

THE EFFECTS OF NATURAL GAS DEVELOPMENT ON SAGEBRUSH STEPPE
PASSERINES IN SUBLETTE COUNTY, WYOMING

by
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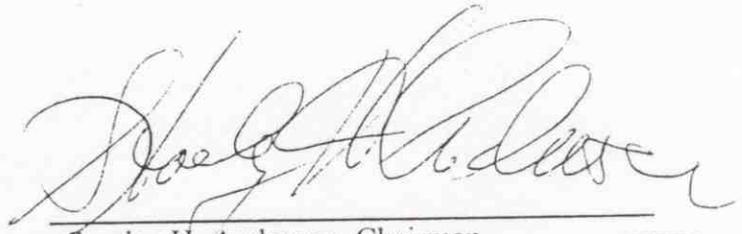
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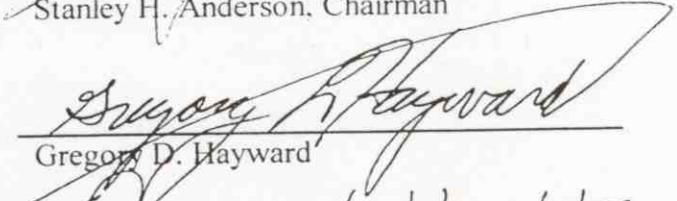
Because natural gas extraction is pervasive throughout the sagebrush steppe of Wyoming, this project was undertaken to evaluate the impact that development of the sagebrush steppe dominated Pinedale Anticline Project Area will have on passerines. During the spring and summer of 1999 and 2000, 50-meter radius point counts were used to determine the distribution and habitat associations of the breeding bird community within the project area and to determine how roads associated with gas development affect bird distribution. Common species include horned larks (*Eremophila alpestris*), Brewer's sparrows (*Spizella breweri*), sage sparrows (*Amphispiza belli*), sage thrashers (*Oreoscoptes montanus*), and vesper sparrows (*Pooecetes gramineus*). While sagebrush obligates were positively correlated with measures of sagebrush height and plot shrubbiness, the majority of variation in species abundance was not correlated with changes in habitat physiognomy. To assess the impact of natural gas development, bird distribution was also measured along roads associated with natural gas extraction. The study encompassed dirt roads in the Jonah Field II and Pinedale Anticline Project Area. Along these roads, traffic volume was low, and ranged between 700 – 10 vehicles/day. Results indicate that songbird density, particularly Brewer's and sage sparrows, and the guild of sagebrush obligates were reduced by 50% within 100-meters of roads. Evidence suggests that the cause of bird declines along roads may be two fold. Declines were associated with both traffic disturbance and with a shift in species composition, as horned larks were attracted to dirt roads to forage for seeds. Increases in horned larks along roads may decrease the attractiveness of the surrounding habitat to other species.

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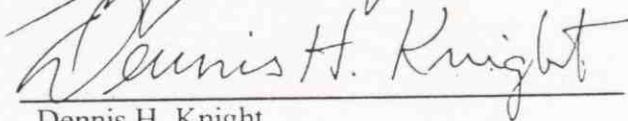
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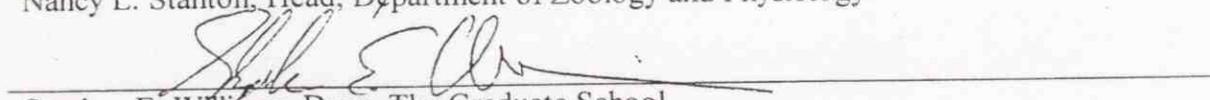


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Chapter I

Passerine Response to Natural Gas Development and Extraction in Pinedale, Wyoming: Introduction and Background

INTRODUCTION

Sagebrush-grasslands occur throughout the Intermountain West, covering much of the Great Basin and Wyoming Basin and extending into portions of southwestern Montana, western Colorado, and northern New Mexico. Covering approximately 63 million hectares, sagebrush-grasslands are classified into two broad zones, sagebrush steppe and Great Basin sagebrush shrubland (Fig. 1) (West 1996). Sagebrush steppe is co-dominated by sagebrush (*Artemisia tridentata* spp.), perennial bunchgrasses, and forbs. Encompassing 44.8 million hectares, sagebrush steppe occurs primarily in the northern portion of the Intermountain West and at increasingly high elevations to the south (West and Young 2000). South of the sagebrush steppe, Great Basin sagebrush shrubland extends from the Great Basin south. The Great Basin sagebrush type is characterized by a dryer climate and is dominated by big sagebrush with sparse grass cover (Fig. 1) (West and Young 2000).

The climate of sagebrush dominated landscapes leads to semi-desert conditions where snow is the predominate form of precipitation; winters are long, summers are hot, and winds are persistent (West and Young 2000). Annual precipitation is variable and averages 246 mm in sagebrush steppe and between 158-419 mm in the Great Basin (West 1983, West and Young 2000). While variation in precipitation has little effect on sagebrush cover and stature, annual variation in grass and forb cover can be substantial (Rotenbery and Wiens 1980).

The breeding bird communities of sagebrush-grasslands are characterized by low species density (0.5-2 pairs / hectare) and low species richness (3-6 passerines) (Wiens 1985). Despite low bird diversity, over 100 species have been recorded foraging and nesting in sagebrush habitats (Braun et al. 1976). The avifauna is comprised of sagebrush obligates, species almost entirely dependent on sagebrush communities, which include Brewer's sparrow (*Spizella breweri*), sage sparrow (*Amphispiza belli*), sage thrasher (*Oreoscoptes montanus*), and sage grouse (*Centrocercus urophasianus*); and near

obligates such as the green-tailed towhee (*Pipilo chlorurus*). Other birds frequently found in the sagebrush-grassland include the ferruginous hawk (*Buteo regalis*), golden eagle (*Aquila chrysaetos*), prairie falcon (*Falco mexicanus*), sharp-tailed grouse (*Tympanuchus phasianellus*), mourning dove (*Zenaida macroura*), burrowing owl (*Speotyto cunicularia*), common nighthawk (*Chordeiles minor*), ash-throated flycatcher (*Myiarchus cinerascens*), horned lark (*Eremophila alpestris*), western meadowlark (*Sturnella neglecta*), Brewer's blackbird (*Euphagus cyanocephalus*), and vesper sparrow (*Pooecetes gramineus*) (Braun et al. 1976).

HABITAT SELECTION: AN OVERVIEW

Traversing the landscape across different vegetation types, one begins to notice that different animals are found in distinct habitats. This pattern of animal distribution results from each animal's requirements for food, water, and shelter. The variable distribution and structure of these factors influence an organism's survival and productivity, and therefore restrict an animal's topographic range (Hildén 1965). This theory suggests that patterns in habitat occupancy should be linked to individual fitness and that the best habitats should have the highest density of individuals suited to exploit those resources (Wiens, 1985). While density can be a misleading measure of habitat quality (Van Horn 1983), the study of habitat selection focuses on mechanisms by which an animal selects its geographic distribution, home range, and utilization of specific resources within that range.

Selection suggests a process where an animal uses resources out of proportion to availability (Johnson, 1980). It is a behavioral process operating at the level of the individual (Krebs 1994). The theory that animals are adapted to specific habitats gains credibility if it can be shown that habitat features are responsible for physiological differences between closely related species, or that species exhibit morphologic adaptations that enable them to better use a specific resource (Cody 1985). The idea of synmorphosis is balanced by the realization that animals, especially migratory species, often must survive in a variety of habitats during the year. Thus fine tuning of behavior and physiology may not be advantages (Cody 1985).

The mechanism by which an animal selects habitat is divided into ultimate and proximate factors (Hildén 1965). Ultimate factors relate directly to survival and have

evolutionary consequences, while proximate factors are the cues used to select specific habitat features. In a more pedagogical sense, ultimate and proximate factors relate the questions of why and how respectively.

The study of habitat selection focuses on determining the proximate cues that individuals use to select habitat. It is qualified by the realization that often habitat decisions are made before the ultimate factors that affect survival and reproduction, such as food availability to feed young, are observable (Cody 1985). Selection is a hierarchical process where higher order decisions are conditional upon habitat decisions previously made at larger scales (Johnson 1980). Four orders of habitat selection are recognized. First-order selection relates to an individual's geographic distribution. Second-order selection pertains to the selection of a home range within its geographic distribution. The use of specific habitat features within the home range, such as nest sites, song perches, and foraging sites, is third-order selection. Finally, if third-order selection determines foraging sites, fourth-order selection is the procurement of food within those sites (Johnson 1980).

AVIAN HABITAT SELECTION IN SAGEBRUSH-GRASSLANDS

The study of habitat selection is framed by the assumptions that resource limitation causes relatively strong and continuous selection, communities are in equilibrium with resources, and competition is a major guiding force in determining community structure and patterns of species' habitat occupancy (Wiens 1985). Attracted by the simplicity of the sagebrush-grassland bird community, John A. Wiens and John T. Rotenberry spent over a decade examining patterns in bird habitat association to discern how inter-specific competition affects community structure and habitat selection (Wiens 1977).

For birds, physical habitat structure (physiognomy) is considered an important niche dimension as it directly provides courtship and display sites, nesting substrate, protection from predators, shelter from climactic stresses, and indirect cues of prey availability and condition suitability for reproduction (Hildén 65; James 71; Wiens and Rotenberry 1981a). In a continental analysis of breeding bird habitat associations spanning tall-grass prairie through shrubsteppe environments, Wiens and Rotenberry found that shrubsteppe bird population densities were positively correlated with several

measures of habitat structure. Habitat associations on this broad continental scale provide a coarse description of the biogeographic range of these shrubsteppe species and little inference into patterns of habitat selection (Wiens 1985). This is evidenced by the uncoupling between physiognomy and sagebrush steppe breeding bird populations on a smaller, regional scale. At the regional scale, floristics and the cover of certain shrub species were better predictors of species abundance than physiognomy. However, even at the regional scale, much of the variation in avian abundance remained unexplained after consideration of habitat features. The few significant correlations within the analysis may therefore be spurious (Wiens and Rotenberry 1981a). These results, combined with the finding that individual species abundance and distribution varied independently of one another, suggest that biotic interactions such as competition play a minor role in structuring the sagebrush-grassland bird community (Rotenberry and Wiens 1980a, 1980b; Wiens and Rotenberry 1981a).

Other studies also have corroborated the view that competition plays a relatively minor role in structuring the sagebrush steppe avian community. Brewer's sparrows and sage sparrows, despite similar size, broadly overlapping territories, and similar nesting requirements, rarely interact behaviorally (Wiens 1985). Also, dietary studies within shrubsteppe systems reveal that birds within this community overlap in type and size of insect prey consumed despite significant inter-specific differences and intra-specific sexual dimorphism in body and bill size. Furthermore, while different species in the same area have broad dietary overlap, conspecifics consume different items in different areas, suggesting that these birds are responding opportunistically to what is available locally (Wiens and Rotenberry 1979, Wiens and Rotenberry 1980a).

These habitat association patterns of sagebrush-grassland birds do not mesh with conventional ideas of "optimal" expression of habitat associations due to the constraints of competition. Wiens (1974, 1977) suggested that within the variable climatic environment of sagebrush-grasslands, three core assumptions of competition theory are not satisfied. These assumptions are that selection of the considered attributes is intense and continuous; the community is at an equilibrium determined by resource limitation, and therefore suitable habitats are completely saturated; and that competition is the major selective force acting upon resource-utilization and species distribution. However, in

variable environments where unpredictable climactic conditions lead to periodic episodes of resource superabundance, these assumptions are not met.

In sagebrush-grassland ecosystems precipitation is concentrated into the winter and the quantity is unpredictable from year to year. Like grasslands, primary productivity is concentrated into a brief growing season and pulses of available food resources are often in excess of consumer demands (Wiens 1974). The breeding bird communities of sagebrush-grasslands are primarily insectivorous, with daily energy demands never exceeding 0.7% of the insect standing crop (Rotenberry 1980a). While resources may at times become limiting, sagebrush-grassland birds are frequently prevented from reaching carrying capacity by limitations placed on multiple brooding due to the short, hot breeding season, increased predation during wet years, and constraints on wintering populations (Wiens 1974, 1977; Rotenberry 1980b; Rotenberry and Wiens 1989). As a result, suitable habitat within the sagebrush-grassland bird community is frequently unsaturated, and the cost (reduced fitness) associated with non-optimal selection of habitats and foraging behavior is minimal. Instead, the shrubsteppe avian community is characterized by a guild of generalists that during the breeding season take advantage of resources that are locally abundant (Wiens 1974, 1977; Rotenberry and Wiens 1980; Wiens and Rotenberry 1981a; Wiens 1985).

The literature supports the theory that sagebrush birds utilize resources in a generalist manner during the breeding season. Within this system, the evolutionary impetus for specialization is rare. Resources are frequently superabundant, and suitable habitat is often left unoccupied due to constraints placed on reproduction by climatic variability. Instead of niche differentiation and resource specialization, a guild of generalists has developed with broadly overlapping territories, diets, and habitat associations, and has led to the decoupling of breeding-bird abundance and habitat variables.

Interannual variability in abundance and site occupancy also contributes to this decoupling within the avian community. Often, suitable habitat remains unoccupied and changes in species abundance do not appear to reflect any intrinsic measure of habitat quality. While research has documented mechanisms that could have lead to the

formation of this community's generalist behavior, less information is available on why interannual habitat occupancy varies to the degree that it does.

Two hypotheses have been proposed to explain the observed pattern in habitat occupancy. The first explanation is that within the variable environment of the sagebrush steppe, birds track "resource hotspots" (Cody 1985, Wiens 1985, Rotenberry and Wiens 1998). Cody (1985) first suggested that grassland birds, in response to unpredictable climate and its effect on resource abundance, might track resource availability. In such a system, breeding site fidelity should be poorly expressed and certain habitats may be occupied only during particularly dry or wet years. The concept of resource tracking has also been used to explain variable pattern in breeding bird abundances in the sagebrush steppe bird community (Rotenberry and Wiens 1980a, 1980b; Wiens and Rotenberry 1981a).

A recent study provides some evidence of interannual, local-scale resource tracking (Rotenberry and Wiens 1998). In an 800 m x 300 m study area, vegetation characteristics of Brewer's and sage sparrows use patches (a patch being defined as a contiguous association of living and or dead shrub material) differed from patches sampled at random. This pattern was consistent over successive seasons despite interannual variation in patch characteristics (Rotenberry and Wiens 1998). Rotenberry and Wiens (1998) point out that interannual patch selection patterns are highly correlated with interannual changes in random patch characteristics. They conclude that these species are tracking interannual changes in habitat.

However, a strong correlation between interannual variation in use and random patch characteristics suggests that changes in selected habitats mirror interannual changes in local habitat and not the tracking of resource hotspots by individuals. Furthermore, site fidelity seems to be at least marginally expressed by shrubsteppe birds. Banding studies in Oregon reveal that sage sparrows and to a lesser extent Brewer's sparrows have a strong likelihood of breeding in the same location as they did in the previous year (Wiens 1985). Also, studies investigating the effect of sagebrush manipulations have illustrated that Brewer's and sage sparrow abundance respond slowly to significant changes in habitat structure (Schroeder and Sturges 1975, Castrale 1982, Rotenberry and

Knick 1999). Finally, resource tracking, if measured at the appropriate scale, should strengthen not weaken correlations between physiognomy and species abundance.

A more plausible explanation for the apparent decoupling of habitat physiognomy and breeding bird density in the sagebrush steppe environment is that winter mortalities affect site occupancy on the breeding grounds (Rotenberry and Knick 1999). Except for the horned lark, the avian community of the sagebrush steppe is migratory and winter in southern United States thousands of kilometers south of their breeding grounds. The prevailing view is that winter mortality regulates bird populations within the sagebrush steppe (Wiens and Rotenberry 1981b, Dunning and Brown, 1982, Dunning 1986, Rotenberry and Knick 1999). Hence, unoccupied breeding territories may result from winter mortalities in the south and not from any intrinsic characteristic of breeding habitat quality. If breeding bird habitat is not saturated, as appears to be the case in sagebrush steppe (Rotenberry and Wiens 1980, Wiens and Rotenberry 1981b), suitable territories may remain unoccupied for several years (Rotenberry and Knick 1999).

Despite overall ambiguity in correlations between species abundance and habitat structure, some broad patterns in the habitat associations of sagebrush-grassland breeding bird communities do exist. Brewer's sparrows, the most abundant species in sagebrush-grasslands, are positively correlated with big sagebrush, total shrub cover, bare ground, measures of horizontal habitat heterogeneity, and patch size; and they are negatively correlated with grass cover (Wiens and Rotenberry 1980, 1981a). Sage sparrows have a similar distribution to Brewer's sparrows are found at sites with high sagebrush cover, and show some patch size sensitivity (Knick and Rotenberry 1995, 1999). The sage thrasher, like the Brewer's and sage sparrow, is a sagebrush obligate and is positively correlated with shrub cover, bare ground, and measures of horizontal habitat heterogeneity (Wiens and Rotenberry 1980, 1981a).

THE SAGEBRUSH STEPPE OF WYOMING: DISTRIBUTION AND MANAGEMENT CONCERNS

Wyoming boasts the highest sagebrush cover of any western state (Beetle and Johnson 1980), with sagebrush covering approximately 8.4 million hectares, equivalent to 33.4% of the state's area (Driese et al 1997). Despite the abundance of sagebrush communities throughout the West, shrubsteppe bird populations have declined over the

past 30 years more consistently than any other group of birds in the United States (Saab and Rich 1997). In the Intermountain West more than 50% of sagebrush-grassland species are declining (Saab and Rich 1997). Of those bird species that breed in sagebrush shrublands, 17 species, including sagebrush obligates such as Brewer's sparrow, sage sparrow, and sage thrasher, score high on the Partners in Flight's priority ranking in one or more of eight western states (Paige and Ritter 1999).

Sagebrush manipulation with herbicides, mechanical removal, and prescribed fires has fragmented the sagebrush steppe. Sagebrush grows slowly, and therefore, once disturbed, it takes years for the community to recover (Harniss and Murray 1973). Although sagebrush manipulation is important to ranching interests, sagebrush treatments can negatively impact wildlife populations. Studies have illustrated declines in sage grouse in response to sagebrush treatment (Wallestad 1975).

Western sagebrush management practices of concern to avian communities include cattle ranching, recreation, prescribed burns, wildfires, and farming (Paige and Ritter 1999). Ranching is important economically and socially in western states. However, less than 1% of sagebrush steppe remains untrammelled by livestock. Roughly 50% of sagebrush steppe is lightly to moderately grazed and has remnants of native forb cover, while 30% is heavily grazed and the native understory has been replaced by introduced annuals (West 1988, 1996). Since 1900, sagebrush communities have been manipulated through mechanical alteration, prescribed burning, and chemical treatment to increase forage for livestock. By conservative estimates, more than 10% of western sagebrush communities have been altered by some form of treatment, and by 1974, over 30% of Colorado sagebrush communities had received some form of treatment (Braun et al. 1976).

Regardless of the removal method (burning, mechanical, or chemical spraying), sagebrush manipulation reduces an important stratum for shrub nesting birds and increases the openness of the area (Best 1972, Schroeder and Sturges 1975, Castrale 1982, Kerley and Anderson 1995, Knick and Rotenberry 1995). The effect of manipulation is a decline in sagebrush obligate bird abundance and an increase in open and grass tolerant species such as horned larks, vesper sparrows, and western

meadowlarks (Best 1972, Castrale 1982, Peterson and Best 1987, Kerley and Anderson 1995).

Recreational activities and farming also affect the sagebrush-grassland avian community. Recreational activities such as camping, hiking, biking, and off-road driving can degrade habitats through the trampling of plants and cryptogamic crusts, the increased incidence of fire, weed invasion, nest abandonment, and road kills (Paige and Ritter 1999). Dryland farming and human development also impact sagebrush habitats by converting contiguous sagebrush communities into fragmented patches. Dry land farming aided by irrigation has converted over half of Washington State's sagebrush habitat into farms. The remaining 50% of Washington's sagebrush exists in isolated fragments, with only 12% managed by state agencies. The balance is under private and corporate ownership (Dobler et al. 1996).

In Wyoming there is growing concern about the effect of natural gas and oil field development on the state's sagebrush steppe communities. Since the discovery of oil and gas in Wyoming in the 1930's, resource development has become prevalent throughout the state. Natural gas is a clean and efficient fossil fuel, and per BTU produces 85% - 96% less emissions than the combustion of either coal or oil. Natural gas consumption is expected to increase by over 40% by the year 2015, expanding natural gas' share of the national energy market to 28% (PIC Technologies and Bureau of Land Management 1999). While the development of domestic energy sources is important for economic stability and to reduce United States' dependency on foreign energy sources, there is concern about the effect gas development will have on Wyoming's wildlife. This project was initiated to examine the potential impact of natural gas development on passerines breeding within the sagebrush steppe dominated Pinedale Anticline Project Area (PAPA).

STUDY OBJECTIVES

It is anticipated that the effects of natural gas development and extraction on the avian community of this sagebrush dominated projected area will be both positive and negative. While the potential effects of development will have different ramifications for different species, it is important to note that development does not necessarily present a negative relationship with the associated avian community. For example, gas structures such as holding tanks provide nesting structures for common ravens (*Corvus corax*), and

roads associated with development provide advantageous foraging conditions for horned larks who forage on windblown seeds deposited in the lee of gravel on dirt roads. At the same time, vegetation clearing associated with well pad, road, and pipeline construction will create a direct loss of habitat, the effect of which may be compounded by the introduction of exotic species along disturbed habitats, increased noise associated with construction and extraction, increased human presence, and habitat fragmentation.

The two goals of my study are (1) to provide baseline data on avian abundance, community structure, and habitat associations in the PAPA, and (2) to assess the potential response of passerines to natural gas development and extraction. Because roads are the most conspicuous disturbance associated with natural gas development, my assessment of development impact focused on changes in bird distribution along roads associated with development. My specific objectives for chapter two were:

- 1) Identify correlations between species abundance and vegetation characteristics.
- 2) Identify habitat characteristics based on song perch location.
- 3) Identify habitat characteristics of nest site location for sagebrush obligate species.

For chapter three, my objective was to examine changes in species abundance and composition within 100-m of road corridors relative to species abundance and composition outside of the 100-m buffer.

STUDY AREA

The Pinedale Anticline Project Area (PAPA) is located along the western edge of central Wyoming in Sublette County. The project area is bordered to the east by Highway 191 and to the west by the Green River. The town of Pinedale demarcates the project's northeast boundary, and the Jonah II Field, approximately 56 kilometers south of Pinedale, marks the project's southern boundary (Fig. 2). The Pinedale Anticline Project Area encompasses 80,000 hectares (197,345 acres) and is dominated by sagebrush and high-desert vegetation. Riparian vegetation and wetlands associated with the Green and New Fork River floodplains occur along the project's east and west boundaries. The area is dominated by Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*), with portions of basin big sagebrush (*Artemisia tridentata* ssp. *tridentata*) located throughout the bottoms of draws. Common grasses and forbs within the PAPA include crested wheat grass (*Agropyron cristatum*), smooth wildrye (*Elymus glaucus*),

needle and thread grass (*Stipa comata*), indian rice grass (*Oryzopsis hymenoides*), squirrel tail (*Elymus elymoides*), penstemon (*Penstemon spp.*), lupine (*Lupinus spp.*), white-stemmed globe mallow (*Sphaeralcea munroana*), wild flax (*Linum perenne*), fringed sagewort (*Artemisia frigida*), desert buckwheat (*Eriogonum spp.*), carpet phlox (*Phlox hoodii*), desert paintbrush (*Castilleja chromosa*), birdsbeak (*Cordylanthus ramosus*), purple aster (*Machaeran canexcens*) and vetch species (*Hedysarum spp.*) (Lyon 2000). The Bureau of Land Management manages 80% of the project area (63,828 hectares), while the remainder is state and private lands (3,952 hectares, and 12,084 hectares respectively) (PIC Technologies and Bureau of Land Management 1999, Bureau of Land Management 2000).

