REPRODUCTIVE ECOLOGY OF THE SAGE SPARROW (*AMPHISPIZA BELLI*), AND ITS RELATIONSHIP TO THE CHARACTERISTICS OF NATIVE AND CHEATGRASS (*BROMUS TECTORUM*) DOMINATED HABITATS

By

LISA ELAINE FITZNER

A thesis submitted in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE IN BIOLOGY

WASHINGTON STATE UNIVERSITY
School of Biological Sciences

May 2000

To the Faculty of Washington State University:

The members of the Committee appointed to examine the thesis of LISA ELAINE FITZNER find it satisfactory and recommend that it be accepted.

Chair

ACKNOWLEDGMENT

This thesis is the result of hard work by many individuals. Help ranged from simple words of encouragement to long days in the field. It would have been impossible to conduct this study without the assistance of others and I am greatly appreciative.

My committee chair Dr. John A. Hall provided a guiding hand but allowed me the freedom to learn at my own pace. John's commitment and continued support assured the success of this project. Committee members Drs. Don Miller, John Paznokas, and William H. Rickard provided insightful direction, much needed criticism, and the logistical ability to continue. Another committee member, Dr. Matthew Vander Haegen, introduced me to passerine research. His field savvy, knowledge of computers, and statistics was of great help throughout this entire study.

The amount of help I received from volunteers was amazing. It takes a great deal of stamina to wake at 4:00 am and spend long hours in the field, but it's much harder when you're doing it for free. Kathy Criddle spent two field seasons volunteering. She was reimbursed for only a small fraction of her time and no words can properly thank her. Tracy Walsh spent an entire field season tracking sage sparrows with no compensation. Karen Kronner helped trap and track birds but, best of all, supplied encouragement and a shoulder to lean on. The artistic skills of Elizabeth Krecker were graciously appreciated. I hope the knowledge that volunteers gained during this study will help them in all of their future endeavors.

Larry Cadwell and members of the Ecology group at Battelle Pacific Northwest Laboratory, graciously provided me with field help, computer time, equipment, and

advice. John Nugent and Rhett Zufelt, though busy with their own research, took the time to guide me through "high tech" bird mapping and GIS analysis. Satellites and computers are no challenge to these guys. Rob Burrows and Ted Feldpausch, Associated Western University participants assigned to Battelle, awoke early to assist in the collection of field data. Their observations added greatly to this study.

Financial support from The Nature Conservancy made it possible for me to hire a stellar field botanist, Jay Goodwin. With Jay's assistance I was able to collect quality vegetation data that were an essential part of this thesis.

Washington Department of Fish and Wildlife (WDFW) and especially Dave Brittell, John Pierce, and Roger McKeel enabled me to make this study a reality. They provided me with the time off from work, financial and technical support, guidance, and encouragement. Typical of WDFW staff these guys do what it takes to conserve Washington's wildlife. Mike Nelson, a WDFW biologist, diligently tracked birds and used his superior sleuthing abilities to locate many well hidden sage sparrow nests.

My mother, Charlotte Jackson, provided me with everything from encouragement and childcare to technical advice. Brant Fitzner lovingly gave of his mom's time and patiently listened as I taught him about avian ecology. In addition to helping with the logistics of family life, my good friend Terry Phillips hung in there when it seemed like birds took precedence over everything else.

REPRODUCTIVE ECOLOGY OF THE SAGE SPARROW (*AMPHISPIZA BELLI*), AND ITS RELATIONSHIP TO THE CHARACTERISTICS OF NATIVE AND CHEATGRASS (*BROMUS TECTORUM*) DOMINATED HABITATS

Abstract

by Lisa Elaine Fitzner M.S.
Washington State University
May 2000

Chair: John A. Hall

Once a common breeding passerine in shrub-steppe habitats of the interior Columbia Basin, the sage sparrow (*Amphispiza belli*) is now a candidate for threatened or endangered status in Washington. To better understand the breeding ecology and habitat requirements of this species, I studied sage sparrows nesting in both native bunchgrass and cheatgrass (*Bromus tectorum*) dominated shrub-steppe communities on the U.S. Department of Energy's Hanford Site.

Sage sparrows began nesting in early March and fledged their last young by mid-July. Pairs breeding early (March), or late in the season (June and July), had lowered risk of nest predation and greater reproductive success than birds that nested in either April or May.

Early and / or late nesting birds often endured relatively extreme ambient temperature conditions. My results suggest that sage sparrows use nest placement to help moderate temperatures at their nest sites. Nests initiated during cooler temperatures were located on the ground underneath downed and dead big sagebrush

(*Artemisia tridentata*) or standing shrubs, but after temperatures rose all nests were placed within the sagebrush canopy. This use of behavioral thermoregulation by sage sparrows may allow for an extension of the breeding season into periods when eggs / young are less vulnerable to snake predation.

Colonization of shrub-steppe communities by invasive plant species potentially contributes to the loss of usable breeding habitat for the sage sparrow. I examined the relationship between the floristic and structural components of both cheatgrass-dominated and native bunchgrass dominated communities and further related measures of these components to the pairing status, reproductive success, and territory size of birds breeding on the Hanford Site. Cheatgrass cover was negatively related to that of native bunchgrasses, bare ground, and sagebrush cover. A similar negative correlation was observed between cheatgrass cover and territory size; however, this relationship was significant only at the territory level. A significant relationship did not exist between cheatgrass cover and sage sparrow pairing or nesting success; however, more cheatgrass was present in territories of unpaired males and less was present in those territories that contained a greater number of successful nests.

TABLE OF CONTENTS

Page

ACKNOWLEDGMENTS iii

ABSTRACT v

LIST OF TABLES x

LIST OF FIGURES xii

GENERAL INTRODUCTION 1

CHAPTER ONE

REPRODUCTIVE ECOLOGY OF SAGE SPARROWS (*AMPHISPIZA BELLI*) ON THE HANFORD SITE

1. INTRODUCTION 6

2. STUDY AREA AND METHODS 10

Study site selection and establishment 11

Selection of breeding birds 12

Territory delineation 13

Determination of reproductive status 13

Nest shrub characterization 16

Statistical analysis 16

RESULTS 18

Breeding season chronology 18

Pair bond establishment and maintenance 18

Nesting parameters 19

Nest parasitism, abandonment, and predation 22

Nest success and daily survival rates 23

Nest placement 24

DISCUSSION 30

SUMMARY 35

LITERATURE CITED 37

CHAPTER TWO

THE RELATIONSHIP BETWEEN CHEATGRASS (*BROMUS TECTORUM*) COVER AND SAGE SPARROW (AMPHI*SPIZA BELLI*) TERRITORY SIZE / REPRODUCTIVE SUCCESS . . . . . .

INTRODUCTION 40

STUDY AREA AND METHODS 43

Study area 43

Habitat characterization 45

Statistical analysis 46

RESULTS 48

Habitat characteristics 48

Territory size 54

Relationships between habitat variables and territory size . . 55

The relationship between nest success, territory size and habitat variables 56

DISCUSSION 59

Habitat characteristics 59

The relationship between sage sparrow territory size and shrub-steppe habitat components 61

The relationship between reproductive success / pairing status and territory size, and cheatgrass cover 63

SUMMARY 65

LITERATURE CITED 67

APPENDIX

1. Plant species by study site 70

LIST OF TABLES

CHAPTER ONE

REPRODUCTIVE ECOLOGY OF SAGE SPARROWS (*AMPHISPIZA BELLI*) BREEDING ON THE HANFORD SITE

1. Number of sage sparrow territories, pairs, and unpaired males monitored during 1996 and 1997 20

2. Percentage of nests initiated by month and by nest attempt number for 39 sage sparrow pairs during 1996 and 1997 . . 21

3. Sage sparrow nesting parameters during 1996 and 1997 22

4. Nest fate and success rates during 1996 and 1997 24

5. Sage sparrow nest shrub vigor (mean of ranked categories) measured during1996 and 1997. Shrub vigor (categorized percentage of shrub with live foliage) = 1: 0 to 25%, 2: 26 to 50%, 3: 51 to 75%, 4: 76 to 100% 27

6. Sage sparrow nest placement parameters for nests placed within the shrub canopy by study site during 1996 and 1997 29

LIST OF TABLES CONTINUED

CHAPTER TWO

THE RELATIONSHIP BETWEEN CHEATGRASS (*BROMUS TECTORUM*) COVER AND SAGE SPARROW (*AMPHISPIZA BELLI*) TERRITORY SIZE / REPRODUCTIVE SUCCESS

1. Habitat characteristics of sage sparrow territories on each of 6 study sites during 1996 and 1997. Figures are based on the average of pooled data from territories for each year. 49

2. Results of Pearson Product-Moment correlation analysis between mean cheatgrass cover and other habitat variables at the study site and territory level of analysis during 1996 and 1997 53

3. Mean territory size (ha) of sage sparrows: 1996 and 1997 54

4. Correlations coefficients of relationships between sage sparrow territory size and habitat characteristics at both the study site and territory levels of analysis: 1996 and 1997 . . 56

5. Mean percentage of cheatgrass cover within sage sparrow territories containing 0, 1, or 2 successful nests: 1996 and 1997 57

6. Comparison of territory size and habitat variables for territories of paired and unpaired males 59

LIST OF FIGURES

CHAPTER ONE

. . . . . .

REPRODUCTIVE ECOLOGY OF SAGE SPARROWS (*AMPHISPIZA BELLI*) ON THE HANFORD SITE

1. Location of the U.S. DOE Hanford Site, and study site locations 8

2. Orientation of sage sparrow nests (elevated nests only) located on the Hanford Site during 1996 and 1997. Each square signifies the number of nests facing a particular direction 25

3. Percentage of sage sparrow nests placed in the shrub canopy during semi-monthly intervals during 1996 and 1997 and average daily mean semi-monthly temperature . . 28

CHAPTER TWO

THE RELATIONSHIP BETWEEN CHEATGRASS (*BROMUS TECTORUM*) COVER AND SAGE SPARROW (*AMPHISPIZA BELLI*) TERRITORY SIZE / REPRODUCTIVE SUCCESS

1. Location of the U.S. DOE Hanford Site, and study site locations 44

2. Yearly percentages of cheatgrass cover within sage sparrow territories on each of 6 study sites. Values represent the average of pooled data from territories on each site 51

3. Relationship between the coverage of cheatgrass and bare ground during 1996 and 1997. Values represent the yearly mean for each study site 52

4. The relationship between sage sparrow territory size and cheatgrass cover during 1996 and 1997 58

Dedication

This thesis is dedicated to my late husband Richard Fitzner.
His inspiration lives on.

GENERAL INTRODUCTION

This thesis is composed of two chapters that individually constitute separate manuscripts. Each chapter is written in a format dictated by the journal to which it will be submitted for publication. Although the master's candidate is the senior author, both chapters may have at least dual authorship. The information presented describes the breeding ecology of the sage sparrow and how predation pressure and habitat conditions have affected various aspects of reproduction.

The sage sparrow is a medium-sized passerine that occurs within the sagebrush (*Artemisia* spp.) habitats west of the Rocky Mountains and south to the chaparral and sagebrush scrub of Baja California (Martin and Carlson 1998). Five subspecies of sage sparrow currently are identified, one of which, *Amphispiza belli nevadensis*, nests in the shrub-steppe habitat of the Columbia Basin of Washington and Oregon (Altman and Holmes 2000). Because sage sparrows are dependent on sagebrush-dominated communities for at least a portion of their life cycle, they are considered to be an obligate species in regard to their habitat requirements (Braun and others 1976; Dobler 1996). Loss, fragmentation, and degradation of shrub-steppe habitats prompted Washington Department of Fish and Wildlife to identify the sage sparrow as a state candidate for threatened and / or endangered status in the early 1990's (Harriet Allen, Washington Department of Fish and Wildlife, WA. pers. comm.).

Shrub-steppe habitats are in rapid decline. Analysis of satellite imagery suggests that habitat loss, mostly as a result of agricultural development, within the Columbia Basin exceeds 60% (Dobler 1992; DOE-RL 1996). Remnant habitat is often

degraded by the proliferation of non-native annual grasses and forbs, primarily cheatgrass (*Bromus tectorum*) (Hall 1998; Knick 1999). When cheatgrass occurs within the shrub-steppe understory, an increase in fire frequency / intensity may result (Knick 1999). Because cheatgrass readily exploits disturbed environments and demonstrates superior competitive abilities compared to the native flora (Brandt and Rickard 1994), cheatgrass cover increases with each successive burn while the coverage of native flora declines. This ultimately results in a positive feedback loop in which shrub-steppe converts into a shrubless cheatgrass plain (Knick 1999).

Preservation of extant shrub-steppe habitats occurs primarily on state and federally owned lands. For example, the Hanford Site, administered by the U.S. Department of Energy (USDOE), constitutes much of the relatively undisturbed shrub-steppe acreage remaining in the interior Columbia Basin (Smith 1994; DOE-RL 1996). Although USDOE has protected from development and conversion most of Hanford's habitats above 500 m, wildfire has removed most of the big sagebrush (*Artemisia tridentata* / *Pseudoroegneria* [=*Agroppyron*] *spicata*) cover from this area. Lower elevations, while still containing unfragmented stands of big sagebrush, have been re-zoned to include industry and mining in addition to preservation (DOE-RL 1999).

Knowledge of reproductive parameters, such as nesting success and clutch size, is important for understanding the ecology, evolution, and population viability of birds (Rotentberry and Wiens 1989). Factors that affect these parameters, such as predation, may in turn influence life history traits and habitat use by a species (Martin 1988). Chapter 1 of this thesis describes the reproductive parameters of sage sparrows nesting on the lower elevations of the Hanford Site during 1996 and 1997. Differences

in nesting success, clutch size and nest placement that occur over the course of a breeding season, and the selective pressures that may contribute to these differences, also are discussed.

Despite the factors that may confound the link between measures of habitat quality and breeding bird abundance / reproductive success, some studies have discovered a relationship between these variables (Wiens 1985; Vickery and others 1992). This is especially true for studies that evaluate correlational patterns between habitat floristics and the distribution and abundance of bird species on a more local scale of analysis (Wiens 1985). Chapter 2 of this thesis begins by examining how the floristic and structural characteristics of native shrub-steppe communities correlate with the amount of cheatgrass cover. The presence of cheatgrass is further related to the territory size, mating status, and reproductive success of sage sparrows nesting on 6 study sites. Each site differs in the amount of cheatgrass (2 to over 60% coverage), bare ground, and herbaceous plant species, but each site contains > 20% big sagebrush. An understanding of the link between cheatgrass and its effect on habitat characteristics of shrub-steppe communities, and how these variables subsequently relate to sage sparrow territory size / reproductive success, will provide a better understanding of the breeding ecology of the sage sparrow. It may also help identify a threshold of cheatgrass cover that potentially results in an increase in sage sparrow territory size and subsequent decline in sage sparrow breeding densities. Such information can form the first step toward improving our understanding of how invasive plant species such as cheatgrass affect the reproductive success, and ultimately the population viability, of shrub-steppe passerines.

LITERATURE CITED

Altman B, Holmes A. 2000. Conservation strategy for landbirds in the Columbia Plateau of eastern Oregon and Washington. Final draft. Oregon-Washington Partners in Flight. p 1-96.

Brandt CA, Rickard WH. 1994. Alien taxa in the North American shrub-steppe four decades after cessation of livestock grazing and cultivation agriculture. Biological Conservation 68:95-105.

Braun CE, Baker MF, Eng RL, Gashwiler JS, Schroeder MH. 1976. Conservation committee report on effects of alteration of sagebrush communities on the associated avifauna. Wilson Bulletin 88:165-171.

