

AN ABSTRACT OF THE THESIS OF

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Abstract approved: _____

Robert G. Anthony

Recent declines in loggerhead shrike (*Lanius ludovicianus*) populations have prompted studies of the nesting ecology and habitat associations of shrikes throughout their range, but there is a paucity of information on shrikes nesting in shrubsteppe plant communities. Therefore, I studied nesting success and habitat relationships of loggerhead shrikes in shrubsteppe communities in southcentral Washington during the spring and summer of 1988 and 1989. Loggerhead shrikes were present at Hanford year-round but most were migratory, arriving by March and departing by September. Numbers of adults and juveniles peaked in May and July, respectively. Nesting was initiated in March and continued through August. In 1988, clutch initiations peaked in early May with a secondary peak in mid-June; in 1989 a single peak occurred in mid-April. Fledgling shrikes were first seen on 6 May in 1988 and 7 May in 1989. The Mayfield estimate of nest survival from egg laying to fledging was 57% (N = 59). Of 207 nesting pairs, a minimum of 19% re-nested from 1 - 3 times following nest failures, at least 5% fledged two broods in one nesting season, and 85% eventually produced fledglings. The major cause of nest failure was depredation by gopher snakes (*Pituophis melanoleucus*; 52%;

N = 21), black-billed magpies (*Pica pica*) and common ravens (*Corvus corax*; 33%), and coyotes (*Canis latrans*; 14%). Average clutch size was 5.9 ± 0.2 [SE] eggs (N = 35); 5.1 ± 0.3 (N = 17) young fledged per successful nest; and 2.3 ± 0.2 young survived per brood at two weeks post-fledging (N = 40). Ninety-six percent of 113 territories occupied by shrikes in 1988 were reoccupied in 1989.

Shrikes nested only in shrub-dominated plant communities and were rare or absent in grasslands, riparian zones, and areas dominated by exotic plants and rabbitbrush (*Chrysothamnus* spp.). Densities were highest in mixed shrub, lowland sagebrush, and bitterbrush communities (3.5, 3.4, and 2.1 pairs/km², respectively), and lower in upland sagebrush (0.6 pairs/km²) and rabbitbrush communities. Nesting territories (N = 297) were characterized by a mosaic of patches of tall, robust shrubs and openings of grassland or sand dunes. Mixed shrub and lowland sagebrush communities had greater interspersed patches and openings than did other communities. Shrike density was apparently limited by the scarcity of shrub patches in the bitterbrush community and by the lack of openings in the upland sagebrush community. Nesting in the rabbitbrush community was restricted to small patches of big sagebrush (*Artemisia tridentata*) interspersed among the dominant rabbitbrush. Shrikes were most abundant in areas of flat topography, deep soils, and relatively high horizontal and vertical structural diversity. Such diversity occurred only in late seral big sagebrush and bitterbrush communities that had been patchily burned. Shrike nest sites had greater canopy cover of tall shrubs (big sagebrush; antelope bitterbrush, *Purshia tridentata*; spiny hopsage, *Grayia spinosa*; and mock orange, *Philadelphus lewisii*), less annual grass cover, and taller shrubs than did non-nest sites. Shrubs containing shrike nests were taller, larger, and closer to an edge than were non-nest shrubs. Nest shrubs were frequently part of a continuous clump formed by other shrubs and wind-lodged tumbleweeds (*Salsola kali*). Shrikes preferred big sagebrush and antelope bitterbrush for nest

shrubs, used mock orange in proportion to its availability, and avoided spiny hopsage, gray rabbitbrush (*Chrysothamnus nauseosus*), and green rabbitbrush (*Chrysothamnus vicidiflorus*). Of 313 nests located, 97% were in shrubs, 2% were in trees, and 1% were in wind-lodged tumbleweeds and vines. The probability of fledging was greater in nests which were better concealed from view than in more visible nests. Shrikes selected tall, dense, live shrubs for roosts; slightly shorter live shrubs for nest substrates; and dead shrubs for perches. Shrubs used for any of these purposes were taller than the mean shrub height within 50 m of the nest.

Reproductive Success and Nesting Habitat
of Loggerhead Shrikes in Shrubsteppe Communities

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REPRODUCTIVE SUCCESS AND NESTING HABITAT OF LOGGERHEAD SHRIKES IN SHRUBSTEPPE COMMUNITIES

General Introduction

The loggerhead shrike (*Lanius ludovicianus*) is a predatory passerine that inhabits open country with interspersed shrubs or trees (Miller 1931, American Ornithologist's Union 1983). Shrikes are dietary generalists, preying on a wide variety of species such as grasshoppers, beetles, mice, lizards, songbirds, and small snakes (Miller 1931). Shrikes hunt from perches in areas of low ground cover, where prey detection is presumably increased (Smith 1973, Craig 1978, Mills 1979, Morrison 1980, Kridelbaugh 1982). In the breeding season, most prey are captured within 65 m of the nest, which is placed in a dense shrub or small tree (Miller 1931). Shrikes are associated with edge habitats (McNicholl 1986) where perches and nests are located near open spaces for foraging.

Although loggerhead shrikes now occur from southern Canada to northern Mexico and from the Atlantic to the Pacific coast (Miller 1931, Bent 1950), their habitat requirements probably caused them to be rare in the forested areas of eastern North America and in the prairie regions of the Midwest prior to Euroamerican settlement (Fraser and Luukkonen 1986). Fraser and Luukkonen (1986: 936) hypothesized that historically shrikes "reached their greatest numbers in the brushlands and deserts of the southwestern and south-central United States, where they still are relatively abundant."

Loggerhead shrike populations throughout North America have declined 3.7% annually between 1965 and 1979 (Bystrack 1981, Morrison 1981, Robbins et al. 1986). Declines have been most severe in the eastern United States (Bystrack 1981,

Morrison 1981, Robbins et al. 1986), where shrikes are listed as threatened or endangered in several states (Brooks and Temple 1986, Fraser and Luukkonen 1986). The main factor limiting shrike populations is not clear (Fraser and Luukkonen 1986, Tyler 1992), although habitat loss (Graber et al. 1973, Kridelbaugh 1982, Siegel 1980, Luukkonen and Fraser 1987, Gawlick and Bildstein 1990, Scott and Morrison 1990), pesticide contamination (Erdman 1970, Busbee 1977, Anderson and Duzan 1978, Morrison 1979, McNicholl 1986, Blumton et al. 1990), interspecific competition (Robbins et al. 1986), roadkill mortality (Novak 1989), and overwintering mortality (Blumton 1990, Brooks and Temple 1990a) have been proposed as potential causes. In order to determine the cause of the declines there have been numerous studies of the nesting ecology and habitat associations of shrikes in areas where their populations have declined (Graber et al. 1973, Anderson and Duzan 1978, Siegel 1980, Kridelbaugh 1982, Luukkonen and Fraser 1987, Scott 1987, Brooks and Temple 1990a and 1990b, Novak 1989, Blumton 1990, Gawlick and Bildstein 1990, Tyler 1992). There have been few studies of stable shrike populations (Miller 1931, Porter et al. 1975, Bohall-Wood 1987), and there is a paucity of information on shrikes in shrubsteppe communities.

One of the 11 subspecies of loggerhead shrikes, *L. l. gambeli* Ridgway or the California shrike, occurs in the shrubsteppe of eastern Washington (Miller 1931). Little is known of the current status of this subspecies, although Breeding Bird Surveys show a 4.4% annual decline between 1968 and 1989 in breeding populations of shrikes in the Columbia Basin, and a 11.4% annual decline in Washington State between 1980 and 1989 (D. Bystrack pers. comm. 1991). As a result of this perceived population decline the U. S. Fish and Wildlife Service (1991) is reviewing the species for designation as threatened or endangered, and the Washington Department of Wildlife (1987) has proposed the species be classified as sensitive.

In the spring and summer of 1988 and 1989 I studied loggerhead shrikes in

shrubsteppe communities of southcentral Washington. The purpose of my study was to provide information on the abundance, productivity, and habitat relationships of shrikes in shrubsteppe communities that have been minimally altered since Euroamerican settlement. Information gathered on shrikes nesting in their historic habitat may illuminate reasons for their declines elsewhere. Specifically my objectives were to:

- 1) Describe the breeding chronology and reproductive success of loggerhead shrikes.
- 2) Determine shrike density in various plant communities during the nesting season.
- 3) Investigate nest site selection by shrikes in shrub-dominated plant communities.

This thesis is written in two chapters to facilitate publication as manuscripts. Chapter One presents research on the first objective above, while Chapter Two concerns the second and third objectives. The Literature Cited section contains references for both chapters.

CHAPTER 1. NESTING CHRONOLOGY AND REPRODUCTIVE SUCCESS OF LOGGERHEAD SHRIKES IN SHRUBSTEPPE COMMUNITIES

Introduction

Loggerhead shrike (*Lanius ludovicianus*) populations have declined throughout North America (Bystrack 1981, Morrison 1981, Robbins et al. 1986), prompting the U. S. Fish and Wildlife Service (1991) to list the species as a candidate for threatened or endangered status. There have been numerous studies of shrike reproductive ecology in ecosystems that have been highly modified by farming and intensive livestock grazing (Graber et al. 1973, Porter et al. 1975, Anderson and Duzan 1978, Siegel 1980, Kridelbaugh 1982, Bohall-Wood 1987, Luukkonen and Frazer 1987, Brooks and Temple 1990a, Novak 1989, Blumton 1990, Gawlick and Bildstein 1990, Tyler 1992) or the introduction and dominance of exotic species (Scott 1987). There have been few studies of shrike populations in relatively undisturbed plant communities (Miller 1931, Wiens 1973, Wiens and Rotenberry 1981), and there remains a paucity of information on shrikes nesting in shrubsteppe communities. The purpose of this study was to describe the breeding chronology and reproductive success of loggerhead shrikes in shrubsteppe communities of southcentral Washington.

Study Area

The Hanford Site of southcentral Washington (Figure 1) was purchased by the federal government in 1943 and has since been operated by the Department of

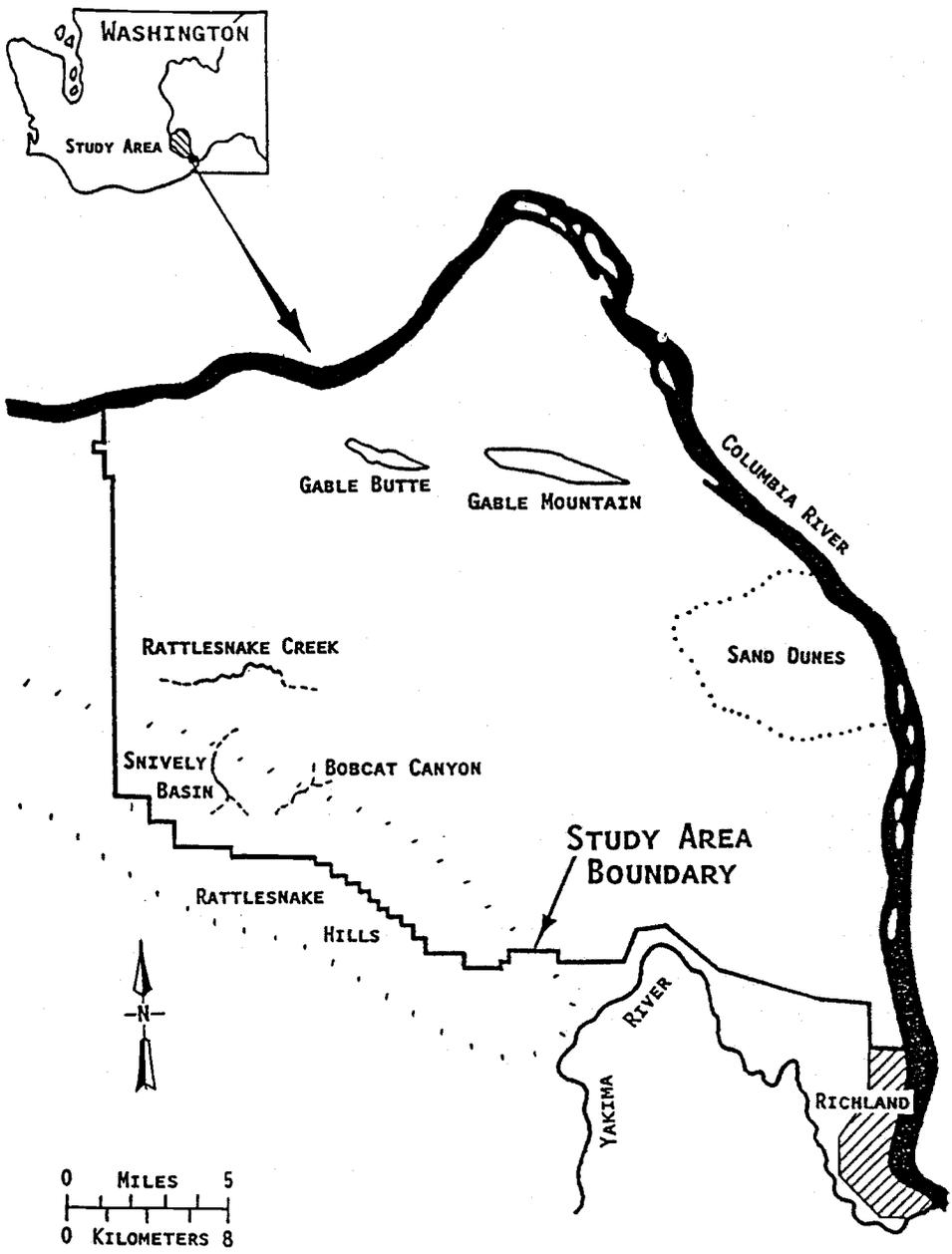


Figure 1. Map of study area.

Energy for the production of nuclear materials. Most human activity is restricted to a few widely-spaced industrial complexes and the intervening land consists of shrubsteppe vegetation that has been free from livestock grazing, agriculture, and public access for about 45 years (Rickard and Poole 1989). The current distribution of plant communities at Hanford is probably similar to that of pre-Euroamerican times (Daubenmire 1970).

I restricted my study to 830 km² of the Hanford Site lying south and west of the Columbia River (Figure 1). Elevations range from 190 m near the Columbia River to 1060 m on Rattlesnake Mountain, and most of the topography is flat to gently rolling. The climate is arid with hot summers and moderately cold winters. Precipitation falls mostly between October and May, with a mean of 16 cm per year (Rickard 1988). The study area lies within the big sagebrush (*Artemisia tridentata*)/bluebunch wheatgrass (*Agropyron spicatum*) vegetation zone (Daubenmire 1970). The dominant plant communities are upland sagebrush (*Artemisia tridentata*/*Agropyron spicatum*-*Poa sandbergii*), lowland sagebrush (*Artemisia tridentata*/*Poa sandbergii*-*Bromus tectorum*), bitterbrush (*Purshia tridentata*/*Oryzopsis hymenoides*-*Stipa comata*), and mixed shrub (*Artemisia tridentata*-*Purshia tridentata*/*Poa sandbergii*-*Oryzopsis hymenoides*-*Stipa comata*) (see Chapter 2 and Appendix 1 for community descriptions).

Methods

I observed the behavior of adult shrikes to determine their breeding status (single or paired), nesting chronology, and probable nest location (Miller 1931, Kridelbaugh 1982, Scott 1987). After 5 - 20 minutes of observation I searched the area on foot to locate nests. I recorded the number of eggs and young in the nest

and the stage of development of young (Miller 1931). To reduce the chance of my visits influencing reproductive success (Scott 1987), I minimized the number and duration of nest visits, avoided nest visits when black-billed magpies (*Pica pica*) or common ravens (*Corvus corax*) were present, followed circuitous rather than direct routes to nest shrubs, and did not physically mark the location of nests. I usually made three visits per nest: one to confirm the nest and record the nesting stage, a second near the suspected hatching date, and a final visit to determine the number of young fledged. Between nest checks I observed adults at active nest sites (those with either eggs or young) to detect behavioral changes associated with nest failure (Miller 1931). When a nest failed I searched the nest area for indicators of the cause of failure. If the nest was depredated I identified the probable species of predator by the condition of the nest and nest shrub and by the presence of tracks, fur, or feathers near the nest.