The Pinedale Anticline Project Area provides habitat for a number of species of migratory songbird, a resident population of sage grouse, pronghorn antelope (*Antilocapra americana*), and crucial winter range for mule deer (*Odocoileus hemionus*). Common bird species in the PAPA include sagebrush obligates (Brewer's sparrow, sage sparrow, and sage thrasher) and non-sagebrush obligates (horned lark and vesper sparrow). Other species sporadically distributed throughout the PAPA include green-tailed towhees, lark buntings (*Calamospiza melanocorys*), mourning doves, and rock wrens (*Salpinctes obsoletus*).

The first natural gas well was drilled in the PAPA in 1939. However, only recently, after the application of new natural gas extraction technologies within the Jonah Fields south of the PAPA, has there been interest in developing the area. Between 1939 and 1997, only 23 wells were drilled within the project area. In May, 1998, the BLM's Pinedale field manager approved limited exploratory drilling of 45 wells prior to completion of the final Environmental Impact Statement (PIC Technologies and Bureau of Land Management 2000).

During the project, between May 1999 and July 2000, development within the PAPA was limited to the installation of a few exploratory wells and extensive seismographic surveys throughout the project area during the fall of 1999. The final EIS was approved in late July 2000. Full development of this field began that July and is expected to continue for the next 10-15 years. While development is expected to be concentrated within a 5-km buffer around the anticline crest (running north to south

through the PAPA), the BLM has leased all but 19 km² of the area. Numerous "hot spots" may be developed outside this buffer zone. The BLM's record of decision approved the construction of 700 producing well pads with minimum spacing of 16 hectares (40-acres) between pads (6 wells/km², equivalent to 16 wells/mile²). To achieve 700 producing wells, as many as 900 well pads could be constructed since it is expected that up to 200 of constructed wells will be dry or uneconomical to develop (Bureau of Land Management 2000).

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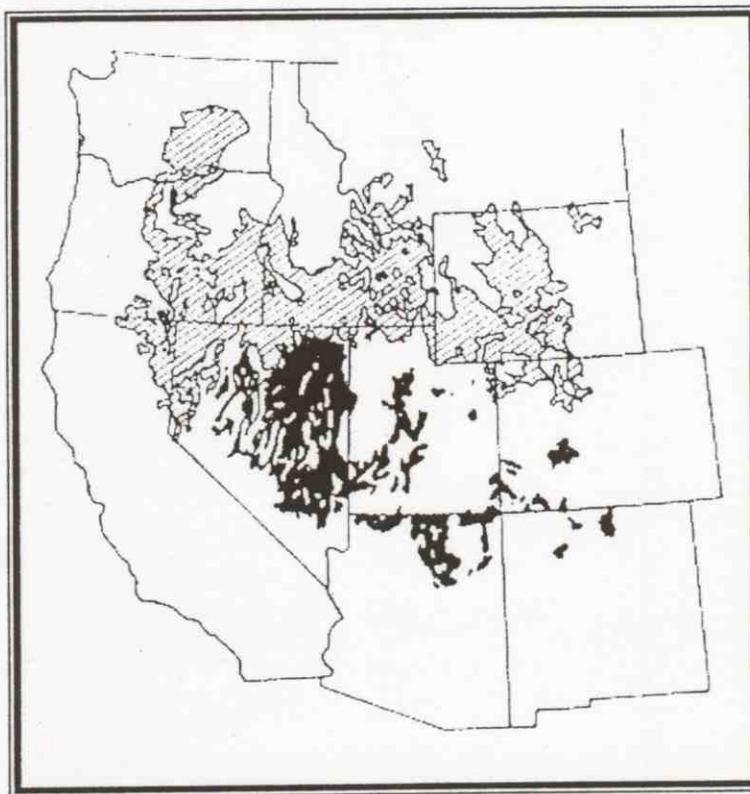


Figure 1.1. Distribution of the sagebrush steppe and Great Basin sagebrush types (adapted from Küchler 1970). Some sagebrush vegetation in California is not shown.

▨ = Sagebrush steppe ■ = Great Basin Sagebrush (Adapted from Küchler 1970)

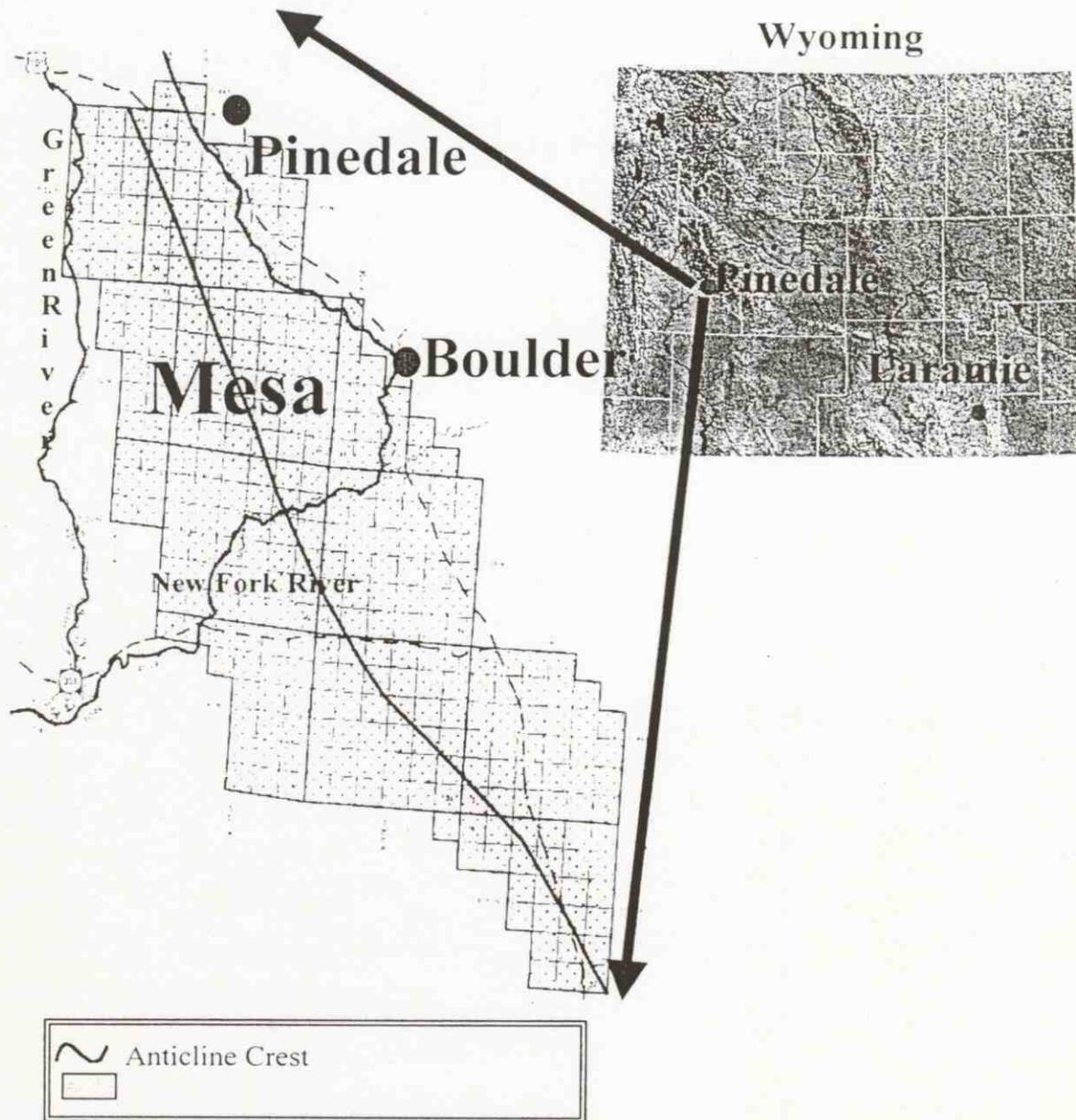


Figure 1.2. Pinedale Anticline Project Area, Sublette County, Wyoming.

Chapter II

Avian Community Structure and Habitat Associations within the Sagebrush Steppe of the Pinedale Anticline Project Area, Sublette County, Wyoming

INTRODUCTION

It has long been accepted that species are found in habitats where their requirements for survival and reproduction are met (Anderson, 1981). The study of habitat selection in birds focuses on the identification of those proximate cues to which birds respond during territory establishment. This process is confounded by the fact that birds often establish territories long before the ultimate factors that determine survival and productivity, such as food availability, are apparent (Cody 1985). For birds, physiognomy (habitat structure) has repeatedly been shown to be important in determining bird distribution and abundance (MacArthur and MacArthur 1961, James 1971, Anderson and Shugart, 1974). It is believed that vegetation structure provides those proximate cues through which birds assess habitat suitability and the availability of important resources such as food, nest sites, refuge from predators, and shelter from the environment (Hildén 1965). Clearly birds do not respond to habitat variables independently, but instead respond to a suite of habitat characteristics simultaneously. This species-specific preference for certain visual combinations of vegetation structure is analogous to James's (1971) niche-gestalt.

Habitat associations of the sagebrush-steppe breeding bird community have been studied extensively (Wiens 1974; Rotenberry 1978; Wiens and Rotenberry 1980, 1981, 1998; Wiens et al. 1987; Knopf et al. 1990; Knick and Rotenberry 1995, 1999; Rotenberry and Knick 1999). Low species abundance and diversity characterize this community (Wiens 1985). Common species include sagebrush obligates such as the Brewer's sparrow (*Spizella breweri*), sage sparrow (*Amphispiza belli*), sage thrasher (*Oreoscoptes montanus*), and grassland species such as horned larks (*Eremophila alpestris*) and vesper sparrows (*Pooecetes gramineus*). The climate of the sagebrush steppe is characterized by semi-desert. Winter snowfall is the predominate form of precipitation; winters are long, summers are hot, and winds are persistent. Annual precipitation is variable and averages 246 mm in sagebrush steppe and between 158-419

mm in the Great Basin (West 1983; West and Young 2000). While variation in precipitation has little effect on sagebrush (*Artemisia tridentata*.) cover and stature, its effect on grass and forb cover can be substantial (Rotenberry and Wiens 1980). Within the shrubsteppe, breeding bird populations rarely reach densities approaching carrying capacity, in part due to limitations placed on multiple broods by the hot, short breeding seasons, increased predation during wet years, and constraints on wintering populations (Wiens 1974, 1977; Rotenberry 1980; Rotenberry and Wiens 1989). As a result, suitable habitat within the sagebrush steppe bird community is frequently unsaturated, and the cost (reduced fitness) associated with non-optimal selection of habitats and foraging behavior is minimal (Wiens 1974, 1977). Within this system, the evolutionary impetus for specialization is rare. Instead of niche differentiation and resource specialization, a guild of generalists has developed with broadly overlapping territories, diets, and habitat associations (Wiens and Rotenberry 1979, 1981). This generalized behavior has led to the decoupling of breeding-bird abundance and measures of habitat structure.

In Wyoming, sagebrush steppe covers approximately 33.4% of the land area (Driese et al. 1997). Although the relationship between habitat structure and breeding bird abundance in these communities is poorly expressed, the prevalence of this habitat type, and the current development trends throughout the sagebrush steppe, necessitate investigation of the habitat associations of this breeding bird community.

The goal of my study was to examine habitat associations of the breeding bird community within the Pinedale Anticline Project Area (PAPA), an 80,000-hectare, Wyoming big sagebrush-dominated management area in the beginning phases of natural gas development. Habitat associations were investigated at the territory level by comparing species abundance in point counts and bird-centered locations with habitat physiognomy. The objectives of the study were to: (1) document the distribution of breeding birds within the project area; (2) examine how habitat features best the distribution of the breeding bird community; (3) and compare the vegetation structure of bird-centered use plots among different species and between use and random locations.

METHODS

Study Area and Plot Location

The study was conducted in the Pinedale Anticline Project Area, as described in chapter one. Breeding bird abundance was surveyed using 50-m radius point counts (Ralph et al. 1995) between May 15 and the end of June 2000. Points were grouped in five areas throughout the PAPA and distributed in a manner that surveyed a range of sagebrush canopy cover and height typical of the study area. Each group contained 20 points spaced at 250-m intervals to ensure independence of counts. Two of the groups (40 points) were located in the northern portion of the PAPA on the Mesa, an elevated plateau that covers approximately one-third of the study area (Fig 2.1). This area was typified by relatively tall (>25cm average sagebrush height), dense, homogenous stands of sagebrush. Another three groups (60 points) were located within the central part of the project area between the southern portion of the Mesa and north of Highway 351 (Figure 2.1). At this site, sagebrush cover was more variable and had lower stature than on the Mesa.

Counts were surveyed for five minutes. Time began once the observer reached the 50-m boundary of the plot. Walking slowly towards the point's center, the observer would record and map all birds detected by sight and sound. Birds that were flushed into the site upon approach were not recorded unless they returned to the plot later in the survey. Point counts were visited three times during the 2000 breeding season and were surveyed between the hours of 0520 and 0830 on rain free mornings with wind speeds below 15 km/hr. Twenty points could be surveyed per morning. On consecutive visits, points were surveyed in reverse order to ensure equal dispersion of points within the sampling period. Mean number of point count detections were calculated by averaging count totals from the three visits for the number of each species detected, as well as the number of sagebrush obligates (sum of Brewer's sparrow, sage sparrow, and sage thrasher).

Vegetation Structure

Vegetation measurements were recorded at each point to examine correlations between bird abundance and habitat structure and vegetation floristics. Vegetation structure was evaluated along line transects and included measures of canopy cover,

shrub density, grass and forb cover, vegetation density, and horizontal heterogeneity (Table 2.1). Four 50-m tapes were oriented at 90° angles to each other and extended into each of the four point count quadrants. On each 50-m transect, vegetation measurements were recorded along three 10-m intervals, namely, 10-20m, 25-35m, and 40-50m, from the plot's center.

The line-intercept method (Canfield 1941) was used to determine the percent canopy cover of live and dead sagebrush and live rabbitbrush (*Chrysothamnus spp.*). The height and species of each intercepted shrub was recorded and used to determine average height of each shrub species within the plot ($\sum_{i=1}^n (\text{height}_i * \text{length}_i) / \sum_{i=1}^n (\text{Length}_i)$). Live and dead sagebrush density (plants/m²) was determined using a 1-m wide band transect taken along each of the twelve 10-m transect sections (James and Shugart 1970).

Percent cover of grasses, forbs, litter, bare ground, lichen, cactus, cow dung, and total ground cover was determined by class using a 20 cm x 50 cm Daubenmire frame (Daubenmire 1959). Cover classes were 0-5%, 5-25%, 25-50%, 50-75%, 75-95%, and 95-100%. Daubenmire frame samples were taken at 24 sites per plot, six along each 50-m transect, and centered at 12.5 m, 17.5 m, 27.5 m, 32.5 m, 42.5 m, and 47.5 m from the plot's center. Total cover for each variable was calculated by averaging the 24 Daubenmire frame samples taken within the plot.

A density board (20 cm x 100 cm) was used to calculate the average vegetation density within each decimeter interval (10-cm), average maximum vegetation height, and an index of plot shrubbiness. Density board samples were recorded at 24 sites within each plot, and samples were taken in the same location as Daubenmire frame samples. Vegetation density within each decimeter interval was estimated by walking 5 m away from the density board, in a direction perpendicular to the transect and recording the percent of the density board covered by all vegetation forms. Cover classes were the same as those used for the Daubenmire frame. Vegetation density within each decimeter interval was calculated by averaging the values obtained from the plot's 24 density board samples. Maximum height of vegetation for each plot was the average maximum decimeter with vegetation cover. An index of plot shrubbiness was calculated as the vegetation density within the first two decimeters.

Horizontal heterogeneity was measured as the between-sample variation in vertical structure and was indexed by using the coefficient of variation (CV) between the 24 samples of maximum vegetation height recorded with the density board (CVMAXHT) (Wiens and Rotenberry 1980). To correct for small sample bias, the following estimate of CV was used:

$$CV = (1 + (1 / 4n)) (s * 100 / Y_{\text{bar}})$$

(Sokal and Braumann 1980).

Bird-Centered and Random Plots

Vegetation characteristics were also measured at bird-centered locations to examine habitat associations within territories (Johnson 1980, James 1971, Larson and Bock 1986). Fifteen-meter radius (0.07-hectare) plots were centered on locations of singing males and nest locations that were encountered while walking between point count survey locations. These sites were flagged, and vegetation was sampled at the end of the survey season to limit disturbances within the study area. Paired random plots were also sampled and were located randomly at a distance between 100 – 200 m from bird-centered locations. Point zero seven-hectare plots were used rather than 0.04 hectare plots (James 1971), to maintain consistency between studies already conducted within the project area and throughout Wyoming's sagebrush steppe (Hollaran 1999, Lyon 2000).

Vegetation sampling methodologies were similar to those used to measure vegetation attributes of point counts. Four 15-m tapes, centered on the bird use or random locations were extended at 90° to each other and oriented in a random direction. The line-intercept method (Canfield 1941) was used to estimate the percent live and dead sagebrush, and live rabbitbrush canopy cover along each 15-m transect. Live and dead sagebrush density was measured using 1-m wide band transect. Daubenmire frame (Daubenmire 1959) and density board samples were taken at twelve locations within each plot and were located along each transect at a distance of 2 m, 6 m, and 10 m from the plot's center.

Statistical Analysis

Plot-Level Analysis of Habitat Selection

Poisson regression was used to model second order (territory level) selection (Johnson 1980) based on habitat associations of individual species and the guild of

sagebrush obligates. Poisson regression was used because means from count data are Poisson in distribution, and transformations of count data fail to satisfy the assumptions of linear regression (Ramsey and Schafer 1997). Poisson regression is a generalized linear model in which the logarithms of the mean response are linear in the regression coefficients. $\text{Log}(\mu) = \beta_0 + \beta_1x + \dots + \beta_{i_x}x_i$, or equivalently, $\mu = \exp(\beta_0 + \beta_1x + \dots + \beta_{i_x}x_i)$ (Ramesy and Schafer 1997). Poisson distributions have the following characteristics: the variance equals the mean, distributions tend to be skewed to the right, and asymmetry is more pronounced when means are small, as with point count data. Traditional transformations of count data fail to meet the assumptions of linear regression, which include equal variance (log transformation of the response) and linearity of the response with predictor variables (square root transformation of the response) (Ramsey and Schafer 1997). Therefore Poisson regression was used to model habitat associations.

Appropriate models were investigated using best subsets linear regression with the log-transformed count data as the response and measures of vegetation structure as the predictor variables. This procedure provided a rough estimate of predictor variables to include in Poisson regression models of habitat associations. Models were judged to be statistically significant at the 0.05 level by using the drop-in-deviance test, which is analogous to linear regression's extra sum of square residuals and compares the deviance statistic from a full model to that of a reduced model. The sampling distribution of the drop in deviance has an approximate chi-square distribution with degrees of freedom equal to the number of coefficients in the full model minus the number of coefficients in the reduced model. Other tests of significance, such as tests of residuals and the deviance goodness-of-fit test, are inappropriate when Poisson means are small (less than five). Therefore they were loosely interpreted when assessing the statistical significance of the model (Ramesy and Schafer 1997).

Bird-Centered Use vs. Random Analysis

In the study of habitat associations based on bird-centered plots, discriminant function analysis (DFA) was used to ordinate species along multi-dimensional habitat space to provide inference into species habitat associations and relative species habitat preference (James 1971, Sedwick 1987). Discriminant analysis is comprised of two statistical procedures, discrimination and classification (Klecka 1980). Discrimination

uses several variables (measures of habitat structure) to maximize the degree of separation between groups (individual species) based on habitat associations. Classification is used to measure the fit of the model and prediction capabilities of discriminant functions (Klecka 1980, Pavlacky 2000). Because multicollinearity between discriminating variables can lead to spurious results, Pearson's correlation procedure was used to identify correlated variables. When variables were highly correlated ($r > 0.70$), one of the variables was dropped from the analysis (Anderson and Shugart 1974).

The Statistical Program for the Social Sciences computer package (SPSS Version 10.0) was used to perform all DFA. The assumption of homogeneity of the correlation matrix was confirmed using the Box's M test procedure. It was hypothesized *a-priori* that species would discriminate based on measures of sagebrush height and stand decadence. Variables assessed for use in this model included live and dead sagebrush canopy cover, height of live and dead sagebrush, rabbitbrush canopy cover, average maximum height, grass cover, forb cover, litter cover, and an index of plot shrubbiness. DFA was conducted on six bird species, namely, Brewer's sparrow, green-tailed towhee, horned lark, sage sparrow, sage thrasher, and vesper sparrow, and a combination of these species grouped into three guilds, grassland species (horned lark and vesper sparrow), sagebrush obligates (Brewer's sparrow, sage sparrow, and sage thrasher), and the green-tailed towhee ($n = 76$). Discriminant functions with a P -value < 0.05 were considered statistically significant, and functions were interpreted and named based on the variable exhibiting the greatest structure loadings (Klecka 1980). Classification was used to assess the appropriateness of the discrimination, and prior probabilities were adjusted to reflect the relative abundance of each species or guild in the analysis.

Paired t -tests were used to assess differences between use and random locations for each individual. The vegetation parameters that were assessed included live and dead sagebrush canopy cover, sagebrush height, average maximum vegetation height, and an index of plot shrubbiness. Tests were considered significant at $\alpha = 0.05$. Because multiple tests of the same hypothesis were conducted, a Bonferroni correction was applied to the decision rule of each test to maintain a family error rate of 0.05 (α critical = 0.01).

RESULTS

The vegetation within the Pinedale Anticline Project Area is dominated by Wyoming big sagebrush (*Artemisia tridentata wyomingensis*) and occurs in a continuous, homogenous stand. Aside from light cattle grazing in the spring, and treatment of a few areas by aerial spraying of the herbicide 2,D-4 in the 1960's, the vegetation is relatively undisturbed. Average sagebrush cover was 17%, and ranges between 7% - 26%. The mean sagebrush height within surveyed plots was 22 cm (12 cm – 36 cm) (Table 2.2). The northern portion of the PAPA, which is at a higher elevation than the rest of the project area, has greater sagebrush canopy cover and heights, as well as greater grass and forb cover (Table 2.3). Within the study area, mean number of total detections per point count was 1.67 (SE = 0.10), and 1.00 (SE = 0.089) for sagebrush obligates, equivalent to 2.12 and 1.27 individuals per hectare, respectively (Table 2.4). Differences in vegetation structure were reflected in point count means. In the northern PAPA, mean number of detections of sagebrush obligate and Brewer's sparrow were twice as great as in the southern portions of the study area ($P < 0.000$). Conversely, mean detections of vesper sparrows were three times greater in the southern portion of the study area. Overall, total mean number of detections per point count was 24% greater in the northern PAPA, a difference that was not statistically significant ($P = 0.057$) (Table 2.5).

Five common species, Brewer's sparrows, horned larks, sage sparrows, sage thrashers, and vesper sparrows, dominate the avifauna of the PAPA. The Brewer's sparrow is the most common species and accounts for half of all bird detections. Brewer's sparrows also dominated at higher elevations, in the northern portion of the PAPA, Brewer's sparrows dominate, but relative abundance of vesper sparrows increased at lower elevations to the south (Fig. 2.2). Ninety-nine of the 100 point counts had at least one detection during the course of three visits. Brewer's sparrows occurred in 77, horned larks in 45, sage sparrows in 53, sage thrashers in 10, and Vesper sparrows occurred in 56 of the 100 points surveyed. Other species found scattered throughout the PAPA included willets (*Catoptrophorus semipalmatus*), common nighthawks (*Chordeiles minor*), rock wrens (*Salpinctes obsoletus*), mallards (*Anas platyrhynchos*), American widgeon (*Anas americana*), common ravens (*Corvus corax*), and green-tailed towhees. Many of the rarer species were found in habitats that were sparsely distributed

throughout the study area. For example, Rock wrens were associated with rock outcroppings and down cut banks of intermittent streams that drain the project area. Various species of waterfowl such as mallards and American widgeon used cattle reservoirs, common ravens nested on structures associated with natural gas extraction, and green tailed-towhees inhabited areas where winter snow deposition increased shrub diversity. A number of other species are found throughout the PAPA during migration including long-billed curlews (*Numenius tenuirostris*), Say's phoebes (*Sayornis saya*), white-crowned sparrows (*Zonotrichia leucophrys*), and dark-eyed juncos (*Junco hyemalis*) (Table 2.6 for complete species list).