Dobler FC, Eby J, Perry C, Richardson S, Vander Haegen M. 1992. Status of Washington's shrub-steppe ecosystem: extent, ownership, and wildlife/vegetation relationships. Olympia, WA: Shrub-steppe project, phase one completion report. Washington Department of Fish and Wildlife. p 1-39.

[DOE-RL] U.S. Department of Energy. 1996. Draft Hanford Site Biological Resources Management Plan. Richland, WA: US DOE, Richland Operations Office. DOE/RL 96-32.

[DOE-RL] U.S. Department of Energy. 1999. Final Hanford comprehensive land-use plan environmental impact statements. Richland, WA: US DOE, Richland Operations Office. DOE/EIS-0222.

Hall JA (editor). 1998. Biodiversity of the Hanford Site: 1997 annual report. The Nature Conservancy of Washington, Seattle. 75 p.

Knick ST. 1999. Requiem for a sagebrush ecosystem? Northwest Science 73:53-57.

Martin J W, Carlson BA. 1998. Sage Sparrow (*Amphispiza belli*). In: Poole A, Gill F, editors. No. 326. The Birds of North America, Inc., Philadelphia, PA. 20 p.

Martin TE. 1988. Processes organizing open-nesting bird assemblages: competition or nest predation. Evolutionary Ecology 2:37-50.

Smith MR. 1994. Evaluating the conservation of avian diversity in eastern Washington: a geograpic analysis of upland breeding birds [thesis]. Seattle, WA: University of Washington. 101 p.

Rotenberry JT, Wiens JA. 1989. Reproductive biology of shrubsteppe passserine birds: geographical and temporal variation in clutch size, brood size, and fledgling success. Condor 91:1-14.

Vickery PD, Hunter ML, Wills JV. 1992. Is density an indicator of reproductive success. Auk 109: 706-710.

Wiens JA. 1985. Habitat selection in variable environments: shrubsteppe birds. In: Cody ML, editor. Habitat selection in birds. New York: Academic Press. p 227-251.

CHAPTER ONE

REPRODUCTIVE ECOLOGY OF SAGE SPARROWS (*AMPHISPIZA BELLI*) ON THE HANFORD SITE

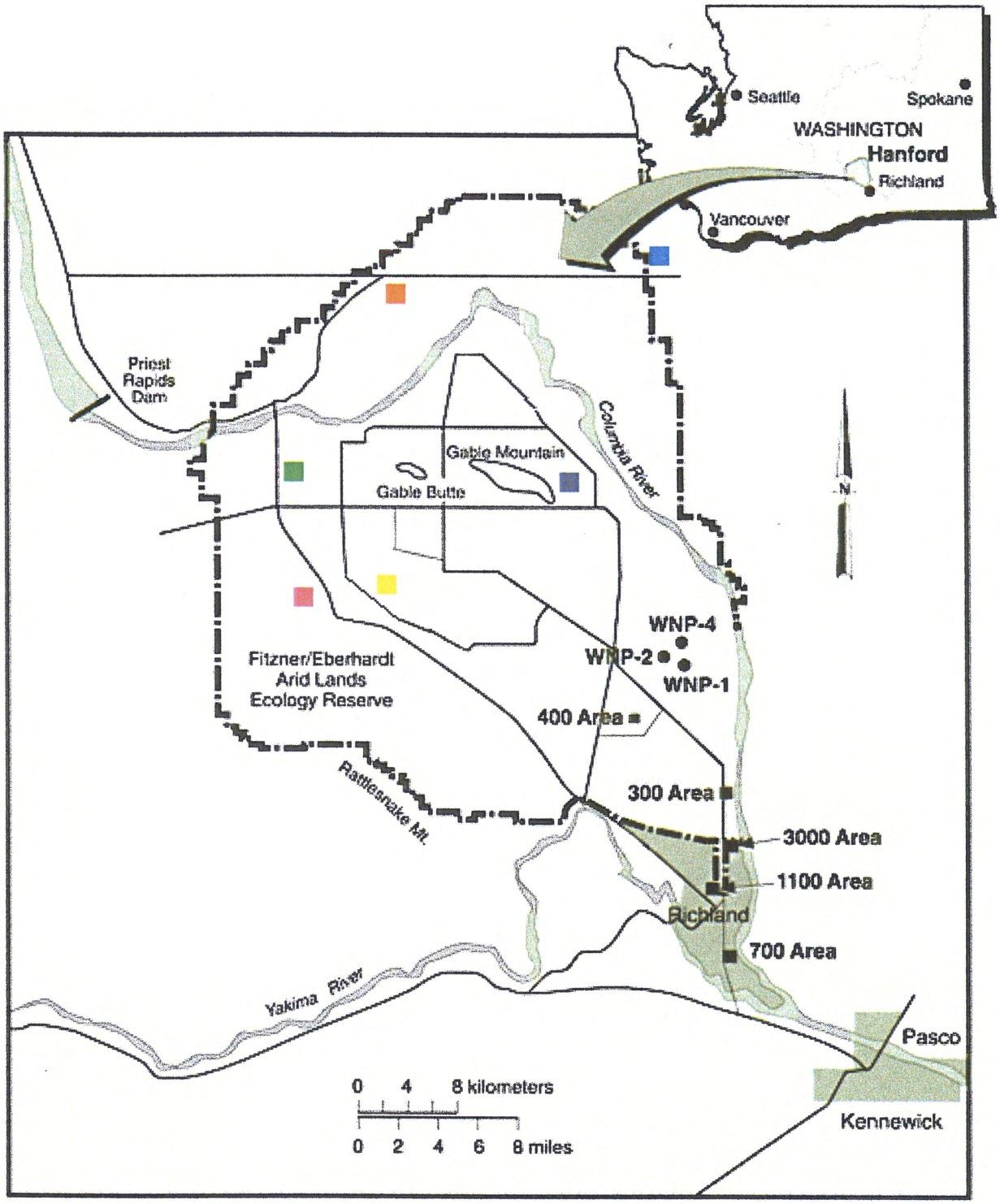
The sage sparrow (*Amphispiza belli*) is a common nesting passerine in shrub-steppe ecosystems of the western United States (Wiens 1985). In Washington sage sparrow breeding habitat is limited to the sagebrush communities of the interior Columbia Basin. Conversion of the shrub-steppe for agriculture and urbanization has subsequently resulted in a dramatic loss of sage sparrow breeding habitat. Continued degradation and fragmentation of the shrub-steppe prompted Washington Department of Fish and Wildlife to identify the sage sparrow as a candidate for threatened and / or endangered status in the early 1990's (Harriet Allen, Washington Department of Fish and Wildlife, WA. pers. comm.). Previous research (Vander Haegen and others 2000) suggest that sage sparrows require large, unbroken blocks of shrub-steppe for breeding. Public ownerships, such as the U.S. Department of Energy Hanford Site located in southcentral Washington (Fig. 1), likely provide some of the last relatively large unfragmented refugia.

Sage sparrow breeding habitat on the Hanford Site extends from the lowest elevations (190 m) to the slopes of the Rattlesnake Hills and Saddle Mountains (in excess of 1000 m). The sparrow's range on Hanford is currently limited, however, to elevations below 500 m as wildfire in recent years removed much of the big sagebrush (*Artemisia tridentata / Pseudoroegneria* [=*Agroppyron*] *spicata*) above this level. Although spring comes early to the lower elevations of the Hanford Site, this area is the hottest, driest location in the Columbia Basin (Rickard and Schuler 1988).

Knowledge of nesting parameters, such as clutch size or nesting success, is important in understanding the ecology and evolution of birds (Rotenberry and Wiens (1989). Several authors have studied this species, including Rotenberry and Wiens (1989); Rich (1980b); Reynolds (1981); Peterson and Best (1985); and Keany and others (1996), but little detail is known about sage sparrows nesting at low elevations. Findings from research conducted at primarily higher elevations with cooler climates suggest that geographically distinct breeding populations have similar nesting parameters but may differ in some aspects of their breeding behavior (Martin and Carlson 1998). Differences in reproductive variables or behavioral characteristics may be especially apparent in populations that have adapted to specific habitat characteristics or unusual climatic conditions.

Predation is the primary cause of nesting mortality for many bird species (Nice 1957). Within large tracts of contiguous sagebrush habitat, in which nest abandonment rates are low and parasitism by cowbirds is minimal (Martin and Carlson 1998), predation can play a major role in determining the reproductive success of sage sparrows. On Hanford, snakes likely represent the primary predator of sage sparrow nests (Rotenberry and Wiens 1989) and may therefore play a key role in determining reproductive success.

Nest predation can be a strong agent of selection on bird species (Martin 1987). When nest predation differs between areas and / or habitats, it can influence the life-history traits of bird species (Martin 1988). For example, nesting strategies that reduce the probability of predation by one species may differ considerably from those that



- Saddle Mountain (SM)
- Gate 118
- Army Loop (AL)
- Gable Mountain (GM)
- Highway 24 (Hwy. 24)
- Yakima Barricade (YB)

Figure 1. Location of the U.S. Department of Energy Hanford Site and study site locations.

minimize the probability of predation by another species (Martin 1987). Given that the geographic distribution of predators may differ, birds nesting in different areas may demonstrate different nesting strategies. The climate of the lower elevations of the Hanford Site provides a relatively long breeding season over which temperatures increase substantially from February through summer. Sage sparrows nesting on Hanford may have adapted behaviors that enable them to nest over a wide range in temperature. Birds that use these behaviors may be able to extend their breeding season into periods when the activity of some predators are reduced (for example, snake dormancy periods) or when other prey species are more available. Thus, the use of certain behaviors can indirectly contribute to reproductive success through a reduction in predation. Herein I examine the chronology of the breeding cycle, nest placement, daily nest survival rates, and predation rates. I then discuss how the strategies used by sage sparrows at Hanford may differ from what has been observed in other locales and why these particular behaviors may have been selected for.

STUDY AREA AND METHODS

The study area was located on the U.S. Department of Energy Hanford Site in southcentral Washington State (Fig.1). The 1450 km^2 Hanford Site was acquired in 1943 by the federal government as a national security area for the production of weapons grade plutonium. Ongoing activities include: nuclear waste management, environmental restoration and associated research and monitoring. Most of the Hanford Site has remained off-limits to the public since 1943.

The Hanford site is located in the Columbia Basin region of southcentral Washington. Climatically, Hanford is characterized by dry, hot summers and cool wet winters with most of the precipitation falling between October and April (Schuler and others 1993).

Shrub-steppe vegetation on the Hanford site falls within the big sagebrush / bluebunch wheatgrass (*Artemisia tridentata* / *Pseudoroegneria* [=*Agroppyron*] *spicata*) vegetation zone (Daubenmire 1970). In an undisturbed state this plant association is characterized by an overstory of mostly big sagebrush, an understory layer of bluebunch wheatgrass, a slightly shorter understory layer of Sandberg's bluegrass (*Poa sandbergii* [included within *Poa secunda*]), and a microbiotic crust consisting of crustose lichens and acrocarpous mosses (Daubenmire 1970). Other shrubs such as rabbitbrush (*Chrysothamnus* species), hopsage (*Grayia spinosa*), bitterbrush (*Purshia tridentata*), and greasewood (*Sarcobatus vermiculatus*) are also present in variable amounts (Franklin and Dyrness 1973). Vegetation within this broad zone varies according to edaphic conditions (soil related), elevation, and slope (Daubenmire 1970).

Although much of the region was historically dominated by bluebunch wheatgrass, habitats on the Hanford Site below 275 m in elevation are nearly devoid of this species (Cline and others 1977). Vegetation at low elevations is frequently characteristic of the big sagebrush / Sandberg's bluegrass potential plant community type (Hall 1998). This community type seems to be limited to areas with fine textured soils (silt loams) or those soil types that contain a mixture of silt loams and sand. Big sagebrush, the dominant overstory shrub in these communities, often grows taller here then that typically found at higher elevations (William Rickard, Pacific Northwest National Laboratory, Richland, WA, pers. comm.). The preponderance of taller shrubs at lower elevations is likely the result of sandy soils that facilitate deep water percolation to the root zone and reduced water competition from shallow-rooted plants that are commonly found on heavier soils (William Rickard, Pacific Northwest National Laboratory, Richland, WA, pers. comm.).

Study Site Selection and Establishment

I selected study sites that could be used for evaluating the reproductive ecology of the sage sparrow (this study) and for another study that examined the relationship between shrub-steppe habitat characteristics and sage sparrow reproductive success and territory size (Chapter 2). Because many environmental variables could potentially confound the later (habitat) study, I selected study sites that would create homogeneity between treatments. For example, all study sites were located below 300 m. At these elevations sage sparrows are the dominant nesting passerine and have little interspecific competition from Brewer's sparrows (*Spizella breweri*) or sage thrashers

(*Oreoscoptes montanus*) (Vander Haegen and others 2000). Although some of Hanford's soil types at these elevations are sandy, I selected study sites containing soils that were at least partially composed of silt loam. Understory vegetation found in these habitats are characterized by having a preponderance of Sandberg's bluegrass, or if disturbed, cheatgrass. I randomly selected sites that occurred along a continuum of cheatgrass cover values. Study sites were located in relatively unfragmented stands of big sagebrush with > 20% canopy cover.

For each study site I randomly selected a starting point within the big sagebrush stand. Two hundred m from the starting point, and on a bearing that ran with the longest dimension of the shrub stand, I centered a 250 x 250 m (6.2 ha) plot. I established a total of six study sites throughout Hanford Site (Fig. 1).

Selection of Breeding Birds

I followed selected male sage sparrows and, in some cases their mates, for their entire reproductive cycles or until birds had ceased territorial defense and could no longer be tracked. In 1996 this period extended from early April to the first week in July. During 1997 the field season extended from mid-March until mid-July. When fewer than 4 territories overlapped with the plot boundaries I also observed males whose territories adjoined the plot. Thus, I made observations on a minimum of 4 male sage sparrow territories at each study site. In all I monitored 30 territories in 1996 and 31 in 1997.

Any singing male that I consistently observed with another sage sparrow I considered to be paired. This included males who were initially unpaired, but who

eventually succeeded in finding a mate even though young may have not been produced. If more than one male / pair occupied a territory during the course of a nesting season, I selected the male / pair who defended the territory for the longest period of time.

Territory Delineation

Territory mapping was conducted to aid in the location of nests and for another study that related territory size to habitat characteristics. I used a combination of the flush technique described by (Wiens 1969) and subsequent behavioral observations. I marked all individual song perches with colored flagging that was unique to each territory. To identify song perch location I used a Magellan hand held global positioning system (GPS) that recorded universal transverse mercator (UTM) coordinates. All coordinates were later processed to compensate for selective-availability error. This provided a position accurate to approximately 3 m. A minimum of 15 points, but usually many more, were used to delineate the territory perimeter.

Determining Reproductive Status

Twice each week for at least 30 minutes I followed territorial males and their mates (if located). If I was unable to locate a territorial male and / or the associated female during a site visit, I made an extra effort to locate a member of this pair during the next observation period. Sage sparrow behavior often provided clues that helped me gauge an individuals reproductive status. For example, if a female was absent from a territory for several observation periods, but the male was actively singing, I concluded she was likely incubating. If both members of the pair became elusive,

young likely had hatched, and I began looking for evidence of parental food provisioning behavior. These observations facilitated my ability to locate nests and / or determine the success of a particular nesting attempt.

I located nests by following birds to nests sites and through opportunistic sightings, behavioral clues, or systematic searches within the territory. After locating a nest I used a combination of colored flagging, nest site descriptions, and compass bearings to relocate it. I took care to place the nest location flag at least 5 m from the nest site. Because of the abundance of flagging on the study site, I felt it was unlikely that a predator would single out these nest location flags.

I primarily followed males because of their relative ease of visibility. Although tracking females was more difficult I focused on them whenever possible because they returned to nests sites more frequently than did their mates.

