Long-term monitoring at experimental forests and ranges can help track population trends of these essential species.

The need for long-term, multidisciplinary research will increase in response to the difficult environmental challenges we face. Relatively few areas exist whose primary objective is to facilitate long-term research, particularly areas of this size. SJER continues to provide opportunities for ecosystem research applicable to a broader geographic area. Collaborative research at SJER has and will continue to provide needed answers to questions related to birds and their conservation, but it is not being used to its full potential. Opportunities for interdisciplinary research include studies on range ecology and grazing effects, effects of fire, particularly prescribed fire, fragmentation, climate change, and invasive species. Such studies will help facilitate the synthesis of information for understanding complex and changing environments.

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