Poisson Regression

Best subsets linear regression yielded few significant correlations between the log-transformed response of mean point count detections and measures of habitat structure (Table 2.7). Therefore, Poisson regression was only used to model habitat associations of Brewer's sparrows and sagebrush obligates. In both models, an index of plot shrubbiness, the vegetation density within the first two decimeters, was the best predictor of species abundance. This index was highly correlated with sagebrush canopy cover ($r = 0.64$), sagebrush height ($r = 0.72$), litter cover ($r = 0.82$), and maximum vegetation height ($r = 0.89$). Brewer's sparrow abundance increased by 50% for each 10% increase in shrubbiness (Table 2.8, Fig.2.3; 95% CI = 25% - 81%, drop-in-deviance $P < 0.0001$, Wald's $P < 0.0001$). Sagebrush obligate abundance increased by 42% for each 10% increase in shrubbiness (Table 2.9, Fig. 2.3; 95% CI = 21% - 66%, drop-in-deviance test $P < 0.0001$, Wald's $P < 0.0001$).

Discriminant Function Analysis

Discriminant function analysis was used to investigate relative habitat associations of the sagebrush steppe breeding bird community. Three separate analyses were conducted, one discriminating between species, another between guilds based on habitat structure measured at song post locations, and a third discriminating between species based on habitat associations of nest sites.

In the species wide analysis of song post data, DFA produced one statistically significant discriminant function with average sagebrush height and dead sagebrush canopy cover as the discriminating variables (Wilk's $\lambda = 0.220$, $df = 10$, $p < 0.000$,

canonical $R^2 = .757$ (Table 2.10). In this analysis, sagebrush height exhibited the greatest explanatory power, with dead sagebrush canopy cover providing little inference (Table 2.10). Group centroids were negative for the horned lark and vesper sparrow, near zero for the Brewer's sparrow, and positive for the sage sparrow, sage thrasher and green-tailed towhee (Table 2.10). DFA correctly classified 46.1% of the 76 cases, a classification rate 14.4% greater than that expected by random assignment (Table 2.11). Misclassification was common between the grassland species (horned lark and vesper sparrow), and between sagebrush obligates (Brewer's sparrow, sage sparrow, and sage thrasher), but classification was good for the vesper sparrow and green-tailed towhee (Table 2.11).

Because DFA failed to discriminate between species within the same guild, DFA was also run on the same data set with species grouped by guild. Guilds included grassland species (horned lark and vesper sparrow), sagebrush obligates (Brewer's sparrow, sage sparrow, and sage thrasher), and the green-tailed towhee. DFA produced two statistically significant discriminant functions using sagebrush height and dead sagebrush cover as discriminating variables. Discriminant function one (DF1) accounted for the majority of the differences in guild habitat associations (Wilk's $\lambda = .250$, $df = 4$, $p < 0.000$, canonical $R^2 = .728$). Within DF1, sagebrush height had the greatest discriminating power (Table 2.12). Group centroids were negative for grassland birds, positive for sagebrush obligates, and greatest for the green-tailed towhee. The second discriminating function (DF2) described differences in guild habitat association based on the amount of dead sagebrush canopy cover (Wilk's $\lambda = .917$, $df = 4$, $p = 0.012$, canonical $R^2 = 0.083$) (Table 2.12). Group centroids were negative for the green-tailed towhee and grassland birds, and positive for sagebrush obligates (Table 2.12, Fig. 2.4). DFA correctly classified 89.5% of the 76 cases, a classification rate 80.6% greater than that expected by random case assignment (Table 2.13).

DFA was used to investigate relative bird-habitat associations based on nest sites for four species, namely, Brewer's sparrow, horned lark, sage sparrow, and sage thrasher. DFA produced one statistically significant discriminant function based on sagebrush height and dead sagebrush canopy cover (Wilk's $\lambda = 0.485$, $df = 6$, $P = 0.001$, canonical $R^2 = 0.440$) (Table 2.14). Sagebrush height and dead canopy cover provided similar

discriminating power (Table 2.14). Group centroids were negative for the horned lark and sage sparrow, and positive for the Brewer's sparrow and sage thrasher (Table 2.14). DFA correctly classified 52.9% of the 34 cases, a classification rate 35.1% better than expected by random case assignment (Table 2.15).

Habitat Use vs. Random Locations

Paired *t*-tests were used to discern if patterns in species habitat use differed from what was locally available. Vegetation structure variables at song posts did not differ statistically from paired random sites for either the horned lark or vesper sparrow (Table 2.16). Vegetation structure at Sagebrush obligate song posts had greater big sagebrush heights and canopy cover than paired random sites (Table 2.16). Vegetation structure at nest sites did not differ from random sites for any of the species analyzed (Table 2.17).

DISCUSSION

Within the Pinedale Anticline Project Area, species abundance was only loosely correlated with measures of vegetation structure and floristics. This pattern of species distribution is common within sagebrush steppe habitats (Wiens and Rotenberry 1980, 1981; Wiens 1985; Wiens et al. 1987), where species abundance is often below the habitat carrying capacity (Wiens 1974, 1977) and habitat occupancy is more a function of population processes that occur during the winter than of habitat quality on the breeding ground (Rotenberry and Knick 1999). Interannual variation in site occupancy also confounds studies of habitat associations at this scale (Wiens and Rotenberry 1981, Knick and Rotenberry 1995, Rotenberry and Knick 1999). Within the sagebrush steppe, widely distributed species usually have few significant associations with habitat structure, while species with localized distributions exhibit habitat affinities (Wiens and Rotenberry 1981). For example, within the PAPA, the five core species (Brewer's sparrow, horned lark, sage sparrow, sage thrasher, and vesper sparrow) were weakly correlated with habitat physiognomy, whereas green-tailed towhees and rock wrens were found either in areas of increased shrub diversity (towhees) or near rock outcroppings and down cut banks (rock wrens).

Despite their loose correlation, some patterns in species abundance were apparent. Sagebrush obligate abundance, especially the Brewer's sparrow, was positively correlated with measures of sagebrush height. Sagebrush height and an index of plot

shrubbiness were the best predictors of sagebrush obligate abundance. This is contrasted by previous work on sagebrush steppe avifauna, which suggests that at this scale sagebrush obligates are better correlated with cover of specific shrub species than with measures of physiognomy (Wiens and Rotenberry 1980, 1981; Knopf et al. 1990). However, within the PAPA, sagebrush distribution was relatively homogeneous and floristics variation was minimal. Specific shrub species, which in previous studies elucidated relationships between abundance and floristics, were virtually absent from this study area. Spiny hopsage (*Grayia spinosa*) and shadescale saltbush (*Atriplex confertifolia*) were absent, grease wood (*Sarcobatus spp.*) occurred in only one plot, and rabbitbrush distribution was sparse and of low stature.

The observed association between species abundance and habitat structure differs from patterns found in previous studies conducted in other areas, which illustrates that habitat selection is a process that operates at the level of the relative abundance of habitat features and not on a hierarchical evaluation of features considered individually. For example, a state-wide analysis of species habitat association in sagebrush communities in Washington showed that sagebrush obligates were most strongly associated with sagebrush canopy cover (Dobler et al. 1996), where mean sagebrush canopy cover was only 6.7% with a maximum cover of 19.2%. In the PAPA, 6% sagebrush canopy cover is the area low, and 17% cover is the mean. Perhaps, once bird species are within the appropriate general habitat configuration, individuals fine-tune their habitat use based on what is locally limiting (Wiens and Rotenberry 1981). Sagebrush canopy cover may constrain habitat use in Washington, but sagebrush height may have been more confining in my study area.

Brewer's sparrow nesting requirements may explain some of their correlation with sagebrush structure. Whereas sage sparrows will nest on the ground, Brewer's sparrows build their nests in the sagebrush canopy and require bushes tall enough to provide both an elevated nest platform and sufficient cover above the nest. Peterson and Best (1985) found that Brewer's sparrow's nests were never located below 20 cm, and in my study, nest heights were never below 21 cm, nor in bushes less than 30 cm tall. Also, no Brewer's sparrow nests were found in the 60 points located in the central PAPA where AVEMAXHT was only 20 cm. This suggests that habitat use may have a threshold were

patterns in use are manifest when habitats characteristics are below some threshold value but ambiguous when values are above (Wiens 1985).

Analyses of relative habitat associations using discriminant analysis also illustrated the importance of physiognomy in structuring habitat use patterns. In all functions, sagebrush height had the greatest power in discriminating between species and guilds. Stand decadence, as indicated by dead sagebrush canopy cover, was another important discriminating variable. Grassland species and green-tailed towhees were negatively associated with shrub decadence. The green-tailed towhee was only found in stands where sagebrush was mixed with snowberry, agreeing with previous studies that have shown that green-tailed towhees are associated with ecotones between sagebrush and other shrub species (Knopf et al. 1990). At these sites, snow loading increased the vigor of the plants in these stands, resulting in less dead sagebrush cover. The negative correlation between the abundance of grassland species and stand decadence was weak and may have been an artifact of the negative association between grassland birds and vertical structure.

Previous studies investigating the relationship between sagebrush decadence and habitat use have examined the relationship at the patch scale (Knopf et al. 1990, Rotenberry and Wiens 1998, Rotenberry and Knick 1999). Patches are defined based on their discontinuity with the surrounding habitat matrix. Patches are considered to be more or less contiguous associations of living and/or standing dead shrub material, understory forbs, grasses, and leaf litter that are distinctly set apart from neighboring patches by open, vegetation-free areas (Rotenberry and Wiens 1998). These studies found that Brewer's and sage sparrows selectively foraged in taller, more vigorous patches, and selection of vigorous patches probably reflects relative arthropod abundance (Rotenberry and Wiens 1998). Vigorous shrubs with dense, leafy foliage likely support more herbivorous insects, which, during the breeding season, comprise the majority of the diet of adult and nestling Brewer's and sage sparrows (Rotenberry and Wiens 1998).

While shrub vigor clearly imparts some foraging advantages, investigations at this scale ignore the possible importance of the matrix within which vigorous patches are imbedded. Sagebrush stands are typically uneven-aged with mature plants in the majority (Passey and Hugie 1962). When compared to younger stands, decadent,

uneven-aged stands are more open (Lommasson 1948) with less evenly distributed shrubs (Passey and Hugie 1962). While vigorous patches may provide favorable foraging sites, it is undetermined what roll stand decadence plays in determining the suitability of sagebrush habitats for sagebrush obligates. In other habitats, changes in plant community succession have been associated with changes in bird communities (Bond 1957, Anderson 1980); and within sagebrush habitats, sage grouse select decadent stands for nesting (Hollaran 1999, Lyon 2000). Although successional change within sagebrush communities is more related to overall stand structure than to changes in plant species composition, the increased structural diversity and heterogeneity created by decadence may be an important characteristic of sagebrush habitats.

Community wide DFA was unable to discriminate between the relative habitat associations of individual sagebrush obligate species, possibly due to small sample size. However, this is typical within this guild (Wiens and Rotenberry 1980, 1981). Breeding ground distributions below carrying capacity and frequent resource superabundance has led to little resource partitioning within this guild. Instead, these species seem to respond opportunistically to what is locally available, interspecific interactions are rare and species abundance varies independently of one another. Grouping species by guild provided a more biologically meaningful discrimination. In the guild based analysis, sagebrush obligates were positively associated with vegetation structure, a pattern that may be a function of their nesting requirements (Castrel 1982) and song post selection. For example, grassland species, specifically the horned lark, have evolved aerial territory displays, an adaptation to the paucity of elevated perches in grasslands, whereas sagebrush obligate species predominantly sing from elevated perches (Castrel 1983, Wiens et al. 1990).

Comparisons of species habitat use verses random locations also illustrated the loose coupling between habitat structure and species distribution. In the territory analysis based on song posts, sagebrush obligates appeared to select for taller sagebrush stands. This pattern may be attributed to song post selection biases; however, this bias should have been reduced by sampling vegetation around perch sites on a scale larger than the individual bush or patch. Also, Brewer's sparrows frequently sing from the same shrub in which they forage (Rotenberry and Wiens 1998). Based on this analysis, sagebrush

obligates use habitat in a nonrandom fashion. Sagebrush obligate nest site selection did not differ statistically from random plots. Again small sample size may have obfuscated patterns. However, the placement of nest sites within an area similar to the surrounding matrix may be biologically meaningful, as it is a behavior that could reduce nest predation.

CONCLUSION

Within the Pinedale Anticline Project Area, sagebrush occurs with a continuous, homogeneous cover with little variation in shrub species richness. Within this matrix, variations in bird species abundance are most strongly correlated with vegetation structure. Sagebrush obligates and the green-tailed towhee use habitats with greater average sagebrush heights than either the horned lark or vesper sparrow. Within the PAPA, sagebrush height is greater at the higher elevations in the northern portion of the study area, and there, concentration of sagebrush obligates is greatest. However, despite some patterns, the majority of variation in species abundance is not correlated with changes in habitat structure. Though sagebrush obligates are dependent on sagebrush, within this avian community, breeding ground distributions below carrying capacity and frequent resource superabundance has lead to little resource partitioning. Instead, these species seem to respond opportunistically to what is locally available; interspecific interactions are rare, and variation in species abundance occur independently of other species and habitat structure.

MANAGEMENT IMPLICATIONS

Throughout their range, Brewer's sparrows and to a lesser extent sage sparrows have undergone significant declines over the last 40 years (Sauer et al. 1997). Part of the reason is the prevalence of conversion and management caused fragmentation of sagebrush habitats throughout the West. In Washington, land use changes including dry land farming have resulted in the loss of over half of Washington's shrubsteppe habitats (Dobler et al. 1996). In Idaho, land use and invasion of exotic species such as cheatgrass (*Bromus tectorum*) and Russian thistle (*Salsola australis*) have resulted in the conversion of over 30% of southern Idaho's shrublands into annual grasslands, and shrub habitats now exist as fragmented patches (Whisenant 1990). In Colorado, herbicide treatment alone has altered over 30% of the sagebrush steppe (Braun et al. 1976). Formerly, shrub

dominated landscapes occurred in vast, unbroken tracts (Yenson 1980, Young 1989), and it is likely that this avian community is adapted to the relatively contiguous expanse of sagebrush within shrub dominated landscapes (Knick and Rotenberry 1995). In southern Idaho, both Brewer's sparrow and sage sparrow distributions are affected by landscape-level patterns in sagebrush and its distribution relative to land uses such as agriculture, cheatgrass invasion, and measures of habitat fragmentation (Knick and Rotenberry 1995, 1999; Rotenberry and Knick 1999).

Unlike its neighboring states, Wyoming's sagebrush steppe is relatively intact. Although sagebrush treatment and human development have impacted this community, sagebrush is still widely distributed throughout the state in large, unbroken stands. However, development trends threaten the integrity of Wyoming's sagebrush landscape. Threats to this system include human development, exotic species invasion, habitat manipulation for fire control and to increase forage for domestic cattle, and oil and natural gas development. While sagebrush obligate numbers are rarely at carrying capacity, fragmentation of this habitat could negatively impact these species.

Within the framework of natural gas development, the construction of roads, pipelines, and well pads will cause a direct loss of habitat. Perhaps the greatest impact however, on the avian community will be the effect development has on the pattern of sagebrush distribution. Alone, development of the PAPA may have little impact on passerine populations throughout Wyoming, but the cumulative impact of state wide patterns of development in sagebrush communities could cause substantial habitat fragmentation that impacts the sagebrush avian community negatively.

Future monitoring within the Pinedale Anticline Project Area and throughout Wyoming should focus on how habitat fragmentation associated with natural gas extraction and other forms of land use impact this breeding bird community. Future surveys should consider the use of larger radius point counts. Though unlimited radius counts have been used in other studies (Knick and Rotenberry 1995, 1999), increased noise disturbance within natural gas development areas may reduce the accuracy of this technique. Instead, point count radii between 100 m – 150 m might be more applicable. Because densities based on point counts of different radii are not comparable (Hutto et al.

1986), future surveys employing larger radii counts should note detections within the first 50m so that densities can be compared to my study.

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Table 2.1. Vegetation variables measured at each point count, bird-centered, and random location. See text for description and calculation.

Variable	Code	Units
<i>Band Transect</i>		
Live Sagebrush Density	Live Den	Bush / m ²
Dead Sagebrush Density	Dead Den	Bush / m ²
<i>Line-Intercept</i>		
% Cover Sagebrush	Sage Cov	% Cover
% Cover Dead Sagebrush	Dead Cov	% Cover
% Cover Rabbit Brush	RB Cov	% Cover
Average Sagebrush Height	Sage Ht	Cm
Average Dead Sagebrush Height	Dead Ht	Cm
Average Rabbit Brush Height	RB Ht	Cm
<i>Daubenmire Frame</i>		
% Cover Grass	%Grass	% Cover
% Cover Forbs	%Forb	% Cover
% Cover Litter	%Lit	% Cover
% Cover Bare Ground	%Bare	% Cover
% Cover Lichen	%Lich	% Cover
% Cover Cactus	%Cact	% Cover
% Cover Cow dung	%Cow	% Cover
% Total Cover	%TOT Cov	% Cover
<i>Density Board</i>		
Vegetation density in First Decimeter	10 DEC	% Cover
Vegetation density in Second Decimeter	20 DEC	% Cover
Vegetation density in Third Decimeter	30 DEC	% Cover
Vegetation density Fourth Decimeter	40 DEC	% Cover
Vegetation density in Fifth Decimeter	50 DEC	% Cover
Vegetation density Sixth Decimeter	60 DEC	% Cover
Vegetation density in Seventh Decimeter	70 DEC	% Cover
Vegetation density in Eighth Decimeter	80 DEC	% Cover
Vegetation density in Ninth Decimeter	90 DEC	% Cover
Vegetation density in Tenth Decimeter	100 DEC	% Cover
Average Maximum Height of Vegetation	AVE MAX HT	Cm
Shrubbiness (vegetation density in the first two decimeters)	SHRUB20	%
Coefficient of Variation for Maximum Decimeter with Vegetation Cover	CVMAXHT	%

Table 2.2. Vegetation characteristics of surveyed point counts (n = 100) within the Pinedale Anticline Project Area.

Variable	PAPA Mean	Minimum	Maximum
<i>Band Transect</i>			
Live Den	2.56 (0.06)	0.85	4.42
Dead Den	0.44 (0.02)	0.10	1.43
<i>Line-Intercept</i>			
Sage Cov	16.60 (0.39)	6.83	25.70
Dead Cov	3.91 (0.12)	0.94	7.11
RB Cov	0.73 (0.07)	0.0	3.28
Sage Ht	21.76 (0.59)	12.18	35.97
Dead Ht	15.91 (0.46)	9.45	27.09
RB Ht	9.75 (0.41)	4.18	33.67
<i>Daubenmire Frame</i>			
%Grass	7.44 (0.30)	2.50	17.08
%Forb	5.61 (0.30)	0.73	14.69
%Lit	23.95 (0.68)	7.08	37.81
%Bare	63.91 (0.88)	42.81	83.23
%Lich	2.77 (0.09)	2.40	8.65
%Cact	0.12 (0.03)	0.0	2.00
%Cow	2.08 (0.04)	0.0	2.08
%TOT Cov	36.01 (0.87)	17.0	57.0
<i>Density Board</i>			
10 DEC	38.18 (1.08)	10.00	67.19
20 DEC	19.14 (1.11)	1.88	55.00
30 DEC	8.07 (0.78)	0.0	37.29
40 DEC	2.73 (0.38)	0.0	19.27
50 DEC	0.69 (0.14)	0.0	6.25
AVEMAX HT	23.09 (0.51)	8.75	37.92
SHRUB20	28.66 (1.06)	5.94	61.09
CVMAXHT	113.11 (0.62)	107.61	165.07

Table 2.3. Comparison of vegetation structure between the northern and central PAPA. T-tests, assuming unequal variance were used to compare vegetation structure within point counts located in the northern PAPA (n = 40), and central PAPA (n = 60). Bolded variables are significantly different at alpha = 0.05 (Bonferroni critical alpha = 0.00417). Values in parentheses are standard errors.

Variable	Northern Mean	Central Mean	t-value	P-value
		<i>Line-Intercept</i>		
Sage Cov	18.55 (0.616)	15.31 (0.428)	4.33	< 0.000
Dead Cov	3.97 (0.184)	3.87 (0.166)	0.41	0.686
RB Cov	0.593 (0.078)	0.815 (.105)	-1.71	0.091
Sage Ht	27.84 (0.502)	17.71 (0.422)	15.45	< 0.000
Dead Ht	20.57 (0.433)	12.81 (0.303)	14.70	< 0.000
RB Ht	8.10 (0.380)	10.85 (0.625)	-3.76	< 0.000
		<i>Daubenmire Frame</i>		
%Grass	9.00 (0.384)	6.39 (0.366)	4.91	< 0.000
%Forb	7.59 (0.444)	4.29 (0.311)	6.09	< 0.000
%Lit	27.95 (0.944)	21.28 (0.773)	5.46	< 0.000
%Bare	56.70 (1.05)	68.72 (0.847)	-8.94	< 0.000
		<i>Density Board</i>		
AVE MAX HT	27.22 (0.774)	20.33 (0.360)	8.07	< 0.000
SHRUB20	37.44 (1.456)	22.81 (0.887)	8.58	< 0.000

Table 2.4. Mean number of point count detections by species and guild for the Pinedale Anticline Project Area (n = 100). Values in parentheses are bird densities in individuals per hectare.

	Mean	Min	Max	SE
Obligates	1.17 (1.48)	0.0	3.67	0.089
BRSP	0.83 (1.06)	0.0	3.00	0.074
HOLA	0.24 (0.03)	0.0	1.67	0.033
SAGS	0.29 (0.37)	0.0	1.30	0.034
SATH	0.05 (0.06)	0.0	0.67	0.015
VESP	0.36 (0.46)	0.0	1.67	0.042
TOTAL	1.78 (2.26)	0.0	5.00	0.102

Table 2.5. Relative bird abundance within the two surveyed areas of the Pinedale Anticline Project Area. T-tests assuming unequal variance were used to compare point count means located in the northern PAPA (n = 40), with means from the central PAPA (n = 60). Bolded variables are significantly different at alpha = 0.05 (Bonferroni critical alpha = 0.0071). Values in parentheses are standard errors.

	Northern PAPA	Central PAPA	t-value	P-value
Obligates	1.64 (0.136)	0.85 (0.098)	4.69	< 0.000
BRSP	1.21 (0.158)	0.58 (0.080)	4.39	< 0.000
HOLA	0.25 (0.049)	0.23 (0.045)	0.34	0.737
SAGS	0.37 (0.058)	0.23 (0.041)	1.94	0.057
SATH	0.06 (0.026)	0.04 (0.018)	0.61	0.544
VESP	0.13 (0.037)	0.52 (0.058)	-5.78	< 0.000
Total	2.01 (0.136)	1.62 (0.132)	1.93	0.057

Table 2.6. Bird species list for Pinedale Anticline Project Area (spring and summer 1999 – 2000). C = common, observed > 20 times. U = uncommon, seen < 20, and > 10 times. R = rare, seen less than 10 times. L = common but with a localized distribution. M = observed during migration only, S = spring / summer, W = winter, RES = year-round resident.