I determined nest initiation dates by direct observation or by back-dating from hatching or fledging dates. In back-dating, I allowed 5 days for egg laying, 17 days for incubation (which begins with laying of the penultimate egg), and 19 days for the nestling period (Miller 1931, Porter et al. 1975, Blumton 1990). In calculating the number of eggs per clutch, I included only nests that I found prior to or during egg laying and that I checked again less than three days after clutch completion. I based the number of young fledged on the number of young present in the nest at 16 - 18 days post-hatching, plus any fledglings I noted in nearby shrubs and trees. I determined the number of fledglings surviving at 2 weeks post-fledging by repeatedly flushing and counting the young at nest sites.

Statistical Methods

I used the Mayfield-40% method (Mayfield 1961, 1975; Johnson 1979) to calculate survival probabilities of nests. The 40% method minimizes the positive

bias in survival rates produced by infrequent nest checks (Johnson 1979). I used program MICROMORT (Heisey and Fuller 1985) to perform calculations. I divided the nesting cycle into incubation (egg-laying through hatching) and nestling (hatching through fledging) stages, and assumed all nests within each stage had equal survival probabilities (Heisey and Fuller 1985). I used likelihood ratio tests to test the assumption that daily survival rates were constant within the two nesting stages and to test for differences in survival rates between the two stages (White 1983, Heisey and Fuller 1985). I used a Z test to determine if nest survival rates differed between years (MICROMORT User's Guide). Results are reported as $\bar{x} \pm$ standard error. I used a 2 x 2 contingency table to compare reproductive success of shrike nests that were less than versus greater than one km from raven nests.

Results

Nesting Chronology

Loggerhead shrikes were present at the Hanford Site throughout the year, although numbers were low and variable from September through February. The majority of loggerhead shrikes at Hanford were migratory, arriving by March and departing by September (Figure 2). The total number of shrikes observed during driving transects (see Chapter 2) peaked in July, but the number of adults peaked in May (Figure 3). Shrike abundance declined after July, and by September very few shrikes remained at Hanford (Figure 3).

Shrikes initiated nesting in March (Figure 4). The earliest date of egg laying was 26 March 1988 and 28 March 1989, and I saw fledglings first on 6 May 1988 and 7 May 1989. In 1988, the period of clutch initiation was prolonged with peaks in early May and mid-June; the last clutch was initiated in mid-July (N = 35 broods).

Nesting Chronology

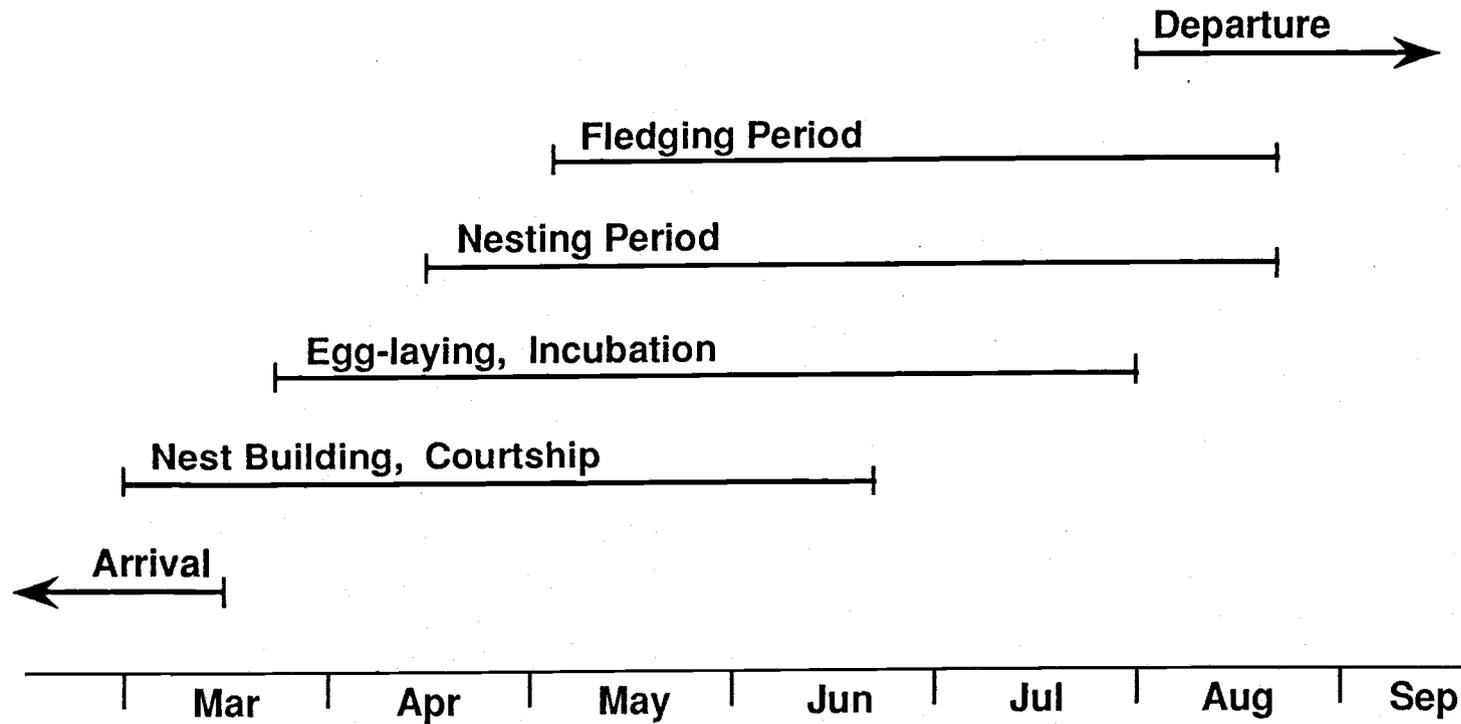


Figure 2. Nesting chronology of loggerhead shrikes in the Columbia Basin, Washington, 1988-89.

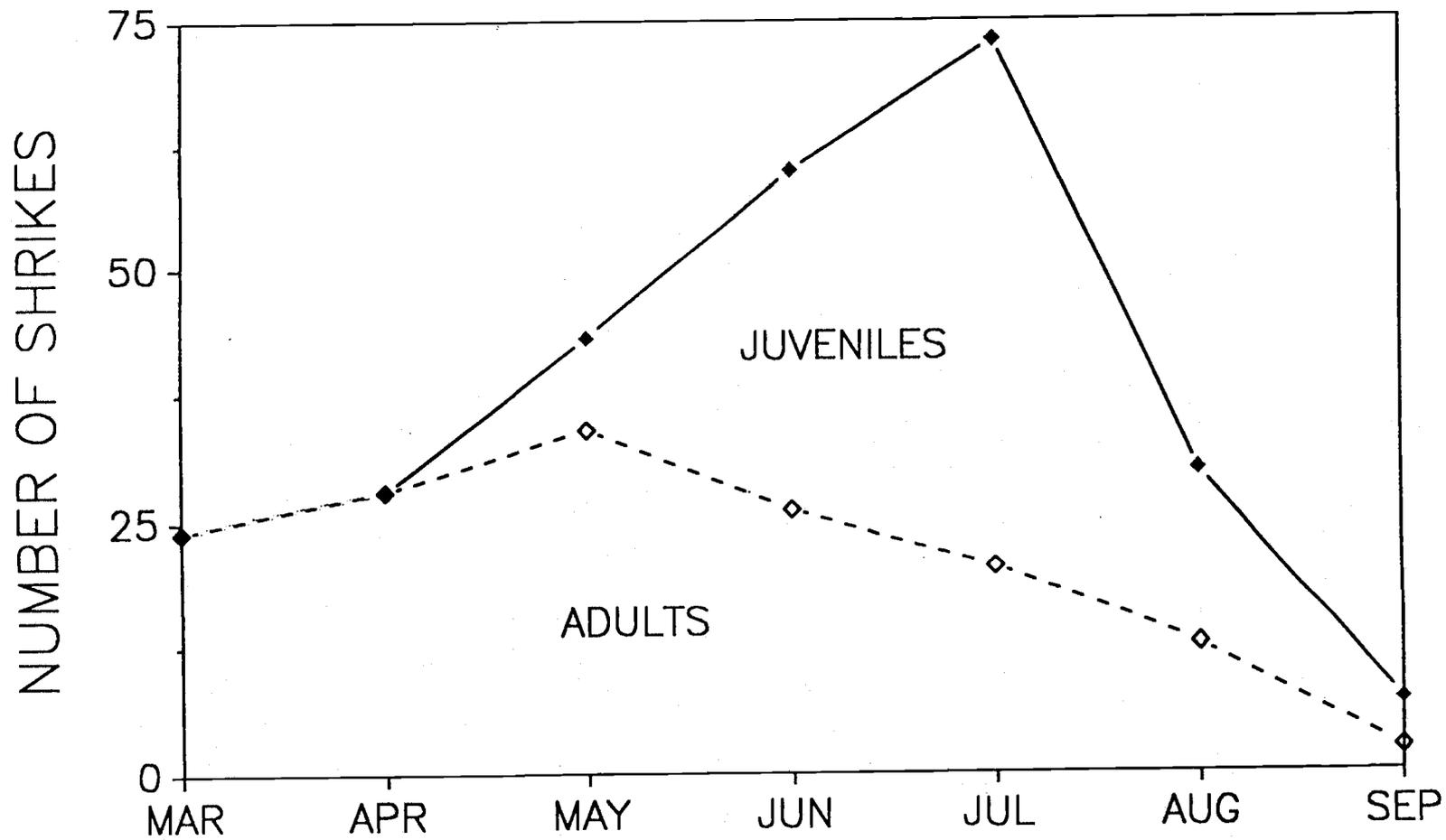


Figure 3. Number of loggerhead shrikes detected along a 154 km driving transect in Washington, 1989.

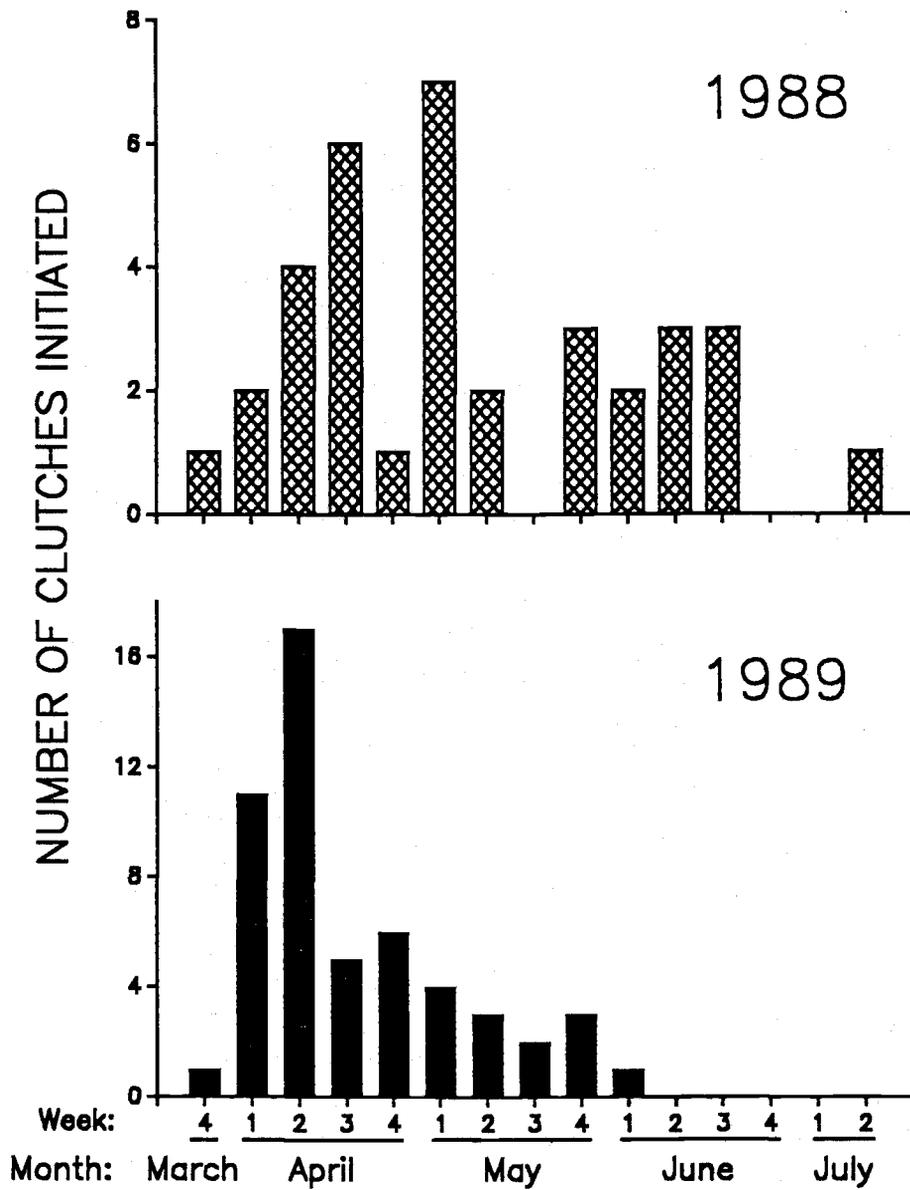


Figure 4. Frequency distribution of dates of egg laying by loggerhead shrikes in Washington in 1988 (N = 35) and 1989 (N = 53).

In 1989, clutch initiation peaked in mid-April and continued until early June (N = 53 broods). Ninety-six percent of 113 territories occupied by shrikes in 1988 were reoccupied in 1989.

Reproductive Success

Completed clutches contained a mean of 5.9 ± 0.2 eggs (N = 35) and 98% of 615 eggs that survived to time of hatching successfully hatched. Eleven percent of 104 clutches that hatched contained at least one egg that failed to hatch. An average of 5.1 ± 0.3 young fledged per successful nest (N = 17) and 2.3 ± 0.2 young were alive per brood at two weeks post-fledging (30 - 35 days post-hatching; N = 40).

The Mayfield estimate of nest survival was 57% for both years combined (Table 1). Nest survival was significantly higher in 1989 (64%) than in 1988 (51%; z statistic = 10.0, $P < 0.01$). Nest survival rates were greater during the nestling period than during incubation for each of the two years, although the difference was not significant when data from both years were combined (likelihood ratio test, $P > 0.10$).

Shrikes commonly renested following nest failure: 14% (N = 89) and 24% (N = 118) of pairs made at least two nest attempts in 1988 and 1989, respectively. Two percent and 8% of pairs successfully raised two broods in 1988 and 1989, respectively. Because these are known rates, the actual rates of renesting and double-brooding were likely greater. As a result of renesting, 76% and 90% of nesting pairs eventually fledged young in 1988 and 1989, respectively. The rate of nesting success per pair did not differ between years ($X^2 = 1.01$, $P = 0.31$).

Of 29 failed nests, 93% were depredated and 7% were abandoned. Gopher snakes (*Pituophis melanoleucus*), corvids (black-billed magpies and common ravens), and coyotes (*Canis latrans*) depredated 52%, 33%, and 14% of nests

Table 1. Probabilities of survival^a of loggerhead shrike nests during incubation and nestling stages in Washington, 1988-89.

Year	N ^b	Incubation		Nestling		Incubation and Nestling	
		% Survival	95% CI	% Survival	95% CI	% Survival	95% CI
1988	32	58.7	40.4 - 84.6	84.6	69.9 - 100.0	51.1	34.3 - 75.8
1989	27	74.2	55.3 - 99.2	84.8	70.4 - 100.0	64.0	45.9 - 89.0
Combined	59	65.5	51.5 - 83.1	84.7	74.2 - 96.7	57.1	44.0 - 73.9

^a The rates given are based on the Mayfield-40% method (Johnson 1979).

^b N = number of nests.