Once I located a nest, I ceased observations on the associated pair and routinely examined the nest contents. To minimize disturbance and maximize the number of nests under observation, I limited nest checks to once every 3 to 4 days. When nestlings approached the age of fledging, I made nest checks more frequently. Although less frequent nest checks reduced the sample size available for some analyses (for example, incubation / nestling periods), this information is readily available in the literature and, therefore, did not warrant increased nest visitation rates. Nests used to determine the laying rate were located while the nest was being constructed or during the laying period. For active nests I recorded the number of eggs / nestlings and their approximate age at each nest visit. I defined the incubation period as the days elapsed between the date the last egg of a clutch was laid until the last day eggs were

incubated. Nestling periods were measured from the day the first chick hatched to the day the last chick fledged. I considered nests to contain hatchlings if at least one egg hatched. I determined hatching success by dividing brood size by clutch size. Because few nests were found at the start of nesting, and observed nest mortality is less when nests are observed for a shorter amount of time, I calculated survival rates and nest success using days of exposure as described by Mayfield (1975). Mayfield's method equalizes the disparity in survival rates between nests found early and those found late in the nesting cycle by taking into account the amount of time each nest is under observation.

If I found that a nest was empty near an anticipated fledging date, I searched the surrounding vicinity until I confirmed the presence / absence of fledglings. If a nest could not be located, I also used the presence of fledglings to determine nest fate. Sometimes the behavior of the parent birds aided in the determination of nest fate. For example, observations of skittish adults repeatedly carrying food into the same location was an obvious clue to nestling presence. I defined a successful nesting attempt as one in which the laying stage had been reached. A nest was deemed successful if at least 1 young was fledged.

During 1996 I conducted a limited amount of banding with individually identifiable color leg bands and U.S. Fish and Wildlife Service leg bands. In 1997, I color banded nearly all of the adult sage sparrows on my study plots. Although I was able to define the territories of unbanded birds, the colored leg bands facilitated identification of individuals when more than one bird was present near the periphery of a territory.

Nest Shrub Characterization

I recorded the following measurements of the nest shrub: height, maximum diameter, width perpendicular to the maximum, and shrub vigor (% of shrub with live foliage). I also recorded the number of branches supporting the nest, the diameter of the largest supporting branch, and the nest orientation relative to the mainstem, nest height as measured from its bottom to the ground, and the distance from the nest-rim to the closest point along the top of the shrub. I also recorded the same measurement from nests located off the study plots but did not examine these nests for reproductive data.

Statistical Analysis

I used simple linear regression to test for relationships between variables. In addition I used Welch's approximate t-test (Zar 1996) to test for differences between means found in this study and those means found by other authors. These analyses were conducted using the program Systat version 8.0 (Wilkinson 1998). I tested for differences between daily survival rates of nests using a chi-square analysis and a variance-covariance matrix developed by Hines and Sauer (1989). Measures of variability are reported as standard deviations unless otherwise indicated. All analyses were deemed significant if $P \leq 0.05$. Because each analysis examined a different set of parameters, sample sizes may differ.

I used the Breeding Bird Field protocol established by Martin and others (1997) to establish nest initiation dates. Because this protocol uses previously established incubation / nestling periods to determine nest initiation dates and, because I had a

relatively small sample of complete nests from which to calculate these dates, I used nest chronology data established by others. These included a 4-day laying period, 12-day incubation period, and 8-day nestling period, with the last day of laying counted as the first day of incubation (Matthew Vander Haegen, WA Dept. of Fish and Wildlife, Olympia, WA, pers. comm.). Although widely used to establish starting / ending periods of the nesting cycle, calculation of nest initiation dates from intermittent nest checks are necessarily approximate. To compensate for this lack of precision, I separated nest height data, from nests initiated during the 1st and 2nd halves of each month, into separate periods. I then compared the percentage of elevated nests with average mean daily ambient temperature measured at 30 locations across the Hanford Site. Temperature data were obtained from the web site: http//etd.pnl.gov:2080/HMS/.

RESULTS

Breeding Season Chronology

Sage sparrows arrived on study sites by late February but did not begin establishing territories until early March. Most territory boundaries were clearly defined by late March; however, in two cases males did not begin defending territories until late April. Territorial defense generally continued through June but differed in duration between individual males. By early July the amount of vocalizing had drastically declined and adults aggregated in small flocks close to their original territories. It was nearly impossible to track birds after this time, as singing was sporadic and territory defense was reduced substantially.

Pair Bond Establishment and Maintenance

The number of territories, pairs, and lone males I observed on study sites differed between years (Table 1) and, in a small number of cases, within the course of a nesting season. Mated pairs occupied 90% (1996) and 80% (1997) of territories with unpaired or lone males defending the remaining portion throughout the breeding season. Two males, that were initially unpaired, later secured mates, but only 1 male successfully produced young.

Individual pairs seemed to be at least seasonally monogamous, with the exception of 1 male who changed partners during the middle of the breeding season. His 1st mate, who disappeared for the 2nd half of the nesting season, was later observed in a flock of sage sparrows not far from their original territory. I do not know if she reproduced with another male. The only other mate changes observed took place near

the close of the nesting season. In 2 cases previously paired females became associated with males from adjoining territories. At least 1 male, banded in 1996, returned to the same general locale with a different female in 1997. This suggests that pair bonds may only be seasonal.

Infrequently, I observed sage sparrow pairs / unpaired males abandon their territories during the course of a single breeding season. In one example a breeding pair abandoned it's territory following continued aggression from a late arriving unpaired male. In another example, an unpaired male departed his small territory after the surrounding birds repeatedly challenged him. In both cases departing birds had been present on their territories for at least 1 month and the remaining occupants defended their new, or expanded territories, for the remainder of the breeding season. The loss of females elicited different responses from different males. For example, when one female died early in the breeding season, her mate ceased all defense and disappeared but, when another female died near the end of the season, the male remained and continued to defend his territory. In another case the female died (or abandoned) while young were in the nest. Her mate continued to brood and feed nestlings until the nest was depredated.

Nesting Parameters

I located a total of 75 nests (26 in 1996 and 49 in 1997) during the course of this study. During the 1996 and 1997 breeding seasons individual sage sparrow pairs nested up to 4 times with 3 pairs (8 %) nesting a single time, 10 pairs (26%) nesting twice, 23 pairs (59%) making 3 attempts, and only 2 pairs (5%) nesting 4 times. The

only conditions under which a pair did not renest was when a member of the pair abandoned / died, or when an unpaired male did not secure a mate until relatively late in the breeding season. The mean number of repeated nesting attempts per pair, when all attempts were known, was 2.5 ± 0.74 (range 1 to 4; $n = 15$) in 1996 and 2.7± 0.69 (range 1 to 4; $n = 23$) in 1997.

Nest initiation dates for both years of the study ranged from 10 March to 26 June. The latest date that young successfully fledged from a nest was 18 July. Except for nests that were started in early March, I found little synchronization of nest initiation dates (Table 2). Initiation dates for later nests seemed to depend on the success of previous nests. For example, pairs that successfully fledged young delayed initiation of of fledglings was used to document a nesting attempt the date of nest initiation was not

TABLE 1. Number of sage sparrow territories, pairs, and unpaired males monitored during 1996 and 1997.

Study Site	No. Territories		No. Pairs		No. Unpaired Males	
	1996	1997	1996	1997	1996	1997
Army Loop	5	4	5	4	0	0
Gate 118	5	5	4	5	1	0
Highway 24	4	4	3	2	1	2
Gable Mt.	6	5	5	5	1	0
Saddle Mt.	5	7	5	6	0	1
Yakima Barricade	5	6	5	3	0	3
Total	30	31	27	25	3	6

known. Because Table 2 excludes nests without known initiation dates, a greater number of nesting attempts is possible in later versus earlier nesting attempts. the next nesting attempt compared with pairs whose nests had failed. If the presence

I determined clutch sizes from a total of 53 nests. The mean clutch size based on the pooled data from both years was 3.4 ± 0.77 SD (range 2 to 5). Clutch sizes were similar in both years of the study (Table 3). These figures might slightly underestimate mean clutch size as nests could have been partially depredated before I located them. The large majority of nests contained either 3 (35%) or 4 (49%) eggs, whereas relatively few contained 2 (13%) or 5 (4%) eggs and none contained 1 egg. Clutch size differed between breeding attempts. First attempts averaged 3.1 ± 0.73 (*n* = 14) eggs per nest, whereas clutch sizes for second attempts were slightly larger (3.7 ± 0.70 [*n* = 22]). Mean clutch sizes declined in the 3rd (3.2 ± 0.80 SD) [*n* = 14]) and 4th (3.0 ± 0.0 [*n* = 1]) attempts.

TABLE 2. Percentage of nests (number of nests) initiated by month and by nest attempt number for 39 sage sparrow pairs during 1996 and 1997.

Nest Attempt No. (n)	March	April	May	June
1 (24)	63 (15)	33 (8)	4 (1)	0 (0)
2 (27)	0 (0)	26 (7)	63 (17)	11 (3)
3 (20)	0 (0)	5 (1)	70 (14)	25 (5)
4 (2)	0 (0)	0 (0)	0 (0)	100 (2)
Mean % [a]	20 (15)	22 (16)	44 (32)	14 (10)

[a] mean percentage is the percentage of all nest attempts (1st, 2nd, 3rd and 4th) initiated by month.

I found incubation and nestling periods to be similar during 1996 and 1997 (Table 3). They did differ, however, both between pairs and between nest attempts by individual pairs; thus, a range rather than a mean is given in Table 3. The egg laying rate was 1 per day ($n = 4$). Although the number of nests producing at least one hatchling was higher in 1997 than in 1996, the number of hatchlings per nest was slightly lower (Table 3).

TABLE 3. Sage sparrow nesting parameters during 1996 and 1997.

Nesting Parameter	1996	1997	1996 & 1997
Clutch Size $\bar{x} \pm$ SD (n); range	3.6 ± 0.93 (14); 2–5	3.4 ± 0.67 (39); 2–4	3.4 ± 0.77 (53); 2–5
Incubation Period in days (n)	11–13 (4)	11–14 (8)	11–14 (12)
Hatching Success[1]	76 (11)	84 (22)	81 (33)
Hatchlings per nest $\bar{x} \pm$ SD (n); range	3.0 ± 1.00 (19);1–5	2.9 ± 0.72 (28); 2–4	3.0 ± 0.83 (47);1–5
Nestling Period in days (n)	8–11 (4)	8–11 (7)	8–11 (11)

[1] percentage of nests containing at least 1 hatchling.

Nest Parasitism, Abandonment, and Predation

I observed little parasitism by brown-headed cowbirds (0% in 1996 and 6% in 1997) of active sage sparrow nests in my study area (Table 4). Only 1 of the 4 parasitized active nests I observed successfully fledged a single cowbird. Nests were not usually checked following depredation or departure of young; however, on 2

occasions cowbirds did lay eggs in nests that had been previously depredated. Few nests (2 during each field season) were abandoned for undetermined reasons.

I observed both full and partial predation of sage sparrow nests. Although birds would continue to brood following partial predation of nestlings, 1 partially depredated nest that contained eggs was abandoned. Nest predation rate differed by 17% between 1996 and 1997 (Table 4). The percentage of depredated nests also differed between months with 19% of the nest predation occurring during March, 50% in April, 56% in May, and 25% in June. Nearly all nest predation occurred unobserved; however, on 2 occasions I found gopher snakes (*Pituophis melanoleucus*) coiled within the cup of previously active nests. In both cases parents harassed the intruder, suggesting that the nests had been depredated recently. Biologists working on a companion study during the same time period also found several sage sparrow nests that contained gopher snakes (Matthew Vander Haegen, Washington Department of Fish and Wildlife, Olympia, WA, pers. comm). The only example of predation on an adult sage sparrow I documented was a dead, banded adult female. I found her lying beneath her depredated nest and appearing to have been partially ingested, then egested by a snake.

Nest Success and Daily Survival Rates

The majority of pairs had at least 1 (49%) or 2 (36%) successful nests. Few pairs were entirely unsuccessful (13%) or had 3 successful nests (2%). The percentage of successful nests declined between 1996 and 1997, as did the probability of nest success (Table 4). The daily survival rate of nests did not differ significantly

between years ($X^2 = 1.16$, $P = 0.28$, $df = 1$). A difference among nesting attempts was evident when I pooled the data across years and compared the daily survival rates of individual nesting attempts. I found a significant difference among survival rates for the 1st (0.98) 2nd (0.93), and 3rd (0.93) nesting attempts ($X^2 = 7.7$, $P = 0.02$, $df = 2$). A test to determine which survival rates contributed the most to this difference revealed a significant difference between the 1st and each of the later 2 attempts (Hines and Sauer 1989).

TABLE 4. Nest fate and success rates during 1996 and 1997.

Nesting Parameter	1996 n = 26	1997 n = 48	1996 & 1997 n = 74
% Abandoned (no.)	8 (2)	4 (2)	5 (4)
% Predated (no.)	31 (8)	48 (23)	42 (31)
% Parasitized (no.)	0 (0)	6 (3)	4 (3)
% Unknown Fate (no.)	8 (2)	0 (0)	5 (2)
% Successful Nests (no.)	54 (14)	42 (20)	46 (34)
Probability of Success[1]	0.34	0.20	0.24
Daily Survival Rates[1] ± SE	0.96 ± 0.013	0.94 ± 0.011	0.95 ± 0.009

[1] Mayfield (1975)

Nest Placement

Sage sparrows chose big sagebrush, either live or dead, almost exclusively for nesting cover. Only one out of 75 nests was located in another shrub species (gray rabbitbrush [*Chrysothamnus nauseosus*]). Nests were constructed either on the ground ($n = 43$) or within the shrub canopy ($n = 32$).

Sage sparrows oriented their nests in many directions relative to the mainstem of the nest shrub; however, an easterly orientation occurred most frequently, whereas a westerly orientation seemed to be avoided (Fig. 2). Adults placed nests within individual shrubs that had little overlap with surrounding shrubs.