Common name	Species epithet	Frequency	Season
mallard	<i>Anas platyrhynchos</i>	L	S
American wigeon	<i>Anas americana</i>	L	S
golden eagle	<i>Aquila chrysaetos</i>	C	W/S
northern harrier	<i>Circus cyaneus</i>	C	S
sharp-shinned hawk	<i>Accipiter striatus</i>	R	S
Swainson's hawk	<i>Buteo swainsoni</i>	U	S
red-tailed hawk	<i>Buteo jamaicensis</i>	C	S
ferruginous hawk	<i>Buteo regalis</i>	R	S
American kestrel	<i>Falco columbarius</i>	C	S
prairie falcon	<i>Falco mexicanus</i>	U	S
sage grouse	<i>Centrocercus urophasianus</i>	C	RES
killdeer	<i>Charadrius vociferus</i>	L	S
willet	<i>Catoptrophorus semipalmatus</i>	C	S
long-billed curlew	<i>Numenius americanus</i>	R	M
Wilson's phalarope	<i>Phalaropus tricolor</i>	R	M
red-necked phalarope	<i>Phalaropus lobatus</i>	R	M
mourning dove	<i>Zenaida macroura</i>	R	S
burrowing owl	<i>Speotyto cunicularia</i>	R	S
common nighthawk	<i>Chordeiles minor</i>	C	S
northern flicker	<i>Colaptes auratus</i>	L	S
Say's phoebe	<i>Sayornis saya</i>	U	M
horned lark	<i>Eremophila alpestris</i>	C	RES
bank swallow	<i>Riparia riparia</i>	L	S
cliff swallow	<i>Hirundo pyrrhonota</i>	L	S
barn swallow	<i>Hirundo rustica</i>	L	S
common raven	<i>Corvus corax</i>	C	S/RES?
rock wren	<i>Salpinctes obsoletus</i>	L	S
mountain bluebird	<i>Sialia currucoides</i>	U	M
Townsend's solitaire	<i>Myadestes townsendi</i>	U	M
sage thrasher	<i>Oreoscoptes montanus</i>	C	S
loggerhead shrike	<i>Lanius ludovicianus</i>	R	S
yellow-rumped warbler	<i>Dendroica coronata</i>	U	M
green-tailed towhee	<i>Pipilo chlorurus</i>	L	S
Brewer's sparrow	<i>Spizella passerina</i>	C	S
vesper sparrow	<i>Pooecetes gramineus</i>	C	S
sage sparrow	<i>Amphispiza belli</i>	C	S
lark bunting	<i>Calamospiza melanocorys</i>	U	S
savannah sparrow	<i>Passerculus sandwichensis</i>	U	M

Table 2.6. Species list (continued)

Common name	Species epithet	Frequency	Season
white-crowned sparrow	<i>Zonotrichia leucophrys</i>	U	M
dark-eyed junco	<i>Junco hyemalis</i>	U	M
western meadowlark	<i>Stunella magna</i>	C	S
Brewer's blackbird	<i>Euphagus cyanocephalus</i>	U	S
brown-headed cowbird	<i>Molothrus ater</i>	R	S

Table 2.7. Results from best subset regression of the log-transformed response (number of point count detections) with measures of habitat structure as predictors. The best one, two, and three variable models are given for each species and guild analyzed.

Variables		r^2	R^2_{adj}	c-p	s
<i>Sagebrush obligates</i>					
1	SAGEHT	0.289	0.281	12.7	0.740
2	SAGECOV + RBCOV	0.340	0.325	7.5	0.717
3	SAGEHT + 10DEC + AVEMAXHT	0.358	0.337	6.9	0.711
<i>Brewer's Sparrow</i>					
1	SAGEHT	0.287	0.280	11.4	0.785
2	SAGEHT + RBCOV	0.349	0.334	4.8	0.755
3	SAGEHT + RBCOV + SHRUBBINESS	0.367	0.345	4.3	0.748
<i>Horned Lark</i>					
1	%LIT	0.039	0.028	3.0	0.698
2	SAGEHT + %LIT	0.089	0.068	0.3	0.683
3	SAGEHT + %LIT + RBCOV	0.132	0.102	-1.7	0.671
<i>Sage Sparrow</i>					
1	DEADCOV	0.045	0.034	7.8	0.722
2	10DEC + AVEMAXHT	0.084	0.064	5.9	0.711
3	SAGEHT + 10DEC + AVEMAXHT	0.172	0.143	-0.9	0.680
<i>Sage Thrasher</i>					
1	DEADHT	0.019	0.008	8.4	0.385
2	SAGECOV + 10DEC	0.069	0.048	5.4	0.377
3	SAGECOV + %TOTCOV + 10DEC	0.084	0.053	6.0	0.377
<i>Vesper Sparrow</i>					
1	SAGEHT	0.198	0.189	2.0	0.722
2	SAGEHT + RBCOV	0.221	0.203	1.4	0.716
3	SAGEHT + RBCOV + AVEMAXHT	0.232	0.206	2.1	0.714

Table 2.8. Results from Poisson regression predicting mean number of Brewer's sparrow detections based on habitat shrubbiness (% vegetation cover within 20cm of the ground).

$$\text{Brewer's Sparrow} = e^{(-1.4592 + 0.4090 \cdot \text{SHRUB20})}$$

-Variable	Coefficient	Standard Error	Chi2	Pr > Chi2
Constant	-1.4592	0.3384	18.59	< 0.0001
SHRUB20	0.4090	0.0949	18.57	< 0.001

Source	df	Deviance
Model	1	17.6948
Error	98	54.2469
Total	99	71.9417

Table 2.9. Results from Poisson regression predicting mean number of sagebrush obligate detections based on habitat shrubbiness (% vegetation cover within 20cm of the ground).

$$\text{Sagebrush Obligates} = e^{(-0.9157 + 0.2819 \cdot \text{SHRUB20})}$$

Variable	Coefficient	Standard Error	Chi2	Pr > Chi2
Constant	-0.9157	0.2819	10.55	< 0.0012
SHRUB20	0.3477	0.0809	18.48	< 0.0001

Source	df	Deviance
Model	1	17.6663
Error	98	55.4013
Total	99	73.0677

Table 2.10. Discriminant functions, structure coefficients and group centroids for community wide DFA based on song post location with cases grouped by species.

Discriminant Function	Structure Coefficients	P-value
DF1: Vertical Structure		0.000
SAGEHT	0.986	
DEADCOV	0.163	

Group Centroids

Species	DF1
Brewer's Sparrow	-0.012
Horned Lark	-2.002
Sage Sparrow	0.358
Sage Thrasher	1.214
Vesper Sparrow	-1.820
Green-Tailed Towhee	4.094

Table 2.11. Classification matrix for community wide DFA based on song post locations with cases grouped by species.

	Species	Predicted Group Membership						Total
		BRSP	HOLA	SAGS	SATH	VESP	GTTO	
Original	BRSP	4	0	12	0	1	0	17
	HOLA	2	0	0	0	7	0	9
	SAGS	5	0	10	2	2	0	20
	SATH	1	0	4	2	0	1	8
	VESP	1	0	2	0	12	0	15
	GTTO	0	0	0	0	0	7	7
Count	BRSP	23.5	0	70.6	0	5.9	0	100
	HOLA	22.2	0	0	0	77.8	0	100
	SAGS	25.0	0	50.0	10.0	10.0	5.0	100
	SATH	12.5	0	50.0	25.0	0	12.5	100
	VESP	6.7	0	13.3	0	80.0	0	100
	GTTO	0	0	0	0	0	100	100

46.1% of original grouped cases correctly classified.

$\tau = 0.144$

Table 2.12. Discriminant functions, structure coefficients and group centroids for community wide DFA based on song post location with cases grouped by species.

Discriminant Function	Structure Coefficients	<i>P</i> -value
DF1: Vertical Structure		0.000
SAGEHT	0.979	
DEADCOV	0.156	
DF2: Decadence		0.012
SAGEHT	0.202	
DEADCOV	0.988	

Group Centroids		
Guild	DF1	DF2
Grassland Birds	-1.811	-0.278
Sagebrush Obligates	0.347	0.236
Green-Tailed Towhee	3.981	-0.566

Table 2.13: Classification matrix for community wide DFA based on song post locations with cases grouped by species.

Guild		Predicted Group Membership			Total
		Grassland bird	Sage Obligates	GTTO	
Original Count	Grassland Birds	19	5	0	24
	Sage Obligates	2	42	1	45
	GTTO	0	0	7	7
%	Grassland Birds	79.2	20.8	0	100
	Sage Obligates	4.4	93.3	2.2	100
	GTTO	0	0	100	100

89.5% of original grouped cases correctly classified

$Tau = 0.806$

Table 2.14. Discriminant functions, structure coefficients and group centroids for community wide DFA based on nest site location with cases grouped by species.

Discriminant Function	Structure Coefficients	<i>P</i> -value
DF1: Vertical Structure		0.001
SAGEHT	0.933	
DEADCOV	0.733	

Group Centroids

Species	DF1
Brewer's Sparrow	0.642
Horned Lark	-1.584
Sage Sparrow	-0.340
Sage Thrasher	0.554

Table 2.15. Classification matrix for community wide DFA based on nest site locations with cases grouped by species.

	Species	Predicted Group Membership				Total
		BRSP	HOLA	SAGS	SATH	
Original	BRSP	10	1	1	1	13
	HOLA	1	5	0	0	6
	SAGS	3	2	3	0	8
	SATH	5	0	2	0	7
Count	BRSP	76.9	7.7	7.7	7.7	100
	HOLA	16.7	83.3	0	0	100
	SAGS	37.5	25.0	35.7	0	100
	SATH	71.4	0	28.6	0	100

52.9% of original grouped cases correctly classified.

$Tau = 0.351$

Table 2.16. Habitat use based on song post use vs. random locations. Paired *t*-tests were used to test the difference between vegetation characteristics at bird-centered plots located at song post vs. paired random locations. Bolded variables are significantly different (Bonferroni adjusted critical alpha <0.01). Variables in parentheses are standard errors.

	Use mean	Random mean	<i>t</i> -value	<i>P</i> -value
<i>Brewer's Sparrow n = 17</i>				
SAGEHT	29.7 (0.91)	22.4 (1.80)	-4.083	0.006
SAGECOV	21.1 (1.05)	15.9 (1.23)	-3.176	0.001
DEADCOV	5.92 (0.56)	4.68 (0.52)	-1.721	0.104
AVEMAXHT	28.2 (1.30)	23.1 (1.28)	-3.595	0.002
SHRUB20	41.3 (3.37)	29.2 (2.76)	-3.241	0.005
<i>Horned Lark n = 9</i>				
SAGEHT	20.0 (1.69)	23.0 (1.58)	2.026	0.077
SAGECOV	14.5 (1.35)	17.9 (0.87)	2.019	0.078
DEADCOV	4.48 (0.64)	5.47 (0.51)	1.737	0.121
AVEMAXHT	21.6 (1.38)	23.3 (1.41)	0.693	0.508
SHRUB20	25.4 (3.87)	31.2 (3.35)	0.905	0.392
<i>Sage Sparrow n = 20</i>				
SAGEHT	31.6 (1.23)	22.1 (1.41)	-5.768	0.000
SAGECOV	21.6 (0.95)	16.7 (1.31)	-3.241	0.004
DEADCOV	6.41 (0.38)	4.47 (0.44)	-3.124	0.006
AVEMAXHT	29.3 (1.44)	22.0 (1.25)	-4.035	0.001
SHRUB20	41.3 (3.14)	28.4 (2.99)	-3.363	0.003
<i>Sage Thrasher n = 8</i>				
SAGEHT	35.7 (1.61)	24.0 (2.28)	-3.117	0.017
SAGECOV	22.1 (1.74)	16.0 (2.31)	-2.965	0.021
DEADCOV	6.89 (0.63)	4.60 (0.96)	-2.384	0.049
AVEMAXHT	33.9 (1.76)	22.9 (1.99)	-4.162	0.004
SHRUB20	46.1 (3.69)	24.3 (3.31)	-5.686	0.001
<i>Vesper Sparrow n = 15</i>				
SAGEHT	21.0 (1.28)	20.4 (1.34)	-0.321	0.753
SAGECOV	17.7 (1.12)	15.4 (1.32)	-1.581	0.136
DEADCOV	4.95 (0.37)	5.17 (0.48)	0.364	0.712
AVEMAXHT	21.8 (1.10)	22.4 (1.35)	0.376	0.713
SHRUB20	32.9 (3.25)	30.2 (3.56)	-0.610	0.552
<i>Green-Tailed Towhee n = 7</i>				
	Mean	Min	Max	
SAGEHT	48.46 (1.52)	43.1	55.24	
SAGECOV	30.04 (1.62)	25.03	37.12	
DEADCOV	5.902 (0.62)	3.95	9.033	
AVEMAXHT	49.64 (1.58)	44.17	55.00	
SHRUB20	55.25 (4.31)	40.31	73.75	

Table 2.17. Habitat use based on nest sites vs. random locations. Paired *t*-tests were used to test the difference between vegetation characteristics at bird-centered plots located at nest sites vs. paired random locations. Bolded variables are significantly different (Bonferroni adjusted critical alpha <0.01). Variables in parentheses are standard errors.

	Mean Use	Paired Random	<i>t</i> -Value	<i>P</i> -value
<i>Brewer's Sparrow n = 13</i>				
SAGEHT	32.0 (1.28)	30.6 (1.35)	-0.789	0.446
SAGECOV	18.4 (1.45)	16.0 (1.62)	-1.613	0.133
DEADCOV	4.54 (0.64)	4.54 (0.56)	-0.004	0.977
AVEMAXHT	26.7 (1.96)	26.7 (2.07)	-0.025	0.851
SHRUB20	36.4 (2.69)	35.0 (3.86)	-0.297	0.980
<i>Horned Lark n = 6</i>				
SAGEHT	18.7 (2.53)	27.0 (3.55)	2.173	0.082
SAGECOV	7.61 (3.64)	18.4 (3.28)	2.765	0.040
DEADCOV	1.03 (0.28)	5.02 (1.87)	1.989	0.103
AVEMAXHT	15.1 (1.48)	25.7 (3.84)	2.142	0.085
SHRUB20	14.0 (4.00)	27.8 (6.54)	1.492	0.196
<i>Sage Sparrow n = 8</i>				
SAGEHT	24.4 (3.15)	24.1 (2.10)	-0.094	0.927
SAGECOV	18.0 (1.38)	15.6 (2.58)	-0.781	0.460
DEADCOV	4.21 (0.83)	3.66 (0.67)	-0.388	0.710
AVEMAXHT	24.0 (2.82)	22.5 (1.75)	-0.390	0.708
SHRUB20	31.8 (3.72)	31.7 (4.04)	-0.010	0.993
<i>Sage Thrasher n = 7</i>				
SAGEHT	30.1 (2.13)	26.8 (2.62)	-1.305	0.240
SAGECOV	17.6 (2.77)	18.6 (3.20)	-0.382	0.715
DEADCOV	5.34 (0.92)	3.69 (0.50)	-1.660	0.148
AVEMAXHT	26.8 (2.22)	25.4 (2.14)	-0.398	0.704
SHRUB20	33.0 (5.25)	34.7 (4.20)	0.307	0.771

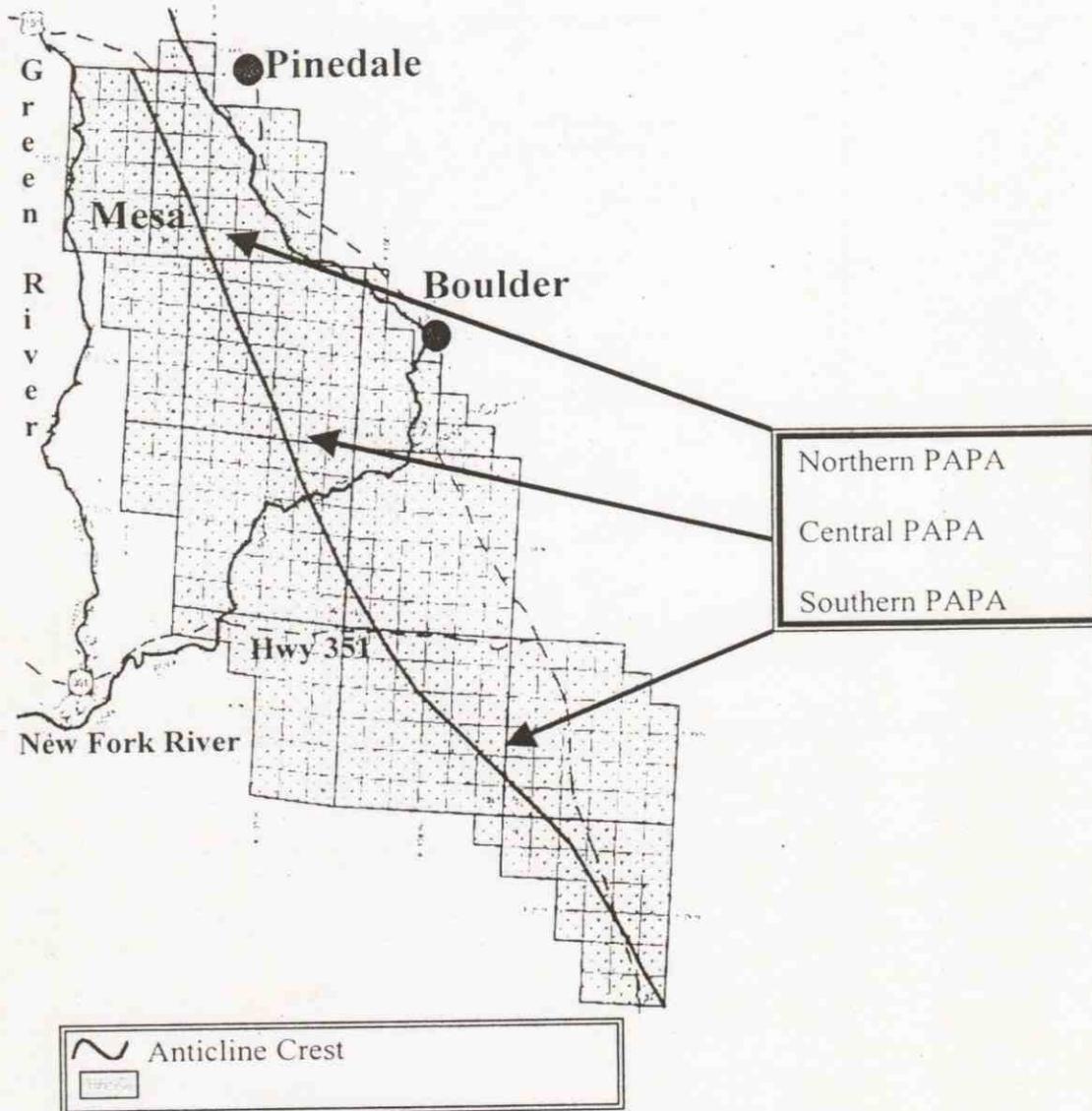
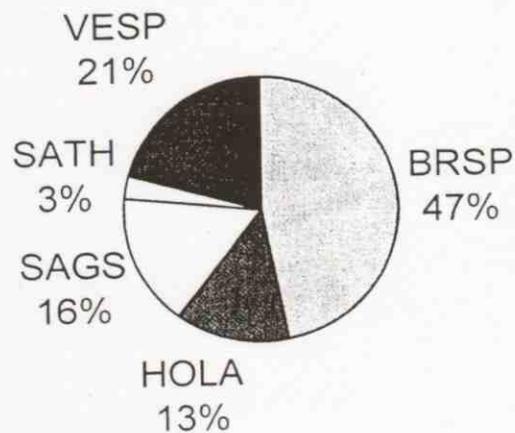


Figure 2.1. Pinedale Anticline Project Area, Sublette County, Wyoming. Northern, central, and southern portions of the project area are highlighted.

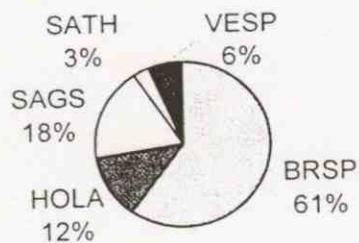
A)

Relative Species Abundance Within the PAPA



B)

Relative Species Abundance in the Northern PAPA



C)

Relative Species Abundance in the Central PAPA

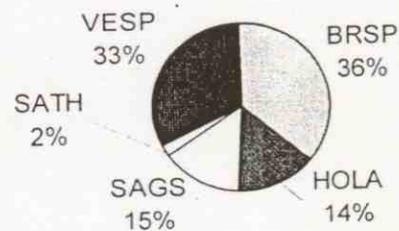
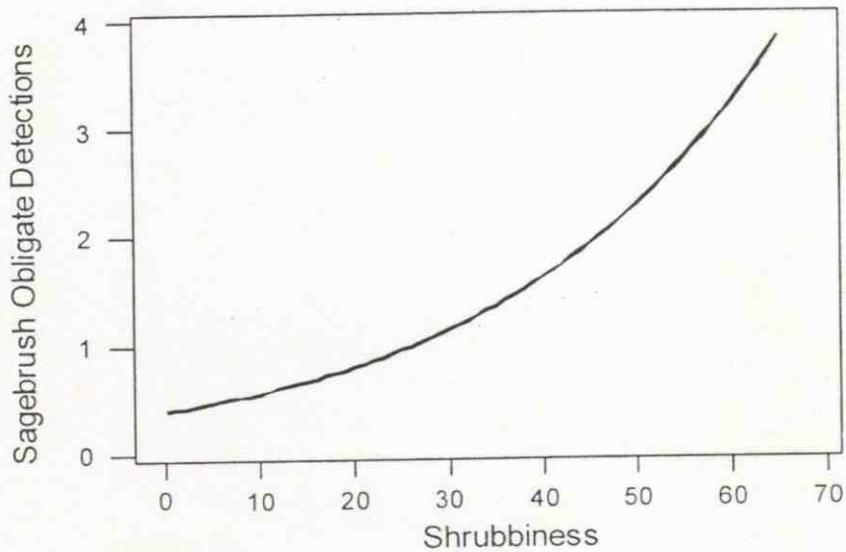


Figure 2.2. Relative species composition within the Pinedale Anticline Project Area (A), northern portion of the project area (B), and central project area (C).

(A)



(B)

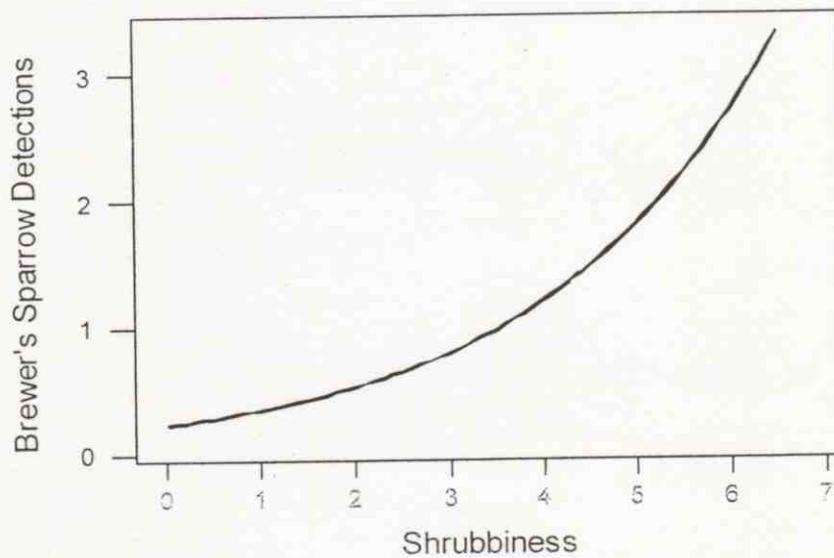


Figure 2.3. Results from Poisson regression predicting the mean number of sagebrush obligate (A), and Brewer's Sparrow (B) detections based on habitat shrubiness.