(N = 21), respectively. Shrike nests within 1 km of active raven nests failed more often (51%, N = 49) than did nests located farther from ravens (23%, N = 114; $X^2 = 12.7$; $P < 0.001$). The entire brood was lost in all depredations. I saw no evidence of brood reduction by cannibalism and none of the 66 shrikes (13 adults, 53 nestlings and fledglings) I handled were emaciated.

Discussion

Nesting Chronology

Loggerhead shrikes that breed north of California are largely migratory and winter in areas with fewer than 10 days of snow cover annually (Miller 1931). I observed both loggerhead and northern (*Lanius excubitor*) shrikes at Hanford in the winter but the near absence of shrikes in September and in early February may indicate that the loggerhead shrikes at Hanford in winter are migrants, while Hanford's breeding population winters elsewhere.

Shrikes in southern Washington initiated clutches in late March rather than in April, as reported by Miller (1931) for this area. Egg laying dates in Virginia (Luukkonen and Fraser 1987), Missouri (Kridelbaugh 1982), and on San Clemente Island (Scott 1987) were bimodal with peaks four to six weeks apart, and shrikes often produced two broods per year in these areas. The only population in which double-brooding was not reported was in Colorado, where there was only one peak in egg laying dates (Porter et al. 1975). Most shrike pairs at Hanford produced only one brood, and the distribution of egg laying dates was only weakly bimodal, due primarily to renesting in 1988.

The difference in peak dates of clutch initiation between years may have been due to weather; spring rains came about one month later in 1988 than in 1989,

and this may have delayed nest initiation. Blumton (1990) found that rain was an important influence on the onset of nesting in Virginia.

Reproductive Success

The mean clutch size (5.9) and the number of young fledged per successful nest (5.1) at Hanford represented the second highest rates reported in this and 12 other studies (Graber et al. 1973, Porter et al. 1975, Anderson and Duzan 1978, Siegel 1980, Kridelbaugh 1982, Luukkonen and Fraser 1987, Scott 1987, Novak 1989, Gawlick and Bildstein 1990, Brooks and Temple 1990a, Blumton 1990, Tyler 1992). Clutch size (6.4) and number fledged per successful nest (5.4) were higher only in Colorado (Porter et al. 1975). Loggerhead shrikes exhibit a latitudinal cline in clutch size and incidence of double-broodedness; smaller clutches and a higher incidence of double-broodedness are more frequent at lower latitudes (Kridelbaugh 1982). Although Hanford is higher in latitude than Colorado, shrikes at Hanford had smaller clutches and a higher incidence of double-broodedness. This apparent incongruity may be due to the higher elevation of the Colorado study site (1430 m; Wiens 1973) as compared to 250 m at Hanford.

Hatchability of eggs (98%) at Hanford exceeded rates reported for shrikes in other studies (83% in Illinois, Anderson and Duzan 1978; 93% in Missouri, Kridelbaugh 1982; 91% in Virginia, Luukkonen and Fraser 1987; 81% in Oklahoma, Tyler 1992) and for passerines in general (91%; Koenig 1982).

Juvenile shrikes are dependent on their parents for 3 - 4 weeks post-fledging, and young shrikes fly very poorly and are highly vulnerable to depredation after fledging (Miller 1931, Smith 1972, Scott 1987, Luukkonen and Fraser 1987). The time of greatest mortality for juvenile shrikes is during this post-fledging period, so estimates of reproductive success based solely on fledging rates may be positively biased (Scott 1987, Novak 1989). Post-fledging mortality limited population growth

in New York (Novak 1989), but survival after this period is apparently very high. Blumton (1990) attached radiotransmitters to 17 fledgling shrikes and observed 100% survival between 40 and 88 days of age. In Virginia (Luukkonen and Fraser 1987) and on San Clemente Island (Scott 1987, Scott and Morrison 1990), 34% and 40% of fledglings disappeared prior to independence, respectively. At Hanford, 55% of young fledged were lost prior to independence, but the number of young surviving to independence (2.3 ± 0.2 young/brood fledged) was still similar to that observed in Virginia (2.6 ± 0.2 young/brood fledged; Luukkonen and Fraser 1987) and significantly ($P < 0.05$) greater than that observed on San Clemente Island, California (1.7 ± 0.1 young/brood fledged; Scott 1987). Similar to Luukkonen and Fraser (1987) and Scott (1987), I assumed that most of the brood reduction was due to mortality rather than to early dispersal of young. The appropriateness of this assumption is supported by Blumton's (1990) finding that young shrikes remained in nest areas an average of 59 days after fledging. However, the low number of young I detected in the post-fledging period may have been influenced by difficulty in finding fledglings in the shrubby environment.

The median rate of nesting success in the 12 studies listed above was 62%, with a range of 43% (Siegel 1980) to 80% (Graber et al. 1973). The Mayfield estimate of nest survival at Hanford (57%) is well within this range, and the 95% confidence limits (44% - 74%) lie within the range of mean nesting success rates reported elsewhere.

Depredation was the major cause of nest failure at Hanford and in several other studies (Porter et al. 1975, Siegel 1980, Luukkonen and Fraser 1987, Scott 1987, Scott and Morrison 1990). Corvids depredated shrike nests in Colorado (Porter et al. 1975), Alabama (Siegel 1980), Virginia (Luukkonen and Fraser 1987), San Clemente Island (Scott 1987), and New York (Novak 1989). At Hanford, shrike nests that were within 1 km of raven nests were about twice as likely to fail as were

nests more distant from ravens. Snakes were the likely predators of shrike nests in Alabama (Siegel 1980), Missouri (Kridelbaugh 1982), Virginia (Luukkonen and Fraser 1987), and South Carolina (Gawlik and Bildstein 1990). Rotenberry and Wiens (1989) found that depredation was a major factor in reducing reproductive success of passerines in shrubsteppe communities and noted that snakes were the principal nest predators in southcentral Washington.

Shrike productivity was apparently limited by food availability in agricultural areas of Virginia, where adults resorted to cannibalism of nestlings in an apparent attempt to reduce brood size (Luukkonen and Fraser 1987, Blumton 1990). I found no evidence that lack of food limited shrike reproductive success at Hanford as I observed no cases of cannibalism or starvation. The average clutch size exceeded the average number of young fledged by 0.8 individuals, and this difference can be accounted for by the hatchability rate of eggs.

The rate of territory reoccupancy at Hanford (96%) was much higher than that reported for populations in Minnesota (47%, Brooks and Temple 1990a), Missouri (54%, Kridelbaugh 1982), Oklahoma (13%, Tyler 1992), and San Clemente Island, California (mean of 65%, declining from 90% to 30% over 4 years; Scott and Morrison 1990). The high rate of territory reoccupancy at Hanford may indicate high survival rates of adults or a shortage of suitable nest sites (see Chapter 2).

Nesting success for shrikes at Hanford exceeded the average rate for temperate zone passerines (47%, Ricklefs 1973), and other authors have concluded that poor reproductive success was not responsible for the widespread decline in shrike populations (Kridelbaugh 1982, Luukkonen and Fraser 1987, Brooks and Temple 1990a). The lack of mortality data prohibit complete assessment of the status of shrikes at Hanford, but reproductive success was comparable to that found in other recent studies. All but one (Porter et al. 1975) of the studies were of

declining populations, however, and speculation on the status of shrikes at Hanford based on these comparisons may not be appropriate.

CHAPTER 2. HABITAT SELECTION BY LOGGERHEAD SHRIKES IN SHRUBSTEPPE COMMUNITIES OF WASHINGTON

Introduction

Loggerhead shrikes inhabit a diversity of landscapes including croplands, pasturelands, desert scrublands, shrubsteppe, and open parklands (Atkinson 1901, Miller 1931, Bent 1950, Graber et al. 1973, Wiens 1973, Porter et al. 1975, Craig 1978, Bildstein and Grubb 1980, Wiens and Rotenberry 1981, Kridelbaugh 1982, Fraser and Luukkonen 1986, Bohall-Wood 1987, Luukkonen and Fraser 1987, Novak 1989, Gawlick and Bildstein 1990, Brooks and Temple 1990b, Blumton 1990, Tyler 1992). Characteristics of shrike breeding habitat have been quantified in the pasturelands and croplands of Colorado (Porter et al. 1975), Alabama (Siegel 1980), Missouri (Kridelbaugh 1982, 1983), Virginia (Luukkonen and Fraser 1987), South Carolina (Gawlick and Bildstein 1990), and Minnesota (Brooks and Temple 1990b); and on San Clemente Island, California (Scott 1987), which has been highly altered by exotic plants and feral herbivores. Quantitative descriptions of shrike nesting habitat in mostly unaltered communities are sparse (Wiens 1973, Wiens and Rotenberry 1981).

The purpose of this study was to describe characteristics of shrike nesting habitat in native shrubsteppe communities in southcentral Washington. I examined habitat selection by shrikes at three spatial scales. At the coarsest scale, I examined selection between plant communities by determining shrike densities in major plant communities. I then examined selection within communities by comparing characteristics of nest sites to those of nearby, randomly chosen, unused sites. At the finest scale, I compared characteristics of shrubs used by shrikes for nesting,

roosting, or perching to other shrubs in the immediate nest area. Specifically, I tested the hypotheses that:

1. Shrike densities were not different among the major plant communities.
2. Shrike nest sites and nest shrubs were not different in structure or species composition from unused sites and shrubs;
3. Nests from which young fledged were not different structurally from failed nests; and
4. Shrubs used by shrikes for nesting, roosting, or perching were different from shrubs available within 50 m of the nest.

Study Area

The Hanford Site of southcentral Washington (Figure 1) has been operated by the Department of Energy for the production of nuclear materials since 1943. Prior to federal purchase, livestock grazing and some irrigated farming occurred along the Columbia River and the upland streams. Human activity now centers around a few industrial complexes, and most of Hanford's 1470 km² consists of native shrubsteppe vegetation that has been free from livestock grazing, agriculture, and public access for about 45 years (Rickard and Poole 1989). The current density and distribution of shrubs at Hanford is probably similar to that of pre-Euroamerican times (Daubenmire 1970), although understory vegetation across much of the site is now dominated by exotic annuals, especially cheatgrass (*Bromus tectorum*). Much of Hanford is arable when irrigated (Hajek 1966), and most similar land in the Columbia Basin was converted to agriculture by the early 1900's (Dobler and Eby 1990). As a result, Hanford is the largest block of shrubsteppe remaining in Washington with vegetation structure similar to that of pre-

Euroamerican times.

I restricted my study to 830 km² of the Hanford Site lying south and west of the Columbia River. Elevations range from 190 m near the Columbia River to 1060 m on Rattlesnake Mountain. With the exceptions of Gable Butte and Gable Mountain (Figure 1), the topography of the Hanford Site is flat to gently rolling. Precipitation averages 16 cm per year, most of which falls between October and May (Rickard 1988). The climate is arid with hot summers and moderately cold winters (Rickard 1988). The study area lies within the big sagebrush (*Artemisia tridentata*)/bluebunch wheatgrass (*Agropyron spicatum*) vegetation zone (Daubenmire 1970). I classified the vegetation of the study area into nine plant communities based on present dominant plant species, topography, and soil texture. Appendix 1 contains quantitative community descriptions. I define a "plant community" as a distinct aggregation of plants that occur together in a specific environment.

Upland Sagebrush: Stands of Wyoming big sagebrush (*A. t. wyomingensis*) with an understory of bluebunch wheatgrass and Sandberg's bluegrass (*Poa sandbergii*) occur on silt loam soils (Wildung 1977) above 250 m in elevation. Shrub cover ranges from 20 to 40%, and shrub height averages about 1 m. There is little interspersions of shrubs and openings, due primarily to the stand-replacing nature of wildfire in this community of continuous fuels and upsloping topography.

Mesic Uplands: Alluvial fans in Bobcat Canyon and Snively Basin (Figure 1) support mesic vegetation dominated by widely-spaced mock orange (*Philadelphus lewesii*) shrubs. Dense stands of cheatgrass dominate the understory.

Lowland Sagebrush: A mixture of Wyoming big sagebrush and the slightly taller and more robust Basin big sagebrush (*A. t. tridentata*) dominate the lowland sagebrush community. Shrub cover averages 15 - 20%, shrub heights average about 1.2 m, and cheatgrass and Sandberg's bluegrass dominate the understory. Soils

range from silt loams to loamy sands (Wildung 1977) and the topography is mostly level. Wildfires have created a mosaic of shrub patches and grassy openings with a high degree of interspersions in this community.

Bitterbrush: The east central portion of the study area (Figure 1) is a mosaic of active sand dunes up to 12 m in height, grass-dominated dune troughs, and semi-stabilized dunes dominated by antelope bitterbrush (*Purshia tridentata*). A sparse understory of perennial grasses (Indian ricegrass, *Oryzopsis hymenoides*; needle-and-thread, *Stipa comata*; and prairie junegrass, *Koeleria cristata*) and forbs (evening primrose, *Oenothera pallida*, Franklin's sandwort, *Arenaria franklinii*, and gray cryptantha, *Cryptantha leucocephala*) occurs on semi-stabilized dunes. Wildfires have killed most shrubs in the dune troughs, resulting in dominance by Sandberg's bluegrass, cheatgrass, and needle-and-thread.

Mixed Shrub: The topography, soils, and vegetation of the mixed shrub community are intermediate between characteristics of the lowland sagebrush and bitterbrush communities. Varying proportions of big sagebrush (mostly *A. t. tridentata*), bitterbrush, spiny hopsage (*Grayia spinosa*), gray rabbitbrush (*Chrysothamnus nauseosus*), and green rabbitbrush (*C. vicidiflorus*) comprise the shrub layer, and the understory is dominated by cheatgrass, needle-and-thread, Sandberg's bluegrass, and Indian ricegrass. Shrub cover ranges from 5 to 15%, and average shrub height is about 1.5 m. In this community wildfire has produced a mosaic of shrub patches and grassy or sandy openings.

Rabbitbrush: Oldfields and other mechanically disturbed areas have revegetated with gray and green rabbitbrush, cheatgrass, and weedy annual forbs. Small plantings of black locust (*Robinia pseudo-acacia*), Siberian elm (*Ulmus* spp.), and fruit trees persist at scattered homesteads associated with the oldfields.

Greasewood: Greasewood (*Sarcobatus vermiculatus*) is restricted to one alkaline flat of less than 7 km² near Rattlesnake Creek (Figure 1). Shrub density is

about 25% and the very sparse understory is dominated by saltgrass (*Distichlis stricta*) and cheatgrass.

Riparian: Riparian vegetation occurs in a narrow band along streams in Bobcat Canyon and Snively Basin, and along Rattlesnake Creek and the Columbia River (Figure 1). Black cottonwood (*Populus trichocarpa*), willow (*Salix* spp.), elderberry (*Sambucus cerulea*), red-osier dogwood (*Cornus stolonifera*), chokecherry (*Prunus virginiana*), serviceberry (*Amelanchier alnifolia*), and golden currant (*Ribes aureum*) crowd the edges of the upland streams, and the understory is dominated by cheatgrass. Riparian vegetation along the Columbia River is sparse due to water fluctuations and flood scouring, and is dominated by black cottonwood, silver poplar (*Populus* sp.), hawthorn (*Crataegus douglasii*), and mulberry (*Morus alba*).

Grassland: Wildfire has eliminated shrubs from much of Hanford, resulting in seral grassland communities. Dominant grasses include bluebunch wheatgrass on silty sites, and Indian ricegrass, needle-and-thread, and prairie junegrass on sandy sites. Sandberg's bluegrass and cheatgrass are common throughout. Rabbitbrush is the first shrub species to recolonize burned areas (Daubenmire 1970) and it occurs sporadically in small patches throughout the grassland community.

Methods

Nest Site Distribution

To determine the distribution of shrike nest sites at Hanford, I conducted surveys by driving slowly (8 - 20 km/hr) along nearly all roads between March and June. I mapped the location and recorded the age (adult or fledgling) and behavior of all shrikes. I verified that shrikes had established a breeding territory by observing territorial or nesting behavior, by observing adults in the same location

for three or more times, or by locating active nests.