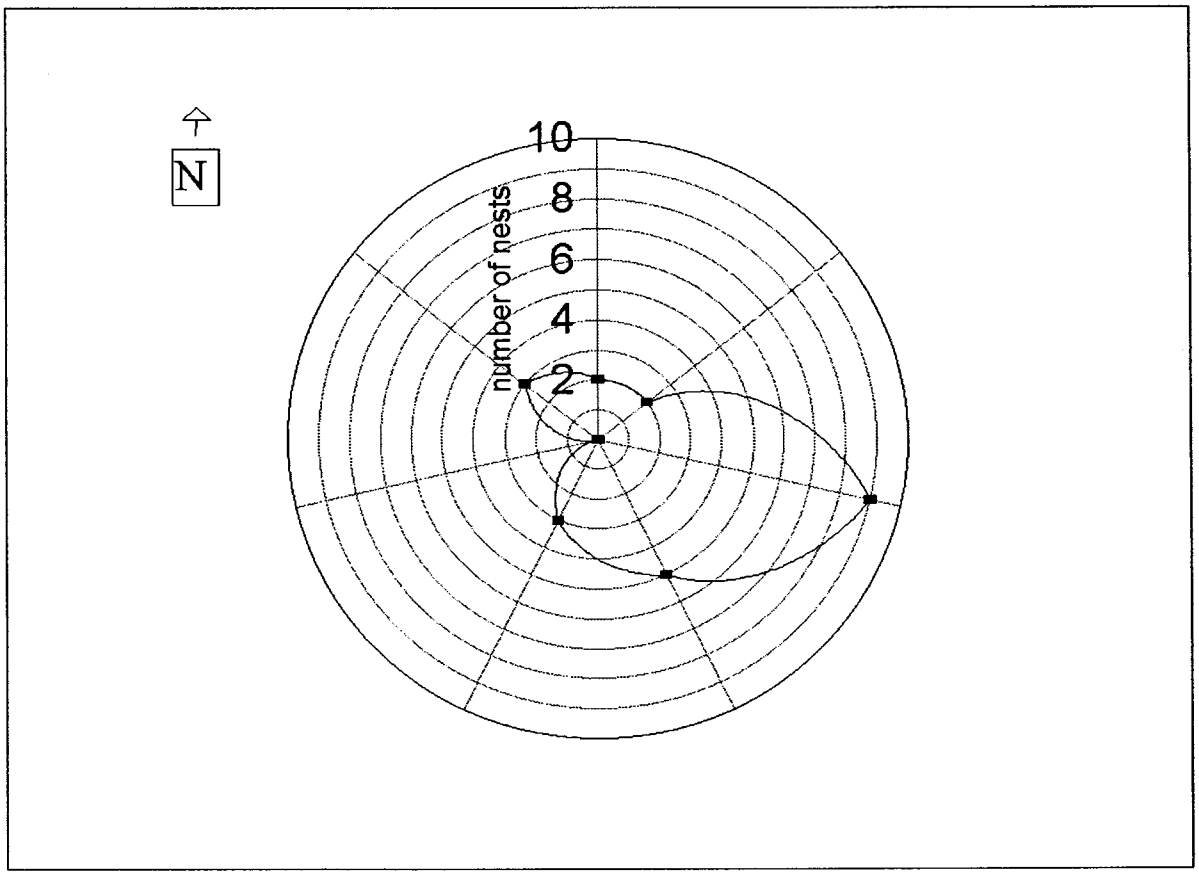


Figure 2. Orientation of sage sparrow nests (elevated nests only) located on the Hanford Site during 1996 and 1997. Each square signifies the number of nests facing a particular direction.

A total of 70 shrubs that contained nests or shrubs / logs that covered nests, were measured during the course of this study. Shrubs that contained nests within the canopy were taller ($\bar{x}$ = 101.6 ± 31.07 cm) than those standing or down dead shrubs that had nests placed beneath them ($\bar{x}$ = 83.5 ± 36.42 cm). Nests were supported by a mean of 3.3 ± 0.70 branches, with the diameter of the largest supporting branch averaging 2.6 ± 1.13 cm.

In both years of the study sage sparrows placed the majority of their nests on the ground (1996: 54% [n = 14]; 1997: 59% [n = 29]). Ground nests found early in the nesting season were placed either underneath big sagebrush or, quite commonly, under large pieces of downed and dead big sagebrush. As the breeding season progressed, nest placement frequently occurred below, or within the canopy of live, big sagebrush. As a result, the vigor of shrubs with nests was less during the first 2 months (March and April) of the nesting season than during the subsequent 2 months (May and June). This trend occurred during both years (Table 5).

This trend toward use of shrubs with increased vigor often occurred in conjunction with a movement of nests from the ground into the shrub canopy. The percentage of nests that were elevated within the shrub canopy increased over the course of the nesting season during both years of the study (Fig. 3). Sage sparrows placed 100% of nests initiated before 15 April (n = 19) on the ground but by June had elevated nearly all of their nests 89% (n = 8) in the shrub canopy. During this time (March through June) the average daily mean semi-monthly temperature rose over 20 °F, ranging from the mid 40's to nearly 70 °F (Fig. 3).

TABLE 5. Sage sparrow nest shrub vigor (mean of ranked catagories) measured during 1996 and 1997. Shrub vigor (categorized percentage of shrub with live foliage) = 1: 0 to 25%, 2: 26 to 50%, 3: 51 to 75%, 4: 76 to 100%.

Month	1996	1997
March / April	1.3	1.6
May / June	3.8	2.5

Once sage sparrows elevated their nests from the ground into the shrub canopy, a variety of factors seemed to show complicated relationships to characteristics of the nest shrub. For example, the mean distance from the nest to the ground at each study site stayed near or below the vertical center of the shrub (Table 6). In addition, the amount of variance in nest height explained by changes in shrub height was low (r^2 = 0.24, P = 0.009, n = 28). Although birds did not apparently raise the height of their nests as a function of nesting in taller shrubs, they also did not demonstrate a strong tendency to place nests at a constant height above the ground (Table 6). A stronger relationship between shrub height and the distance between the nest and the top of the shrub (r^2 = 0.59, P < 0.001, n = 28); however, suggested that this later measure of nest placement was to some degree dependent on shrub height. Apparently birds increased the amount of shrub canopy above their nests as shrub height increased but did so independent of maintaining a constant nest height. Sage sparrows nesting in the shrub canopy placed their nests on branched portions of the mainstem or, more frequently, between the mainstem and the shrub periphery (Table 6).

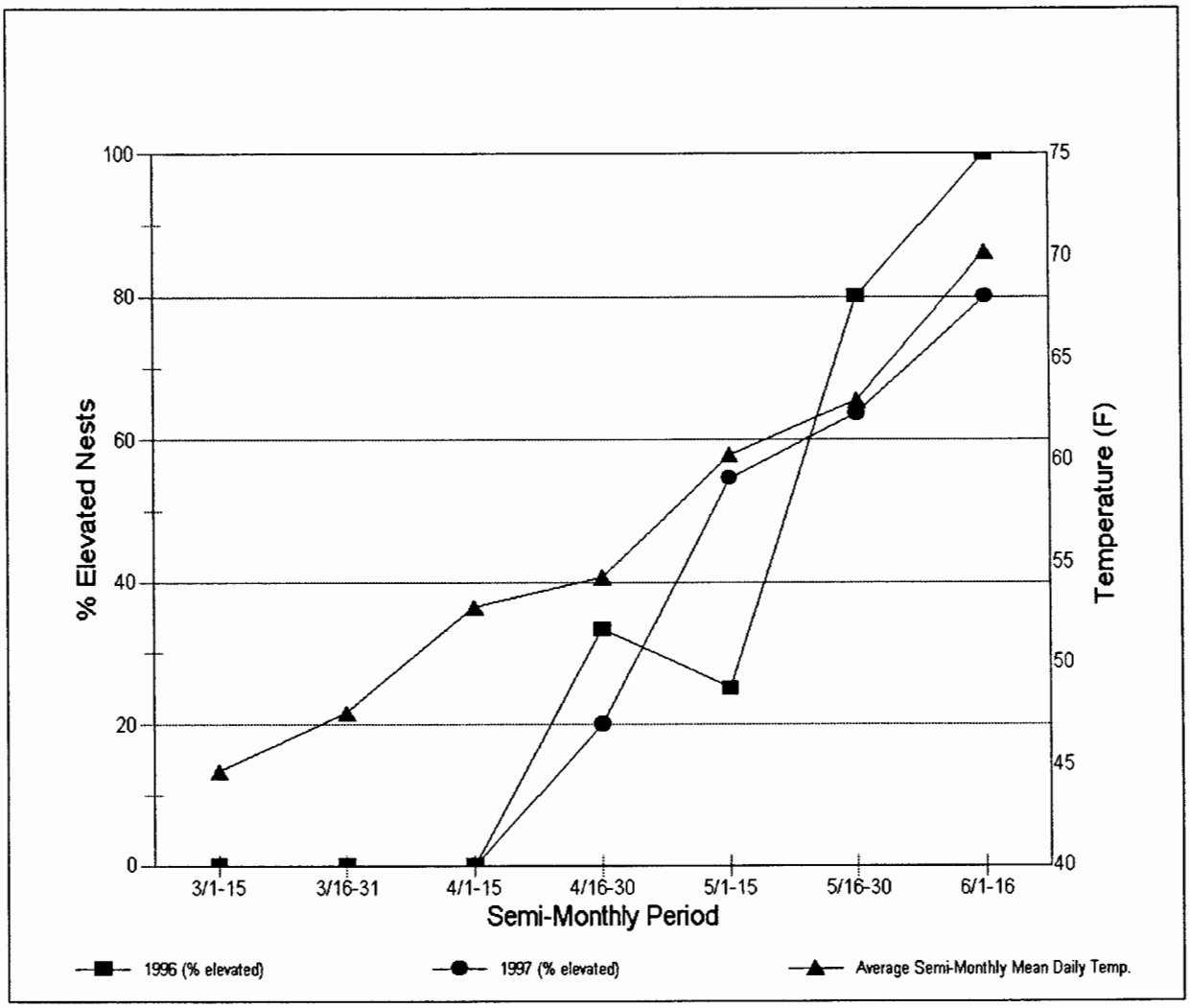


FIGURE 3. Percentage of sage sparrow nests placed in the shrub canopy during semi-monthly intervals during 1996 and 1997 and average semi-monthly mean daily temperature. Sample sizes given as semi-monthly period: year = elevated/total nests: 3/1-15: 1996 = no data, 1997 = 0/3; 3/16-31:1996 = 0/3, 1997 = 0/8; 4/1-15: 1996 = 0/2, 1997 = 0/3; 4/16-30: 1996 = 2/6, 1997 = 1/5; 5/1-15: 1996 = 1/4, 1997 = 6/11; 5/16-31: 1996 = 4/5,1997 = 7/11; 6/1-15: 1996 = 3/3, 1997 = 4/5.

Table 6. Sage sparrow nest placement parameters for nests placed within the shrub canopy by study site during 1996 and 1997.

Variable	Study Site[a]						
	GM n = 4	SM n = 10	YB n = 6	AL n = 4	24 n = 2	118 n = 2	Overall Mean[b] n = 6
Mean nest shrub height (cm) ± SD	101.8 ± 27.55	82.6 ± 31.81	103.3 ± 21.78	142.0 ±12.36	117.5 ±17.68	95.0 ± 28.28	101.6 ± 31.07
Mean nest height (cm) ± SD	56.3 ± 10.31	30.1 ± 10.25	42.8 ± 20.19	46.8 ± 24.27	47.5 ± 10.61	52.5 ± 24.75	41.8 ± 17.63
Mean distance from nest to shrub perimeter (cm) ± SD	17.3 ± 6.08	25.9 ± 12.22	31.2 ± 32.55	39.5 ± 14.29	27.5 ± 3.54	57.5 ± 81.32	30.1 ± 24.87
Mean distance from nest to mainstem (cm) ± SD	25.0 ±19.58	10.0 ± 18.86	15.7 ± 12.11	37.5 ± 26.30	35.0 ± 35.36	47.5 ± 53.03	21.8 ± 23.99
Mean distance from nest to top of shrub (cm) ± SD	41.0 ±18.00	47.0 ± 23.22	48.5 ± 17.83	73.8 ± 13.15	52.5 ± 17.68	32.5 ± 10.61	49.6 ± 20.78
Relative nest height %[c]	55	36	41	33	40	55	41

[a] Study Sites: GM = Gable Mountain; SM = Saddle Mountain; YB = Yakima Barricade; AL = Army Loop; 24 = Highway 24; 118 = Gate 118
[b] Mean ± SE
[c] mean nest height/mean nest shrub height

DISCUSSION

My study of sage sparrow breeding ecology for birds nesting on the Hanford Site during 1996 and 1997 yielded results similar in many respects to those found for sage sparrows nesting elsewhere. As is typical with most widely distributed passerines, however, some differences between breeding populations seem evident.

Sage sparrows arrived on Hanford by early February, about one month earlier then the date reported by Rotenberry and Wiens (1991). Differences in arrival dates at these locations may be related to elevation rather than latitude, as study sites on Hanford are markedly lower in elevation ($\bar{x}$ = 200 m) but higher in latitude (46°25') than those reported by Rotenberry and Wiens (1991) for Cabin Lake, Oregon (1360 m, 43°30'; respectively).

Breeding pairs occupied most territories; however, 5 out of 6 study sites contained at least 1 unpaired male. The percentage of territories occupied by unpaired males during this study (15%) was less than the 47% reported by Reynolds (1981), but more than the 0% reported by Wiens and others (1985). The reason for the differences in the number of unpaired males present at different locations is unclear, but some authors (Reynolds 1981), have suggested a possible relationship between pairing status and habitat quality. Clearly, the number of unpaired males present at any given time can also be related to female mortality as at least 2 of the males present on my study sites became unpaired (1 positively due to the death of his mate), during the course of a single season. Similar to Rich (1980a) the majority of sage sparrows seemed to be already paired upon arrival at the study site. Males are able, however, to attract mates at a later date as 2 males on my study sites became paired after most

birds had already initiated their 2nd nests. Nearly all males seemed to be at least seasonally monogamous; however, 1 male changed partners and bred with a new female in the middle of the nesting season. Toward the end of the 1997 nesting season, 2 previously paired females became associated with new males from adjoining territories. In both cases the males who had originally paired with these females had departed, suggesting that sage sparrows may only be seasonal monogamous .

Incubation and nestling periods closely corresponded with data summarized by Martin and Carlson (1998). Clutch sizes found during this study ($\bar{x}$ = 3.4 ± 0.77, n = 53); however, differed significantly (t = 4.13, P < 0.001, df = 36) from those recorded during 1981 in Idaho by Reynolds ($\bar{x}$ = 2.8 ± 0.4 SD, n = 13) and those described by Rotenberry and Wiens (1989; $\bar{x}$ = 3.06 ± 0.06 SE, n = 53), for Washington, Oregon, and Nevada (t = 3.03, P < 0.005, df = 82). Seventy percent of the nests observed by Rotenberry and Wiens (1989) contained 3 eggs, whereas nearly half (49%) of the nests located during this study contained 4 eggs. The range in the number of eggs per clutch for sage sparrows (2 to 5) reported here was greater than what previously has been reported for the *nevadensis* subspecies (Martin and Carlson 1998). Although the reasons for the relatively greater clutch size found for birds nesting on Hanford is not clear, Lack (1968) suggests that clutch size may be related to food availability (Lack 1968). The fact that clutch size was greatest during the 2nd nesting attempt, when insects appeared to be more abundant, agrees with Lack's hypothesis.

Similar to the observation of M. Misenhalter (as cited in Martin and Carlson 1998) most of Hanford's sage sparrows attempted to nest more than once per year. Although Misenhalter does not specify the number of nesting attempts, he suggests

that most individuals *(nevadensis* subspecies*)* are able to raise 2, or occasionally 3 broods per year. The majority of pairs I observed, however, were only able to produce 1 successful nest (= 1 brood) but usually made 3 and occasionally 4 nesting attempts per year.

Similar to the findings from this subspecies, Hanford's sage sparrows preferentially chose big sagebrush as their nest shrub. On my study sites, the mean nest shrub height (101.6 ± 31.08 cm, $n = 28$) was significantly higher ($t = 5.48$, $P < 0.001$, $df = 33$) than those found by Rich (1980b)(67.1 ± 8.4 cm, $n = 14$) or those reported by John Rotenberry (mean of 68.7 ± 21.7 cm, $n = 92$ [$t = 5.23$, $P < 0.001$, $df = 35$]) (pers. comm., as cited in Martin and Carlson 1998). The use of taller nest shrubs by Hanford's sage sparrows may reflect availability. Much of the big sagebrush located on the lower elevations of Hanford is taller than what is commonly observed elsewhere in the interior Columbia Basin (William Rickard, Pacific Northwest National Laboratory, Richland, WA, pers. comm.). In addition to using taller nest shrubs, Hanford sage sparrows placed nests higher within the shrub canopy than what previously has been reported. On Hanford mean nest height for elevated nests (41.8 ± 17.6 cm, $n = 32$) was significantly greater ($t = 2.45$, $P < 0.02$, $df = 34$) than that (34.0 ± 8.0 SD, $n = 135$) reported by Peterson and Best 1985.