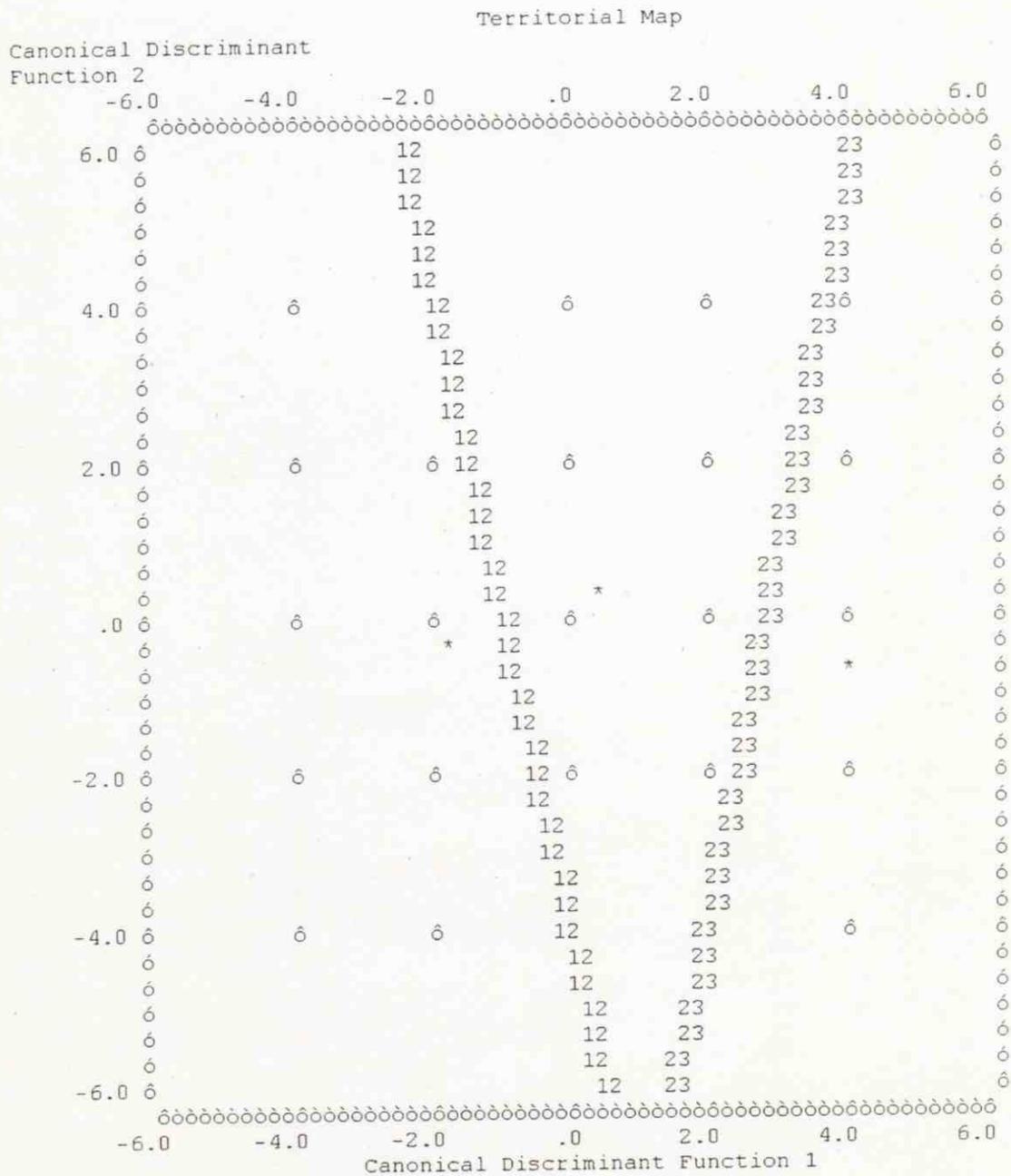


Figure 2.4. Two-function plot of group centroids for the analysis of relative song perch selection by grassland species (group 1), sagebrush obligates (group 2), and green-tailed towhees (group 3). "*" = group centroid.

Chapter III

Passerine Response to Roads Associated with Natural Gas Extraction in a Sagebrush Steppe

INTRODUCTION

Roads are a conspicuous landscape feature and have been providing social and economic connectivity for human populations for thousands of years (Bennett, 1991). However, with the advent of the automobile, transportation corridors have proliferated across the landscape of every industrialized nation. The Australian continent has over 900,000-km of roads and only 18 million people (Lamont and Blyth 1995). In the Netherlands, main road density (traffic volume between 10,000 and 50,000 vehicles per day) is 1.5 km/km². In the United States, roads cover over 1% of the landscape, an area equal to the size of South Carolina. Surprisingly, 10% of the 6.2 million-km of U.S. public roads occur in our National Forests (Forman and Alexander, 1998).

While the ecological effects of roads can be positive, such as in the indirect preservation of native grassland species in agriculturally developed areas (Bennett 1991; Warner 1992; Lamont and Blyth 1995; Straker 1998), most ecological impacts are negative. Trombulak and Frissell (2000) identified seven general ways in which roads affect terrestrial and aquatic habitats: (1) increased mortality from road construction, (2) increased mortality from collisions with vehicles, (3) modification of animal behavior, (4) alteration of physical environment, (5) alteration of chemical environment, (6) spread of exotic species, and (7) increased habitat alteration and use by humans. It is estimated that the ecological impacts of roads affect between 15% – 20% of the United States' land area (Forman 2000).

The impact of roads with high traffic volumes (> 10,000 vehicles/day) on breeding bird populations is well documented. In a study of breeding bird densities in deciduous and coniferous woodlands in the Netherlands, 60% of species analyzed (26 of 43 species) showed evidence of decreased densities adjacent to roads. Detectable effect zones, based on regression models, were between 40 m to 1,500 m for roads with traffic volumes of 10,000 vehicles/day, and 70 m to 2,800 m where traffic volumes exceeded 60,000 vehicles. Traffic noise and its rate of attenuation were the best predictors of this

pattern. Within 250 m of roadways, reductions in bird densities varied between 20% – 98% depending on species (Reijnen et al. 1995).

Studies of how roads affect habitat quality for a breeding population of willow warblers (*Phylloscopus trochilus*) showed a 33% reduction in breeding male density within 200-m of a road with a traffic volume of 50,000 vehicles per day. Lower density within this 200-m zone was due to a decrease in the presence of older males, and as a result, the proportion of yearling males was 50% higher than adjacent areas. Within this zone the proportion of yearling males rearing young was also about 40% lower than adjacent areas (Reijnen and Foppen 1994). Yearling males that nested within this 200-m zone moved greater distances to new breeding territories in successive years than did yearling males whose previous territories were outside this road zone. The movement direction of yearling males that had previously nested within the road zone was away from the road, implying that once yearling males had matured, they fled the road zone to which they had been relegated as yearlings (Foppen and Reijnen 1994). Both productivity and population demographics from these studies suggest that the habitat quality within these road zones is reduced, and the area within the road zone may serve as a population sink for willow warblers (Reijnen and Foppen 1994, Foppen and Reijnen 1994).

Breeding birds in grassland communities adjacent to roads also showed similar reductions in densities. However, because noise attenuates slower in open habitats, reductions in breeding bird density were observed at greater distances from the road than in wooded habitats (van der Zande et al. 1980, Reijnen et al. 1996).

Clearly roads with high traffic volumes impact breeding bird populations and habitat quality. However, little information is available on the impact roads with low traffic volumes (< 700 vehicles/day) have on bird communities. New road construction in the United States is expected to be of this low volume type, especially in rural areas and areas associated with resource extraction (National Research Council 1997 Trombulak and Frissell 2000). In Wyoming, resource extraction is prevalent and a major source of tax revenue. In 2000, the assessed value of minerals extracted from Wyoming exceeded four billion dollars and provided the state with 279 million dollars in mineral severance taxes. The value of oil and gas alone exceeded 62% of the total value of

minerals extracted from Wyoming (Department of Revenue 2001). While oil and gas extraction is a valuable source of revenue for Wyoming and an important domestic energy source, oil and gas extraction often requires intense road development. This project's goal is to examine how roads associated with natural gas extraction in western Wyoming affect sagebrush steppe breeding bird distribution and species composition along roadways.

METHODS

Study Area and Site Selection

This study was carried out along roads within two adjacent natural gas development areas in western Wyoming, the Pinedale Anticline Project Area (PAPA), and the Jonah Field II (Fig. 3.1). The Jonah Field II is a developed natural gas field with a well density of 3 wells per km² (8 wells/miles²). The PAPA, north of the Jonah II, is a field in the beginning phase of natural gas development. The PAPA is located along the western edge of central Wyoming in Sublette County. The project area is bordered to the east by Highway 191 and to the west by the Green River. The town of Pinedale demarcates the project's northeast boundary, and the Jonah II Field, approximately 56 kilometers south of Pinedale, Wyoming, marks the project's southern boundary. The Pinedale Anticline Project Area encompasses 80,000 hectares, of which the Bureau of Land Management manages 80%. The vegetation in both the Jonah II Field and PAPA is dominated by Wyoming big sagebrush (*Artemisia tridentata ssp. wyomingensis*) with portions of basin big sagebrush (*Artemisia tridentata ssp. tridentata*) located throughout the bottoms of draws (PIC Technologies and Bureau of Land Management 1999; Bureau of Land Management 2000). Common passerines breeding in these areas include sagebrush obligates such as the Brewer's sparrow (*Spizella breweri*), sage sparrow (*Amphispiza belli*), and sage thrasher (*Oreoscoptes montanus*), and grassland species such as the horned lark (*Eremophila alpestris*) and vesper sparrow (*Pooecetes gramineus*).

Breeding bird distribution was surveyed along four roads within this study area. Three dirt roads, the Lumman Road serving as the main access to the Jonah Field II, the Mesa Road in the northern portion of the PAPA, the Oil Well Road running north-south along the northern PAPA, and Highway 351 which bisects the southern PAPA and is a

paved road between Highway 191 and Big Piney. Bird distribution was also surveyed along a pipeline right of way. The vegetation within 8 m of pipelines is cleared and replanted with grass. Inclusion of a pipeline in this study provides a reference site with a similar surface disturbance to roads but one that lacks the associated traffic (Fig. 3.2). Road sections were selected for flat topography and homogeneous vegetation structure and floristic composition. Within selected road sections, eight transects were run perpendicular to the road. Transects were located by randomly choosing a starting point for the first transect and then spacing transects at 300 m intervals.

Traffic volume was measured with pneumatic axle counters. These counters consisted of a counter connected to a 2-cm diameter rubber hose that was stretched across the road. To ensure that recorders were working properly, two counters, spaced 1 m apart, were placed across straight road sections in each study area and were monitored daily throughout the breeding period (May 15-June 30). Since pneumatic counters counted axles, not vehicles, dividing the total number of axles counted by two created an index of daily traffic volume (cars/day). Average daily traffic volume was calculated as the average of the total traffic volume throughout the season.

Breeding Bird Distribution

Breeding bird density was surveyed between May 15 and the end of June 1999 and 2000 using 50-m fixed-radius point counts. During the 1999 field season, two roads were surveyed, the Mesa and Lumman Roads (referred to hereafter as Mesa I and Lumman I sites). Along each road, eight transects were run perpendicular to the road, and transects were spaced 300 m apart. Points were spaced 250m apart along these transects and were located at distances of 50 m, 150 m, 300 m, 400 m, and 550 m from the edge of where the maintained road surface ended and natural vegetation began (Fig. 3.3). Road width varied between 8-11 m, and the total width of disturbed vegetation varied from 14.5 – 25 m (Fig. 3.4). Points on adjacent transects had the opposite dispersion. For example, a road running east to west would have points distributed at varying distances to the north and south of the road. If points were located along one transect at distances of 50 m, 300 m, and 500 m to the north of the road, and at 150 m and 400 m south of the road, points on adjacent transects would be located at 150 m and 400 m on the north side, and 50 m, 300 m, and 550 m on the south side (Fig. 3.5). This

dispersion of points provided eight independent samples of breeding bird densities within each 100-m distance class. Distance classes ranged from 0-100 m, 100-200 m, 250-350 m, 350-450 m, and 500-600 m from the road for points located at 50 m, 150 m, 300 m, 400 m, and 550 m, respectively.

During the 2000 field season, two additional roads (Oil Well Road, and Highway 351), a pipeline, and additional sites along both the Mesa and Lumman Roads (referred to as Mesa II and Lumman II sites) were added to the study. To concentrate sampling effort where the road effect was potentially greatest, breeding bird densities were sampled only out to 200 m away from dirt roads and pipelines and out to 350 m from the paved highway. Ten transects were placed along each study site, providing ten independent samples of bird density within each distance class (0-100 m and 100-200 m). Because Highway 351 was a paved road with relatively high traffic volumes, points were located at 50 m, 150 m, and 300 m from the road surface. Along highway 351 there were 14 independent samples of bird density within three distance classes (0-100 m, 100-200 m, and 250-350 m) (Table 3.1).

Point centers were permanently marked with plastic-capped re-bar stakes. Stakes were set below the height of the surrounding vegetation to reduce their attractiveness as perches and song posts. Birds were never observed using these stakes as perch sites or song posts. Because roads served as a natural 50-m boundary marker for points centered at 50 m from the road, 10 cm x 10 cm neon flags were used to mark the 50-m boundary of points located further than 50-m from the road.

Points were visited three times during each field season. Counts from successive point visits were combined by averaging the number of detections of individual species and sagebrush obligates (sum of Brewer's sparrow, sage sparrow, and sage thrasher) for the three visits. Twenty counts were conducted per morning between 0520 hrs and 0830 hrs on rain free mornings with wind speeds below 15 km/hr. Points were visited in the order in which they were located along transects. Upon reaching a transect's end, the observer would continue counts on the adjacent transect. To ensure that stations were visited both early and late in the daily sampling period, points were surveyed in reverse order on consecutive visits.

Counts at each point lasted for five minutes. Time began once the observer reached the 50-m boundary of the plot. Walking slowly towards the plot's center, the observer would record and map all birds detected by sight and sound. Birds that were flushed into the plot upon approach were not recorded unless they returned to the plot later in the survey.

Vegetation Structure

To ensure that vegetation characteristics were comparable between distance classes, all vegetation measurements were recorded at each survey site (Table 3.2). The vegetation variables were evaluated along line transects. Two 50-m tapes were extended in opposite directions from the center of points and were oriented at a 45° angle to the road. Surveyed quadrants were selected at random. Along each 50-m tape, vegetation measurements were recorded along three 10-m intervals, namely, 10-20 m, 25-35 m, and 40-50 m, from the plot's center.

The line-intercept method (Canfield 1941) was used to determine the percent canopy cover of live and dead sagebrush and live rabbitbrush (*Chrysothamnus spp.*). The height and species of each intercepted shrub were recorded and used to determine the average height of each shrub species within the plot ($\sum_{i=1}^n (\text{height}_i * \text{length}_i) / \sum_{i=1}^n (\text{Length}_i)$). Live and dead sagebrush density (plants/m²) was determined using a 1-m wide band transect taken along each of the six 10-m transect sections (James and Shugart 1970).

Percent cover of grasses, forbs, litter, bare ground, lichen, cactus, cow dung, and total ground cover were determined by class using a 20 cm x 50 cm Daubenmire frame (Daubenmire 1959). Cover classes were 0-5%, 5-25%, 25-50%, 50-75%, 75-95%, and 95-100%. Daubenmire frame samples were taken at 12 sites within each plot, six along each 50-m transect, and centered at 12.5 m, 17.5 m, 27.5 m, 32.5 m, 42.5 m, and 47.5 m from the plot's center. Total cover for each vegetation variable was calculated by averaging the 12 samples within each plot.

A density board (20 cm x 100 cm) was used to calculate the average vegetation density within each decimeter interval (10-cm), average maximum vegetation height, and an index of plot shrubbiness. Density board samples were recorded at 12 sites within each plot and were taken at the same locations as Daubenmire frame samples. Percent

vegetation density within each decimeter interval was estimated by walking 5 m away from the density board in a direction perpendicular to the transect and recording the percent of the density board covered by all forms of vegetation. Cover classes were the same as those used for the Daubenmire frame. Percent vegetation density within each decimeter interval was calculated by averaging the values obtained from the plot's 12 density board samples. Maximum height of vegetation for each plot was the average maximum decimeter with vegetation cover. An index of plot shrubbiness was calculated as the total vegetation density within the first two decimeters.

Horizontal heterogeneity was measured as the between-sample variation in vertical structure and was indexed by using the coefficient of variation (CV) between the 12 samples of maximum height of vegetation recorded with the density board (CVMAXHT) (Wiens and Rotenberry 1980). To correct for small sample bias the following estimate of CV was used:

$$CV = (1 + (1 / 4n)) (s * 100 / Y_{\text{bar}})$$

(Sokal and Braumann 1980).

Statistical Analysis

One-tailed *t*-tests assuming unequal variance were used to compare relative breeding bird densities adjacent to roads (within 100 m) with those recorded at greater distances. The density of species compared in this analysis included Brewer's sparrow, horned lark, sage sparrow, and sagebrush obligates (sum of Brewer's sparrow, sage sparrow, and sage thrasher). Tests were considered significant at $\alpha = 0.05$. Because multiple tests of the same hypothesis were conducted, a Bonferroni correction was applied to the decision rule of each test to maintain a family error rate of 0.05 (critical $\alpha = 0.0125$). Vegetation characteristics were compared adjacent to and away from the road using two-tailed *t*-tests assuming unequal variance. Seventeen vegetation variables with the greatest potential to influence species distribution were compared. Measured variables included live and dead sagebrush density, live and dead sagebrush cover, percent cover of grass, forbs, litter, and total cover, live and dead sagebrush height, vegetation density in decimeters 10 cm – 40 cm, average maximum vegetation height, shrubbiness, and horizontal heterogeneity. Separate-variance *t*-tests were employed for all *t*-tests because the separate-variance approach is more conservative than the pooled-

variance approach when sample sizes differ (Ramsey and Schafer 1997). The Mann-Whitney test was used to compare the median values of horizontal structural heterogeneity (CVMAXHT) within and outside the 100-m road zone. The Mann-Whitney test provides greater power than *t*-tests when the sample distribution is non-normal and is recommended when comparing measures of heterogeneity based on correlation coefficients (Sokal and Braumann 1980). Because it is important to demonstrate the comparability of vegetation structure and cover between road adjacent sites and sites outside the road zone, tests were considered significant at $\alpha = 0.1$. Because multiple tests of the same hypothesis were conducted, a Bonferroni correction was applied to the decision rule of each test to maintain a family error rate of 0.05 (critical $\alpha = 0.0058$). Tests were performed for each study area (Pipeline, Oil Well Road, Mesa I, Mesa II, Lumman I, Lumman II, and Highway 351) and for the combined data from all dirt roads (Lumman I, Lumman II, Mesa I, Mesa II, and Oil Well Road).

To investigate the influence of traffic on bird detectability, traffic volume was measured during counts. At each five-minute point count, the number of cars (two axles) and trucks (> two axles) were recorded. Because weather conditions and time of sampling have a large influence on bird detectability, subsequent day comparisons of changes in individual point count detections relative to the number of vehicles that pass during counts are of little value. Furthermore, bird densities adjacent to roads are influenced by total traffic volume. If traffic volumes change from day to day, bird numbers may increase when traffic is light and decrease when traffic is heavy (weekend vs. weekday effect). The effect of traffic was investigated on a daily basis to isolate the influence of traffic on bird detectability. Simple linear regression was employed using the number of vehicles that passed during a count as a predictor of number of birds detected. Only 2000 field season data from the Lumman and Highway 351 sites were used since other roads had traffic volumes so low that rarely more than two vehicles passed during an entire morning. Also, because the effect of noise on bird detectability should be greatest at sites adjacent to roads, analyses was restricted to point counts located 50 m from the road. This approach provided nine independent estimates of the effect of traffic on bird detectability. The slope from these nine regressions was pooled and a one-sample *t*-test was used to determine if the mean slope differed from zero.

RESULTS

Breeding bird abundance in 1999 was surveyed at 79 sites along the Lumman and Mesa Roads (39 along the Lumman Road, 40 along the Mesa Road). Average total number of birds detected per point count was 2.97 and 3.14 for the Lumman and Mesa Roads, respectively; means were not statistically different. Brewer's sparrows were the most common species detected, accounting for over half of all detections. Sage sparrows and horned larks each accounted for about 20% of detections, while sage thrashers and vesper sparrows each comprised less than 5% of detections. During the 2000 field season, point count means were lower than the previous season. While there was relatively little change in relative abundance, paired *t*-tests showed that point count means declined by 35% (95% CI = 12% - 40%, $P < 0.0000$) and 42% (95% CI = 27% - 57%, $P < 0.0000$) at the Lumman and Mesa Road sites, respectively (Table 3.3, Fig. 3.6).

Vegetation

The vegetation at all study sites was dominated by Wyoming big sagebrush, with an average live sagebrush cover of 16.5% and an average height of 27 cm. Sagebrush cover and height were comparable between all study areas except Highway 351, where sagebrush cover and height were lower (Fig. 3.7). Two-tailed *t*-tests showed no statistical difference in vegetation structure, cover, or heterogeneity between distance classes (within and outside the 100-m road zones) for any of the individual study areas or for the combined data set of all dirt roads (Lumman I, Lumman II, Mesa I, Mesa II, and the Oil Well Road) (Table 3.4 – Table 3.11). The comparability of the vegetation within these two sections was corroborated by the use of discriminant analysis, which failed to classify stands into either road zone or non-road zones on the basis of measures of vegetation structure.

Traffic Volume

Average daily traffic volume during the 1999 field season was 444 cars/day along the Lumman Road and 12 cars/day on the Mesa Road. During the spring of 2000, development activity increased in the Jonah Field II and 2000 traffic volume averaged 697 cars/day. Traffic volume on the Mesa Road showed little change from the previous year (11 cars/day). Average daily traffic volume along the new study sites was 344

cars/day along Highway 351 and 9 cars/day along the Oil Well Road. Vehicles were not present at the pipeline site (Fig. 3.8).

The Lumman Road was the only road with enough traffic to discern temporal patterns in traffic volume. Traffic patterns on the Lumman road reflected work day and work week schedules. Traffic peaked between 0530 and 0900 and thereafter remained fairly steady. On the weekends, traffic volumes dropped to 20% of the workweek volume. On weekdays, between 0500 and 0830, traffic volume was 75 cars/hr. On the weekend, traffic dropped to 15 cars/hr. ($n = 4$).

Breeding Bird Abundance

At the Lumman I site during the 1999 field season one-tailed t -tests showed a statistically significant decrease in sagebrush obligates, Brewer's sparrows, and a marginal decrease in sage sparrows within 100 m of the road. Within the 100-m road zone, densities were reduced by 52% ($P = 0.0008$) for sagebrush obligates, 49% ($P = 0.0045$) for Brewer's sparrow, and 52% ($P = 0.013$) for sage sparrows relative to densities outside of this zone (Table 3.12). Within the 100-m road zone along the Mesa Road, where traffic volume was light, sagebrush obligate density declined by 40% and sage sparrow density declined by 49% relative to densities outside this zone. These declines were not statistically significant ($P = 0.045$ and $P = 0.034$, respectively) (Table 3.13).

New roads were added to the study during the 2000 field season. To concentrate sampling effort where the road effect was potentially greatest, breeding bird densities were sampled only out to 200 m away from dirt roads and pipelines and out to 350 m from the paved highway. Point counts were centered at 50 m and 150 m along dirt roads and pipelines and additionally at 300 m along Highway 351.

Along the natural gas pipeline, comparisons of point count means using one-tailed t -tests showed no observable difference in breeding bird abundance between the two distance classes (0 – 100 m and 100 – 200 m). Sage sparrows showed a statistically insignificant decline of 64% ($P = 0.047$), while Brewer's sparrow density was slightly higher within the 100-m disturbance zone (Table 3.14). Similar comparisons of point count means along road sites illustrate a different trend. Along the Oil Well Road, sagebrush obligate and Brewer's sparrow density declined by 50% ($P = 0.008$) and 59%

($P = 0.012$), respectively, within the 100-m zone (Table 3.15). Along the Mesa I site sagebrush obligates were reduced by 43% ($P = 0.0032$) and sage sparrows by 76% ($P = 0.0012$) within the 100-m road zone (Table 3.16). The largest reductions within the 100-m road zone occurred at the Lumman I site. Within 100-m of this road, sagebrush obligates were reduced by 60% ($P < 0.0000$), Brewer's sparrows by 50% ($P = 0.0005$), and sage sparrows by 76% ($P = 0.0006$), relative to densities outside this zone (Table 3.17).

While bird abundance declined within the 100-m road-zone along all sites, declines were not always statistically significant. Along Highway 351, a paved road with an average daily traffic volume of 344 vehicles, there were no statistically significant differences in point count means for any species (Table 3.18). There were also no statistical differences in means from the Lumman II and Mesa II sites. (Table 3.19, 3.20).

To provide an overall idea of how roads associated with natural gas development affect breeding bird distribution, data from all dirt roads surveyed in 2000 were combined and point count means were examined for evidence of a road effect. Highway 351 was excluded from this analysis because it was a paved road with vegetation that was distinct from other surveyed sites (Fig. 3.7). Within the 100-m zone, sagebrush obligates are reduced by 39% ($P < 0.0000$), Brewer's sparrows by 36% ($P < 0.0000$), and sage sparrows by 57% ($P < 0.0000$), relative to areas outside the 100-m zone. The data also suggest that horned lark abundance may be slightly higher within the road zone (30% greater, $P = 0.023$ for one-tailed t -test for mean road zone $>$ undisturbed zone; Table 3.21).