Shrike Density

Driving Transects. I established a 154 km vehicular transect across the study area to determine shrike densities in the major plant communities. The route traversed eight of the nine plant communities; the upland mesic community was restricted to two small disjunct patches and was not included in the route. I completed the transect once a month between April and August, 1989. Another observer and I traveled the route at 8 - 20 km per hour between dawn and noon, and recorded the number, age, location, and perpendicular distance (measured with a rangefinder) from the transect line (the road) of all shrikes. Shrikes were active throughout the morning hours at temperatures below 85 - 90^o F but sought shade and were less active at higher temperatures (Miller and Stebbins 1964, Craig 1978, pers. obs.), so I discontinued transects when temperatures reached 85^o F. The entire transect route required two mornings, which I did on consecutive days.

Walking Transects. Density estimates obtained from the driving transect were potentially biased by the non-random location of the roads and by the presence of preferred shrike habitat (utility lines and edge habitat) along the roads. In order to obtain unbiased density estimates, I walked variable width line transects (Emlen 1971) in the upland sagebrush, lowland sagebrush, bitterbrush, and mixed shrub communities. I established five to six 3 km² sampling plots in each plant community. These plot sizes were large in comparison to the area covered by each plant community, so random selection of plot locations was impractical. Instead, I spaced the sample plots as evenly as possible across the study area to account for maximum within-community variation. Within each plot, I flagged two parallel lines, 3 km long and 650 m apart, to serve as transect lines. The distance between the paired transect lines was adequate to prevent double-sampling of birds between

lines. I walked each transect line between dawn and mid-morning once in April and again in June of 1989. I recorded the location, age, and behavior of each shrike seen or heard, and the sighting distance and angle from myself to the bird (Burnham et al. 1980). I measured sighting distance with a rangefinder and sighting angle with a sighting compass.

Plot Searches. To evaluate the efficacy of the line transect methods, I thoroughly searched each sample plot (3 km long and 1 km wide, centered on the paired transect lines) for shrikes at 3 - 4 week intervals between April and mid-June. I watched each shrike for 15 - 30 minutes and mapped either its center of activity or nest location (when I found it) on U.S.G.S. 7.5 minute topographic maps. I calculated density by dividing the number of territorial pairs which had nests or centers of activity within the boundaries of the sample plot by the area of the plot. In estimating density, I did not include shrikes which were in the plot but which were apparently nesting outside the plot. If shrikes were absent from a previously identified center of activity on later surveys, but a pair had become established within 250 m of the original point, I considered it to be a shift within a territory, and I tallied one pair. If the distance was greater, I recorded the locations as two separate territories. This criterion was based on 54 hours of intensive, systematic observations of five nesting pairs throughout the nesting cycle in 1988. I found that shrikes remained within 210 m of their nest site 98% of the time (N = 1339 observations) and defended mean areas of 13.9 ± 2.0 ha against conspecifics (Odum and Kuenzler 1955).

Nest Site Characteristics

I quantified structural and vegetational characteristics (Table 2) at 95 nest and 83 non-nest sites during 1988 and 1989. I determined the location of non-nest sites by walking 200 m from the nest shrub in a randomly determined direction.

Table 2. Variables measured to compare loggerhead shrike nest sites to non-nesting areas in the Columbia Basin, Washington, 1988-89.^a

Variable	Description
Annual grass cover Perennial grass cover Annual forb cover Perennial forb cover Litter cover Bareground	Percent canopy cover of groups of similar plant species, as measured by systematic point intercept sampling (Pieper 1973); all dead plant material was considered litter, cryptogam-covered surfaces were considered bareground
Shrub cover: tall species short species dead shrubs ^b	Percent canopy cover of shrub groups, as determined by line intercept sampling (Pieper 1973); live shrubs were categorized as tall (<i>Artemisia tridentata</i> , <i>Purshia tridentata</i> , <i>Philadelphus lewesii</i> , and <i>Grayia spinosa</i>) or short (<i>Chrysothamnus nauseosus</i> and <i>C. vicidiflorus</i>) species.
Height of shrubs: live dead	Average height (cm) of shrubs intercepted by the four 50m line transects
CV of density of: tall shrubs short shrubs dead shrubs ^c	Coefficient of variation ((mean/standard deviation) x 100) of the number of shrubs intercepted along the four 50 m line transects. Tall species were <i>Artemisia tridentata</i> , <i>Purshia tridentata</i> , <i>Philadelphus lewesii</i> , and <i>Grayia spinosa</i> . Short species were <i>Chrysothamnus nauseosus</i> and <i>C. vicidiflorus</i> .
CV in height of shrubs: live dead	Coefficient of variation ((mean/standard deviation) x 100) of the heights of shrubs intercepted along the four 50 m line transects
Vertical density: < 20cm 20-50cm > 50cm ^b	Number of contacts between plants and a thin vertical rod (Wiens 1978); data were collected in intervals of 10 cm, then grouped for analysis
Foliage height diversity and evenness	Shannon-Weaver indices (Pielou 1975, p. 7-17) of diversity and evenness of vegetation heights as computed from vertical density data in 10 cm intervals
Species richness, evenness, and diversity	Shannon-Weaver indices (Pielou 1975, p. 7-17) of richness, evenness, and diversity of plant species encountered along the 50 m line transects
Number of stems ^b	Number of main stems of the shrub that arise from the ground
Shrub height	Distance (cm) from ground to the highest point of the shrub
Clump height	Distance (cm) from ground to the highest point of the vegetation adjacent to and touching the focal shrub
Shrub volume ^b	$4\pi r^3/3$, where r is the mean of shrub height, maximum width of the shrub, and distance across the shrub perpendicular to the maximum width; unit of measure is m ³

Table 2 (continued)

Variable	Description
Clump volume ^b	$4\pi r^3/3$, where r is the mean of clump height, maximum width of the clump, and distance across the clump perpendicular to the maximum width; unit of measure is m^3
% deadwood ^b	Ocular estimate of the percent of the shrub that was dead (mean of observations made from four directions)
Distance to edge ^b	Distance (m) to nearest abrupt change in topography or vegetation
Distance to road ^b	Distance (m) to nearest road
Slope	Percent slope of the ground at the shrub, as measured by a sighting clinometer
Aspect	Compass bearing when facing downhill in the direction of greatest slope, as measured with a sighting compass
Nest concealment	Optical estimate of the percent of the nest obscured from view at a distance of 10 m and a height of 1 m; the value reported is the mean of estimates made from four sides of the shrub
Above-nest canopy closure	Photographs were taken with a 35 mm camera with a wide angle lens facing upward from the nest cup; slides were projected over a 100 dot grid to quantify the percent of canopy closure above the nest
Nest to top of shrub ^b	Distance (cm) from the nest cup to the tallest point of the shrub
Nest to ground	(Shrub height) - (nest to top of shrub)
Nest to stem ^b	Distance (cm) from the nest rim to the nearest main supporting branch of the shrub
Distance to shrub/grass edge ^b	Distance (m) to the nearest interface of shrub- and grass-dominated plant communities

^a The final six variables were used only to characterize nests from which young fledged versus those in which nesting was unsuccessful.

^b Variable was transformed ($\log_{10}(X + 1)$) for statistical analyses.

^c Variable was transformed ($X^{0.5}$) for statistical analyses.

This distance was selected to maximize the chance that the non-nest site was accessible to the nesting pair but not used (Miller 1931, Kridelbaugh 1982, pers. obs.). I centered the plot on the shrub or tree that was closest to this random point and large enough to support a shrike nest. I searched the area within 100 m of the random point for shrike nests; if I found a nest, I rejected the point and randomly selected another.

I made measurements at two spatial scales. At the coarser scale, I quantified ground cover by plant species or cover type within a 50 m radius of nest and non-nest shrubs (Table 2). I established four 50 m line transects radiating outward from the focal shrub. The direction of the first line was determined randomly and the remaining lines were positioned at 90° , 180° , and 270° to the first. Along the transects I recorded shrub intercept (Canfield 1941, Pieper 1973) by species and condition (live or dead). At 5 m intervals (40 locations per plot), I quantified ground cover by point intercept (400 points per plot) (Pieper 1973) and quantified vertical density of vegetation by counting the number of plant contacts with a 6 mm diameter vertical rod (Wiens 1973). In the field I recorded the contacts in 10 cm intervals, but for analysis I combined intervals that corresponded to vegetation classes; the interval of <20 cm corresponded to short grasses (cheatgrass and bluegrass) and forbs; the 20 and 50 cm interval to rabbitbrush and taller bunchgrasses and forbs; and the >50 cm interval to tall shrubs.

At the finer scale, I compared characteristics of the nest shrub to those of the central shrub at the non-nest site. I recorded the species, percent decadence, and structural attributes of the shrubs, as well as slope, aspect, and distance to the nearest edge and road (Table 2). To compare characteristics of nests from which young were fledged to those that failed, I recorded nest concealment, above-nest canopy closure, and the placement of the nest in the supporting shrub (Table 2).

Statistical Methods

Density of Nest Sites. The assumptions of line transect sampling are that animals on the transect line are always detected, animals do not move before detection, animals are not counted more than once, and the detection of each individual is an independent event (Burnham et al. 1980). The open, low vegetation allowed me to easily detect shrikes that were on or near the line, and to detect individuals at a sufficient distance so that the birds rarely moved in response to my presence prior to detection. The distance between transect lines, the high visibility, and the relative scarcity of shrikes insured that I did not count individuals more than once. To satisfy the assumption that detections of individuals are independent, I report the density of shrike family groups rather than of individual shrikes (Burnham et al. 1980).

The number of individuals in a group can influence the probability that the group will be detected, leading to inaccurate density estimates (Drummer et al. 1990). To evaluate this factor, I examined the Pearson correlation coefficients of group size versus the perpendicular distance to groups. Group size was not highly correlated to detection distance for either the walking ($r = -0.034$, $P = 0.64$) or driving ($r = -0.042$, $P = 0.60$) transects.

I used Program TRANSECT (Burnham et al. 1980) to compute estimates of density from driving and walking transects. Program TRANSECT requires at least 40 detections for precise estimation of the effective area sampled (Burnham et al. 1980: 37). I detected fewer than 40 family groups in some plant communities so I used a linear regression technique (McCracken and Ramsey, unpubl.; Appendix 2) that facilitated the pooling of data from all transects to derive estimates of the effective area sampled. Data from walking and driving transects were analyzed separately although the procedures used were similar (Appendix 2).

Nest Site Characteristics. I tested continuous variables for normality (SAS

Institute, Inc. 1987, pg. 350) and transformed ($\log_{10}(X+1)$ or square root) variables as necessary to improve normality. Stepwise discriminant analysis (SAS Institute, Inc. 1987) was used to select the subset of variables which best separated used from non-used sites. All variables selected by the stepwise procedure were retained until the probability of the partial multivariate F-ratio exceeded 0.05 for the next variable to be included in the model. To test the performance of the models, I used discriminant function analysis with prior probabilities of group membership based on group sample sizes. Group sample sizes were at least four times greater than the number of variables in the model in all analyses. Where sample sizes permitted, the discriminant model was developed with a subset of the data and tested on the remainder of the data. The accuracy of discriminant functions in separating groups was evaluated by plotting the discriminant scores in canonical space, with the value of Wilks' Lambda chi-square statistic, and by rates of correct classification of group membership by crossvalidation (SAS Institute, Inc. 1987). T-tests based on group sample sizes were used to compare the observed classification accuracy to the accuracy expected by chance (Hair et al. 1987: 88). The average squared canonical correlation was used to assess the proportion of between-group variance that was explained by the discriminant function (Hair et al. 1987). The relative contribution of each variable in separating the groups was based on their standardized discriminant function coefficients and their order of inclusion into the model.

For categorical variables, I used Bonferroni 95% confidence intervals to compare use to availability (Neu et al. 1974). In interpreting the results of this technique I refer to "preference" when the proportion of use exceeded the percent availability and to "avoidance" when availability exceeded use.

I used one way analysis of variance and Student-Newman-Keuls mean comparison tests to compare heights of shrubs used for nesting, perching, or roosting to other shrubs available at nest sites. Because sample sizes in groups were

not equal, I used multiple comparisons based on the sample size of each group for mean comparison tests (Gibbons 1976). Results are reported as $\bar{x} \pm$ standard error.

Results

Nest Site Distribution

I located a total of 297 occupied nesting territories: 46% in lowland sagebrush, 32% in mixed shrub, 15% in bitterbrush, 5% in upland sagebrush, and 1% in each of the upland mesic and rabbitbrush communities. In all plant communities shrike territories were characterized by a mosaic of patches of tall, robust shrubs and openings of grassland or sand dunes. Nest sites in the rabbitbrush community were restricted to small patches of sagebrush interspersed among the more abundant rabbitbrush.

Shrike Density

Driving Transects. Shrikes were present in all shrub-dominated communities except greasewood, but no shrikes were detected in the riparian or grassland communities (Table 3). Small sample sizes, large variances, and lack of replicates resulted in low power of statistical tests, but there appeared to be some meaningful differences in shrike densities between communities. Mixed shrub, bitterbrush, and lowland sagebrush communities had similar and the highest shrike densities (2.2, 1.9, and 1.5 groups/km², respectively); upland sagebrush and rabbitbrush communities had fewer shrikes (0.8 and 0.7 groups/km², respectively); and greasewood, riparian, and grassland communities had no shrikes.

Walking Transects. Shrike density was more variable and appeared to be greater in April than in June (Table 3). This was probably due to actual change in

Table 3. Density^a of loggerhead shrike groups^b in shrubsteppe communities of the Columbia Basin, Washington, 1989.

PLANT COMMUNITY Survey Method	Total Transect Length (km)	Number of Groups Detected	Number of Groups Per km ²	95% Confidence Interval
BITTERBRUSH:				
plot search		28	1.9	1.6 - 2.2
walking transect:				
April	30.0	18	3.3	1.1 - 5.5
June	30.0	19	2.1	0.9 - 3.2
driving transect	28.3	12	1.9	0.4 - 3.4
MIXED SHRUB:				
plot search		48	2.7	2.2 - 3.2
walking transect:				
April	36.0	39	9.1	5.0 - 13.1
June	36.0	25	3.5	1.5 - 5.4
driving transect	162.0	47	2.2	0.7 - 3.7
LOWLAND SAGEBRUSH:				
plot search		50	2.8	2.3 - 3.3
walking transect:				
April	36.0	30	5.3	2.5 - 8.1
June	36.0	32	3.4	2.0 - 4.8
driving transect	253.5	60	1.5	0.5 - 2.4
UPLAND SAGEBRUSH:				
plot search		8	0.5	0.0 - 1.1
walking transect:				
April	30.0	4	2.0	0.0 - 4.4
June	30.0	2	0.6	0.0 - 1.4
driving transect	30.0	6	0.4	0.0 - 1.2
RABBITBRUSH:				
driving transect	49.0	7	0.4	0.0 - 1.1
GREASEWOOD/RIPARIAN:				
driving transect	8.5	0	0.0	-
GRASSLAND:				
driving transect	239.5	0	0.0	-

^a Density estimates were based on the Fourier Series Estimator of Program TRANSECT (Utah Coop. Wildl. Res. Unit 1988) and on the unpublished method of McCracken and Ramsey (see Appendix 2).

^b Shrike groups were composed of from one to seven shrikes which interacted as a family group.

densities rather than to anomalies in surveys, because in April shrikes were detected in areas where no birds were seen subsequently. In June, shrike densities were greatest in mixed shrub and lowland sagebrush communities (3.5 and 3.4 groups/km², respectively), intermediate in bitterbrush (2.1 groups/km²), and lowest in upland sagebrush (0.6 groups/km²). Shrike density was significantly ($P < 0.05$) lower in the upland sagebrush community than in the mixed shrub and lowland sagebrush communities in June.

Plot Searches. Shrike densities were similar in lowland sagebrush (2.8 groups/km²), mixed shrub (2.7 groups/km²), and bitterbrush (1.9 groups/km²) communities, while shrike density was significantly lower in the upland sagebrush community (0.5 groups/km²; $F = 16.59$, $P < 0.0001$; Table 3).