Nests initiated prior to 15 April were exclusively placed on the ground but, as the breeding season progressed, increasingly greater numbers of nests were elevated within the shrub canopy (Fig. 3). By June nearly all (89%) nests were placed in the canopy. Other studies (Winter and Best 1985) described similar seasonal shifts in nest placement by sage sparrows; however, they compared only the height of nests initiated

early (before 1 June) and late (after 1 June). Rich (1978) noted a similar seasonal shift for sage thrashers and suggested that early season nests placed on the ground may benefit from warmer temperatures at ground level and that later nests placed in the sagebrush canopy, when temperatures are warmer, may benefit from increased air circulation and convective heat loss. The substantial increase and relatively high ambient temperatures found on Hanford during the course of a typical season, suggest that sage sparrows may need to use some type of behavioral thermoregulation to continue nesting when temperatures rise. Although this study was not specifically designed to test the effects of temperature on nest height, it seems likely that sage sparrows elevate their nests in response to increasing temperature. Thus, what is likely a comparatively long breeding season (at the lower elevation of the Hanford Site) may be further extended by appropriate nest placement.

Once nests are moved up into the shrub canopy, other factors related to distance from the nest to the ground or the amount of cover above the nest seem to play a role in nest placement (Rich 1980b; Peterson and Best 1985; Keany and others 1996; this study). Calder (1973) found that the density of vegetation above a nest is of considerable importance in controlling the thermal environment of nesting hummingbirds. Additionally, Reynolds (1981) suggested that to serve a thermoregulatory function the amount of vegetation above the nest may need to reach an optimal value. In this study, although the relationship between nest placement and shrub height are complicated, sage sparrows tended to place their nests near or below the vertical center of the shrub. By placing nests at this level sage sparrows are

ensured of both maintaining air circulation around the nest and receiving shading from an adequate layer of shrub canopy.

Although I observed numerous potential predators of eggs and nestlings including ravens (*Corvus corax*), coyotes (*Canis latrans*), townsends ground squirrels (*Spermophilus townsendi*), and loggerhead shrikes (*Lanius ludovicianus*), gopher snakes seemed to be the most abundant potential predator. As is typical with snake predation, almost all depredated nests were left intact with few signs of disturbance (Best 1974). The lack of disturbance and the presence of gopher snakes in predated nests lead me to conclude that snakes likely were the principal predator on sage sparrow eggs / nestlings on the study area. This conclusion is in agreement with that of Rotenberry and Wiens (1989) who also suggested that gopher snakes are the most common nest predator on their study sites in Washington and Nevada.

To minimize predation, especially by snakes, Hanford's sage sparrows may have adapted a strategy of early nest initiation (that is, prior to snake emergence). This hypothesis is supported by the finding that daily survival rates were significantly higher, and the percent of depredated nests was substantially lower, during March than in April or May. Interestingly, during June, daily survival rates increased and the percentage of depredated nests declined. A reduction in predation rate and a concomitant increase in daily survival rate may have occurred during this time period because fewer and more widely spaced active nests were available to predators.

Although the daily survival rates were highest during the earliest and latest periods of the nesting season, sage sparrows who nest during these periods potentially must endure adverse weather conditions. I suggest that sage sparrows breeding on Hanford

have used behavioral theromoregulation as an effective way to extend their breeding season into periods when climatic conditions are more extreme. By adopting this strategy sage sparrows may decrease the risk of predation and thereby enhance their reproductive success.

SUMMARY

The sage sparrow is a common breeding passerine in unfragmented sagebrush communities of the interior Columbia Basin. Continued loss of breeding habitat prompted Washington Department of Fish and Wildlife to identify the sage sparrow as candidate for threatened or endangered status. The Hanford Site in southcentral Washington provides some of the last unfragmented breeding habitat for the sage sparrow in the ecoregion. Currently most of the breeding habitat on Hanford is located at elevations below 500 m; a portion of this area is now being considered for development.

Life history traits and / or predation pressures may differ between type of habitat or geographic area (Martin 1988; Rotenberry and Wiens 1989). A knowledge of these characteristics on a local geographic level may be needed to effectively manage distinct populations. Sage sparrows breeding on Hanford were similar in many aspects of their reproductive biology to birds that have been studied elsewhere; however, some differences were apparent. For example, sage sparrows seemed to have at least partially compensated for intensive predation pressure by nesting early and renesting (up to 4 times). Sage sparrows are able to nest early and over an extended breeding

season by seemingly using behavioral thermoregulation strategies of nest placement. These strategies include elevating the nest from the ground into the shrub canopy, orientation of the nest within the canopy, and choosing shrubs of the appropriate vigor.

LITERATURE CITED

Best LB. 1974. Blue racers prey on field sparrow nests. Auk 91:168-169.

Best LB. 1978. Field sparrow reproductive success and nesting ecology. Auk 95:9-22.

Calder WA. 1973. Micro habitat selection during nesting of hummingbirds in the Rocky Mountains. Ecology 54:127-134.

Cline JF, Uresk DW, Rickard WH. 1977. Plants and soil of a sagebrush community on the Hanford Reservation. Northwest Science 51:60-70.

Daubenmire R. 1970. Steppe vegetation of Washington. Pullman, WA: Washington Agricultural Experiment Station. Technical Bulletin 62. p 1-131.

[DOE-RL] U.S. Department of Energy. 1996. Draft Hanford Site Biological Resources Management Plan. Richland, WA: US DOE Richland Operations Office, DOE/RL 96-32.

Downs J L, Rickard WH, Brandt CA, Cadwell LL, Cushing EE, Geist DR, Mazaika RM, . Neitzel DA, Rogers LE, Sackschewsky MR, Nugent JJ. 1993. Habitat types on the Hanford Site: wildlife and plant species of concern. PNL-8942. Pacific Northwest Laboratory, Richland, Washington.

ESRI. 1997. Arcinfo verision (7.1.1). Environmental Systems Research Institute. Redlands, California.

Franklin JF,. Dyrness CT. 1973. Natural vegetation of Oregon and Washington. Portland ,OR: USDA Forest Service. General Technical Report PNW-8. p 1-417.

Hall JA, (ed). 1998. Biodiversity of the Hanford Site. 1997 Annual Report. Seattle, WA: The Nature Conservancy. p 1-75.

Hines JE, Sauer JR. 1989. Program CONTRAST - a general program for the analysis of several survival or recovery rate estimates. U.S. Fish and Wildlife Technical Report 24:1-7.

Keany J, Tims J, Rector M, Hollen B. 1996. Sage sparrow and sage thrasher study on the Yakima Training Center and Expansion Area, Yakima, Washington. Fort Lewis, WA: U.S. Army Public Works Division. p 1-63.

Lack D. 1968. Ecological adaptations for breeding in birds. London: Chapman and Hall Ltd. 409 p.

Martin J W, Carlson BA. 1998. Sage Sparrow (*Amphispiza belli*). In: Poole A, Gill F, editors. The Birds of North America, No. 326. Philadelphia, PA: The Birds of North America, Inc. p 1-20.

Martin TE. 1987. Artificial nest experiments: effects of nest appearance and type of predator. Condor 89:925-928.

Martin TE. 1988. Processes organizing open nesting bird assemblages: competition or nest predation? Evolutionary Ecology 2:37-50.

Martin TE, Paine CR, Conway CJ, Hochachka WM, Allen P, Jenkins W. 1997. Breeding Bird Field Protocol. Missoula, MT: Montana Coop. Wildlife Research Unit, University of Montana.

Mayfield HF. 1975. Suggestions for calculating nest success. Wilson Bulletin 87:456-466.

Nice MM. 1957. Nesting success in altricial birds. Auk 74:305-321.

Peterson KL, Best LB. 1985. Nest site selection by sage sparrows. Condor 87: 217-221.

Peterson KL, Best LB. 1986. Diets of nestling sage sparrows and Brewer's sparrows in an Idaho sagebrush community. Journal of Field Ornithology 57:283-294.

Rich TG. 1978. Nest placement in sage thrashers. Wilson Bulletin 90:303.

Rich TG. 1980a. Territorial behavior of the sage sparrow: spatial and random aspects. Wilson Bulletin 92: 425-438.

Rich TG. 1980b. Nest placement in sage thrashers, sage sparrows, and Brewer's sparrows. Wilson Bulletin 92: 362-368.

Rickard WH, Schuler CA. 1988. Descriptions of plant communities at the proposed reference repository location and implications for reclamation of disturbed ground. Richland, WA: US Department of Energy, Pacific Northwest Laboratory, PNL-6496. p 1-21.

Reynolds TD. 1981. Nesting of the sage thrasher, sage sparrow, and Brewer's sparrow in southeastern Idaho. Condor 83: 61-64.

Rotenberry JT, Wiens JA. 1989. Reproductive biology of shrubsteppe passerine birds: geographical and temporal variation in clutch size, brood size, and fledgling success. Condor 91:1-14.

Rotenberry JT, Wiens JA. 1991. Weather and reproductive variation in shrubsteppe sparrows: a hierarchical analysis. Ecology 72:1325-1335.

Schuler CA, Rickard WH, Sargeant GA, 1993. Conservation of habitats for shrub-steppe birds. Environmental Conservation 20:57-64.

Vander Haegen WM, Dobler FC, Pierce DJ. 2000. Shrubsteppe bird response to habitat and landscape variables in eastern Washington, USA. Conservation Biology, In press.

Zar JH. 1996. Biostatistical analysis. Upper Saddle River, NJ: Prentice-Hall. 662 p.
Wiens JA. 1969. An approach to the study of ecological relationships among grassland birds. Ornithological. Monographs 8:1-93.

Wiens JA. 1985. Habitat selection in variable environments: shrubsteppe birds. In: Cody ML, editor. Habitat selection in birds. New York: Academic Press. p 227-251.

Wiens JA, Rotenberry JT, Van Horne B. 1985. Territory size variations in shrubsteppe birds. Auk 102:500-505.

Wiens JA, VanHorne B, Rotenberry JT. 1987. Temporal and spatial variation in the behavior of shrubsteppe birds. Oecologia 73:60-70.

Winter BM, Best LB. 1985. Effects of prescribed burning on placement of Sage Sparrow nests. Condor 87:294-295.

CHAPTER TWO

THE RELATIONSHIP BETWEEN CHEATGRASS (*BROMUS TECTORUM*) COVER AND SAGE SPARROW (*AMPHISPIZA BELLI*) TERRITORY SIZE / REPRODUCTIVE SUCCESS

The once seemingly unending sea of sagebrush that was described by early explorers to the interior Columbia Basin has been drastically altered by habitat conversion, fragmentation, and disturbance. Degradation of the few remaining unfragmented habitats has been accelerated by the invasion of non-native plant species (Knick and Rotenberry 1995; DOE-RL1996; Knick 1999). Cheatgrass (*Bromus tectorum*), the most widely distributed and invasive of these species, is now a component of even the quasi-natural areas within the shrub-steppe ecosystem (Brandt and Rickard 1994).

Within the shrub-steppe communities of Washington, especially the big sagebrush / Sandberg blue grass *(Artemisia tridentata / Poa sandbergii*) zonal association, cheatgrass is a formidable competitor with native flora (Daubenmire 1970). On the Hanford Site in southcentral Washington, cheatgrass growing on abandoned agricultural fields has effectively precluded the regrowth of native vegetation for over 50 years (Brandt and Rickard 1994). Although much is known about the ability of cheatgrass to exclude native plants in oldfields, little is known about the effects of cheatgrass on community composition and structure when it co-occurs with native vegetation within big sagebrush dominated communities. It is likely, however, that cheatgrass successfully competes with native flora when it's present in big sagebrush communities as well as in oldfields (William Rickard, Pacific Northwest National

Laboratory, WA. pers. comm.). If cheatgrass limits the growth, reproduction, and dispersal of native flora, we would expect to find an inverse relationship between cheatgrass cover and the floristic and possibly structural components that typify big-sagebrush ecosystems.

Animals that depend upon big sagebrush communities for much of their life requisites have likely been adversely impacted by the introduction of cheatgrass. Loss of native fauna may occur when cheatgrass increases the intensity and frequency of fire resulting in the loss of sagebrush (Knick 1999). For species such as the sage sparrow (*Amphispiza belli*), whose abundance has been positively related to shrub-steppe habitat components (for example, the ground coverage of sagebrush, bunchgrass, and bare ground) (Larson and Bock 1986; Wiens 1985) the presence of cheatgrass may result in a depletion of those resources required for survival.

For territorial avian species, the majority of life requisites are generally met within the confines of the defended area (Petersen and Best 1987). If the quality of habitat declines, birds may compensate for the subsequent reduction in resources by expanding territory size (Wiens and others 1985). As increased territory size has been found to be inversely correlated with density (Wiens and others 1985), we would potentially expect to find birds nesting in poorer quality habitats to have larger territories and lower densities.

Because many variables, including pairing status, site fidelity, and population levels (Petersen and Best 1987; Wiens and others 1985), potentially confound the relationship between territory size and the density of breeding passerines, caution must be taken when using these variables to predict habitat quality. Inaccurate assessments

of habitat quality could occur if "sinks" (lesser quality habitats in which reproduction is insufficient to balance local mortality) are selected to evaluate habitat-density relationships (Pulliam 1988). Van Horne (1983) proposes that future investigators should be more critical in identifying high quality or critical habitats prior to assessing simple density-habitat quality relationships. Van Horne suggests that an intensive demographic study of a species in a variety of habitats is necessary to study these relationships, but she also concedes that estimates could be greatly improved through attention to the production of juveniles that survive to reproduce. Thus, it might be preferable to define habitat quality as a product of density and reproductive success rather than from density alone. Van Horne's suggestion gains support from the work of Vickery (1992) who found that density alone was a poor measure of habitat quality for 2 out of 3 species of nesting sparrows.

If the assumption that the presence of cheatgrass reduces the "quality" of shrub-steppe habitats is accepted, then one would expect to find a measurable response from a species whose persistence is dependent on these habitats. In this study I first examined the relationship between cheatgrass and certain habitat components of shrub-steppe plant communities. I then attempted to compare the effect of each of these habitat component variables to the territory size and reproductive success of breeding sage sparrows. More specifically, I attempted to answer the following questions:

1) Are there correlations between the coverage of cheatgrass and other habitat variables (both structure and floristics) found within the big sagebrush communities of the Hanford Site?

2) What, if any, is the relationship between the amount of cheatgrass cover and sage sparrow territory size?