Species Composition

Along roads there was a species composition shift, with an increase in horned lark abundance relative to sagebrush obligates. Within the 100-m road zone, horned larks accounted for 31% of detections and sagebrush obligates comprised 66% of observations. Outside the 100-m road zone, horned larks accounted for only 16% while sagebrush obligates increased to 81% of detections (Fig. 3.9).

Traffic Influence on Bird Detectability

Simple linear regression was used to examine the impact of traffic noise on bird detectability. The effect of noise was investigated on a daily basis for those roads where

traffic volume was relatively high (> 100 cars/day). The mean slope of these regression lines did not differ from zero, suggesting that traffic noise does not affect the observer's ability to detect birds using a 50-m radius point count (Fig. 3.10).

DISCUSSION

The results from this provide evidence that roads associated with natural gas development negatively impact sagebrush obligate passerines. Impacts are greatest along access roads where traffic volume is high. The density of sagebrush obligates declined by as much as 60% (95% CI = 40% - 81%) within a 100-m buffer around these roads. Even along roads with light traffic volume (< 12 cars/day), the density of sagebrush obligates was reduced within the 100-m road zone.

Given that sagebrush obligate density is reduced along roads regardless of traffic volume, to what aspects of roads are sagebrush obligate species responding? Other studies illustrate that when traffic volume is greater than 10,000 vehicles/day, birds are responding to the disturbance created by traffic noise (Warner 1992, Foppen and Reijnen 1994, Reijnen and Foppen 1994). Along the Lumman Road, traffic volume is heavy and consistent enough that birds are probably responding to some aspect of traffic such as noise or dust.

However, traffic alone cannot explain the observed reductions in bird abundance along roads with light traffic volumes (< 12 cars/day). Along such roads, two additional mechanisms may be influencing passerine abundance: avoidance of habitat edges and changes in species composition. Along the natural gas pipeline where traffic was absent, sage sparrow density was reduced by 64% within a 100-m buffer of the surface disturbance. ($P = 0.047$). Although not statistically significant, there is some evidence that sage sparrows avoided edges created by surface disturbances. Sage sparrows are area sensitive (Knick and Rotenberry 1995), and while roads created during natural gas extraction do not constitute a fragmentation of the sagebrush steppe, sage sparrows may select against edges created by road construction.

A second mechanism that may contribute to the decline in sagebrush obligates around roads is the observed increase in horned lark abundance within the 100-m road zone. Horned larks are grassland species that are common along dirt roadways (Beason 1995), where they forage on windblown seeds that collect in the lee of gravel on dirt

roads. Within the 100-m road zone, horned larks accounted for 31% of bird detections, while beyond the 100-m, zone they accounted for only 16%. This change in species composition is primarily the result of a decline in sagebrush obligate abundance within the 100-m zone, however, horned lark abundance was slightly higher within the 100-m road zone. Because horned larks observed foraging on roads and road margins were outside point count boundaries and were not included in count totals, estimates of horned lark abundance along roads are conservative. Extensive studies of sagebrush steppe birds illustrate that competition rarely structures this community (Rotenberry and Wiens 1980a, 1980b, Wiens and Rotenberry 1981). Negative interactions between sympatric species are rare in part because resources are rarely limiting and are not concentrated. However, the concentration of seed resources along dirt roads may create a foraging opportunity that horned larks defend. Horned larks are the second largest passerine in the study area, second only to the sage thrasher, and horned larks were repeatedly observed initiating aggressive interactions with Brewer's and sage sparrows along roads. The increased concentration of horned larks along roads may reduce the surrounding habitat's attractiveness to other sympatric species through either exploitative or interference competition.

At all study locations, regardless of traffic volume, sagebrush obligate bird density was reduced within the 100-m road zone. However, at three sites - the Lumnian II, Mesa II, and Highway 351 - reductions were not statistically significant. At the Lumman II and Mesa II sites, small sample size reduced the power of these analyses; reductions less than one third were not statistically significant.

Along Highway 351, bird densities were less, but again reductions were not statistically significant. Three factors may explain this pattern. First, the road was paved. Although pavement allows for greater vehicle speeds, it eliminates the foraging opportunities for horned larks. Paved Highway 351 was the only site where horned larks were reduced within the road zone. Second, a barbed-wire fence ran the length of the highway. This fence was 1.3 m in height, ran parallel to the highway on both sides of the road, and was located about 20 m from the road's edge so that it split the point counts located within the 100-m road zone. Birds were often observed perching on and singing from this fence. If this elevated perch attracted birds or increased their detectability,

relative to other areas, the fence may have inflated detection totals within the 100-m road zone. Finally, Highway 351 was the most xeric study area within the study and had the lowest sagebrush canopy cover and average height of any site. Point detections were lower here than any other area, and the failure to detect significant declines could have been influenced by the overall paucity of birds within the area.

CONCLUSION

Individually, a 50% reduction in sagebrush obligates within 100 m of roads may not be biologically significant. However, when this effect is compounded by the density of roads created during natural gas development and extraction, the area of impact can be substantial. In the Record of Decision, signed in July 2000, the Bureau of Land Management approved the construction of 444 km of roads within the portion of the PAPA under BLM jurisdiction (Bureau of Land Management 2000). If a conservative road width of 10 m is used, roads will cover over 0.7% of the PAPA. If a 100-m buffer is extended around roads, roads will impact over 14.6% of the Pinedale Anticline Project Area.

Within the PAPA, traffic volume will be greatest during the 15-year development period, after which traffic volume should subside. However, this study indicates that bird densities are reduced along roadways regardless of traffic volume. Whether these reductions are in response to traffic, edge avoidance, or increases in horned lark abundance, the effect of roads will continue even after traffic volume subsides and perhaps until the sagebrush vegetation is reclaimed.

My study was conducted during the beginning phases of natural gas development, during which the sagebrush vegetation was still a contiguous stand. As development continues, roads, pipelines, and well pads will perforate sagebrush habitats. Future studies should investigate how birds respond to these development changes. Of particular interest is how birds respond to habitat perforation and fragmentation and how species composition changes as roads create corridors that attract horned larks to new areas formally dominated by sagebrush obligates.

The long-term impact of natural gas development on sagebrush obligate passerines is unclear. Based on this study, sagebrush obligate passerines are expected to decline within the study area. The magnitude of this decline will depend on the amount

of road construction and on bird response to other development activities such as edges created by pipelines, habitat fragmentation, and increases in horned lark abundance.

While sagebrush obligate passerines will decline during natural gas development and extraction within the PAPA, perhaps the more important issue relates to how quickly these populations will recover after the area is abandoned and reclaimed. Relative to larger, longer-lived species such as mule deer (*Oeocoileus hemionus*), pronghorn antelope (*Antilocapra americana*), and sage grouse (*Centrocercus urophasianus*), sagebrush obligate passerines might be more resilient. The temporary (fifty year) loss of crucial winter range for mule deer and pronghorn could have long term effects on winter survival, loss of migration pathways, and population isolation, but passerines are more flexible in their breeding requirements. This suggests that birds may quickly return to their former ranges following reclamation. However, population dynamics are not so simple. Natural gas extraction is expected to increase throughout Wyoming's sagebrush habitat. While the population consequences of development of one natural gas field may not be important, the development of multiple gas fields simultaneously, accompanied by historic sagebrush management practices, could have important long-term population ramifications. Given the inability of sagebrush obligate passerines to expand their populations quickly (Wiens 1974, 1977), it may take decades for sagebrush obligates to recover following reclamation of the Pinedale Anticline Project Area. Further monitoring seems advisable.

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Table 3.1. Description of survey locations, years surveyed, distance classes, and sample size in each distance class.

Location	Years Surveyed	Distance classes	Samples / Distance class
Mesa 1	1999 - 2000	0m - 100m, 100m - 200m, 250m - 350m, 300m - 400m, 500m - 600m	8
Lumman 1	1999 - 2000	0m - 100m, 100m - 200m, 250m - 350m, 300m - 400m, 500m - 600m	8
Hwy 351	2000	0m - 100m, 100m - 200m, 250 - 350m	14
Lumman 2	2000	0m - 100m, 100m - 200m	10
Mesa 2	2000	0m - 100m, 100m - 200m	10
Oil Well Road	2000	0m - 100m, 100m - 200m	10
Pipeline	2000	0m - 100m, 100m - 200m	10

Table 3.2. Vegetation variables measured in road study areas. See text for description and calculation.

Variable	Code	Units
Coverage		
<i>Line-Intercept</i>		
Live Sagebrush Density	Live Den	Bush / m ²
Dead Sagebrush Density	Dead Den	Bush / m ²
% Cover Sagebrush	Sage Cov	% Cover
% Cover Dead Sagebrush	Dead Cov	% Cover
% Cover Rabbit Brush	RB Cov	% Cover
<i>Daubenmire Frame</i>		
% Cover Grass	%Grass	% Cover
% Cover Forbs	%Forb	% Cover
% Cover Litter	%Lit	% Cover
% Cover Bare Ground	%Bare	% Cover
% Cover Lichen	%Lich	% Cover
% Cover Cactus	%Cact	% Cover
% Cover Cow Pie	%Cow	% Cover
% Total Cover	%TOT Cov	% Cover
Structure		
<i>Line-Intercept</i>		
Average Sagebrush Height	Sage Ht	cm
Average Dead Sagebrush Height	Dead Ht	cm
Average Rabbit Brush Height	RB Ht	cm
<i>Density Board</i>		
% Cover in First Decimeter	10 DEC	% Cover
% Cover in Second Decimeter	20 DEC	% Cover
% Cover in Third Decimeter	30 DEC	% Cover
% Cover in Fourth Decimeter	40 DEC	% Cover
% Cover in Fifth Decimeter	50 DEC	% Cover
% Cover in Sixth Decimeter	60 DEC	% Cover
% Cover in Seventh Decimeter	70 DEC	% Cover
% Cover in Eighth Decimeter	80 DEC	% Cover
% Cover in Ninth Decimeter	90 DEC	% Cover
% Cover in Tenth Decimeter	100 DEC	% Cover
Average Maximum Height of Vegetation	AVE MAX HT	cm
Shrubbinness (% cover in first 20 decimeters)	SHRUB20	%
Horizontal Heterogeneity		
Coefficient of Variation For Maximum Decimeter with Vegetation Cover	CVMAXHT	%

Table 3.3. 1999 vs. 2000 point count means for the Lumman 1 and Mesa 1 sites. Paired t-tests were used to test the difference in point count means at each site (n = 39 for Lumman 1, n = 40 for Mesa 1 site). * Denotes significantly higher means. Values in parentheses are standard errors.

Paired *t*-test results:

Location	1999 mean	2000 mean	<i>t</i> - value	<i>P</i> - value
Lumman 1	*2.974 (0.201)	2.197 (0.149)	3.83	0.000
Mesa 1	*3.137 (0.206)	1.817 (.156)	5.68	0.000

Table 3.4. Highway 351 comparison of vegetation cover and structure between 100-m road zone and undisturbed zones. Two-tailed *t*-tests were used to test if vegetation characteristics measured within 100-m of Highway 351 (n=14) were less than characteristics measured between 100-350m from the road (n=28). Bolded variables are significantly different (alpha = 0.1, Bonferroni adjusted critical value = 0.0059). Values in parentheses are standard errors.

Variable	Mean 50m	Mean 150m	<i>t</i>-stat	<i>P</i>-value
<i>Band Transect</i>				
Live Den	1.569 (0.098)	1.632 (0.098)	-0.45	0.65
Dead Den	0.236 (0.037)	0.234 (0.021)	0.04	0.97
<i>Line-Intercept</i>				
Sage Cov	11.45 (1.0)	11.56 (0.84)	-0.08	0.93
Dead Cov	2.32 (0.37)	2.21 (0.24)	0.24	0.81
Sage Ht	21.51 (1.1)	20.43 (0.80)	0.78	0.44
Dead Ht	14.42 (1.0)	13.70 (0.90)	0.52	0.61
<i>Daubenmire Frame</i>				
%Grass	4.48 (0.46)	4.43 (0.39)	0.07	0.94
%Forb	4.26 (0.85)	5.23 (0.54)	-0.97	0.34
%Lit	11.88 (1.5)	13.07 (1.2)	-0.63	0.54
%TOT Cov	22.01 (1.8)	22.46 (1.2)	-0.21	0.84
<i>Density Board</i>				
10 DEC	27.22 (2.0)	26.44 (1.7)	0.29	0.77
20 DEC	10.37 (1.2)	9.92 (1.2)	0.26	0.79
30 DEC	3.36 (0.69)	3.85 (0.84)	-0.45	0.66
40 DEC	1.28 (0.59)	1.56 (0.44)	-0.38	0.71
AVE MAX HT	22.62 (0.83)	19.79 (0.72)	2.57	0.015
SHRUB20	18.79 (1.5)	18.18 (1.4)	0.31	0.76
	Median 50m	Median 150m	<i>w</i>-Stat	<i>P</i>-value
CVMAXHT	118.27	117.0	307	.8833

Table 3.5. Lumman 1 comparison of vegetation cover and structure between 100-m road zone and undisturbed zones. Two-tailed *t*-tests were used to test if vegetation characteristics measured within 100-m of Lumman 1 site (n=8) were less than characteristics measured between 100-600m from the road (n=27). Bolded variables are significantly different (alpha = 0.1, Bonferroni adjusted critical value = 0.0059). Values in parentheses are standard errors.

Variable	Mean 50m	Mean 150m	<i>t</i>-Stat	<i>P</i>-value
<i>Band Transect</i>				
Live Den	1.50 (0.081)	1.482 (0.064)	0.18	0.86
Dead Den	0.338 (0.047)	0.301 (0.020)	0.71	0.49
<i>Line-Intercept</i>				
Sage Cov	15.08 (1.1)	15.05 (0.82)	0.02	0.99
Dead Cov	3.19 (0.67)	3.01 (0.29)	0.24	0.81
Sage Ht	27.44 (1.6)	27.7 (0.94)	-0.14	0.89
Dead Ht	16.39 (1.4)	19.91 (0.83)	-2.14	0.051
<i>Daubenmire Frame</i>				
%Grass	6.98 (.84)	6.12 (0.39)	0.93	0.38
%Forb	5.60 (0.66)	6.45 (0.47)	-1.05	0.31
%Lit	21.22 (3.5)	16.92 (1.2)	1.17	0.28
%TOT Cov	33.36 (3.3)	29.94 (1.5)	0.95	0.36
<i>Density Board</i>				
10 DEC	44.3 (4.5)	42.8 (2.1)	0.32	0.76
20 DEC	28.3 (4.3)	25.7 (2.0)	0.56	0.59
30 DEC	15.0 (3.6)	15.3 (2.0)	-0.08	0.94
40 DEC	6.98 (2.1)	6.80 (1.3)	-0.07	0.94
AVE MAX HT	27.92 (2.0)	26.73 (1.0)	0.52	0.61
SHRUB20	36.30 (4.3)	33.00 (2.1)	0.70	0.50
	Median 50m	Median 150m	<i>w</i>-stat	<i>P</i>-value
CVMAXHT	114.59	116.88	114.0	0.2465

Table 3.6. Lumman 2 comparison of vegetation cover and structure between 100-m disturbance zone and undisturbed zones. Two-tailed *t*-tests were used to test if vegetation characteristics measured within 100-m of the Lumman Road (n=10) were less than characteristics measured between 100-200m from the road (n=10). Bolded variables are significantly different (alpha = 0.1, Bonferroni adjusted critical value = 0.0059). Values in parentheses are standard errors.

Variable	Mean 50m	Mean 150m	<i>t</i>-Stat	<i>P</i>-value
	<i>Band Transect</i>			
Live Den	1.253 (0.09)	1.380 (0.12)	-0.84	0.41
Dead Den	0.230 (0.23)	0.253 (0.035)	-0.55	0.59
	<i>Line-Intercept</i>			
Sage Cov	13.25 (0.86)	15.48 (2.6)	-0.82	0.43
Dead Cov	2.30 (0.36)	2.62 (0.43)	-0.57	0.57
Sage Ht	28.80 (1.5)	30.07 (2.2)	-0.48	0.64
Dead Ht	19.28 (1.9)	19374 (2.0)	-0.17	0.87
	<i>Daubenmire Frame</i>			
%Grass	5.10 (0.49)	6.23 (0.41)	-1.76	0.097
%Forb	6.52 (0.57)	6.73 (1.0)	-0.18	0.86
%Lit	12.21 (1.4)	17.19 (1.7)	-0.88	0.39
%TOT Cov	22.87 (1.8)	26.06 (2.1)	-1.15	0.27
	<i>Density Board</i>			
10 DEC	33.69 (2.5)	34.04 (2.8)	-0.09	0.93
20 DEC	17.98 (2.7)	17.90 (2.8)	0.02	0.98
30 DEC	8.50 (2.1)	7.90 (2.0)	0.21	0.84
40 DEC	2.50 (1.2)	4.23 (1.8)	-0.80	0.43
AVE MAX HT	23.08 (1.5)	24.33 (1.9)	-0.52	0.61
SHRUB20	25.83 (2.5)	25.97 (2.6)	-0.04	0.97
	Median 50m	Median 150m	<i>w</i>-stat	<i>P</i>-value
CVMAXHT	120.71	119.09	110.0	0.4379

Table 3.7. Mesa 1 comparison of vegetation cover and structure between 100-m road zone and undisturbed zones. Two-tailed *t*-tests were used to test if vegetation characteristics measured within 100-m of Highway 351 (n=8) were less than characteristics measured between 100-600m from the road (n=32). Bolded variables are significantly different) alpha = 0.1, Bonferroni adjusted critical value = 0.0059). Values in parentheses are standard errors.

Variable	Mean 50m	Mean 150m	<i>t</i>-Stat	<i>P</i>-value
<i>Band Transect</i>				
Live Den	2.806 (0.26)	2.766 (0.14)	0.14	0.55
Dead Den	0.1917 (0.031)	0.316 (.028)	-2.96	0.0081
<i>Line-Intercept</i>				
Sage Cov	20.54 (0.85)	21.89 (0.82)	-1.14	0.27
Dead Cov	2.65 (0.62)	2.64 (0.21)	0.02	0.99
Sage Ht	28.67 (1.6)	27.90 (0.71)	0.45	0.66
Dead Ht	21.55 (2.3)	19.17 (1.1)	0.93	0.38
<i>Daubenmire Frame</i>				
%Grass	8.23 (0.76)	6.84 (0.41)	1.60	0.14
%Forb	6.72 (1.3)	5.91 (0.47)	0.57	0.59
%Lit	24.11 (2.6)	23.74 (1.3)	0.13	0.90
%TOT Cov	36.51 (2.6)	35.47 (1.4)	0.35	0.73
<i>Density Board</i>				
10 DEC	44.3 (4.4)	46.7 (2.2)	-0.48	0.64
20 DEC	27.58 (3.2)	28.6 (2.3)	-0.26	0.80
30 DEC	15.36 (3.0)	15.4 (1.8)	0.00	1.0
40 DEC	5.03 (1.6)	6.28 (1.1)	-0.63	0.54
AVE MAX HT	25.52 (1.3)	27.01 (0.99)	-0.90	0.38
SHRUB20	35.9 (3.7)	37.6 (2.2)	-0.40	0.70
	Median 50m	Median 150m	<i>w</i>-stat	<i>P</i>-value
CVMAXHT	119.73	117.44	199.5	0.2366

Table 3.8. Mesa 2 comparison of vegetation cover and structure between 100-m road zone and undisturbed zones. Two-tailed *t*-tests were used to test if vegetation characteristics measured within 100-m of the Mesa Road (n=10) were less than characteristics measured between 100-200m from the road (n=10). Bolded variables are significantly different (alpha = 0.1, Bonferroni adjusted critical value = 0.0059). Values in parentheses are standard errors.

Variable	Mean 50m	Mean 150m	<i>t</i>-Stat	<i>P</i>-value
<i>BandTransect</i>				
Live Den	2.048 (0.19)	1.905 (0.13)	2.20	0.044
Dead Den	0.363 (0.086)	0.440 (0.084)	-0.64	0.53
<i>Line-Intercept</i>				
Sage Cov	22.17 (1.1)	18.50 (0.83)	2.67	0.017
Dead Cov	2.15 (0.43)	3.08 (0.50)	-0.42	0.17
Sage Ht	26.91 (1.6)	27.66 (0.98)	-0.41	0.69
Dead Ht	21.59 (1.2)	20.63 (2.1)	0.40	0.70
<i>Daubenmire Frame</i>				
%Grass	8.98 (0.84)	8.67 (1.1)	0.23	0.82
%Forb	7.46 (1.2)	8.98 (1.0)	-0.98	0.34
%Lit	22.27 (2.8)	21.73 (2.4)	0.15	0.89
%TOT Cov	40.73 (2.4)	43.19 (2.8)	-0.67	0.51
<i>Density Board</i>				
10 DEC	43.67 (2.6)	45.04 (2.9)	-0.35	0.73
20 DEC	25.2 (3.2)	30.48 (2.7)	-1.25	0.23
30 DEC	14.25 (2.3)	17.65 (1.4)	-1.26	0.23
40 DEC	5.29 (1.6)	7.25 (1.1)	-1.00	0.33
AVE MAX HT	26.92 (0.74)	29.50 (3.1)	-1.31	0.21
SHRUB20	34.44 (2.8)	37.76 (2.7)	-0.86	0.40
	Median 50m	Median 150m	<i>w</i>-stat	<i>P</i>-value
CVMAXHT	115.59	116.95	96.5	0.5453

Table 3.9. Oil Well Road comparison of vegetation cover and structure between 100-m road zone and undisturbed zones. Two-tailed *t*-tests were used to test if vegetation characteristics measured within 100-m of Oil Well Road (n=10) were less than characteristics measured between 100-200m from the road (n=10). Bolded variables are significantly different (alpha = 0.1, Bonferroni adjusted critical value = 0.0059). Values in parentheses are standard errors.

Variable	Mean 50m	Mean 150m	<i>t</i>-Stat	<i>P</i>-value
<i>Band Transect</i>				
Live Den	1.928 (0.069)	1.948 (0.14)	-0.13	0.90
Dead Den	0.495 (0.054)	0.615 (0.058)	-1.51	0.15
<i>Line-Intercept</i>				
Sage Cov	15.61 (0.94)	18.92 (1.9)	-1.56	0.14
Dead Cov	4.04 (0.56)	4.19 (0.44)	-0.21	0.83
Sage Ht	28.13 (1.4)	28.95 (1.2)	-0.45	0.66
Dead Ht	17.60 (1.1)	18.92 (1.6)	-0.67	0.51
<i>Daubenmire Frame</i>				
%Grass	9.29 (0.99)	9.48 (1.0)	-0.13	0.90
%Forb	9.60 (1.6)	9.29 (0.98)	0.17	0.87
%Lit	24.44 (1.8)	27.52 (2.4)	-1.03	0.32
%TOT Cov	43.00 (2.6)	46.42 (2.4)	-0.98	0.34
<i>Density Board</i>				
10 DEC	39.7 (4.0)	43.1 (3.7)	-0.62	0.54
20 DEC	25.2 (3.6)	32.0 (4.1)	-1.24	0.23
30 DEC	12.15 (2.8)	20.23 (2.9)	-2.00	0.062
40 DEC	4.81 (1.7)	8.15 (2.3)	-1.15	0.27
AVE MAX HT	27.08 (1.8)	30.92 (1.9)	-1.46	0.16
SHRUB20	32.5 (3.6)	37.5 (3.8)	-0.96	0.35
	Median 50m	Median 150m	w-stat	<i>P</i>-value
CVMAXHT	117.96	115.25	127.0	0.1041

Table 3.10. Pipeline comparison of vegetation cover and structure between 100-m disturbance zone and undisturbed zones. Two-tailed *t*-tests were used to test if vegetation characteristics measured within 100-m of the pipeline (n=10) were less than characteristics measured between 100-200m from the road (n=10). Bolded variables are significantly different (alpha = 0.1, Bonferroni adjusted critical value = 0.0059). Values in parentheses are standard errors.