Nest Site Selection

When data from all plant communities were combined, the variables that distinguished shrike nest sites from non-nest sites were shrub cover, annual grass cover, and shrub heights (Table 4). Nest sites had greater canopy cover of sagebrush, bitterbrush, and mock orange; taller shrubs; and less annual grass cover than did non-nest sites. The variables of species evenness and cover of cryptogams and bareground were not selected by the stepwise procedure, but were inversely correlated ($r = -0.71$ and -0.74 , respectively) to the included variable of annual grass cover. The model correctly classified 87% of all observations and explained 56% of the variance between groups (Table 4). The accuracy of this model was supported by a discriminant model constructed from 35 nest and 35 non-nest sites measured in 1988. The stepwise procedure selected the variables of cover of tall shrubs, height of live shrubs, and height of dead shrubs. The resultant model correctly classified 88% of 70 randomly selected observations from 1989, which exceeded the chance classification rate by 38%.

Table 4. Results of stepwise discriminant analysis to compare characteristics of loggerhead shrike nest sites to areas without nests in Washington, 1988-89.

PLANT COMMUNITY Variable	Nest Sites		Non-nest Sites		Standardized Discriminant Function Coefficient
	\bar{X}	95% CI	\bar{X}	95% CI	
ALL PLANT COMMUNITIES:					
Shrub cover: tall species [†]	5.9*	5.3 - 6.6	0.7	0.6 - 0.8	0.822
Height of live shrubs (cm)	121.1*	115.5 - 126.7	68.6	60.2 - 77.1	0.757
Height of dead shrubs (cm)	60.0	53.5 - 66.6	58.1	50.2 - 66.1	0.254
Annual grass cover (%)	12.6*	10.5 - 14.8	19.0	16.3 - 21.7	-0.242
N	95		83		
% Correctly Classified ^a	94.7		78.3		
BITTERBRUSH:					
Shrub cover: tall species [†]	5.5*	4.7 - 6.5	0.0	0.00 - 0.01	0.978
Height of live shrubs (cm)	121.7*	111.7 - 131.7	46.9	32.0 - 61.8	1.033
CV of density of short shrubs	92.9*	71.6 - 114.2	62.5	34.1 - 90.8	-0.691
CV of height of live shrubs	45.7*	41.6 - 49.8	17.6	10.8 - 24.5	1.498
CV of density of tall shrubs	47.9*	41.8 - 54.1	50.5	20.0 - 80.9	-0.543
Shrub cover: short species [†]	1.9*	1.5 - 2.5	0.4	0.3 - 0.5	-0.572
N	30		24		
% Correctly Classified ^b	100.0		83.3		
MIXED SHRUB:					
Shrub cover: tall species [†]	5.1*	4.2 - 6.2	0.3	0.2 - 0.4	1.155
Height of live shrubs (cm)	129.3*	119.0 - 139.7	76.3	61.9 - 90.8	1.019
Perennial forb cover (%)	3.2	2.4 - 4.0	4.7	2.9 - 6.6	-0.579
Vertical density: > 50cm [†]	5.5*	3.9 - 7.7	1.0	0.6 - 1.7	-0.599
Bareground (%)	34.1*	29.4 - 38.8	27.3	24.1 - 30.4	0.372
N	30		26		
% Correctly Classified ^c	86.7		88.5		
LOWLAND SAGEBRUSH:					
Shrub cover: tall species [†]	9.3*	7.8 - 11.0	2.2	1.6 - 3.0	0.923
CV of density of short shrubs	59.5*	31.6 - 87.5	18.4	1.4 - 35.4	0.477
Height of live shrubs (cm)	115.7*	108.1 - 123.3	77.8	64.7 - 91.0	0.507
N	30		28		
% Correctly Classified ^d	90.0		71.4		

^a The total correct classification rate (87.1%) exceeded the proportional chance classification rate (50.2%, $P < 0.001$, Hair et al. 1987); the model explained 56.1% of the variance between groups.

^b The total correct classification rate (92.6%) exceeded the proportional chance classification rate (50.6%, $P < 0.001$, Hair et al. 1987); the model explained 81.1% of the variance between groups.

^c The total correct classification rate (87.5%) exceeded the proportional chance classification rate (50.3%, $P < 0.001$, Hair et al. 1987); the model explained 70.1% of the variance between groups.

^d The total correct classification rate (81.0%) exceeded the proportional chance classification rate (50.1%, $P < 0.001$, Hair et al. 1987); the model explained 51.6% of the variance between groups.

* The means of nest areas and non-nest areas differed univariately (F -test, $P < 0.05$).

[†] Variable was \log_{10} transformed and medians are presented in lieu of means.

Data were also analyzed for each plant community separately, and differences between nest and random sites were found (Table 4). Shrub cover and height of live shrubs were important variables; greater shrub cover and taller shrubs were characteristics of nest sites. Additional variables that were selected varied by community. In the bitterbrush community, nest sites had more rabbitbrush and greater variability in the density and height of shrubs than did non-nest sites. In the mixed shrub community, nest sites had more bareground, more vegetation at heights above 50 cm, and less perennial forb cover than did non-nest sites. In the lowland sagebrush community, rabbitbrush density was more variable at nest than non-nest sites. All of the community specific models correctly classified more than 80% of the observations (Table 4).

Nest sites also differed from non-nest sites in the species composition and condition of shrubs within 50 m of the nest (Figure 5). Nest sites had more live sagebrush, bitterbrush, and hopsage; and less gray rabbitbrush and dead bitterbrush, than did non-nest sites. All other categories were used in proportion to their availability.

Nest Shrub Selection

The discriminant model to distinguish between nest shrubs and non-nest shrubs contained the variables of the height and volume of the shrub clump, number of main stems, and proximity of the shrub to an edge (Table 5). Nest shrubs were taller, had greater volume and fewer main stems, and were closer to an edge than were non-nest shrubs. The model correctly classified 92% of observations and explained 62% of the variance between groups.

Discriminant models for the separate plant communities contained combinations of the variables similar to those selected for the combined data set (Table 5). All of the community specific models correctly classified at least 90% of

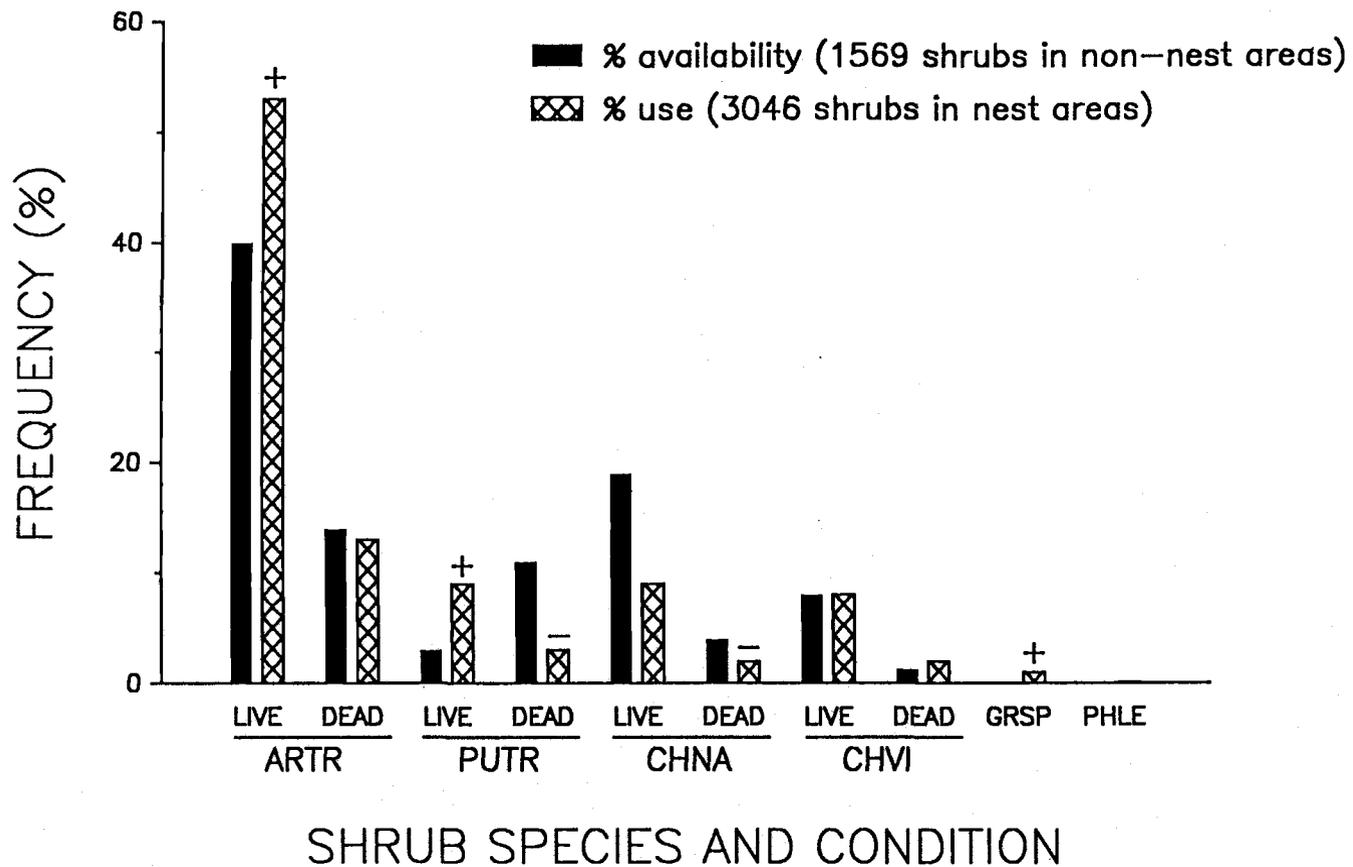


Figure 5. Species composition and condition of shrubs in areas with loggerhead shrike nests versus areas without nests in Washington, 1988-89. Selection (+) and avoidance (-) of categories were determined by Bonferroni 95% confidence intervals (Neu et al. 1974). ARTR = big sagebrush; PUTR = bitterbrush; CHNA = gray rabbitbrush; CHVI = green rabbitbrush; GRSP = spiny hopsage; PHLE = mock orange.

Table 5. Results of stepwise discriminant analysis to compare characteristics of shrubs with loggerhead shrike nests to shrubs without nests in Washington, 1988-89.

PLANT COMMUNITY Variable	Nest Shrubs		Non-nest Shrubs		Standardized Discriminant Function Coefficient
	\bar{X}	95% CI	\bar{X}	95% CI	
ALL PLANT COMMUNITIES:					
Shrub height (cm)	178.5*	174.2 - 182.8	99.3	92.4 - 106.2	0.706
Distance to edge (m) [†]	3.0*	2.6 - 3.5	38.0	27.9 - 51.8	-0.435
Clump volume (m ³) [†]	14.4*	12.7 - 16.4	1.3	1.1 - 1.5	0.674
Number of stems [†]	5.0	4.5 - 5.5	6.0	5.0 - 7.3	-0.320
Clump height (cm)	140.7*	134.5 - 146.8	91.5	85.9 - 97.1	0.191
N		238		85	
% Correctly Classified ^a		95.0		84.7	
BITTERBRUSH:					
Clump volume (m ³) [†]	34.5*	29.2 - 40.7	2.8	2.0 - 3.8	0.842
Shrub height (cm)	195.6*	188.8 - 202.3	103.5	88.3 - 118.6	0.793
Distance to edge (m) [†]	3.0*	2.4 - 3.7	46.0	26.5 - 79.8	-0.424
N		83		25	
% Correctly Classified ^b		96.4		88.0	
MIXED SHRUB:					
Clump volume (m ³) [†]	13.3*	10.9 - 16.3	0.8	0.6 - 1.0	0.762
Distance to edge (m) [†]	2.0*	1.6 - 2.5	36.0	20.7 - 62.6	-0.429
Shrub volume (m ³) [†]	7.4*	6.4 - 8.6	0.8	0.7 - 1.0	0.795
Number of stems [†]	5.0	4.4 - 5.6	5.0	3.9 - 6.5	-0.460
N		72		26	
% Correctly Classified ^c		93.1		84.6	
LOWLAND SAGEBRUSH:					
Shrub height (cm)	164.4*	159.5 - 169.3	88.7	80.8 - 96.7	1.397
Shrub volume (m ³) [†]	5.1*	4.6 - 5.6	0.7	0.6 - 0.9	0.551
Distance to edge (m) [†]	2.5*	1.9 - 3.3	39.0	21.9 - 69.4	-0.261
N		76		29	
% Correctly Classified ^d		98.7		89.7	

^a The total correct classification rate (92.3%) exceeded the proportional chance classification rate (61.2%, $P < 0.001$, Hair et al. 1987); the model explained 62.1% of the variance between groups.

^b The total correct classification rate (94.4%) exceeded the proportional chance classification rate (64.4%, $P < 0.001$, Hair et al. 1987); the model explained 69.4% of the variance between groups.

^c The total correct classification rate (90.8%) exceeded the proportional chance classification rate (61.0%, $P < 0.001$, Hair et al. 1987); the model explained 65.9% of the variance between groups.

^d The total correct classification rate (96.2%) exceeded the proportional chance classification rate (60.0%, $P < 0.001$, Hair et al. 1987); the model explained 74.7% of the variance between groups.

* The means of nest shrubs and non-nest shrubs differed univariately (F-test, $P < 0.05$).

[†] Variable was \log_{10} transformed and medians are presented in lieu of means.

observations and explained more than 65% of the variance between groups.

Shrikes were also selective in the species of the nest shrub, preferring big sagebrush and bitterbrush and avoiding spiny hopsage, gray rabbitbrush, and green rabbitbrush (Figure 6). In the mixed shrub community where both sagebrush and bitterbrush were available, shrikes preferred sagebrush but used bitterbrush in proportion to its availability (Figure 6).

A discriminant model comparing characteristics of successful and failed nests contained the variables of nest concealment, distance to edge, and clump volume (Table 6). Successful nests were better concealed from view than were failed nests. Inclusion of the other two variables in the model appeared to be spurious because neither their medians (univariate F test, $P > 0.10$) nor their variances (test of homogeneity of covariance matrices for distance to edge: $X^2 = 0.007$, $P = 0.93$; for clump volume, $X^2 = 0.68$, $P = 0.41$) differed between groups. Overall performance of the model was poor; it correctly classified 72% of observations and explained only 20% of the between-group variability (Table 6). The model correctly classified 89% of successful nests, but only 29% of failed nests. Nesting success was independent of the species of nest shrub (for big sagebrush, bitterbrush, and all other species combined; $X^2 = 0.17$, $P = 0.68$).

Characteristics of Nest, Perch, and Roost Shrubs

For nesting, shrikes preferred live bitterbrush; avoided rabbitbrush and dead sagebrush; and used other species and condition classes in proportion to their availability ($X^2 = 337.2$, $P < 0.001$) (Figure 7). For roosting, shrikes preferred live bitterbrush; used live sagebrush and dead bitterbrush in proportion to their availability; and avoided all other categories ($X^2 = 59.3$, $P < 0.001$). For perching, shrikes preferred bitterbrush and dead sagebrush; used live sagebrush in proportion to its availability; and avoided rabbitbrush ($X^2 = 203.1$, $P < 0.001$).