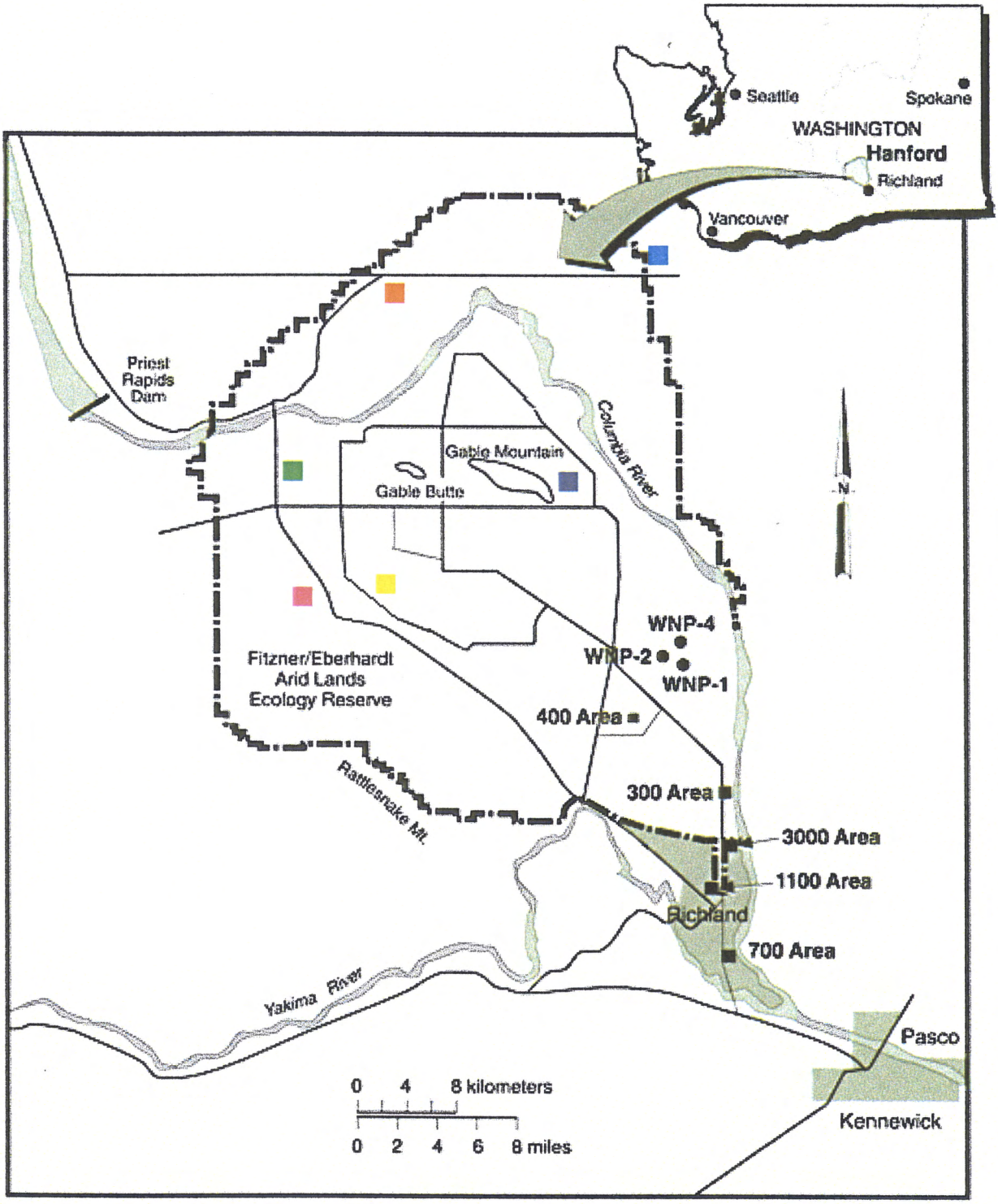
3) Does reproductive success differ between cheatgrass infested habitats and those habitats that typify "native" plant communities?

STUDY AREA AND METHODS

For information on selection of study sites, identification of sage sparrows for observation, territory delineation, determination of reproductive status and more detail on study area description, refer to the *Study Area and Methods* section of Chapter One.

Study Area

The study area was located on the U.S. Department of Energy Hanford Site in southcentral Washington State (Fig.1). In 1943 the federal government acquired the 1450 km^2 Hanford Site for the production of weapons grade plutonium. Current uses include the cleanup of nuclear waste, scientific research, and the preservation of native ecosystems. Most of the Hanford Site has remained off-limits to the public since 1943.



Saddle Mountain (SM)
Gate 118
Army Loop (AL)
Gable Mountain (GM)
Highway 24 (Hwy. 24)
Yakima Barricade (YB)

Figure 1. Location of the U.S. Department of Energy Hanford Site and study site locations.

The climate of Hanford is characterized by cool wet winters and hot dry summers (DOE-RL 1996). In an undisturbed state, these climatic conditions have contributed to a plant community in which sagebrush and perennial bunchgrasses dominate. On Hanford, loamy soil communities occurring above 275 m, are dominated by bluebunch wheatgrass (*Pseudoroegneria* [= *Agropyron] spicata*) Cline and others (1977). Below this elevation, in communities containing a mixture of sand and silt loam soils, Sandberg's bluegrass (*Poa sandbergii* [included within *Poa secunda*]) is the dominant bunchgrass. More than 60% of the ground in these communities is barren or supports a thin curst of algae, mosses, or lichens (Cline and others 1977). Where man-induced disturbances have occurred, shrub-steppe communities contain a greater ground coverage of non-native annual grasses and forbs. The most abundant of these species, cheatgrass, is known to effectively compete with native flora (Brandt and Rickard 1994) and, in some cases, can become the dominant understory species.

Habitat Characterization

I characterized vegetation along a single 100 m transect placed within the boundary of each sage sparrow territory. For the starting point of each transect, I randomly selected a song perch on the territory perimeter. The transect was orientated through the mid-point of the territory and in some cases traversed it almost entirely. Because territory boundaries were not consistent between breeding seasons, I selected a new transect location for each year. I quantified habitat variables within each of 20 microplots (20 X 50 cm), spaced at 5-m intervals along each transect (Daubenmire 1970). I estimated the percent cover, to as low as 1%, for each plant species that

occurred within the microplot. In addition, I also estimated the percent cover of bare ground, which included any microbiotic crust that was present. I then averaged habitat data across all microplots within the territory. For analysis I grouped individual species into larger categories such as: native grass, forbs, other shrub species, or no plants (including bare ground and microbiotic crust).

I determined shrub cover using line-intercept sampling (Phillips 1959) along the same transect used for microplots. For an individual shrub, I recorded species identity, start position on the tape (to the nearest cm), ending position, height (in cm), and maximum and minimum diameter (in cm). I treated individual shrubs that overlapped along the transect and dead material independently. I summed shrub cover by species for each transect and converted the sum to a percentage value.

Statistical Analysis

I quantified habitat variables for each individual territory and pooled these data for analysis at the study site level. Although I originally intended to use the study plot as an experimental unit, the borders of some territories extended a substantial distance outside of the plot boundaries. Heterogeneity of understory vegetation on individual study sites led me to conclude that characterization of habitat components within the plot boundaries would not adequately describe those territories whose borders exceeded the plot boundaries. I chose instead to characterize the vegetation for each territory and then use the pooled data to test for effects at the site-level. For all analyses I set the level of significance at $P \leq 0.05$. If necessary, data were appropriately transformed prior to analysis.

I used the Pearson Product-Moment Correlation to test for a relationship between cheatgrass the following parameters: sage sparrow territory size, reproductive success (number of successful nests per territory), and other habitat variables. I also used correlation analysis to test for relationships between sage sparrow reproductive success and territory size. The strength of individual correlations were judged using criteria established by Fowler and Cohen (1998): very weak (0.00 to 0.19); weak (0.20 to 0.39); modest (0.40 to 0.69); and strong (0.70 to 0.89). Because small sample sizes (n = 6 for the site level analysis) can lead to spurious results (Zar 1996), and larger sample sizes may be required to confirm the statistical significance of weak correlations (Fowler and Cohen 1990), I also conducted correlation analyses at the territory level. These data may not, however, be as rigorous as those conducted on data pooled by study site as territories found within an individual study site may not be independent from one another.

To test for significant differences between means, I used the Student's t-test. When more than 2 means were compared, I used a 1-way analysis of variance (ANOVA). When results from ANOVA's reached signficance, I used the Bonferonni post-hoc test to identify which pair of means differed significantly (Sokal and Rohlf 1998).

RESULTS

Habitat Characteristics

All study sites exceeded the established selection criteria of > 20% sagebrush canopy cover and < 5% cover of other shrub species. Overstory vegetation was generally homogeneous and contained mature big sagebrush that exceeded on average 98 cm in height (Table 1). The only exception was at the Saddle Mountain study site where abundant big sagebrush regeneration resulted in an overall reduction in mean shrub height. Variability in big sagebrush cover on individual study sites can be attributed in part to between year changes in territory boundaries and the consequent relocation of vegetation transects. Between year changes in shrub cover on individual study sites; however, were not significant (Table 1). The standing dead habitat component was composed almost exclusively of dead big sagebrush.

Cheatgrass cover increased between 1996 and 1997 in 5 out of 6 study sites (Table 1). This increase was significant, however, on only the Gable Mountain site ($t = 4.75$, $P = 0.001$, $df = 9$). With the exception of a significant decline in the amount of bare ground ($t = 3.25$, $P = 0.01$, $df = 9$) there were no other significant changes in habitat variables on Gable Mountain. The study sites maintained the same relative ranking in the amount of cheatgrass cover during both years of the study (Fig. 2).

TABLE 1. Habitat characteristics of sage sparrow territories on each of 6 study sites during 1996 and 1997. Figures are based on the average of pooled data from territories for each year.

	Saddle Mountain		Yakima Barricade		Gable Mountain		Gate 118		Army Loop		Highway 24	
Variable	1996 *n* = 5	1997 *n* = 7	1996 *n* = 5	1997 *n* = 6	1996 *n* = 6	1997 *n* = 5	1996 *n* = 5	1997 *n* = 5	1996 *n* = 5	1997 *n* = 4	1996 *n* = 4	1997 *n* = 4
% Cheatgrass cover mean ± SE	0.7 ± 0.46	2.3 ± 0.99	6.1 ± 2.03	9.9 ± 3.70	13.1** ± 2.62	31.1** ± 2.48	33.5 ± 2.66	31.9 ± 2.01	41.7 ± 2.29	51.4 ± 1.32	55.4 ± 7.51	60.8 ± 2.91
% Native grass cover mean ± SE	29.0 ± 1.09	34.5 ± 2.31	16.0 ± 1.85	13.6 ± 2.86	12.3 ± 2.48	12.0 ± 3.20	4.4 ± 1.06	3.0 ± 0.80	1.4 ± 0.25	1.6 ± 0.85	2.0 ± 0.70	1.8 ± 0.95
% Bare ground cover mean ± SE	61.3 ± 2.06	66.5 ± 1.64	61.1 ± 6.88	71.1 ± 4.40	71.4** ± 2.83	56.6** ± 3.76	56.2 ± 4.24	52.6 ± 2.28	49.5 ± 2.21	36.6 ± 3.38	48.5 ± 7.37	37.9 ± 2.50
% Sagebrush cover mean ± SE	43.6 ± 2.97	38.7 ± 4.47	36.0 ± 5.02	29.8 ± 1.03	29.1 ± 4.40	24.7 ± 1.73	30.2 ± 1.87	28.4 ± 3.50	24.0 ± 3.79	26.1 ± 2.31	28.8 ± 2.76	20.9 ± 1.67
% Standing dead cover mean ± SE	1.7 ± 0.43	3.6 ± 0.81	3.6 ± 0.96	2.5 ± 0.91	1.5 ± 0.59	1.8 ± 0.64	1.3 ± 0.39	1.4 ± 0.28	2.1 ± 0.88	3.4 ± 0.35	4.5 ± 1.17	2.3 ± 0.59
% Sagebrush height mean ± SE	54.8 ± 2.63	66.5 ± 3.57	93.1 ± 2.69	100.0 ± 1.51	96.1 ± 1.61	95.9 ± 4.91	103.2 ± 2.70	104.8 ± 3.83	125.0 ± 5.45	126.4 ± 6.26	103.4 ± 7.59	106.9 ± 4.13
% Forb cover mean ± SE	0.2* ± 0.12	2.15* ± 0.99	7.2 ± 1.55	6.7 ± 2.03	4.5 ± 1.03	6.1 ± 0.99	6.9 ± 0.80	7.7 ± 2.55	2.6 ± 0.36	5.5 ± 1.94	1.1 ± 0.39	2.7 ± 0.26

Significant differences between years identified by superscript: * $P < 0.05$; ** $P < 0.01$.

Native grasses, including: Sandberg bluegrass, Indian rice grass (*Oryzopsis hymenoides*), bottlebrush squirreltail (*Sitanion hystrix*), needle and thread (*Stipa comata*), and *Festuca* spp., were present on the study sites (Appendix 1). Sandberg's bluegrass occurred on all sites and accounted for 82% of the total native grass cover. *Festuca* spp., were present on every study site, and constituted approximately 15% of the total native grass coverage. Bottlebrush squirreltail occurred on 4 out of 6 study sites but contributed only 2% to the total coverage of native grass. Small amounts of Indian rice and needle and thread grass (< 1% combined) were present on 2 of the study sites. Although the amount of native grass present differed between study sites, individually each study site contained a relatively similar percentage of native grasses during both years of the study (Table 1).

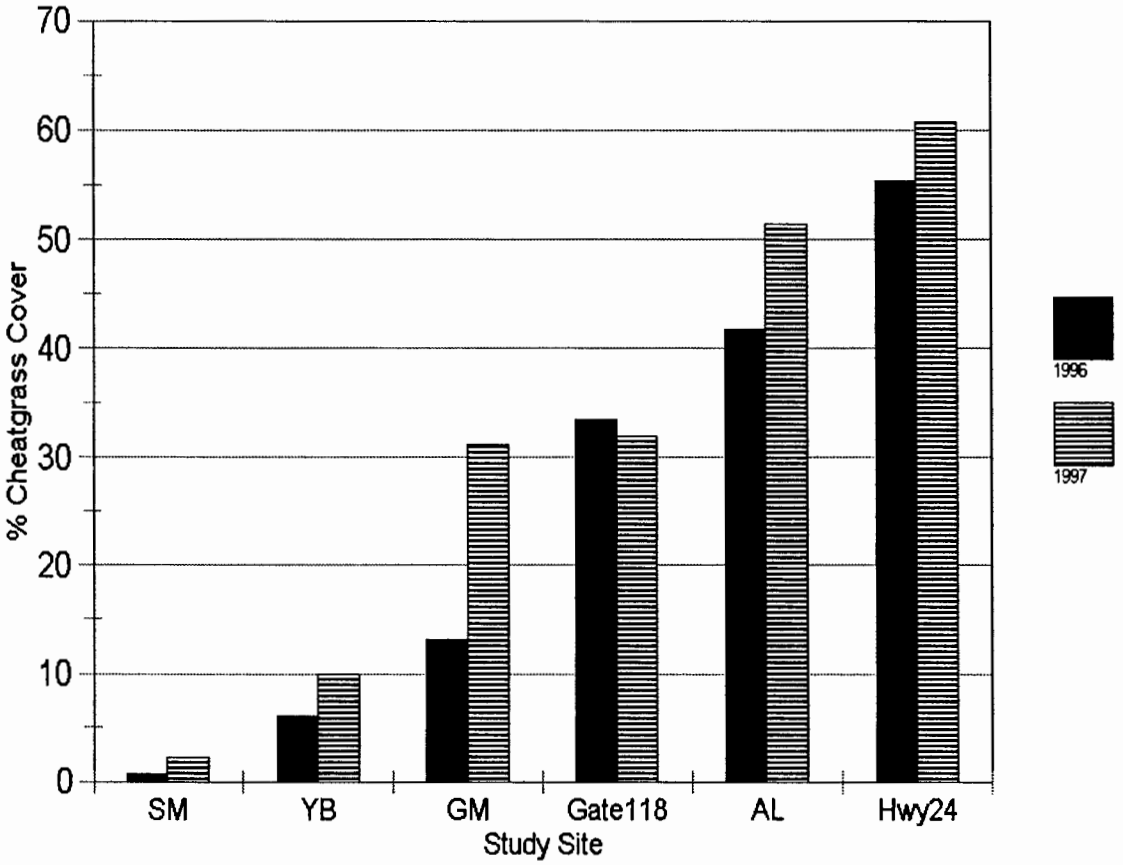


Figure 2. Yearly percentages of cheatgrass cover within sage sparrow territories on each of 6 study sites. Values represent the average of pooled data from territories on each site. Legend: SM = Saddle Mountain, YB = Yakima Barricade, GM = Gable Mountain, Gate 118 = Gate 118, AL = Army Loop, Hwy 24 = Highway 24.

Forb diversity on the study sites was high (Appendix 2), but percent cover was low (Table 1). Forb cover did not differ significantly between years on any study plot with the exception of Saddle Mountain (Table 1). Forb cover may well have constituted

a greater proportion of the total plant, cover but I was unable to conduct vegetation sampling until after the peak bloom.