Variable	Mean 50m	Mean 150m	<i>t</i>-Stat	<i>P</i>-value
<i>Band Transect</i>				
Live Den	2.263 (0.13)	2.113 (0.12)	0.85	0.41
Dead Den	0.4917 (0.018)	0.4700 (0.032)	0.59	0.56
<i>Line-Intercept</i>				
Sage Cov	18.51 (1.1)	17.36 (1.1)	0.72	0.48
Dead Cov	3.670 (0.33)	3.860 (0.28)	-0.45	0.66
Sage Ht	28.61 (1.0)	28.39 (1.0)	0.16	0.88
Dead Ht	18.38 (1.7)	17.68 (1.1)	0.34	0.74
<i>Daubenmire Frame</i>				
%Grass	8.06 (0.35)	9.35 (0.87)	-1.38	0.19
%Forb	8.42 (0.73)	10.19 (0.98)	-1.45	0.17
%Lit	21.73 (2.4)	22.19 (2.5)	-0.13	0.90
%TOT Cov	37.96 (2.3)	41.19 (3.1)	-0.84	0.41
<i>Density Board</i>				
10 DEC	44.00 (3.0)	43.3 (4.0)	0.14	0.89
20 DEC	30.7 (3.7)	30.3 (3.3)	0.09	0.93
30 DEC	15.73 (2.5)	17.58 (2.1)	-0.56	0.58
40 DEC	5.81 (0.99)	7.63 (1.8)	-0.88	0.40
AVE MAX HT	27.67 (1.4)	29.58 (1.4)	-0.99	0.34
SHRUB20	37.36 (3.1)	36.80 (3.6)	0.12	0.91
	Median 50m	Median 150m	<i>w</i>-Stat	<i>P</i>-value
CVMAXHT	118.51	17.7	107.5	0.8898

Table 3.11. Total dirt road comparison of vegetation cover and structure between 100-m disturbance zone and undisturbed zones. Two-tailed *t*-tests were used to test if vegetation characteristics measured within 100-m of all dirt roads surveyed (n=46) were less than characteristics measured between 100-600m from the road (n=88). Bolded variables are significantly different (alpha = 0.1, Bonferroni adjusted critical value = 0.0059). Values in parentheses are standard errors.

Variable	Mean 50m	Mean 150m	<i>t</i>-Stat	<i>P</i>-value
<i>Band Transect</i>				
Live Den	1.964 (0.11)	2.008 (0.083)	-0.33	0.74
Dead Den	0.329 (0.029)	0.350 (0.019)	-0.62	0.54
<i>Line-Intercept</i>				
Sage Cov	17.29 (0.67)	18.24 (0.60)	-1.06	0.29
Dead Cov	2.86 (0.25)	2.98 (0.15)	-0.40	0.69
Sage Ht	27.99 (0.66)	28.87 (0.60)	-0.99	0.33
Dead Ht	19.31 (0.74)	19.68 (0.58)	-0.39	0.70
<i>Daubenmire Frame</i>				
%Grass	7.73 (0.42)	7.02 (0.27)	1.42	0.16
%Forb	7.27 (0.53)	6.78 (0.3)	0.64	0.52
%Lit	20.69 (1.3)	20.63 (0.84)	0.04	0.97
%TOT Cov	35.3 (1.5)	34.6 (1.1)	0.38	0.70
<i>Density Board</i>				
10 DEC	40.9 (1.6)	43.2 (1.3)	-1.11	0.27
20 DEC	24.6 (1.5)	26.5 (1.3)	-0.97	0.33
30 DEC	12.87 (1.2)	14.59 (1.0)	-1.08	0.28
40 DEC	4.83 (0.74)	6.40 (0.66)	-1.58	0.12
AVE MAX HT	26.05 (0.75)	27.21 (0.59)	-1.21	0.23
SHRUB20	32.7 (1.5)	33.6 (1.1)	-0.44	0.66
	Median 50m	Median 150m	<i>w</i>-stat	<i>P</i>-value
CVMAXHT	117.96	117.02	3246.5	0.5088

Table 3.12. 1999 Lumman 1 road comparison of point count means between 100-m road zone and undisturbed zones. One-tailed *t*-tests were used to test if point count means recorded within 100-m of the Mesa Road (n=8) were less than point count means recorded between 100-600m from the road (n=27). Variables in bold are significantly different (alpha = 0.05, Bonferroni adjusted critical value = 0.0125). Values in parentheses are standard errors.

Species	Mean 50m	Mean >150m	95% CI $\mu_{50} - \mu_{150}$	<i>t</i> -stat	<i>P</i> -value
Sagebrush Obligates	1.167 (0.25)	2.41 (0.22)	-1.95 - -0.54	-3.73	0.0008
Brewer's Sparrow	0.792 (0.20)	1.562 (0.17)	-1.32 - -0.22	-2.93	0.0045
Horned Lark	0.500 (0.14)	0.970 (0.16)	-0.85 - 0.03	-1.92	0.034
Sage Sparrow	0.333 (0.11)	0.691 (0.10)	-0.67 - -0.05	-2.40	0.013

Table 3.13. 1999 Mesa 1 road comparison of point count means between 100-m road zone and undisturbed zones. One-tailed *t*-tests were used to test if point count means recorded within 100-m of the Mesa Road (n=8) were less than point count means recorded between 100-600m from the road (n=32). Variables in bold are significantly different (alpha = 0.05, Bonferroni adjusted critical value = 0.0125). Values in parentheses are standard errors.

Species	Mean 50m	Mean >150m	95% CI $\mu_{50} - \mu_{150}$	<i>t</i> -stat	<i>P</i> -value
Sagebrush Obligates	1.42 (0.45)	2.35 (0.20)	-2.04 - 0.18	-1.90	0.045
Brewer's Sparrow	1.00 (0.33)	1.453 (0.16)	-1.26 - 0.36	-0.65	0.12
Horned Lark	0.833 (0.19)	0.719 (0.12)	-0.37 - 0.60	0.51	0.62
Sage Sparrow	0.375 (0.15)	0.740 (0.11)	-0.76 - 0.03	-1.96	0.034

Table 3.14. Pipeline comparison of point count means between 100-m disturbance zone and undisturbed zones. Two-tailed *t*-tests were used to test the difference between point count means recorded within 100-m of a natural gas pipeline (n=10) and counts recorded between 100-200m from the pipeline (n=10). Values in parentheses are standard errors.

Species	Mean 50m	Mean 150m	95% CI $\mu_{50} - \mu_{150}$	t-stat	P - value
Sagebrush Obligates	1.33 (0.19)	1.433 (0.12)	-0.59 – 0.39	-0.44	0.67
Brewer's Sparrow	1.167 (0.17)	0.933 (0.17)	-0.19 – 0.66	1.17	0.26
Horned Lark	0.433 (0.15)	0.333 (0.11)	-0.29 – 0.49	0.54	0.60
Sage Sparrow	0.133 (0.054)	0.367 (0.092)	-0.46 – -0.004	-2.18	0.047

Table 3.15. Oil Well Road comparison of point count means between 100-m road zone and undisturbed zones. One-tailed *t*-tests were used to test if point count means recorded within 100-m of the Oil Well Road (n=10) were less than point count means recorded between 100-200m from the road (n=10). Variables in bold are significantly different (alpha = 0.05, Bonferroni adjusted critical value = 0.0125). Values in parentheses are standard errors.

Species	Mean 50m	Mean 150m	95% CI $\mu_{50} - \mu_{150}$	t-stat	P-value
Sagebrush Obligates	1.167 (0.14)	2.33 (0.39)	-1.77 – -0.30	-2.82	0.0083
Brewer's Sparrow	0.633 (0.12)	1.50 (0.31)	-1.59 – -0.14	-2.64	0.0120
Horned Lark	0.300 (.10)	0.200 (0.074)	-0.17 – 0.372	0.78	0.45
Sage Sparrow	0.133 (0.074)	0.233 (0.10)	-0.363 – 0.16	-0.80	0.22

Table 3.16. 2000 Mesa 1 road comparison of point count means between 100-m road zone and undisturbed zones. One-tailed *t*-tests were used to test if point count means recorded within 100-m of the Mesa Road (n=8) were less than point count means recorded between 100-600m from the road (n=32). Variables in bold are significantly different (alpha = 0.05, Bonferroni adjusted critical value = 0.0125). Values in parentheses are standard errors.

Species	Mean 50m	Mean >150m	95% CI $\mu_{50} - \mu_{150}$	<i>t</i> -stat	<i>P</i> -value
Sagebrush Obligates	0.917 (0.18)	1.615 (0.14)	-1.17 - -0.23	-3.13	0.0032
Brewer's Sparrow	0.667 (0.21)	1.052 (0.13)	-0.92 - 0.15	-1.58	0.07
Horned Lark	0.375 (0.13)	0.281 (0.078)	-0.24 - 0.429	0.61	0.55
Sage Sparrow	0.125 (0.088)	0.531 (0.075)	-0.65 - -0.16	-3.53	0.0012

Table 3.17. 2000 Lumman 1 road comparison of point count means between 100-m road zone and undisturbed zones. One-tailed *t*-tests were used to test if point count means recorded within 100-m of the Lumman Road (n=8) were less than point count means recorded between 100-600m from the road (n=27). Variables in bold are significantly different (alpha = 0.05, Bonferroni adjusted critical value = 0.0125). Values in parentheses are standard errors.

Species	Mean 50m	Mean >150m	95% CI $\mu_{50} - \mu_{150}$	<i>t</i> -stat	<i>P</i> -value
Sagebrush Obligates	0.792 (0.15)	1.963 (0.14)	-1.60 - -0.74	-5.69	0.0000
Brewer's Sparrow	0.708 (0.13)	1.407 (0.12)	-1.07 - -0.32	-3.91	0.0005
Horned Lark	0.417 (0.16)	0.432 (0.11)	-0.44 - 0.41	-0.08	0.94
Sage Sparrow	0.083 (0.055)	0.420 (0.077)	-0.53 - -0.14	-3.57	0.0006

Table 3.18. Highway 351 comparison of point count means between 100-m road zone and undisturbed zones. One-tailed *t*-tests were used to test if point count means recorded within 100-m of the Oil Well Road (n=14) were less than point count means recorded between 100-400m from the road (n=28). Values in parentheses are standard errors.

Species	Mean 50m	Mean >150m	95% CI $\mu_{50} - \mu_{150}$	<i>t</i> -stat	<i>P</i> -value
Sagebrush Obligates	0.881 (0.20)	1.000 (0.11)	-0.60 – 0.36	-0.52	0.30
Brewer's Sparrow	0.571 (0.17)	0.750 (0.10)	-0.58 – 0.23	-0.91	0.19
Horned Lark	0.190 (0.11)	0.488 (0.099)	-0.60 – 0.002	-2.02	0.052
Sage Sparrow	0.238 (0.095)	0.226 (0.067)	-0.227 – 0.25	-0.54	0.54

Table 3.19. Lumman 2 road comparison of point count means between 100-m road zone and undisturbed zones. One-tailed *t*-tests were used to test if point count means recorded within 100-m of the Lumman Road (n=10) were less than point count means recorded between 100-200m from the road (n=9). Values in parentheses are standard errors.

Species	Mean 50m	Mean 150m	95% CI $\mu_{50} - \mu_{150}$	<i>t</i> -stat	<i>P</i> -value
Sagebrush Obligates	1.533 (0.30)	1.963 (0.18)	-1.18 – 0.32	-1.23	0.12
Brewer's Sparrow	1.10 (0.25)	1.556 (0.21)	-1.15 – 0.24	-1.39	0.092
Horned Lark	0.833 (0.24)	0.593 (0.20)	-0.43 – 0.91	0.76	0.77
Sage Sparrow	0.233 (0.087)	0.333 (0.11)	-0.40 – 0.20	-0.71	0.24

Table 3.20. Mesa 2 road comparison of point count means between 100-m road zone and undisturbed zones. One-tailed *t*-tests were used to test if point count means recorded within 100-m of the Mesa Road (n=8) were less than point count means recorded between 100-600m from the road (n=27). Values in parentheses are standard errors.

Species	Mean 50m	Mean >150m	95% CI $\mu_{50} - \mu_{150}$	<i>t</i> -stat	<i>P</i> -value
Sagebrush Obligates	1.333 (0.23)	1.767 (0.26)	-1.18 - 0.31	-1.23	0.12
Brewer's Sparrow	1.00 (0.16)	1.30 (0.20)	-0.85 - 0.25	-1.15	0.13
Horned Lark	0.600 (0.19)	0.367 (0.13)	-0.25 - 0.72	1.02	0.32
Sage Sparrow	0.300 (0.10)	0.300 (0.06)	-0.26 - 0.26	0.00	0.50

Table 3.21. Total dirt road comparison of point count means between 100-m road zone and undisturbed zones. One-tailed *t*-tests were used to test if point count means recorded within 100-m of all dirt roads surveyed (n=46) were less than point count means recorded between 100-200m from dirt roads (n=88). Variables in bold are significantly different (alpha = 0.05, Bonferroni adjusted critical value = 0.0125). Values in parentheses are standard errors.

Species	Mean 50m	Mean >150m	95% CI $\mu_{50} - \mu_{150}$	<i>t</i> -stat	<i>P</i> -value
Sagebrush Obligates	1.094 (0.10)	1.799 (0.082)	-0.97 - -0.45	-5.38	0.0000
Brewer's Sparrow	0.833 (0.084)	1.292 (0.076)	-0.68 - -0.23	-4.04	0.0000
Horned Lark	0.514 (0.082)	0.360 (0.052)	-0.038 - 0.35	1.59	0.023
Sage Sparrow	0.181 (0.038)	0.417 (0.041)	-0.35 - -0.13	-4.21	0.0000

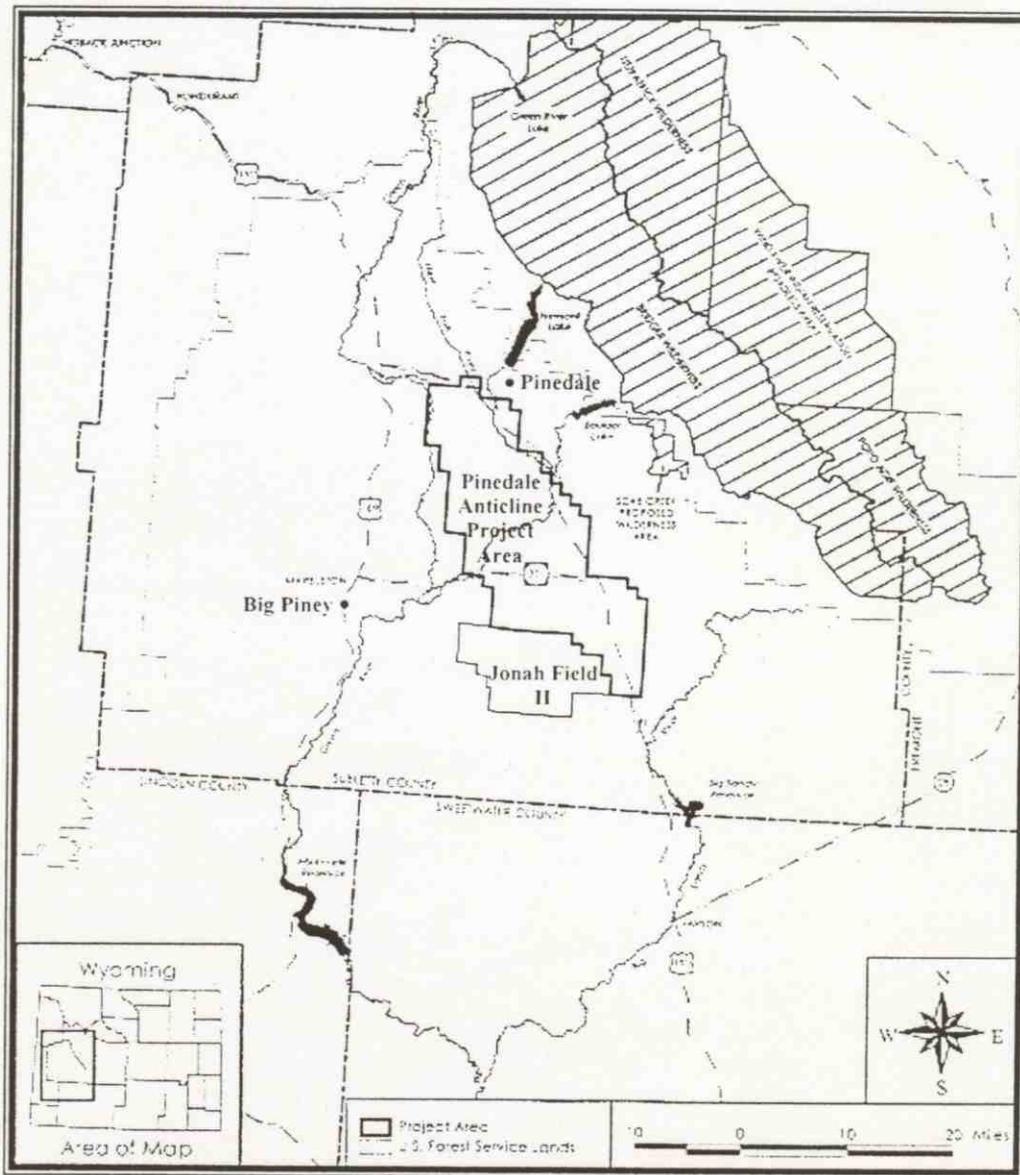


Figure 3.1. General location of Pinedale Anticline Project Area and Jonah Field II.
(From PIC Technologies 2000)

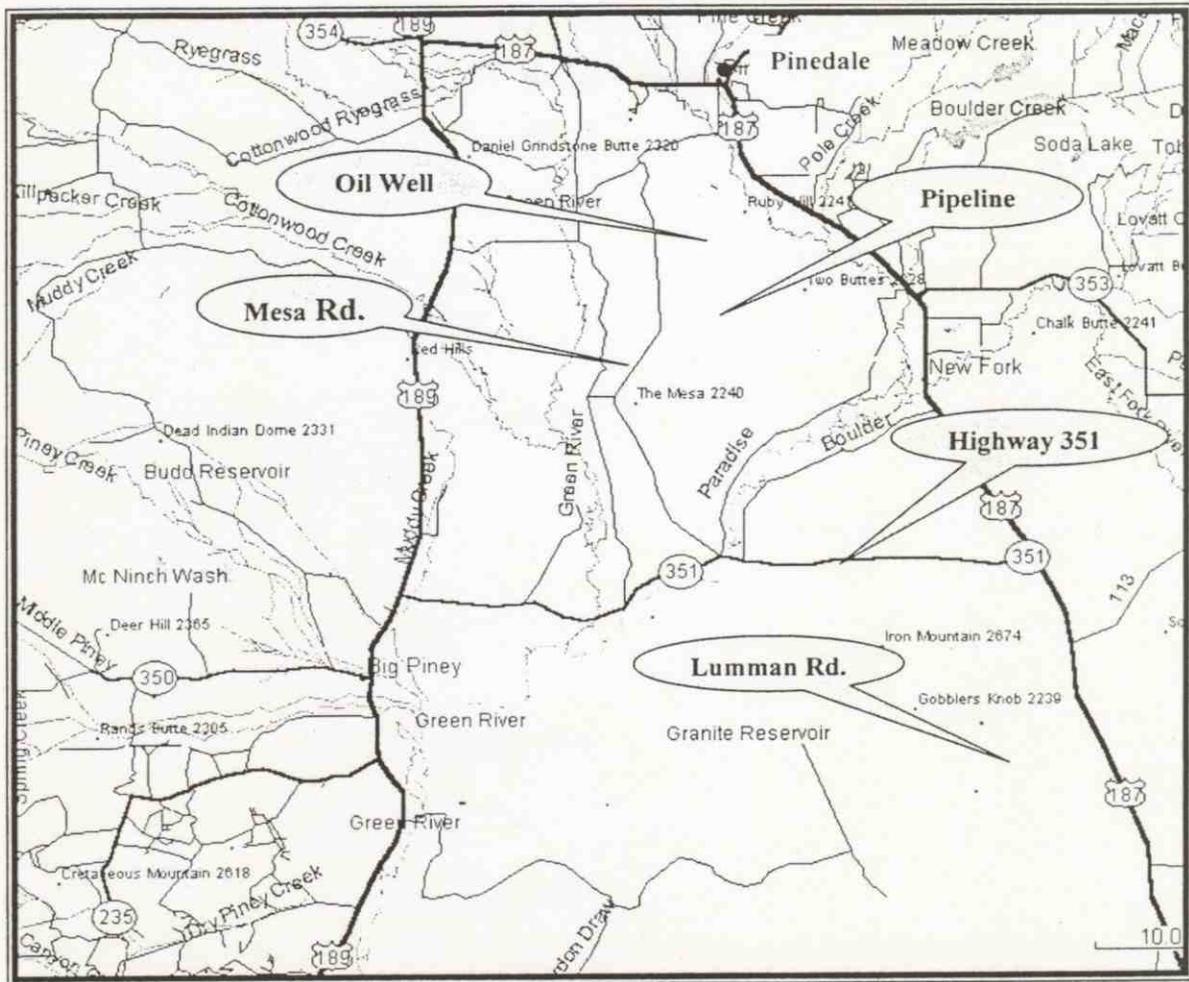


Figure 3.2. Location of road and pipeline study sites.

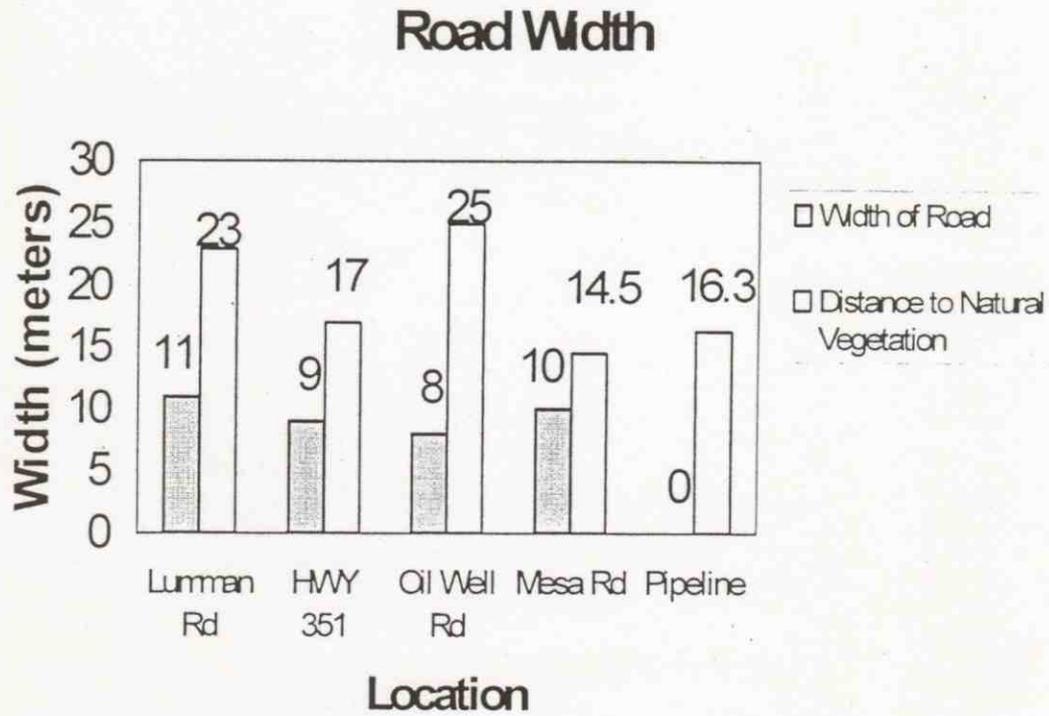


Figure 3.3. Road surface width and width of vegetation disturbance.

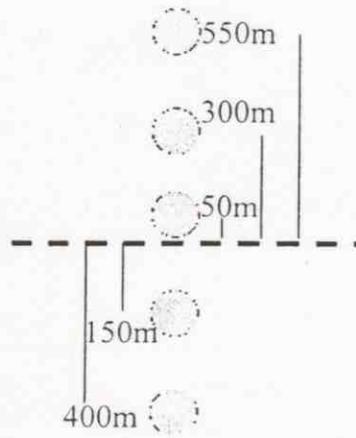


Figure 3.4. Distribution of point counts adjacent to roads.