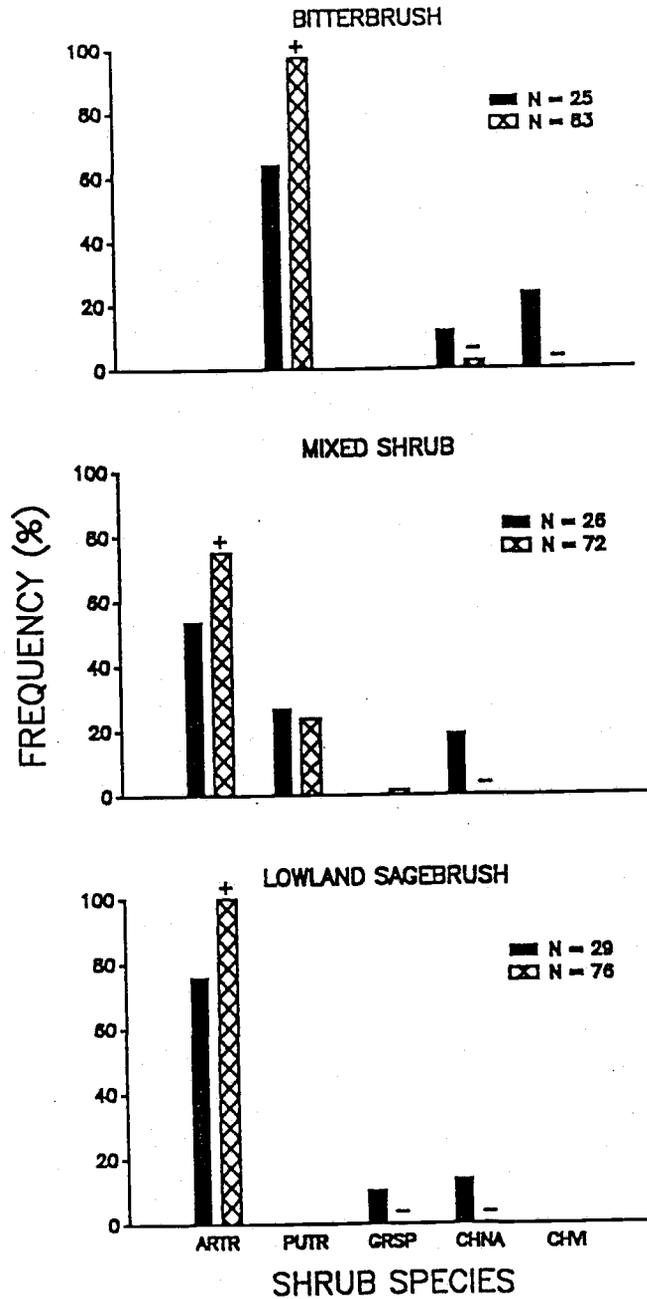


Figure 6. Species composition of shrubs with loggerhead shrike nests (black bars) compared to shrubs without nests (crosshatched bars) in three shrubsteppe communities in Washington, 1988-89. Selection (+) and avoidance (-) of categories were determined by Bonferroni 95% confidence intervals (Neu et al. 1974). ARTR = big sagebrush; PUTR = bitterbrush; GRSP = spiny hopsage; CHNA = gray rabbitbrush; CHVI = green rabbitbrush.

Table 6. Results of stepwise discriminant analysis to compare characteristics of loggerhead shrike nest shrubs with successful nesting attempts to those with failed nesting attempts in Washington, 1988-89.

Variable	Successful Nests		Failed Nests		Standardized Discriminant Function Coefficient
	\bar{X}	95% CI	\bar{X}	95% CI	
Nest concealment (%)	86.9*	83.6 - 90.2	69.8	61.1 - 78.6	1.166
Distance to shrub/grass edge (m) [†]	2.0	1.5 - 2.6	2.0	1.3 - 3.2	-0.509
Clump volume (m ³) [†]	13.4	10.7 - 16.7	16.2	11.4 - 23.0	-0.511
N		90		35	
% Correctly Classified ^a		88.9		28.6	

^a The total correct classification rate (72.0%) exceeded the proportional chance classification rate (59.7%, $P < 0.001$, Hair et al. 1987), and the model explained 20.3% of the variance between groups.

* The means of successful and failed nests differed univariately (F-test, $P < 0.05$).

[†] Variable was log₁₀ transformed and medians are presented in lieu of means.

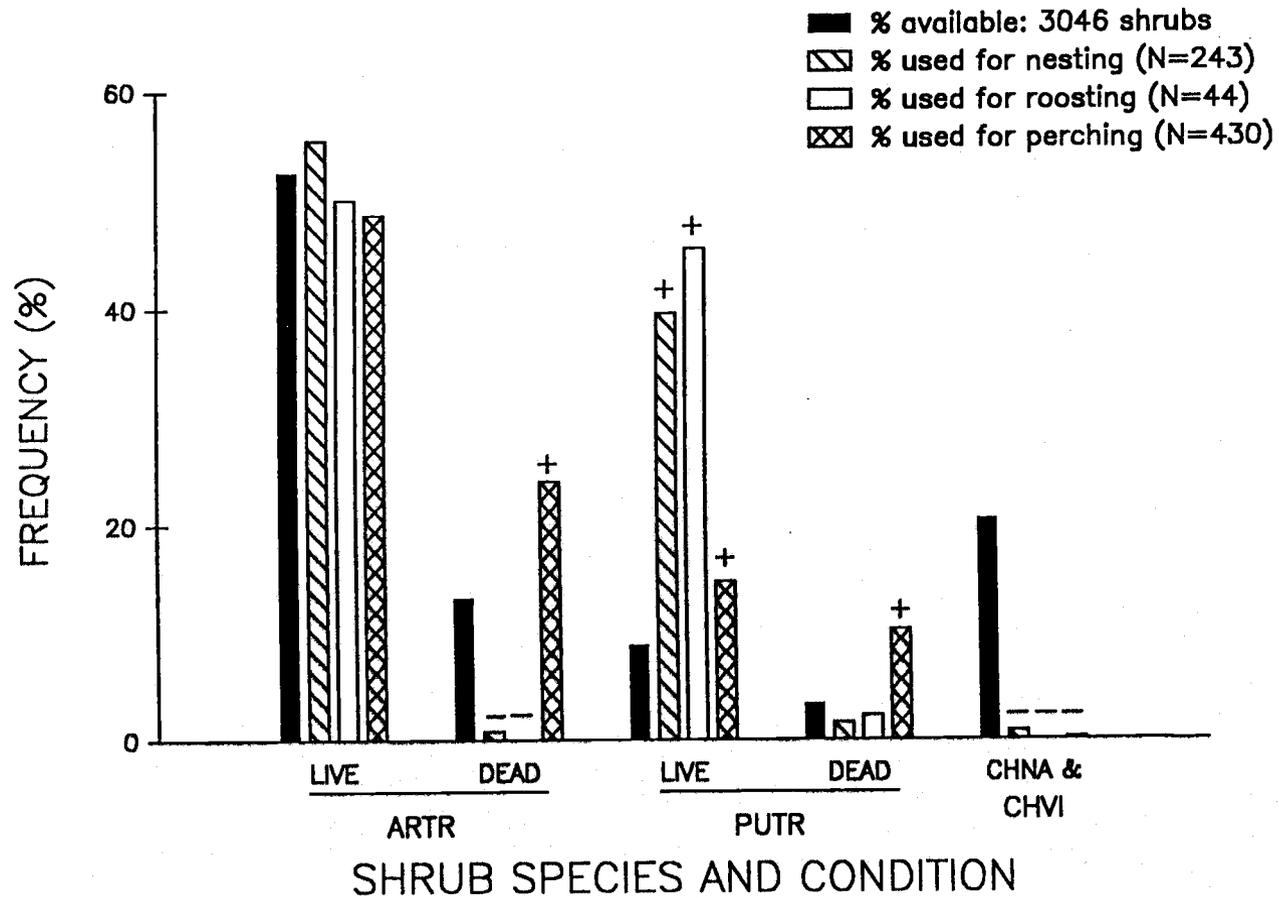


Figure 7. Species composition and condition of shrubs used by loggerhead shrikes for nesting, roosting, and perching in Washington, 1988-89. Selection (+) and avoidance (-) of categories were determined by Bonferroni 95% confidence intervals (Neu et al. 1974). ARTR = big sagebrush; PUTR = bitterbrush; CHNA = gray rabbitbrush; CHVI = green rabbitbrush.

Mean heights of shrubs by species and condition class in nest areas were: live bitterbrush, 156.2 ± 2.5 cm (N = 400); dead bitterbrush, 93.6 ± 4.3 cm (N = 111); live sagebrush, 110.6 ± 1.1 cm (N = 1757); dead sagebrush, 67.1 ± 1.6 cm (N = 407); live mock orange, 150.3 ± 6.2 cm (N = 11); live spiny hopsage, 79.5 ± 3.4 cm (N = 46); dead spiny hopsage, 61.0 (N = 1); live gray rabbitbrush, 66.5 ± 1.5 cm (N = 281); dead gray rabbitbrush, 44.8 ± 2.4 cm (N = 59); live green rabbitbrush, 63.3 ± 1.2 cm (N = 227); and dead green rabbitbrush, 48.8 ± 2.2 cm (N = 51). The mean height of all shrubs in the nest area, exclusive of nest shrubs, was 91.9 ± 0.8 cm (N = 3046).

Mean heights of shrubs used by shrikes for nesting (178.4 ± 2.2 cm; N = 243), roosting (210.4 ± 6.2 cm; N = 44), and perching (168.3 ± 4.2 cm; N = 450) differed from one another, and all were taller than the mean height of shrubs available in the nest area (Student-Newman-Keuls means comparison, $P < 0.05$).

Discussion

Efficacy of Survey Techniques

Density estimates varied by survey method, so the choice of the most efficient survey technique for future studies will depend upon available time and staff, amount of land to be surveyed, and the desired precision of the density estimate (Table 7). Driving transects yielded estimates of acceptable accuracy but high variability per number of detections, making this technique most suitable for detecting presence/absence or relative abundance of shrikes (Table 7). Density estimates based on driving transects may have been biased by the presence of the road itself and of utility lines that paralleled the roads, creating edge habitat with limitless tall perches favored by foraging shrikes (pers. obs.). Variability was lower

Table 7. Comparison of survey techniques to estimate shrike density in shrubsteppe communities in Washington, 1988-89.

Survey Method	Time and Personnel Required	Accuracy of Density Estimate	Precision of Density Estimate	Comments
Driving Transects	2 people/ 20 minutes/ km ²	Variable; dependent on road location; tends to underestimate	Moderate	Use for determining relative abundance in various plant communities and for large areas.
Walking Transects	1 person/ 1 hour/ km ²	High	Variable; high precision requires large sample size	Use for determining densities. Surveys in June give best estimate of the density of nesting pairs.
Plot Search	1 person/ 3-5 hours/ km ²	High; tends to slightly underestimate density if only pairs with nests in the plot are counted.	High	Use only if data on productivity, or location or characteristics of nest-sites are required.

per number of detections for walking transects than for driving transects, but walking transects were more time consuming (Table 3). Density estimates from the June walking transects were quite similar to the "true" density as determined by plot searches, whereas data from the April transects produced inflated and imprecise density estimates (Table 3). Plot searches were time intensive (Table 7), but they were efficient when it was necessary to collect data on other population characteristics such as nesting status and reproductive success.

Shrike Density

I believe that plant communities at Hanford were at or near maximum shrike capacity during this study. This conclusion is based on the extremely high rate of territory reoccupancy (96%), the rather uniform distance between nest sites in homogeneous communities, the surplus of shrikes seen in April that apparently failed to establish nesting territories, and the overflow of nesting shrikes into suboptimal nest sites such as seral grasslands. Shrikes nested in tumbleweeds (*Salsola kali*) surrounding dead shrubs in these areas, but nests failed to produce young and were abandoned after one nesting attempt.

Shrike densities at Hanford are among the highest recorded to date. Based on the number of individuals (rather than shrike groups) detected in June walking transects, shrike densities were 8.2, 7.0, 6.1, and 0.8 individuals/km² in the mixed shrub, lowland sagebrush, bitterbrush, and upland sagebrush communities, respectively. Shrike density in mixed shrub, lowland sagebrush, and bitterbrush communities exceeded densities reported for Great Basin shrubsteppe (1 - 5 individuals/km²; Wiens and Rotenberry 1981) and the desert grasslands of New Mexico (4.7 individuals/km²; Wiens 1973).

The average nearest neighbor distance between simultaneously occupied shrike nests is also indicative of nesting density. This distance was 545.7 ± 79.4 m in

Virginia ($N = 5$; Luukkonen and Fraser 1987), 842.9 m on San Clemente Island (Scott 1987), and 610 m in the lowland sagebrush and mixed shrub communities in this study. I conclude that shrike densities at Hanford were roughly comparable to the maximum densities observed in Virginia, and probably greater than densities on San Clemente Island. An essential difference between Hanford and the other study sites, however, was that most shrike territories at Hanford were contiguous with other territories and the study area appeared completely stocked with nesting pairs. In Virginia (Luukkonen and Fraser 1987) and on San Clemente Island (Scott 1987), most territories were not contiguous and there appeared to be a surplus of suitable nesting sites.

Shrike densities in this study far exceeded densities elsewhere in Washington shrubsteppe. The Washington Department of Wildlife censused breeding birds along variable width line transects at 55 randomly selected shrubsteppe sites in eastern Washington from 1988 to 1990 (F. Dobler, pers. comm. 1991). Twenty-seven shrikes were detected in this study, for a linear density of 0.1 shrikes per km (F. Dobler, pers. comm. 1991). Using the same field methods I detected an average of 1.9 and 1.2 shrikes per km in April and June, respectively, in the mixed shrub, lowland sagebrush, and bitterbrush communities. Only in the upland sagebrush community was shrike density (0.1 shrikes per km) similar to that observed by Dobler. These data indicate that shrike densities in the mixed shrub, lowland sagebrush, and bitterbrush communities at Hanford were about 12 - 19 times greater than in the remainder of eastern Washington. The difference in shrike density may be related to habitat structure and species composition. Nearly all shrubsteppe in areas of flat topography and deep soil was converted to agriculture in the early 1900's, and most of the shrubsteppe now remaining in Washington is limited to rocky or steep sites where farming is impractical (Dobler and Eby 1990). Steep slopes, rocky sites, and shallow soils support upland shrub communities little used by

shrikes at Hanford, and most remnant patches of shrubsteppe in Washington have been modified by fire suppression, livestock grazing, introduction of exotic species, and habitat fragmentation.

Habitat Selection Between Plant Communities

A common assumption is that "individual organisms select particular habitats because they thereby enhance their fitness" (Rosenzweig 1985: 518). For shrikes the choice of nesting habitat is critical because the nesting site must contain suitable nest and perch sites, adequate foraging area, and enough prey to sustain the adults and brood throughout the nesting cycle. Throughout their range, shrikes have been consistently associated with open habitats, foraging areas with low ground cover, elevated perch sites, and dense trees or shrubs for nesting (see Brooks and Temple 1990b). Selection of nest sites in habitats with these components presumably increases the fitness of the nesting shrikes.

Shrikes rely on a broad variety of plant communities to satisfy these basic habitat requirements. In the eastern and midwestern United States shrikes forage in grazed pastures, mowed hayfields, lawns, and cultivated fields, and nest in isolated trees or hedgerows (Graber et al. 1973, Kridelbaugh 1982, Bohall-Wood 1987, Luukkonen and Fraser 1987, Novak 1989, Gawlick and Bildstein 1990, Brooks and Temple 1990b, Blumton 1990, Tyler 1992). In the unfarmed, ungrazed shrubsteppe communities of this study, tall shrubs provide perch and nest sites while grassy and sandy openings provide open areas of low cover for foraging. Shrikes were most abundant in communities with high interspersion of shrub patches and grassy or sandy openings. Shrikes were absent from grasslands, which had abundant foraging area but lacked nest and perch sites; and there were few shrikes in the upland sagebrush community where there was an abundance of shrubs for perching and nesting but few open areas for foraging. In the bitterbrush community shrikes

nested in nearly every sizeable shrub patch, indicating that shrike density was probably limited by the availability of shrub patches.

Shrikes were uncommon or absent, however, in several communities that contained the basic habitat elements. The scarcity of shrikes in the rabbitbrush community may have been related to the relatively dense ground cover of cheatgrass in this community, because prey are less vulnerable to capture by raptors in areas of dense ground cover (Bechard 1982, Janes 1985, Toland 1987, Preston 1990). Another possible cause is the lack of suitable perch and nest sites. Although rabbitbrush appears similar to big sagebrush, most rabbitbrush shrubs were shorter than the mean height of nest and perch shrubs, and the lack of horizontal branching in rabbitbrush made it too unstable to support nests or perching shrikes. Similarly, Wiens and Rotenberry (1981) found that shrike density was inversely related to cover of gray rabbitbrush.