Visual inspection of habitat data (for example, see Fig. 3) suggested possible correlations existed between cheatgrass cover and cover estimates of at least some of the other habitat variables. To test these potential correlations, I analyzed the relationship of habitat variables using site and territory levels.

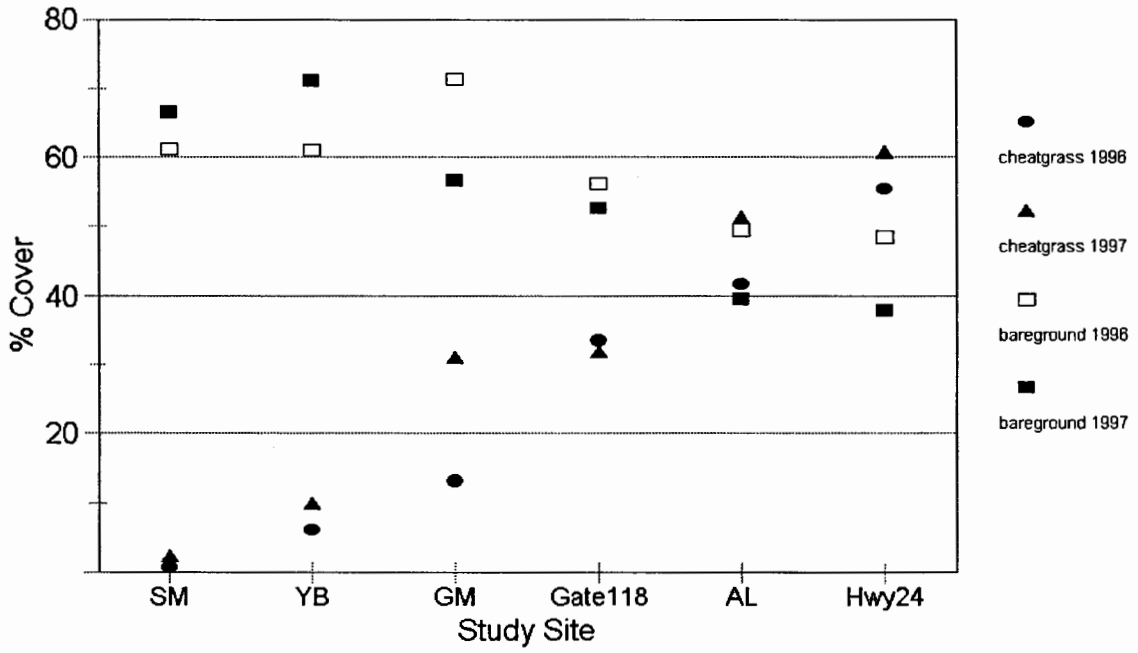


Figure 3. Relationship between the coverage of cheatgrass and bare ground during 1996 and 1997. Values represent the yearly mean for each study site. See Fig. 2 for legend.

The results of correlation analysis between cheatgrass and several other habitat characteristics revealed that strong relationships existed during both years of the study (Table 2). These relationships included a significant negative correlation between cheatgrass cover and the cover of each of native grass, bare ground, and big sagebrush and a positive correlation with big sagebrush height. The correlation between cheatgrass cover and the cover of native forbs or standing dead big sagebrush although positive, was generally weak and non-significant.

TABLE 2. Results of Pearson Product-Moment correlation analysis between mean cheatgrass cover and other habitat variables at the study site and territory level of analysis during 1996 and 1997.

	Site Level		Territory Level	
Habitat Variable	1996	1997	1996	1997
Native grass cover	-0.98**	-0.92**	-0.92***	-0.86***
Bare ground cover	-0.72	-0.93**	-0.55**	-0.83***
Big sagebrush cover	-0.85*	-0.91*	-0.56**	-0.64**
Big sagebrush height	0.81*	0.92*	0.75***	0.78***
Dead big sagebrush cover	0.30	0.04	0.28	0.10
Native forb cover	0.21	0.03	0.16	0.18

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

Territory Size

The overall mean territory size averaged across all study sites was similar during both years of the study (1996 = 2.11 ± 0.60 ha, SE = 0.596; 1997 = 2.05 ± 0.48 ha, SE = 0.478). Between-year differences in mean territory size at individual study sites (Table 3) were not significantly different. Mean territory size, however, differed greatly between some study sites (Table 3). I used a 1-way ANOVA to determine if this variation was significant. The variation between sites was significant in both years of the study (1996: F = 6.86, $P < 0.001$, df = 5; 1997: F = 9.91, $P < 0.001$, df = 5). Mean territory size at the Highway 24 study site was significantly larger (Bonferonni post-hoc test; all $P < 0.005$) than at all other sites except Yakima Barricade ($P = 0.61$) in 1996 and Army Loop ($P = 0.98$) in 1997.

TABLE 3. Mean territory sizes (ha):1996 and 1997.

	1996				1997			
Study Site	Mean	SE	Range	n	Mean	SE	Range	n
Saddle Mountain	1.57	0.473	0.92 - 3.43	5	1.18	0.142	0.75 - 1.56	7
Yakima Barricade	2.02	0.325	1.32 - 3.17	5	1.70	0.217	1.14 - 2.27	6
Gable Mountain	1.24	0.128	0.69 - 1.52	6	1.62	0.200	1.12 - 2.16	5
Gate 118	1.22	0.143	0.70 - 1.51	5	1.28	0.297	0.62 - 2.10	5
Army Loop	1.56	0.325	0.89 - 2.59	5	2.23	0.449	1.18 - 3.37	4
Highway 24	5.02	1.003	2.26 - 6.74	4	4.32	0.341	3.35 - 4.90	4

Relationships Between Habitat Variables and Territory Size

The use of habitat variables to predict territory size produced mixed results (Table 4). Some of the variables that were negatively correlated with cheatgrass, such as native grass, bare ground, and big sagebrush cover, also were negatively correlated with territory size. The relationships between territory size and most habitat variables; however, tended to be weaker (Table 4). Big sagebrush parameters (cover and height) were variously correlated with territory size, but few relationships showed consistent trends (Table 4). For example, the correlation between territory size and standing dead big sagebrush cover, though consistently positive, was stronger in 1996 than in 1997. Native forb cover was negatively related to territory size during both years and at both levels of analysis; however, the correlation was weak and none of the analyses were significant. The only habitat variable that was more than weakly correlated with territory size during both years of the study, and at both levels of analysis, was cheatgrass. These relationships were significant, however, only at the territory level. The positive relationship between cheatgrass and territory size may in part be attributed to the relatively large amount of cheatgrass and greater territory size present on the Highway 24 study site (Fig. 4).

To further examine the relationship between cheatgrass and territory size, I used a 1-way ANOVA to compare the variation in mean territory size at 3 classes of cheatgrass cover: low (0 to 25%), medium (26 to 50%), and high (51 to 75%). The variation among mean territory size was significant in 1996 ($F = 7.343$, $P = 0.003$, df = 2) and in 1997 ($F = 7.77$, $P = 0.002$, df = 2). Only the high class, however, significantly

contributed to the variation in territory size (Bonferonni post-hoc test, $P \leq 0.01$). Because cheatgrass cover on the Highway 24 site exceeded 50% during both years of the study, I was concerned that the territories on this site might constitute all of the territories in the high cheatgrass cover class. More than one study site, however, contributed to each cover class with the exception of the high class in 1996. In that year this class consisted of territories only from the Highway 24 site.

TABLE 4. Correlation coefficients of relationships between sage sparrow territory size and habitat characteristics at both the study site and territory levels of analysis: 1996 and 1997.

Variable	Site Level		Territory Level	
	1996 n = 6	1997 n = 6	1996 n = 30	1997 n = 31
Cheatgrass	0.45	0.77	0.37*	0.54**
Native Grass	- 0.31	-0.63	-0.23	-0.47*
Bare ground	- 0.57	-0.70	-0.28	-0.44*
Native forbs	- 0.38	-0.38	-0.13	-0.09
Big sagebrush cover	- 0.09	-0.85*	-0.02	-0.31
Big sagebrush height	0.10	0.54	0.09	0.42*
Dead big sagebrush cover	0.91*	0.34	0.46*	0.12

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

The Relationship Between Nest Success, Territory Size and Habitat Variables

The number of successful nests per territory was not significantly correlated with any of the measured habitat characteristics or territory size; however, a trend toward decreased cheatgrass cover existed in territories that contained more than 1 successful

nest (Table 5). I used a 1-way ANOVA to test the hypothesis that territories that produced greater numbers of successful nests contained less cheatgrass. Although the percentage of cheatgrass declined as the number of successful nests increased, the variation among means was not significant. A similar analysis replacing cheatgrass with territory size also resulted in no detection of significant variation among mean territory size for territories that contained 0, 1, or 2 successful nests.

TABLE 5. Mean percentage of cheatgrass cover within sage sparrow territories containing 0, 1, or 2 successful nests:1996 and 1997.

	0 nests	1 Nest	2 Nests
1996 $\bar{x}$ ± SD (n)	no data	29.2 ± 23.70 (11)	18.7 ± 15.88 (13)
1997 $\bar{x}$ ± SD (n)	31.7 ± 24.27 (3)	26.9 ± 24.54 (14)	22.5 ± 13.11 (7)

$P > 0.05$ for all comparisons among nest categories.

Unpaired males were present on 4 out of 6 study sites in 1996 and on 3 out of 6 sites in 1997. Although the territories defended by unpaired males were larger than those for paired males (Table 6), the differences were not significant in either year. A comparison of habitat variables within the territories of unpaired males versus paired males revealed that territories defended by unpaired males contained more cheatgrass and less native grass than those of paired males. None of these differences, however, were statistically significant.

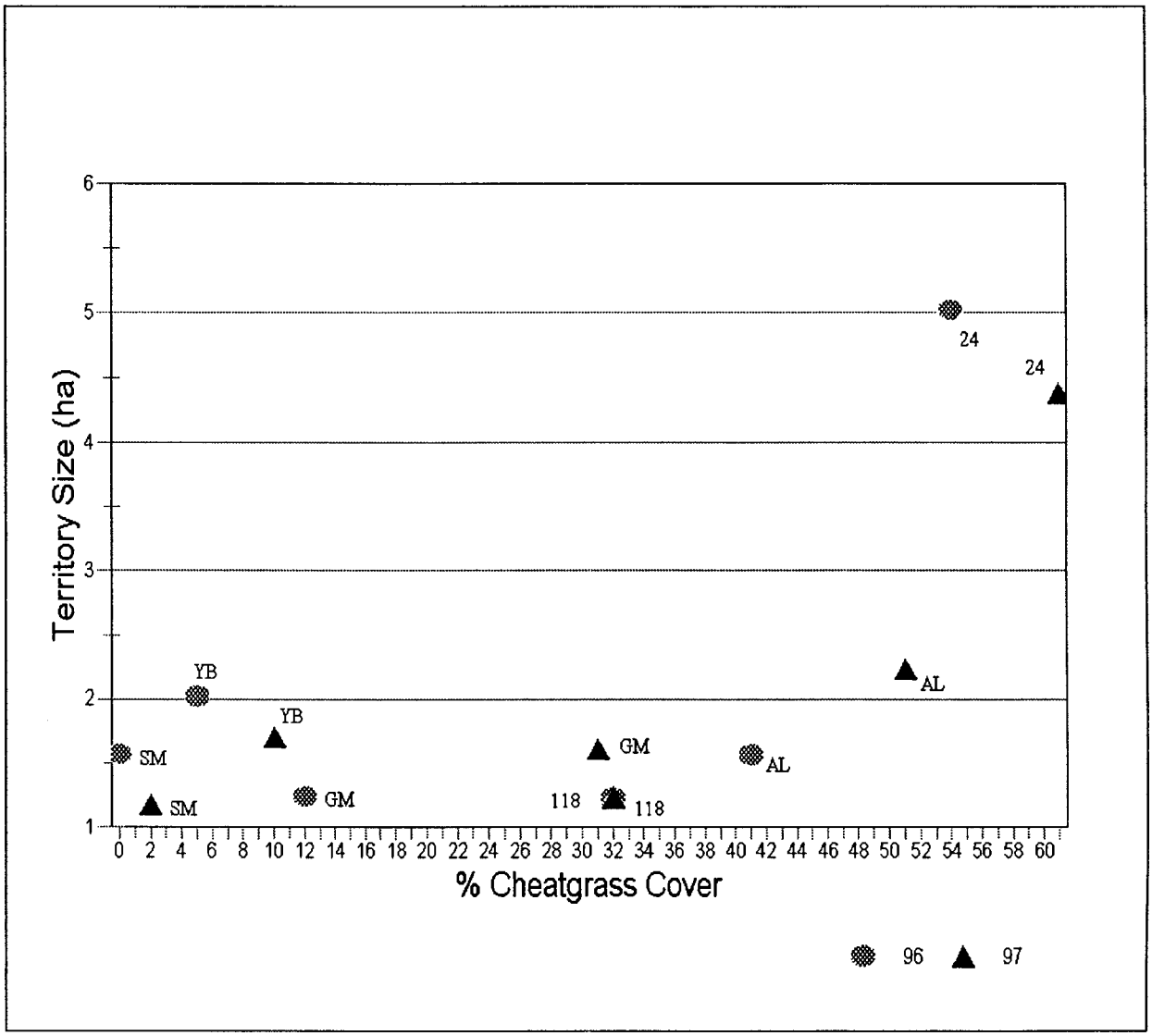


Figure 4. The relationship between sage sparrow territory size and cheatgrass cover during 1996 and 1997. See Fig. 2 for legend.

TABLE 6. Comparison of territory size and habitat variables for territories of paired and unpaired males.

Variable	1996		1997	
	Unpaired ($n = 3$)	Paired ($n = 27$)	Unpaired ($n = 6$)	Paired ($n = 25$)
Territory size (ha) mean ± SD	3.0 ± 2.80	1.9 ± 1.35	2.8 ± 1.57	1.7 ± 0.94
Cheatgrasss cover % mean ± SD	37.4 ± 23.57	21.8 ± 19.89	29.8 ± 27.12	26.4 ± 20.67
Native grass cover % mean ± SD	5.2 ± 7.08	12.0 ± 10.36	10.9 ± 10.82	13.9 ± 14.20
Bare ground cover % mean ± SD	60.8 ± 18.21	59.1 ± 11.77	57.3 ± 17.76	55.7 ± 14.02

$P > 0.05$ for all comparisons between unpaired and paired territories.

DISCUSSION

Habitat Characteristics

Shrub-steppe ecosystems often are considered to be relatively homogeneous (Petersen and Best 1987). On Hanford, shrub-steppe communities tended to be heterogeneous, primarily in regard to the amount of cheatgrass cover present at different locations (Table 1). Variability in cheatgrass cover may be related to previous disturbance, as areas close to the Columbia River were intensively grazed prior to the acquisition of the Hanford Site by the Atomic Energy Commission in 1943 (Brandt and Rickard 1994).

I found cheatgrass ground coverage to be negatively correlated with measures of a few habitat components that typify a native shrub-steppe community (Table 2).

These findings generally concur with those of Daubenmire (1970) and Brandt and Rickard (1994) who suggest that once cheatgrass establishes within a shrub-steppe community little succession to a more native composition and structure occurs. The positive relationship between big sagebrush height and cheatgrass cover reported herein also supports this finding (Table 2). Apparently less recruitment of big sagebrush occurs on sites where cheatgrass cover is high. Remnant shrubs are older and, as a result, tend to be taller. Although dead big sagebrush cover was positively correlated with cheatgrass, the relationship was not significant.