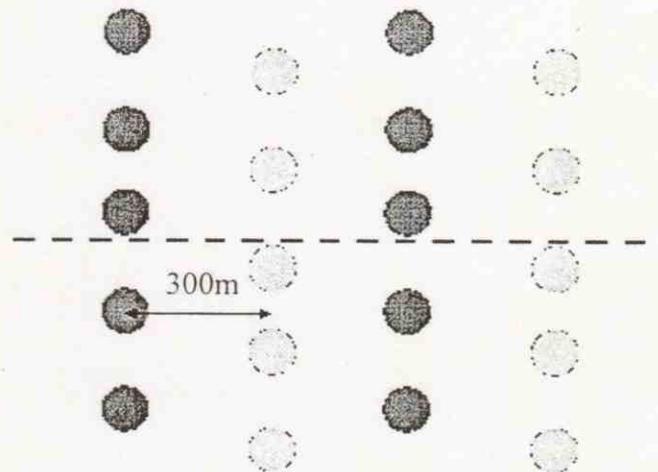


Figure 3.5. Layout of transects and point counts along roads during the 1999 field season.

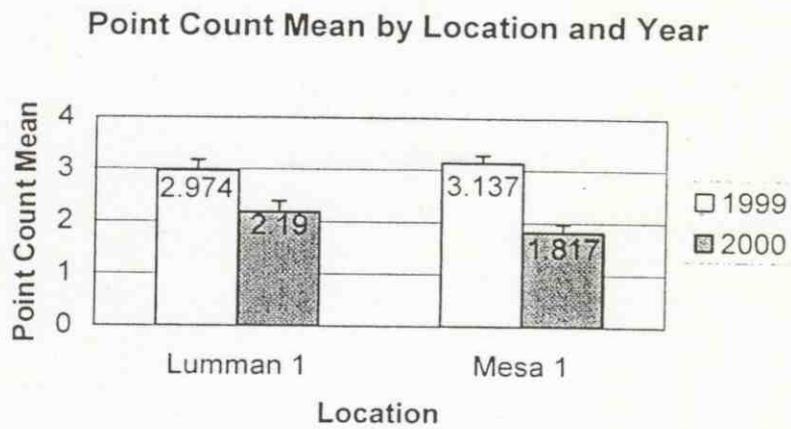


Figure 3.6. Comparison of point count means in 1999 and 2000 for the Lumman 1 and Mesa 1 sites.

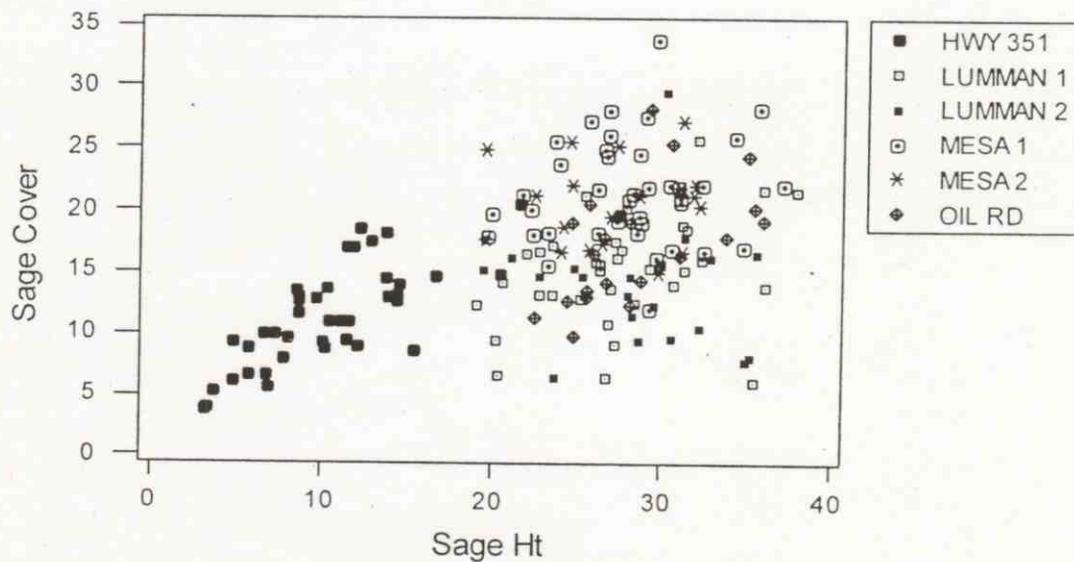


Figure 3.7. Distribution of sagebrush cover and average height along roads in the study area.

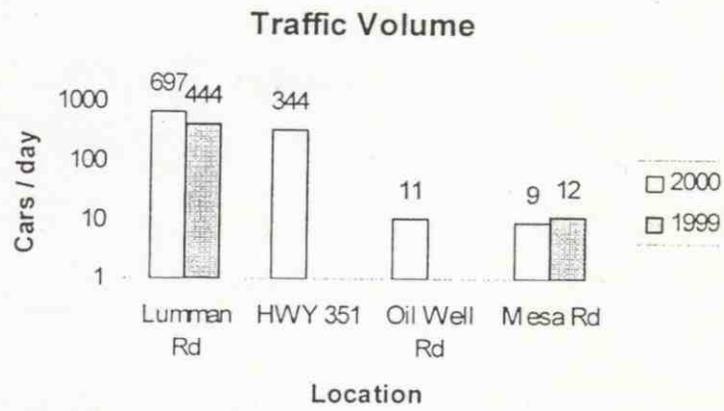
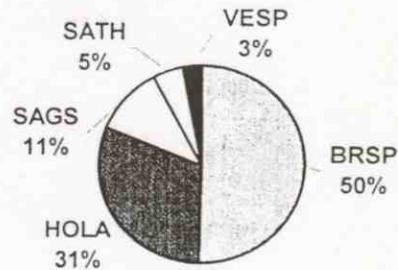


Figure 3.8. Traffic volume in cars / day for each study site. Note the logarithmic scale.

A)

Species Compositiottn Within 100-m Road - Zone



B)

Species Compositiottn Outside 100-m Road - Zone

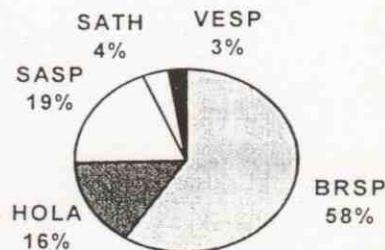


Figure 3.9. Species comparison within (A) and outside (B) of the 100-m road zone for dirt roads surveyed during the 2000 field season ($n = 46$ within and $n = 88$ outside of 100-m road zone). BRSP = Brewer's sparrow, HOLA = horned lark, SAGS = sage sparrow, SATH = sage thrasher, VESP = vesper sparrow.

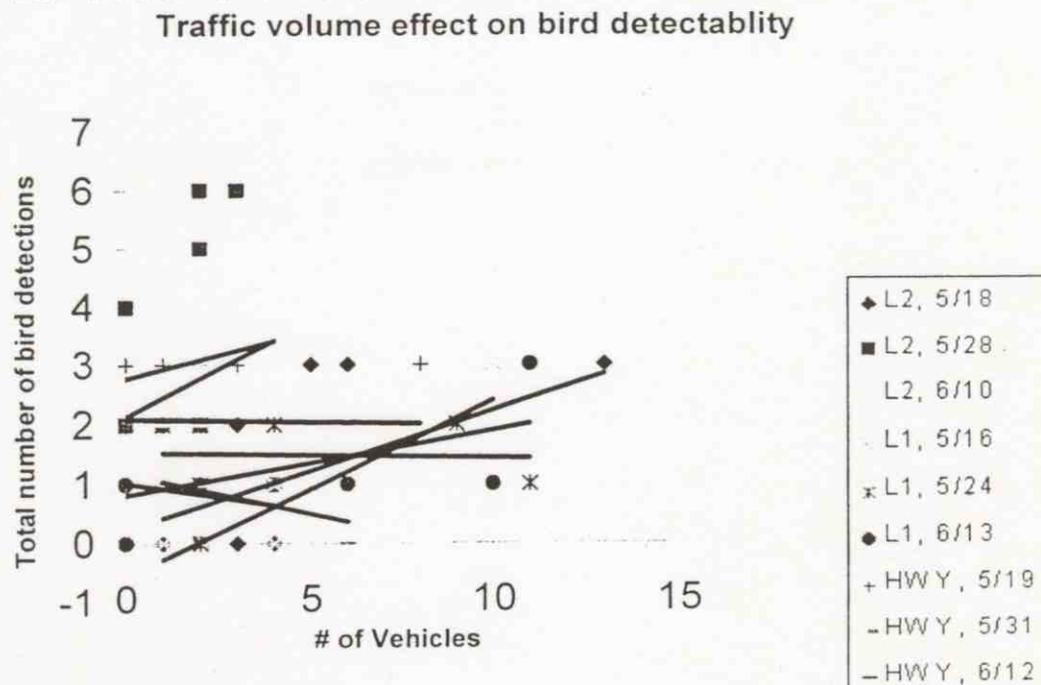


Figure 3.10. Regression of the impact of traffic volume on bird detectability. Regression using number of cars that pass during a five-minute point count as the predictor of number of birds detected. Regression is based on 50m point count data for total birds detected from the Lumman 1 and 2, and Highway 351 sites. Each day is regressed separately, the slope of the regression is recorded. One-sample *t*-tests were used to test whether the mean of the nine regression slopes was less than zero (mean = 0.775, SE = 0.049, $t = 1.58$, $P = 0.15$).

Chapter IV

Summary and Management Implications

INTRODUCTION:

The Pinedale Anticline Project Area (PAPA), Sublette County, Wyoming, encompasses approximately 80,000 hectares and is dominated by Wyoming big sagebrush (*Artemisia tridentata ssp. wyomingensis*). Close to 80% of the area is managed by the Bureau of Land Management, while the remainder is both private and state land. The PAPA provides breeding habitat for a number of songbird species, a resident population of sage grouse (*Centrocercus urophasianus*) and pronghorn antelope (*Antilocapra americana*), and crucial winter range for mule deer (*Odocoileus hemionus*). The PAPA is also located on the top of a geologic feature called an "anticline", where it is anticipated that large, yet unknown quantities of natural gas lie below the ground's surface. While numerous natural gas operators have held leases in the area since the 1950's, only recently, following successful application of new extraction technologies in the Jonah Field II south of the PAPA, has there been interest in fully developing the area. All but 19 km² of the Federal minerals in the PAPA have been leased, and in 1998 the BLM began drafting an environmental impact statement (EIS) for natural gas development within the PAPA. The final EIS was signed and field development began in July 2000. The BLM's record of decision approved the drilling of 900 new wells over the next 10-15 years to achieve 700 producing locations spaced at six wells/km² (16wells/mile²) (PIC Technologies and Bureau of Land Management 1999, Bureau of Land Management 2000).

This project was initiated to investigate the effects of natural gas development and extraction on the breeding passerine population within the Pinedale Anticline Project Area, and was conducted during the spring and summer of 1999 and 2000, prior to EIS completion and full scale field development. The goals of this project were 1) to document the distribution of breeding birds in the project area, 2) examine correlations between bird abundance and habitat physiognomy, 3) compare species relative habitat associations within the study area, and 4) to examine how roads associated with natural gas development affect bird distribution and species composition.

AVIAN HABITAT ASSOCIATIONS

The avifauna of the PAPA is typical of sagebrush steppe habitats, where species diversity and abundance are low. Five common species, Brewer's sparrow (*Spizella breweri*), horned lark (*Eremophila alpestris*), sage sparrow (*Amphispiza belli*), sage thrasher (*Oreoscoptes montanus*), and vesper sparrow (*Pooecetes gramineus*), accounted for over 95% of all point count detections. The Brewer's sparrow, the most common species, accounted for half of bird detections. Bird density based on data from 50-m radius point counts conducted during the spring and summer of 2000 was 2.12 individuals and 1.27 sagebrush obligates per hectare. Other species found breeding in the area include common nighthawks (*Chordeiles minor*), common ravens (*Corvus corax*), rock wrens (*Salpinctes obsoletus*), and green-tailed towhees (*Pipilo chlorurus*).

Species abundance was only loosely correlated with measures of vegetation structure and floristics. Sagebrush obligate abundance, especially that of the Brewer's sparrow, was positively correlated with measure of shrub height. Sagebrush height and plot shrubbiness (vegetation density within 20 cm of the ground) were the best predictors of bird abundance. However, despite correlations, the majority of variation in abundance, presence, and absence were not accounted for by measures of vegetation structure. Other studies have also documented a loose coupling between variation in species abundance and vegetation structure (Wiens and Rotenberry 1980, 1981; Wiens 1985).

The apparent decoupling between species abundance and habitat structure is a result of the unique characteristics of the shrubsteppe avian community. Climate within shrubsteppe habitats is highly variable (West 1983). Precipitation falls primarily during the winter, and interannual variations can be substantial (Rotenberry and Wiens 1980a). Habitat on the breeding ground is rarely saturated (Wiens 1974, 1977), and site occupancy is variable from year to year and possibly more a function of winter mortality than any intrinsic character of breeding ground habitat quality (Rotenberry and Knick 1999). Despite frequent resource superabundance, these species are apparently unable to affect rapid population growth in order to take advantage of available resources, in part due to limits placed on multiple broods by the harsh summer climate (Wiens 1977), increased predation during wet years (Rotenberry and Wiens 1989), and winter mortality (Rotenberry and Knick 1999). Unsaturated habitats and superabundant food resources

reduce the role competition plays in structuring this avian community (Rotenberry and Wiens 1980a, 1980b; Wiens and Rotenberry 1981). Instead, the guild of sagebrush obligates utilize resources in a generalist manner within this community. There is significant dietary overlap in type and size of insects consumed despite interspecific difference in body size and bill morphology, and species consume what is locally available (Wiens and Rotenberry 1979, Rotenberry 1980b). The result is that there are few interspecific differences in habitat use within the guild of sagebrush obligates; species that are widely distributed vary independently of variations in habitat structure.

Species that illustrated the strongest habitat associations were those with distributions associated with habitat features sporadically distributed throughout the study area. Rock wrens were found near rock outcroppings and along the down cut banks the intermittent streams draining the project area. Green-tailed towhees were found in association with slopes where winter snow accumulation increased shrub diversity (primarily snowberry (*Symphoricarpos spp.*)); common ravens nested on top of structures associated with natural gas extraction.

Though the more widely distributed species were poorly correlated with measures of habitat structure, some broad patterns were apparent. Other studies of plot level habitat associations have shown that sagebrush obligate abundance is best correlated with coverage of specific shrub species (Wiens and Rotenberry 1981), but there was little floristic variation in my study area. Within the PAPA, vegetation is dominated by Wyoming big sagebrush. Sagebrush cover is relatively homogeneous and continuous throughout the area. The greatest variation in habitat structure occurs along an elevation gradient, with the northern portion of the PAPA at a higher elevation than the rest of the project area. Sagebrush canopy cover and average height is greater there, perhaps because winter precipitation increases with elevation. Species abundance and overall bird density reflect this pattern in sagebrush structure. Sagebrush obligate bird densities were greater in the northern portion of the project area, while vesper sparrow densities increased at lower elevations where sagebrush cover and height were lower.

PASSERINE RESPONSE TO ROADS ASSOCIATED WITH NATURAL GAS DEVELOPMENT

Because roads are one of the more conspicuous disturbances associated with natural gas development, I examined how roads influence passerine distribution and abundance within the Pinedale Anticline Project Area. Previous studies have shown that when daily traffic volumes are high ($> 10,000$ vehicles/day), passerine abundance is reduced within a zone that extends several hundred meters from the road's edge probably due to noise created by constant, heavy traffic volume (Warner 1992, Foppen and Reijnen 1994, Reijnen and Foppen 1994, Reijnen et al. 1996). However, roads created during natural gas development are not paved and traffic volume is light, ranging from less than 800 vehicles per day along entrance roads to fewer than 10 vehicles per week on roads providing access to individual wells. Despite low traffic volumes, I found that roads associated with natural gas extraction negatively impact sagebrush obligates. The impacts are greatest along access roads where traffic volumes are high and within 100 m of these roads, sagebrush obligates are reduced by as much as 60%. Even along roads with traffic volumes below 12 vehicles per day, sagebrush obligate density was reduced by 50% within the 100-m road zone.

Regardless of traffic volume, sagebrush obligate density is reduced within 100 m of roads associated with natural gas development. Three mechanisms may be responsible for the observed declines 1) noise and dust disturbance created by traffic, 2) increased horned lark abundance along roads which may deter other species from using the area, and 3) avoidance of habitat edges created by roads. Traffic volume along main access roads is relatively continuous throughout the day. It is likely that along such roads, birds are responding to noise and dust created by traffic.

However, on secondary roads where traffic is infrequent, it is unlikely that either noise or dust disturbance are consistent enough to cause the observed reductions in bird density. The second mechanism that may contribute to sagebrush obligate bird decline along roads is the effect that dirt roads have on horned lark distribution. Horned larks are a common grassland species that nest in sagebrush steppe habitats in open areas where sagebrush cover is low. Horned larks are primarily granivorous, and even during the breeding season seeds comprise a large portion of their diet (Rotenberry 1980b, Beason

1995). Horned larks are common along dirt roads (Beason 1995) where they forage on windblown seeds that collect in the lee of gravel. In the PAPA, the concentration of seed resources along dirt roads may attract horned larks to these areas. Within the 100-m road zone horned lark density increased by 30% relative to areas outside this zone ($P = 0.023$, marginally statistically significant at the Bonferroni family correction alpha of 0.0125). Within this road zone horned larks accounted for 31% of species' detections, compared to only 16% outside this zone. Because horned larks observed foraging on roads and road margins were outside point count boundaries, estimates of horned lark abundance within the road zone are conservative. While competition is rare within the sagebrush steppe avian community (Wiens 1977, Rotenberry 1980b), concentration of seed resources along dirt roads may create a foraging opportunity that is defended by horned larks. Horned larks are the second largest passerine in the study area, second only to the sage thrasher, and horned larks were repeatedly observed initiating aggressive interactions with Brewer's and sage sparrows along roads. The increased concentration of horned larks along roads may reduce the surrounding habitat's attractiveness to other sympatric species through either exploitative or interference competition.

A third mechanism that may contribute to sagebrush obligate decline along roads is avoidance of edges created by road construction. Sagebrush naturally occurs in an unbroken, homogeneous stand throughout the PAPA, and roads bisecting the area create a sharp edge that breaks habitat continuity. While not statistically significant, there is some evidence that at least sage sparrows might avoid sagebrush habitats along edges created by surface disturbance. Along the surveyed pipeline, sage sparrow density was 64% lower within the 100-m buffer zone despite traffic absence. Although this decline was not statistically significant ($P = 0.047$), it provides some evidence of edge avoidance.

While a 50% reduction in sagebrush obligate bird density along a single road may not be biologically significant, the effect of the construction of multiple roads within a single development area can be substantial. In the Bureau of Land Management's Record of Decision, the BLM approved the construction of 444 km of roads within the 64,000 ha of the PAPA under their management (Bureau of Land Management 2000), equivalent to an average road density of 0.7 km of road per km² (1.13 miles / mile²). If a conservative

road width of 10 m is used, roads will cover 0.7% of the PAPA. If a 100-m buffer is extended along the roads, roads will impact 14.6% of the Pinedale Anticline Project Area.

MANAGEMENT IMPLICATIONS

The effect of natural gas development and extraction on the avifauna of this sagebrush steppe dominated project area will be both short and long-term. Short-term effects are those that occur during the 50-year development and extraction phase of the project. Short-term impacts include direct habitat loss due to construction of pipelines, roads, and well pads; species response to increased noise, traffic and human presence; changes in species composition resulting from surface disturbance; and localized effects of habitat fragmentation within the project area. The long-term effects of development relate to the ability of the avifauna to recover after completion of extraction operations, field abandonment, and reclamation of the project area. Long-term effects are harder to predict as they depend not only on local reclamation success but on state and region wide patterns in sagebrush management that occur concomitantly with development.

Results from this study indicate that regardless of traffic volume, roads associated with natural gas development will reduce the abundance of sagebrush obligate passerines. While sagebrush obligates are expected to decline, horned lark abundance should increase. Horned larks are year-round residents and have higher fecundity rates than sagebrush obligates. The horned lark can raise more than three broods during a season, compared to the single or double broods of sagebrush obligates; and as winter residents of the area, horned larks are able to nest earlier than sympatric species. In both 1999 and 2000, horned larks were feeding nestlings by May 10, before Brewer's sparrows had returned from their winter grounds. Sagebrush obligate numbers will also be affected by increases in common ravens, as ravens prey on sagebrush obligate nestlings (Martin and Carlson 1998). Ravens were frequently observed nesting on structures associated with gas extraction, and the provision of nesting structures will likely increase raven density in the project area.

Because this study was conducted prior to development, it is unclear what the cumulative effects of roads and other forms of surface disturbance will be. While shrubsteppe species are likely adapted to the large continuous structure of sagebrush

habitats, habitat fragmentation associated with natural gas development will probably affect bird distribution.

The long-term effect of natural gas development depends on the ability of the avian community to recover after extraction completion and reclamation of the area. While breeding ground densities are often below habitat carrying capacity (Wiens 1974, 1977), suggesting that habitat loss will have little impact on sagebrush passerine populations, these species evolved in a continuous landscape of sagebrush habitat and fragmentation could compound the effects of habitat loss.

It is also noteworthy that, sagebrush obligate passerines have been declining over the past forty years throughout their range (Sauer et al. 1997). While the cause of these declines is largely undetermined, fragmentation of sagebrush steppe habitats is probably important. Sagebrush communities throughout the West have been fragmented by conversion to agriculture (Dobler 1996), herbicide and mechanical removal (Braun et al. 1976), exotic species invasion (Whisenant 1990), and human development (Paige and Ritter 1999). In Colorado, herbicide treatment has altered over 30% of that state's sagebrush community (Braun et al. 1976), and in Washington, in part due to agricultural conversion of shrub habitats, only 40% of the state's original 4 million hectares of sagebrush steppe remain (Dobler et al. 1996).

Compared to other western states, Wyoming's sagebrush steppe is relatively unaltered by man. Although areas have been treated, burned, grazed by cattle, and developed, the majority is still untouched. However, expansion of oil and gas development throughout Wyoming's sagebrush steppe communities will probably negatively impact the breeding bird community that depends on this habitat. The ability of bird populations to recover after development is not only dependent on the success of local reclamation, but also on state and region wide management practices that occur concomitantly with development. Clearly the development of a single natural gas field will have few significant long-term ramifications. However, the development of numerous fields statewide combined with other land use practices that alter sagebrush habitats, could reduce the avian community's ability to recover from short-term alterations in habitat and land uses. Therefore, development in sagebrush habitats should

consider not only short-term localized effects, but also the effect that local development has on the region-wide distribution and landscape patterns of sagebrush habitats.

CONCLUSION

Natural gas development in Wyoming is important both for the state's economy and to reduce this country's dependency on foreign energy resources. While surface occupancy during extraction is relatively ephemeral, the ecological impact can be persistent. Over the next few decades, natural gas extraction is expected to increase throughout Wyoming's sagebrush communities. The impact that development will have on the passerines reliant on the sagebrush community will depend on the local intensity and regional patterns of development. Results from this study suggest that sagebrush obligates (Brewer's sparrows, sage sparrows, and sage thrashers) will decline while horned lark numbers will increase during development. These changes in species composition are the result of surface disturbances associated with road construction. My results support arguments for both the complete reclamation of roads after development as well as investigation into technologies that would reduce the proliferation of roads within the Pinedale Anticline Project Area.

Future monitoring of sagebrush steppe avian communities within the Pinedale Anticline Project Area and throughout Wyoming seems warranted. Monitoring should focus on how habitat fragmentation associated with natural gas extraction and other forms of land use impact the bird community and other flora and fauna. Breeding-bird surveys should consider using larger radii point counts than were employed in this study in order to incorporate the variation associated with the patchy distribution of these species within counts. Because densities based on point counts of different radii are not comparable (Hutto 1986), future studies employing larger radii counts should note detection within the first 50 m so that densities can be compared to those from this study.

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