Shrikes were absent from the riparian community and from all shrub-dominated communities within about 500 m of water. The habitat structure of these communities appeared suitable for shrikes, and other studies (Miller 1931, Porter et al. 1975, Luukkonen and Fraser 1987, Scott 1987) have noted that shrikes commonly nest in trees along streamcourses. At Hanford, most of the black-billed magpies, common ravens, and American crows (*Corvus brachyrhynchos*) nested and foraged near water, and it is possible that shrikes avoided areas near water because of high corvid density. Corvids were a major predator of shrike eggs and nestlings in this study (Chapter 1); shrike nests within 1 km of raven nests were twice as likely to fail as more distant nests (Chapter 1); and corvids probably preyed on newly fledged young (Scott 1987). Shrikes vigorously mobbed magpies whenever I saw both species, and I saw adult shrikes dive into shrubs when ravens called or flew overhead. Although I found shrike nests in trees in upland areas, no shrikes used tree nests during my study. Tree groves in uplands nearly always contained active

magpie or raven nests, and frequently nests of both species. Shrikes nested in shrubs near these trees, but used the trees for perches extensively only after the young had become accomplished fliers. It is also possible that shrike abundance near water was limited by competitive interactions with corvids, which, like shrikes, are dietary generalists.

Many researchers have found correlations between the physiognomy and floristic composition of plant communities and habitat selection patterns by birds (see Wiens and Rotenberry 1981, Cody 1985, Knopf et al. 1990), although other cues such as intraspecific population density, interspecific interactions, and nest site fidelity may also influence the selection of nesting habitat (Wiens 1985). At Hanford, shrikes inhabited a variety of plant communities with differing species composition but similar structure. Rotenberry (1985: 213) concluded that "while birds may be differentiating between gross habitat types on the basis of physiognomy, further refinements of their distributions within the proper habitat type may occur with reference to plant taxonomic composition." Shrikes, however, apparently respond more to habitat structure than to floristics even on a local scale, and they thereby expand their options for suitable nesting habitat and can occupy broader geographic ranges (Lauro and Burger 1989).

Habitat Selection Within Plant Communities

Shrike nest sites in this study were characterized by a mosaic of patches of tall, robust shrubs with interspersed openings of grass or sand that had sparse, low vegetation. Because shrikes nested near the edge of shrub patches, nest sites were more structurally complex than unused sites. In nest areas, shrub patches had a multi-layered canopy dominated by big sagebrush and bitterbrush, an understory of native grasses, and about 40% bareground. Although the total vertical density at nest sites and non-nest sites was similar, shrike nest sites had greater cover of tall

shrubs and less ground cover than did unused sites. The shrub patches used by shrikes occurred on flat lands with deep soils and were in late seral condition (Daubenmire 1970).

Nearly all the soils of the Hanford Site are suitable for shrub growth, and only through the action of fire has a mosaic of grassy openings and shrub patches been created (W. H. Rickard, pers. comm, 1988). Sand dunes and blowouts create additional openings in the bitterbrush and mixed shrub communities. Openings at nest sites had more bareground, greater cover of native bunchgrasses, and less cover of cheatgrass than did unused sites. Openings that were dominated by swards of cheatgrass were rarely used by shrikes.

Most other studies of shrike habitat have found that shrike nest sites are characterized by a predominance of grassy cover, with at least a few trees or shrubs present for nesting (Miller 1931, Porter et al. 1975, Siegel 1980, Kridelbaugh 1982, Luukkonen and Fraser 1987, Gawlik and Bildstein 1990, Brooks and Temple 1990, Blumton 1990). In croplands, agricultural practices create an abundance of openings, so this is the first study to identify the importance of fire in maintaining open foraging habitat for shrikes.

In Great Basin shrubsteppe, shrikes were associated with areas of rugged topography, high cover of rocks and shrubs, high shrub species diversity, and tall shrub heights (Wiens and Rotenberry 1981). Shrike density was positively correlated with amount of sagebrush and negatively correlated with amount of gray rabbitbrush (Wiens and Rotenberry 1981). Similarly, nest sites in this study had more bareground, greater shrub cover, taller shrubs, greater cover of sagebrush, and less cover of rabbitbrush than non-nest sites.

Selection for shrub species and condition may reflect the suitability of shrubs for nesting and perching. Dominant shrub species at nest sites were tall, with branching structure adequate to support perching shrikes and nests. The taxa,

abundance, and vulnerability of prey may also vary with different floristic composition and shrub densities (Rotenberry 1985). For example, favored shrike prey such as grasshoppers, lizards, and small mammals were more abundant in sagebrush and bitterbrush communities than in grassland and rabbitbrush communities at Hanford (Sheldon and Rogers 1978, Marr et al. 1988).

Habitat Selection Within Nest Sites

A wide variety of plants have been used for nest substrates by shrikes, and the degree of cover and nest concealment provided by a plant appears to be important in nest site selection (Porter et al. 1975, Luukkonen and Fraser 1987). Miller (1931) reported that California shrikes frequently nested in shrubs, but all subsequent authors have reported that shrikes nested predominantly in trees (Graber et al. 1973, Porter et al. 1975, Siegel 1980, Kridelbaugh 1982, Scott 1987, Luukkonen and Fraser 1987, Gawlik and Bildstein 1990, Brooks and Temple 1990b). The importance of cover in selection of nest substrates was demonstrated in this study: 1) although shrikes selected shrubs that were taller and more robust than average for nesting, they did not use the much taller, less densely-foliaged, trees; 2) nests were often placed in shrubs surrounded by other shrubs or wind-lodged tumbleweeds which extended the cover surrounding a nest; and 3) nesting success was highest in shrubs with dense foliage concealing the nest. Luukkonen and Fraser (1987) found that shrikes preferred trees with vines or other nest-concealing vegetation for nesting, and Gawlick and Bildstein (1990) observed increased success of nests placed in dense evergreen trees.

Plants containing shrike nests at Hanford were the shortest reported, but heights were similar to those reported for four-wing saltbush (*Atriplex canescens*) nest shrubs in Colorado (0.76 m, Porter et al. 1975). Median nest height in other studies was 2.8 m (range of 2.0 - 5.5 m; Porter et al. 1975, Siegel 1980, Kridelbaugh

1982, Scott 1987, Luukkonen and Fraser 1987, Gawlik and Bildstein 1990, Brooks and Temple 1990b), compared to 1.8 m at Hanford.

The proximity of the nest shrub to an edge was important in nest shrub selection at Hanford. This characteristic has not been noted in studies in agricultural areas (Porter et al. 1975, Siegel 1980, Kridelbaugh 1982, Luukkonen and Fraser 1987, Gawlik and Bildstein 1990, Brooks and Temple 1990b, Blumton 1990), probably because nearly all trees and shrubs in agricultural areas occur at the edge of openings. Shrikes obtain most of their food within 65 m of the nest (Miller 1931) and the close proximity of nest shrubs to an opening facilitates foraging near the nest site. In Virginia (Luukkonen and Fraser 1987) and South Carolina (Gawlick and Bildstein 1990) shrike nesting success was higher in nests located near optimal foraging habitat.

In comparison to other shrubs in the nest area, nest shrubs were tall with dense cover concealing the nest and with lateral branching structure adequate to support a nest. These characteristics were best satisfied by live sagebrush, bitterbrush, and mock orange. In general, rabbitbrush was short and had few lateral branches, while dead shrubs of all species lacked dense cover. Roost shrubs were typically the largest, densest shrubs in the nest area, with a nearly impenetrable cover of tumbleweeds and branches beneath the shrub. Shrubs used as perches were tall and provided an unobstructed view of the ground nearby. These shrubs maximized the foraging area visible to the perched shrike and likely increased foraging success (Craig 1978, Mills 1979). The desirability of dead shrubs as perches may also have been related to the abundance of broken, leafless branches which shrikes favored for impaling and dismembering prey (pers. obs.).

CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

Optimal shrike habitat in this study consisted of late seral or climax stands of big sagebrush or bitterbrush that had been partially burned, producing a mosaic of openings and patches of tall, robust shrubs. High horizontal and vertical structural complexity were important characteristics of shrike nest sites, and nearly all shrike territories were located on flat or gently rolling ground with deep, fertile soils.

At present, shrike density is about 12 - 19 times greater at Hanford than in the remainder of eastern Washington (Chapter 2). Nesting habitat at Hanford appeared to be saturated with shrikes, while remnant shrubsteppe patches throughout eastern Washington support vastly reduced numbers of shrikes, probably as a result of altered habitat structure and species composition. Since the time of Euroamerican settlement, shrike abundance has likely declined at a drastic rate similar to that of the loss of native shrubsteppe communities on flat ground and deep soils. At present, shrike populations are declining at a rate of 4.4% per year in the Columbia Basin (Sam Droege, pers. comm., 1988), and populations will continue to decline as native shrubsteppe is lost or modified. I found no evidence of low reproductive success which might explain the observed decline in shrike populations in the Columbia Basin (Chapter 1).

In response to these conclusions, I urge the following actions be taken:

1. Surveys to document the distribution of shrikes in eastern Washington should be conducted. In particular, surveys should determine which plant communities are used by shrikes and the extent to which shrikes coexist with livestock grazing, irrigated and dryland agriculture, recreational activities (especially off-road vehicle use), and housing developments.

2. Shrike densities in various plant communities and in areas of different land management should be determined.

3. Data on reproductive success and survival will be required to determine shrike status and evaluate habitat quality. The importance of a plant community in maintaining a species is dependent on the survival and reproduction of the species in that community, and without such data, the possibility that certain habitats are acting as population sinks cannot be ruled out (Van Horne 1983).

4. Until more is known of the distribution and status of shrikes elsewhere, it would not be prudent to alter shrubsteppe communities with an abundance of shrikes, such as the Hanford Site.

5. Pilot projects in the restoration of degraded shrubsteppe sites and the management of intact sites should be undertaken in the Columbia Basin. Fence lines, field corners, and acreage in conservation reserve programs may provide sites for initial research.

Human-induced perturbation of shrubsteppe communities leads to retrogressive succession, which transforms the diverse native vegetation into a simpler array of communities dominated by exotic species (Daubenmire 1970, Franklin and Dyrness 1973). As the structural complexity and species diversity of pristine shrubsteppe communities is lost, the animal community is simplified and impoverished. This study has demonstrated the importance of a structurally complex shrubsteppe ecosystem to nesting loggerhead shrikes. Only by maintaining the physiognomy, processes, and species composition characteristic of native shrubsteppe communities can we hope to preserve healthy populations of shrikes in Washington.

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APPENDICES

APPENDIX 1. UNDERSTORY VEGETATION OF FIVE SHRUBSTEPPE
COMMUNITIES

Table A.1. Understory vegetation at loggerhead shrike nest sites and at areas without loggerhead shrike nests in Washington, 1988-89.

Cover type	Bitterbrush		Mixed Shrub		Lowland Sagebrush		Upland Sagebrush		Upland Mesic	
	Nest N ^a = 30 $\bar{X}^b \pm SE$	Non-nest N = 24 $\bar{X} \pm SE$	Nest N = 30 $\bar{X} \pm SE$	Non-nest N = 26 $\bar{X} \pm SE$	Nest N = 30 $\bar{X} \pm SE$	Non-nest N = 28 $\bar{X} \pm SE$	Nest N = 3 $\bar{X} \pm SE$	Non-nest N = 3 $\bar{X} \pm SE$	Nest N = 2 $\bar{X} \pm SE$	Non-nest N = 2 $\bar{X} \pm SE$
Bare	57.7 ± 2.0	47.8 ± 2.8	29.5 ± 2.8	23.9 ± 2.1	32.8 ± 2.9	0.8 ± 2.6	10.0 ± 1.7	8.7 ± 1.2	19.0 ± 9.0	15.0 ± 7.0
Cryptogam	5.3 ± 1.1	1.7 ± 0.5	4.6 ± 1.1	3.4 ± 0.7	4.6 ± 1.0	5.7 ± 1.1	21.3 ± 3.8	17.7 ± 8.2	6.0 ± 0.0	11.5 ± 4.5
Litter	18.2 ± 1.1	20.7 ± 1.3	28.8 ± 1.4	29.6 ± 1.3	30.6 ± 1.3	30.4 ± 1.4	34.7 ± 4.7	31.0 ± 6.7	32.0 ± 2.0	32.5 ± 4.5
Annual grasses:	3.7 ± 0.4	7.5 ± 1.3	15.7 ± 1.5	20.9 ± 1.4	19.2 ± 2.2	28.4 ± 2.5	2.3 ± 1.5	12.3 ± 6.9	17.5 ± 9.5	12.0 ± 0.0
<i>Bromus tectorum</i>	3.7 ± 0.4	7.5 ± 1.3	15.7 ± 1.5	20.8 ± 1.4	19.0 ± 2.2	28.4 ± 2.5	2.3 ± 1.5	12.3 ± 6.9	17.5 ± 9.5	12.0 ± 0.0
<i>Festuca octoflora</i>	T ^c	T	T	0.1 ± 0.1	0.2 ± 0.1	T	T	-	-	T
Perennial grasses:	7.8 ± 0.7	10.0 ± 1.2	12.4 ± 1.2	11.0 ± 1.2	9.8 ± 1.4	10.0 ± 1.5	28.0 ± 6.1	23.7 ± 3.0	11.0 ± 1.0	21.0 ± 1.0
<i>Agropyron cristatum</i>	d	-	-	-	0.1 ± 0.1	0.2 ± 0.2	-	-	-	-
<i>Agropyron spicatum</i>	T	-	-	T	-	-	0.7 ± 0.7	-	3.5 ± 0.5	10.5 ± 0.5
<i>Agropyron dasytachyum</i>	0.3 ± 0.1	0.2 ± 0.1	T	T	-	-	-	-	-	-
<i>Elymus flavescens</i>	-	0.1 ± 0.1	-	-	-	-	-	-	-	-
<i>Koeleria cristata</i>	0.3 ± 0.1	0.2 ± 0.1	T	T	T	-	-	-	-	T
<i>Oryzopsis hymenoides</i>	4.2 ± 0.6	2.5 ± 0.6	0.5 ± 0.2	0.4 ± 0.2	T	0.1 ± 0.1	-	-	-	-
<i>Poa bulbosa</i>	-	-	-	-	-	T	-	-	T	-
<i>Poa sandbergii</i>	1.4 ± 0.5	3.2 ± 1.0	9.6 ± 1.3	9.2 ± 1.3	8.7 ± 1.4	9.3 ± 1.5	27.3 ± 5.9	22.3 ± 3.5	7.5 ± 2.5	10.0 ± 2.0
<i>Sitanion hystrix</i>	-	-	-	T	T	T	0.3 ± 0.3	1.0 ± 0.6	-	-
<i>Sporobolus cryptandrus</i>	-	-	-	-	T	T	-	-	-	T
<i>Stipa comata</i>	1.2 ± 0.3	3.6 ± 1.0	2.1 ± 0.7	1.3 ± 0.5	0.7 ± 0.6	0.4 ± 0.2	-	0.3 ± 0.3	-	T
Annual forbs:	2.6 ± 0.4	4.2 ± 0.9	5.6 ± 0.9	6.5 ± 1.1	1.5 ± 0.3	3.6 ± 0.6	0.7 ± 0.7	1.7 ± 0.9	4.0 ± 4.0	1.0 ± 1.0
<i>Epilobium paniculatum</i>	-	T	T	T	T	T	-	T	-	-
<i>Eriogonum vimineum</i>	-	T	0.1 ± 0.1	-	-	T	-	-	-	-
<i>Chenopodium sp.</i>	-	T	-	-	-	-	-	-	-	-
<i>Salsola kali</i>	1.0 ± 0.3	2.6 ± 0.8	3.2 ± 0.7	4.4 ± 0.9	0.5 ± 0.3	2.1 ± 0.6	T	0.7 ± 0.7	1.0 ± 1.0	T
<i>Holosteum umbellatum</i>	T	T	T	T	T	T	-	-	-	-
<i>Chorispura tenella</i>	T	-	T	T	T	T	-	-	0.5 ± 0.5	T