The presence of cheatgrass seems to be closely linked to the amount of bare ground. For example, a significant increase in cheatgrass on the Gable Mountain study site between 1996 and 1997 was accompanied by a significant reduction in the amount of bare ground (Table 1). Additionally, cheatgrass cover was negatively related to the amount of bare ground at both the territory and site levels of analysis (Table 2). These findings concur with a previous observation on Hanford (DOE-RL 1996: D. 42) that areas dominated by cheatgrass tend to have less bare ground as compared with areas in which native perennial bunchgrasses are the major understory components.

Although the results of this study do not prove a causal relationship between cheatgrass cover and the habitat components common to native shrub-steppe, it is apparent that areas that contain substantial amounts of cheatgrass often have reduced cover of native flora and bare ground.

The Relationship Between Sage Sparrow Territory Size and Shrub-Steppe Habitat Components

On the Hanford Site, sage sparrow males tended to defend smaller territories when the amounts of native grass, bare ground and sagebrush cover were relatively high. This finding generally agrees with Wiens and others (1985) who also reported that sage sparrow territory size was negatively correlated with sagebrush and native bunchgrass cover. Because the presence of cheatgrass is negatively correlated with the coverage of native vegetation and bare ground which, in turn, are negatively correlated with territory size, it follows that an increase in cheatgrass cover may correlate with an increase in territory size. Previous studies, which found an inverse relationship between sage sparrow abundance and cheatgrass cover, support this conclusion (Schuler and others 1993; Dobler and others 1996). These studies, however, did not take into account the potential intercorrelation between habitat variables. As Rotenberry and Wiens (1980) suggested, caution must be used when interpreting the relationship between bird abundance and habitat components as a species may vary significantly in abundance with respect to one variable when in fact it is responding to some other variable that is highly correlated with the first.

To help isolate the influence of cheatgrass cover on sage sparrow territory size, I chose study sites that averaged a minimum of 20% big sagebrush cover. At this coverage, territorial / reproductively active male sage sparrows are known to select areas that match the average coverage of sagebrush or are slightly less than average (Larson and Bock 1986; Peterson and Best 1985; Wiens 1985). On Hanford the selection of sites with big sagebrush coverage > 20% only partially controlled for this

complicating variable, as a negative correlation existed between territory size and sagebrush cover in 1997 (Table 4).

Because cheatgrass cover is known to change annually in response to precipitation, some habitat characteristics negatively correlated with this variable (for example, bare ground) may fluctuate in consort. If habitat conditions are degraded by yearly increases in cheatgrass, we also may expect an accompanying change in sage sparrow territory size. On Gable Mountain where cheatgrass cover increased significantly between 1996 and 1997, the increase in territory size was not significant ($t = 1.49$, $P = 0.17$, $df = 9$). Annual fluctuations in cheatgrass levels, either those reported here or in general, possibly are not substantial enough to decrease habitat quality and the resultant need for sage sparrow males to increase their territory size. I suggest it is more likely that a threshold amount of cheatgrass, and subsequent decline in those habitat components that typify a more native shrub-steppe community, must be present before a significant increase in territory size occurs. In this study I found territory size to remain near or below 2 ha until cheatgrass cover exceeded 50% (Fig. 4).

Several studies have positively correlated sage sparrow abundance to the presence of bare ground (Rotenberry and Wiens 1980; Larson and Bock 1986). As sage sparrows spend a significant amount of time foraging on the ground, sufficient amounts of bare ground may be necessary to provide favorable foraging locations (Petersen and Best 1985; Wiens 1985). The observation reported here that sage sparrow territories became smaller as bare ground increases (Table 4) lends support to this conclusion. The strong negative correlation between cheatgrass and bare ground

(Table 2) also suggests that sage sparrow territory size may be indirectly related to cheatgrass cover through the loss of bare ground.

To identify suitable sage sparrow habitat on the Hanford Site, the USDOE developed a habitat model for this species (DOE-RL 1996). Because of the uncertainty of the effects of cheatgrass on sage sparrow habitat utilization, the model includes a maximum threshold value of 25% cheatgrass cover for habitat occupancy by sage sparrows. I suggest that the threshold value for cheatgrass cover suggested by the USDOE may be too low as sage sparrow territory size was not significantly larger until cheatgrass cover exceeded 50%.

The Relationship Between Reproductive Success / Pairing Status and Territory Size and Cheatgrass Cover

Although there was a trend toward greater reproductive success in territories that contained less cheatgrass, I can not rule out the possibility that this relationship was due to random chance. My ability to detect a relationship, if one existed, may have been hampered by small sample size and possibly the insensitivity of my measure of reproductive success (number of successful nests). When I compared this measure of reproductive success to another variable, territory size, I was also unable to detect a significant relationship. One factor that may also have influenced the relationship between reproductive success and cheatgrass cover or reproductive success and territory size is predation. If predators are more abundant in some locations than others and are little influenced by the presence of cheatgrass, the number of successful nests

in a given area may be more dependent upon the abundance of predators than on the amount of cheatgrass cover.

Although I did not discover a significant relationship between territory size and pairing status, a trend toward paired males defending smaller territories was present (Table 6). If territory sizes are smaller in higher quality habitats (this study) and females select males based on habitat quality, then a reasonable expectation is that paired males will have smaller territories than unpaired males. Caution must be used, however, when basing the pairing status of sage sparrows on habitat quality. For example, females may not use breeding habitat as a criterion for mate selection as a portion of sage sparrows arrive on their breeding grounds previously paired (Rich 1980). In addition, the unpaired male category may be composed of more than never paired males, as males whose mates died or left for undetermined reasons may also be included (this study). Studies that compare the territory size of paired versus unpaired males should also consider habitat quality as sage sparrows breeding in degraded habitats may defend relatively larger territories. These confounding factors may help explain the difference between the findings of Petersen and Best (1987), that suggest that paired males defend larger territories than unpaired males, and the results reported here.

Many factors such as site fidelity, population levels, and seasonal use of habitats, potentially complicate the use of territory size / density as an indicator of habitat quality (Van Horne 1983; Wiens and others 1987). To help compensate for these factors, Van Horne (1983) suggests the incorporation of intensive demographic data into studies that attempt to relate habitat quality and species density. Although I

was unable to collect many of the demographic variables she suggests (for example, survival characteristics of each age class), I was able to obtain a measure of reproductive success (the number of successfully fledged clutches per territory). On Hanford, however, the link between reproductive success and habitat quality may have been confounded by a myriad of factors.

Sage sparrows may not respond to some factors that complicate the use of bird density / territory size as an indicator of habitat quality. For example, Wiens (1985) suggests that shrub-steppe passerines do not always saturate available habitats. As a result, habitat selection by sage sparrows may not be affected by the density of individuals in an area. In addition, the strong site fidelity exhibited by sage sparrows, that may result in the continued use of degraded habitats (Wiens and Rotenberry 1985), may also discourage individuals of this species from relocating to new habitats even when densities increase. Birds that nest in higher densities may simply employ other strategies to ensure their reproductive success, such as foraging outside the boundaries of their territories.

SUMMARY

Native plant communities within the interior Columbia Basin have been greatly reduced by agriculture and urbanization. Remaining habitats often contain non-native plant species, some of which (for example, cheatgrass [*Bromus tectorum*]) are pervasive. For species such as the sage sparrow (*Amphispiza belli*), whose continued persistence almost exclusively depends on sagebrush communities, effects of habitat

degradation may be more pronounced than for species whose habitat requirements are less stringent. Understanding the relationship between the presence of cheatgrass and the breeding habitats or ecology of the sage sparrow may enable us to better identify and, ultimately, preserve areas necessary for the survival of this species.

Data collected during the course of this study suggest that cheatgrass cover was negatively correlated with several of the habitat components that characterize bunchgrass dominated shrub-steppe communities. The decline in native flora that accompanied increased cheatgrass cover was also associated with an increase in sage sparrow territory size. Although intercorrelation of habitat variables prevented directly linking changes in cheatgrass cover with territory size, sage sparrows that nested on sites with a relatively high contribution by cheatgrass to the ground cover (for example, > 50 %) did have significantly larger territories than those nesting on sites containing a predominately native understory. Potentially such changes in normative territory size may have fitness consequences for sage sparrow pairs inhabiting such territories. In this study, a significant relationship between cheatgrass cover and sage sparrow pairing or nesting success was not observed; however, more cheatgrass was present in territories of unpaired males and less was present in those territories that contained a greater number of successful nests.

LITERATURE CITED

Best LB. 1978. Field sparrow reproductive success and nesting ecology. Auk 95:9-22.

Brandt CA, Rickard WH. 1994. Alien taxa in the North American shrub-steppe four decades after cessation of livestock grazing and cultivation agriculture. Biological Conservation 68:95-105.

Cline JF, Uresk DW, Rickard WH. Plants and soil of a sagebrush community on the Hanford Reservation. Northwest Science 51:60-70.

Daubenmire R. 1970. Steppe vegetation of Washington. Pullman, WA: Washington Agricultural Experiment Station. Technical Bulletin 62. 131 p.

[DOE-RL] U.S. Department of Energy. 1996. Draft Hanford Site Biological Resources Management Plan. Richland, WA: USDOE, Richland Operations office. DOE/RL 96-32.

Dobler FC, Eby J, Perry C, Richardson S, Vander Haegen M. 1996. Status of Washington's shrub-steppe ecosystem: extent, ownership, and wildlife/vegetation relationships. Olympia, WA: Research Report. Washington Department Fish and Wildlife. p 1-39.

Downs JL, Rickard WH, Brandt CA, Cadwell LL, Cushing EE, Geist DR, Mazaika M, Neitzel DA, Rogers LE, Sackschewsky MR, and Nugent JJ. 1993. Habitat types on the Hanford Site: wildlife and plant species of concern. Richland, WA: Pacific Northwest Laboratory. PNL-8942.

ESRI. 1997. Arcinfo version (7.1.1). Environmental Systems Research Institute. Redlands, California.

Fowler JA, Cohen L. 1998. Practical Statistics for Field Biology. 2nd ed. New York: John Wiley and Sons. 259 p.

Franklin JF, Dyrness CT. 1973. Natural vegetation of Oregon and Washington. Portland, Oregon: USDA Forest Service. General Technical Report PNW-8. p 1-417.

Hurlbert SH. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs. 54:187-211.

Knick ST, Rotenberry JT. 1995. Landscape characteristics of fragmented shrubsteppe habitats and breeding passerine birds. Conservation Biology 9:1059-1071.

Knick ST. 1999. Requiem for a sagebrush ecosystem? Northwest Science 73:53-57.

Larson DL, Bock CE. 1986. Determining avian habitat preference by bird-centered vegetation sampling. Verner J, Morrison ML, Ralph CJ. In: Wildlife 2000: modeling habitat relationships of terrestrial vertebrates. Madison Wisconsin: University of Wisconsin Press. p 37-43.

Martin TE, Roper JJ. 1988. Nest predation and nest-site selection of a western population of the hermit thrush. The Condor. 90:51-57.

Mayfield HF. 1975. Suggestions for calculating nest success. Wilson Bulletin 87:456-466.

Peterson KL, Best LB. 1985. Nest site selection by sage sparrows. Condor 87:217-221.

Peterson KL, Best LB. 1987. Territory dynamics in a sage sparrow population: are shifts in site use adaptive? Behavioral Ecology and Sociobiology 21:351-358.

Phillips EA. 1959. Methods of vegetation study. Holt, Rinehart, and Winston, Inc., 107 p.

Pulliam RH. 1988. Sources, sinks, and population regulation. American Naturalist 132:652-661.

Rich TG. 1980. Territorial behavior of the sage sparrow: spatial and random aspects. Wilson Bulletin 92:425-438.

Rotenberry JT, Wiens JA. 1980. Habitat structure, patchiness, and avian communities in North American steppe vegetation: a multivariate analysis. Ecology: 61:1228-1250.

Rotenberry JT, Wiens JA. 1989. Reproductive biology of shrubsteppe passerine birds: geographical and temporal variation in clutch size, brood size, and fledgling success. Condor 91:1-14.

Rotenberry JT, Wiens JA. 1991. Weather and reproductive variation in shrub steppe sparrows: a hierarchical analysis. Ecology 72:1325-1335.

Schuler CA, Rickard WH, Sargeant GA. 1993. Conservation of habitats for shrub-steppe birds. Environmental Conservation 20:57-64.

Sokal RR, Rohlf FJ, 1995. Biometry. New York: W.H. Freeman and Company. 887 p.

Van Horne B. 1983. Density as a misleading indicator of habitat quality. Journal of Wildlife Management 47: 893-901.

Vickery PD, Hunter ML, Wells JV. 1992. Is density an indicator of reproductive success. Auk 109:706-710.

Wiens JA,1985. Habitat selection in variable environments: shrubsteppe birds. In: Cody ML, editor. Habitat selection in birds. New York: Academic Press. p 227-251

Wiens JA, Rotenberry JT, Van Horne B. 1985. Territory size variations in shrubsteppe birds. Auk 102:500-505.

Wiens JA, Rotenberry JT. 1985. Response of breeding birds to a rangeland alteration in a North American shrubsteppe locality. Journal of Applied Ecology 22:655-668.

Wiens JA, VanHorne B, Rotenberry JT. 1987. Temporal and spatial variation in the behavior of shrubsteppe birds. Oecologia 73:60-70.

Zar JH. 1996. Biostatistical Analysis. 3rd ed. Upper Saddle River, NJ: Prentice-Hall Inc. 662 p.

APPENDIX 1. Plant species found on 6 study sites located on the USDOE Hanford Site: 1996 and 1997. + indicates species presence.

SPECIES	SM	YB	GM	GATE 118	AL	HWY. 24
SHRUBS						
Artemisia tridentata	+	+	+	+	+	+
Chrysothamnus nauseosus	+		+		+	
Chrysothamnus vicidiflorus				+	+	
Grayia spinosa			+			
GRASSES						
Bromus tectorum	+	+	+	+	+	+
Festuca octoflora		+				
Festuca microstachys		+	+			
Festuca species	+	+	+	+	+	+
Oryzopsis hymenoides				+	+	
Poa sandbergii	+	+	+	+	+	+
Poa scabrella				+		
Sitanion hystrix		+	+	+	+	+
Stipa comata			+			
Pseudoregeneria spicata	+					
FORBS						
Achillea millifolium					+	
Ambrosia acanthicarpa					+	
Astragalus caricinus				+		
Astragalus sclerocarpus					+	
Astragalus succumbens				+		
Balsamorhiza careyana		+		+		
Calochortus macrocarpus	+			+		
Chaenactis douglasii		+		+	+	
Collomia grandiflora		+				
Commandra umbellata					+	

SPECIES	SM	YB	GM	GATE 118	AL	HWY. 24
Crepis atrabarba		+		+	+	
Cryptantha circumscissa		+	+		+	
Crypthantha pterocarya				+		
Cymopteris terebinthinus				+	+	
Descurainia pinnata	+	+		+	+	+
Draba verna	+	+	+	+	+	+
Epilobium paniculatum	+	+	+	+	+	+
Erigeron filifolius				+		
Erigeron poliospermus		+				
Eriogonum vimineum			+			
Fritillaria pudica					+	
Gilia minutiflora				+		
Gilia sinuata		+		+		
Helianthus cusickii				+		
Holosteum umbellatum	+	+	+	+	+	+
Lactuca serriola	+		+			+
Lappula redowskii	+					
Lithospermum arvense					+	
Machaeranthera canescens	+	+		+	+	
Microsteris gracilis	+	+	+	+	+	+
Phacelia humilis/glandulifera)		+				
Phlox longifolia	+	+	+	+	+	
Plectris macrocera	+	+	+			
Polemonium micranthum			+			
Salsola kali		+	+		+	+
Sisymbrium altissimum	+	+			+	
Sphaeralcea munroana				+		
Tragopogon dubius		+				