Table A.1 (continued)

Cover type	Bitterbrush		Mixed Shrub		Lowland Sagebrush		Upland Sagebrush		Upland Mesic	
	Nest	Non-nest	Nest	Non-nest	Nest	Non-nest	Nest	Non-nest	Nest	Non-nest
	n=30 $\bar{X} \pm SE$	n=24 $\bar{X} \pm SE$	n=30 $\bar{X} \pm SE$	n=26 $\bar{X} \pm SE$	n=30 $\bar{X} \pm SE$	n=28 $\bar{X} \pm SE$	n=3 $\bar{X} \pm SE$	n=3 $\bar{X} \pm SE$	n=2 $\bar{X} \pm SE$	n=2 $\bar{X} \pm SE$
Annual forbs (continued):										
<i>Descurainia pinnata</i>	0.5 ± 0.1	T	T	T	T	T	-	-	-	-
<i>Draba verna</i>	-	T	0.1 ± 0.1	T	T	-	T	-	-	-
<i>Erysimum</i> sp.	T	T	-	-	-	-	-	-	-	-
<i>Lepidium</i> sp.	-	T	-	-	-	-	-	-	-	-
<i>Sisymbrium altissimum</i>	T	0.1 ± 0.1	0.5 ± 0.3	0.5 ± 0.2	0.2 ± 0.1	0.6 ± 0.2	-	0.7 ± 0.3	0.5 ± 0.5	-
<i>Ambrosia psilostachya</i>	0.3 ± 0.2	0.5 ± 0.2	0.7 ± 0.2	0.7 ± 0.4	T	0.3 ± 0.1	-	-	-	-
<i>Lactuca serriola</i>	T	-	-	-	T	T	-	-	1.0 ± 1.0	-
<i>Lactuca</i> sp.	-	-	-	-	T	T	-	-	-	-
<i>Tragopogon dubius</i>	-	-	T	T	T	T	0.7 ± 0.7	T	-	T
<i>Collinsia</i> sp.	T	T	-	T	-	-	-	-	-	-
<i>Amsinckia tessellata</i>	T	-	0.1 ± 0.1	0.2 ± 0.1	T	T	-	T	1.0 ± 1.0	-
<i>Cryptantha circumscissa</i>	T	T	T	T	T	T	-	-	-	-
<i>Plantago patagonica</i>	-	-	0.1 ± 0.1	0.1 ± 0.1	T	T	-	-	-	-
<i>Phacelia linearis</i>	0.3 ± 0.1	0.4 ± 0.2	T	T	-	-	-	-	-	-
<i>Microsteris gracilis</i>	-	T	0.1 ± 0.1	0.1 ± 0.1	0.2 ± 0.1	0.1 ± 0.1	-	-	-	-
Unknown annual forb	T	T	T	T	T	-	-	-	0.5 ± 0.5	0.5 ± 0.5
Perennial forbs:	4.5 ± 0.5	7.9 ± 0.8	3.2 ± 0.4	4.7 ± 1.0	1.2 ± 0.2	0.6 ± 0.2	2.0 ± 1.2	3.7 ± 2.0	9.0 ± 5.0	7.5 ± 1.5
<i>Calochortus macrocarpus</i>	-	-	T	-	T	-	-	-	-	-
<i>Zigadenus</i> sp.	-	-	-	-	-	-	-	-	-	T
<i>Comandra umbellata</i>	-	T	-	T	T	-	-	-	-	-
<i>Oenothera pallida</i>	0.4 ± 0.1	0.8 ± 0.3	0.2 ± 0.1	0.1 ± 0.1	T	T	-	-	-	-
<i>Eriogonum niveum</i>	0.9 ± 0.3	0.7 ± 0.3	1.3 ± 0.4	2.8 ± 1.0	-	-	-	-	-	-
<i>Rumex venosus</i>	T	T	-	-	-	-	-	-	-	-
<i>Arenaria franklinii</i>	0.3 ± 0.2	0.1 ± 0.1	T	-	-	-	-	-	-	-
<i>Cymopterus terebinthinus</i>	0.7 ± 0.2	0.8 ± 0.3	0.2 ± 0.1	T	T	T	-	-	7.0 ± 7.0	2.5 ± 2.5
<i>Sphaeralcea munroana</i>	-	-	-	-	T	T	-	-	-	-

Table A.1 (continued)

Cover type	Bitterbrush		Mixed Shrub		Lowland Sagebrush		Upland Sagebrush		Upland Mesic	
	Nest n=30 $\bar{X} \pm SE$	Non-nest n=24 $\bar{X} \pm SE$	Nest n=30 $\bar{X} \pm SE$	Non-nest n=26 $\bar{X} \pm SE$	Nest n=30 $\bar{X} \pm SE$	Non-nest n=28 $\bar{X} \pm SE$	Nest n=3 $\bar{X} \pm SE$	Non-nest n=3 $\bar{X} \pm SE$	Nest n=2 $\bar{X} \pm SE$	Non-nest n=2 $\bar{X} \pm SE$
Perennial forbs (continued):										
<i>Astragalus</i> spp.	0.1 ± 0.1	0. ± 0.2	0.1 ± 0.1	T	0.1 ± 0.1	T	T	-	-	0.5 ± 0.5
<i>Lupinus</i> spp.	-	-	-	-	-	-	-	-	-	2.0 ± 2.0
<i>Petalostemon ornatum</i>	T	-	-	-	-	-	-	-	-	-
<i>Psoralea lanceolata</i>	0.3 ± 0.1	1.1 ± 0.3	0.1 ± 0.1	T	-	T	-	-	-	-
<i>Opuntia polyacantha</i>	-	T	T	-	T	-	-	-	-	-
<i>Achillea millefolium</i>	0.1 ± 0.1	0.2 ± 0.1	T	T	T	-	-	-	-	0.5 ± 0.5
<i>Agoseris</i> sp.	T	T	-	-	-	-	-	-	-	-
<i>Balsamorhiza careyana</i>	-	T	T	T	0.5 ± 0.2	0.2 ± 0.1	0.3 ± 0.3	0.3 ± 0.3	-	-
<i>Chaenactis douglasii</i>	T	T	T	-	-	-	-	-	-	-
<i>Cirsium</i> sp.	-	-	-	-	-	-	-	-	2.0 ± 2.0	1.0 ± 1.0
<i>Crepis atrabarba</i>	-	T	-	T	-	-	-	0.7 ± 0.7	T	0.5 ± 0.5
<i>Erigeron linearis</i>	-	-	-	-	T	-	T	-	-	T
<i>Helianthus cusickii</i>	-	-	-	-	T	T	-	T	-	-
<i>Machaeranthera canescens</i>	0.8 ± 0.2	2.9 ± 0.7	0.8 ± 0.2	1.2 ± 0.3	T	0.2 ± 0.1	T	0.3 ± 0.3	-	-
<i>Stephanomeria tenuifolia</i>	-	-	-	-	-	-	-	-	-	-
<i>Penstemon</i> spp.	T	T	-	-	-	-	-	-	-	-
<i>Cryptantha leucophaea</i>	0.2 ± 0.1	T	-	T	-	-	-	-	-	-
<i>Lithospermum ruderale</i>	-	-	-	-	-	-	-	-	-	0.5 ± 0.5
<i>Phacelia hastata</i>	T	T	-	-	-	-	-	-	-	-
<i>Leptodactylon pungens</i>	-	-	-	-	T	0.1 ± 0.1	-	-	-	-
<i>Phlox longifolia</i>	T	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	0.2 ± 0.1	T	1.0 ± 1.0	2.0 ± 1.0	-	-

^a N = number of sample plots.

^b X = average percent canopy cover as determined by point intercept sampling.

^c T indicates the species was present at less than 0.10% cover.

^d - indicates the species was absent.

APPENDIX 2. ANALYTICAL METHODS USED TO CALCULATE SHRIKE DENSITY

The methods presented here were developed and employed by Marti MacCracken and Fred Ramsey of the Statistics Department of Oregon State University.

Perpendicular distances of birds from the transect line were \log_{1n} transformed to improve conformity to the normal distribution. The frequency distributions of the perpendicular distances were examined and outliers (i.e., birds that were detected much farther from the line than were the majority of birds) discarded. Scatterplots of perpendicular distances versus the variables of month of survey, plant community, and shrike age were examined to determine if the number of shrikes detected was related to these variables. For walking transects, the number of shrikes detected appeared to be related to the month of survey and to plant community; for driving transects, only plant community emerged as a possible explanatory variable. Linear regression was used to derive least squares estimates of the regression coefficients for the equation:

$$\log_{1n}(z) = \beta_0 + \beta_1 \text{month} + \beta_2 \text{pc1} + \beta_3 \text{pc2} + \beta_4 \text{pc3},$$

where z = perpendicular distance; month = 0 for April surveys and month = 1 for June surveys; pc1 = 0 if plant community = upland sagebrush and pc1 = 1 if not; pc2 = 0 if plant community = lowland sagebrush and pc2 = 1 if not; pc3 = 0 if plant community = bitterbrush and pc3 = 1 if not. The equation above was used for walking transect data. For driving transects, the equation was:

$$\log_{1n}(z) = \beta_0 + \beta_1 \text{pc1} + \beta_2 \text{pc2} + \beta_3 \text{pc3} + \beta_4 \text{pc4},$$

where $pc4 = 0$ if plant community = rabbitbrush and $pc4 = 1$ if not. In both equations, dummy variables were used to account for the effect that explanatory variables (month and plant community for walking transects; plant community for driving transects) produced upon the number of birds detected. At this point, the least squares estimates for $\beta_1 - \beta_4$ were unbiased for estimating the effective width of the transect, but β_0 was not.

The regression coefficients were then used to adjust all the data from walking transects to the month of April and the mixed shrub plant community with the equation:

$$z_{\text{adjusted}} = z^{-(\beta_0 + \beta_1\text{month} + \beta_2pc1 + \beta_3pc2 + \beta_4pc3)}.$$

Data from driving transects were adjusted to the mixed shrub community using the equation:

$$z_{\text{adjusted}} = z^{-(\beta_0 + \beta_1pc1 + \beta_2pc2 + \beta_3pc3 + \beta_4pc4)}.$$

The adjusted data were pooled and submitted to Program TRANSECT to obtain an estimate of the effective area sampled based on the Fourier Series estimator. The Fourier series estimator is a robust nonparametric procedure that is appropriate for small sample sizes (Burnham et al. 1980). Chi-square goodness-of-fit tests indicated that this estimator was appropriate for data from both the walking ($X^2 = 7.82$, 13 df, $P = 0.85$) and driving ($X^2 = 10.53$, 8 df, $P = 0.23$) transects.

The estimate of effective area sampled was converted to effective transect width by the equation:

$$\text{effective transect width} = \frac{\text{effective area sampled}}{2 \times \text{transect length}}$$

The effective transect width for each plant community and month for walking transects was then computed with the equation:

$$EW_{pc, \text{ month}} = EW_{\text{pooled}}(\beta_1 \text{ month} + \beta_2 pc1 + \beta_3 pc2 + \beta_4 pc3),$$

and for driving transects with the equation:

$$EW_{pc, \text{ month}} = EW_{\text{pooled}}(\beta_1 pc1 + \beta_2 pc2 + \beta_3 pc3 + \beta_4 pc4),$$

where $EW_{pc, \text{ month}}$ = effective width for each combination of month and plant community; and EW_{pooled} = effective width from the pooled data.

These month- and community-specific effective transect widths were then used to obtain density estimates by the equation:

$$\text{density} = \frac{\text{number of shrikes detected}}{(2 \times \text{effective width} \times \text{length of transect surveyed})}$$

The standard errors of the density estimates were obtained by bootstrap.

The regression equation used to adjust the perpendicular distances for pooling of data from the driving transects was:

$$\log_{10}(z) = 3.439 + 0.641pc1 + 0.219pc2 + 0.525pc3 + 0.396pc4,$$

and the Fourier series estimate of the total effective area sampled was 65.37 ha.

The regression equation used to adjust the perpendicular distances for pooling of data from walking transects was:

$$\log_{1n}(z) = 3.366 + 0.519\text{month} + -0.593\text{pc1} + 0.277\text{pc2} + 0.424\text{pc3},$$

and the Fourier series estimate of the total effective area sampled was 59.65 ha.

**APPENDIX 3. MEANS AND STANDARD ERRORS FOR VARIABLES
MEASURED AT SHRIKE NEST SITES AND NON-NEST SITES**

Table A.2. Means, standard errors, and univariate P values of variables measured at 95 loggerhead shrike nest sites and 83 areas without nests in Washington, 1988-89.

Variable	Nest Sites		Non-nest Sites		P Value
	\bar{X}	SE	\bar{X}	SE	
Annual grass cover (%)	12.6	1.1	19.0	1.4	0.0004
Perennial grass cover (%)	10.6	0.7	11.1	0.8	0.64
Annual forb cover (%)	3.2	0.4	4.6	0.5	0.02
Litter cover (%)	26.3	0.9	27.4	0.9	0.36
Bareground (%)	38.6	2.0	29.0	1.9	0.0007
Shrub cover: tall species (%)	7.3	0.4	2.2	0.4	0.001 ^a
Shrub cover: short species (%)	1.1	0.2	1.1	0.3	0.56 ^a
Shrub cover: dead shrubs (%)	1.5	0.2	1.5	0.2	0.92 ^a
Height of live shrubs (cm)	121.1	2.9	68.6	4.3	0.0001
Height of dead shrubs (cm)	60.0	3.3	58.1	4.0	0.71
CV in density of tall shrubs	48.7	2.5	57.4	7.5	0.03 ^b
CV in density of short shrubs	70.5	7.5	43.1	7.0	0.006 ^b
CV in density of dead shrubs	94.3	6.4	63.9	7.0	0.005 ^b
CV in height of live shrubs	37.4	1.5	22.3	2.0	0.0001
CV in height of dead shrubs	28.9	2.0	23.8	2.1	0.08
Vertical density < 20 cm	91.6	5.3	111.5	5.2	0.002 ^a
Vertical density 20-50 cm	24.1	1.7	21.1	1.8	0.13 ^a
Vertical density > 50 cm	11.8	1.2	4.9	0.8	0.0001 ^a
Foliage height diversity	0.6	0.0	0.5	0.0	0.0001
Foliage height evenness	0.7	0.0	0.6	0.0	0.14
Species richness	9.2	0.4	9.2	0.4	0.98
Species evenness	0.6	0.0	0.6	0.0	0.19
Species diversity	0.6	0.0	0.6	0.0	0.44

^a P value for transformed ($\log_{10}(X + 1)$) data.

^b P value for transformed ($X^{0.5}$) data.

Table A.3. Means, standard errors, and univariate P values of variables measured at 238 shrubs with loggerhead shrike nests and 85 shrubs without nests in Washington, 1988-89.

Variable	Nest Shrubs		Non-nest Shrubs		P Value
	\bar{X}	SE	\bar{X}	SE	
Shrub height (cm)	178.5	2.2	99.3	3.5	0.0001
Clump height (cm)	140.7	3.1	91.5	2.9	0.0001
Shrub volume (m ³)	15.9	1.2	2.5	0.7	0.0001 ^a
Clump volume (m ³)	27.5	2.6	2.8	0.7	0.0001 ^a
Number of stems	9.6	0.8	12.3	1.5	0.18 ^a
% deadwood	30.1	1.5	44.1	4.6	0.28 ^a
Distance to edge (m)	9.8	1.0	51.2	5.7	0.0001 ^a
Distance to road (m)	109.7	9.0	129.6	13.9	0.23
Slope (%)	1.1	0.2	1.9	0.7	0.18

^a P value for transformed ($\log_{10}(X + 1)$) data.