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## Site occupancy analysis of the sagebrush lizard (*Sceloporus graciosus*) in the disappearing desert-scrub of the Columbia Basin

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SITE-OCCUPANCY ANALYSIS OF THE SAGEBRUSH LIZARD  
(*SCELOPORUS GRACIOSUS*) IN THE DISAPPEARING DESERT-  
SCRUB OF THE COLUMBIA BASIN

by

Ryan Robert Drake

Accepted in Partial Completion  
of the Requirements for the Degree  
Master of Science

ADVISORY COMMITTEE

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## **MASTER'S THESIS**

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Ryan Robert Drake

May 16, 2018

SITE-OCCUPANCY ANALYSIS OF THE SAGEBRUSH LIZARD  
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A Thesis

Presented to

the Faculty of

Western Washington University

In Partial Completion

of the Requirements for the Degree

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May 2018

## ABSTRACT

The shrub-steppe landscape of the Columbia Basin has been the target of agricultural and urban development, and the resulting fragmentation and degradation has led to the disappearance of unique arid mesohabitats. In central Washington, the sandy lowland habitats resembling desert-scrub, which under natural conditions are characterized by a shrub-and-sand mosaic, have become increasingly degraded by humans directly (*e.g.*, flooding, agriculture) or indirectly (*e.g.* cheatgrass introduction). These habitats have unique community assemblages with species adapted to the sandy substrates and unobstructed matrix between shrubs. While much conservation literature focuses on the loss of shrub-steppe habitat, there has been little research on the effects of loss, fragmentation, and degradation of sandy desert-scrub in the Columbia Basin on small reptile inhabitants. The sagebrush lizard (*Sceloporus graciosus*), an obligate resident of these sandy habitats, serves as a potential model organism to document the effects of desert-scrub loss and degradation. Compared to historical sightings prior to 1980, scant observations of *S. graciosus* within the last decade may be a sign that this species might be disappearing from its Washington range. In this study, I aim to assess whether the sagebrush lizard is still present in much of its original range in Washington, and to determine which aspects of their habitat correlates with population density.

Sandy desert-scrub habitats that are historically known to have or were capable of having sagebrush lizards in Washington and Oregon were chosen as field sites during the summer and early autumn of 2016. Landcover statistics, such as shrub cover and grass cover, and habitat characteristics including wildfire history were determined for use as potential correlates for the rate of sagebrush lizards encountered in each site. Landcover was quantified via supervised classification using aerial photographs, and model accuracy was verified by comparing transect samples from the field. Multidimensional scaling and analyses of similarity were performed to determine which sites formed groups that were dissimilar to

others, and similarity percentages were used to quantify the degree to which each habitat factor contributed to site dissimilarity.

In only 6 out of the 16 sites were sagebrush lizards detected during standard search surveys. In Washington, of the 7 surveyed sites with sagebrush lizard sightings within the past 30 years, only 2 (29%) had detectable individuals. There were no differences between sites where sagebrush lizards were present and absent unless sites within 100 m of a crop field were classified separately, whereupon all five of these sites then fell within one out of two groups with 60% similarity. Percent grass cover was the strongest factor contributing to group differences, with less grass and more open sand found in sagebrush lizard-present sites. Also, sagebrush lizard-absent sites had histories of wildfire. The need to separately classify otherwise suitable habitat near agriculture (and did not have sagebrush lizards) indicates additional negative influences affecting this species presence, since not incorporating this sole variable masks any differences among sites. In general, I infer that wildfire, cheatgrass invasion, and landscape development all have reduced suitable habitat for sagebrush lizards and likely explains their absence in their historic range. Given that the remaining pristine sandy desert-scrub habitats are now fragmented and few in number in the state of Washington, I infer from my results that there is very real cause for concern for the viability of this species in the state. If the challenge this species is facing is representative of other arid endemics, then the widespread changes to the shrub-steppe and desert-scrub landscapes in the Western USA provide many research opportunities in conservation ecology.

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## TABLE OF CONTENTS

Abstract .....	iv
Acknowledgements .....	vi
Table of Figures, Tables, and Equations .....	viii
Introduction .....	1
The macrohabitat: shrub-steppe in Washington .....	3
The mesohabitat: desert-scrub degradation in modified shrub-steppe landscapes .....	7
The microhabitat: relationship of sagebrush lizards to the dune ecosystem .....	10
Study overview .....	12
Hypotheses .....	13
<i>Sceloporus graciosus</i> presence by site .....	13
<i>Sceloporus graciosus</i> abundance as related to habitat disturbance .....	13
<i>Sceloporus graciosus</i> association with microhabitat .....	14
Microhabitat relationship with disturbances .....	15
Relationships between habitat disturbance and species similar to <i>S. graciosus</i> .....	15
Rationale for study and hypotheses .....	16
Methods .....	19
General summary .....	19
Study Sites .....	19
Timing of field surveys .....	25
Weather .....	26
Lizard surveys .....	27
GIS image classification .....	30
Shrub-cover transects .....	31
Statistical analysis .....	32
Results .....	36
Weather during surveys .....	36
Lizard encounters .....	38
Lizard habitat use .....	42
Accuracy analysis of image classification .....	44
Landcover class results .....	45
Discussion .....	52
Sagebrush lizard presence within their WA and OR ranges .....	52
Differences in landscape composition among sites .....	55
Relationship between sagebrush lizard presence and habitat composition .....	56
Presence/absence analysis .....	56
Correlation analysis using rate of encounter .....	64
Conclusions .....	65
Bibliography .....	69
Appendix .....	76

## TABLE OF FIGURES, TABLES, AND EQUATIONS

<b>Figure 1:</b> A sand dune near Moses Lake recently cleared away.....	5
<b>Table 1:</b> Locations of study sites, including the latitude and longitude of coordinates .....	21
<b>Figure 2:</b> Map of survey sites in central Washington .....	22
<b>Figure 3:</b> Map of survey sites in southeastern Oregon .....	23
<b>Equation 1:</b> Percent Core Area.....	32
<b>Equation 2:</b> Similarity Index .....	33
<b>Figure 4:</b> Illustrative models for PCA and GPI .....	34
<b>Figure 5:</b> Total number of sagebrush lizards, sorted by air temperature when spotted .....	37
<b>Figure 6:</b> Map of survey sites in WA indicating presence and absence of sagebrush lizards.....	39
<b>Table 2:</b> Comparisons among sites for search effort and frequency of sightings of the lizards <i>Sceloporus</i> <i>graciosus</i> and <i>Uta stansburiana</i> .....	41
<b>Figure 7:</b> Bar plots showing the percent shrub and grass cover in unburned and burned sites.....	46
<b>Figure 8:</b> Scatterplots with significant correlations .....	48
<b>Figure 9:</b> Multidimensional scaling plot of all surveyed sites .....	49
<b>Figure 10:</b> Scatterplots of nonsignificant correlations with encounter rate for <i>Sceloporus graciosus</i> .....	50
<b>Figure 11:</b> Scatterplots of nonsignificant correlations with encounter rate for <i>Uta stansburiana</i> .....	51
<b>Figure 12:</b> Box plots showing landscape measures for sites where sagebrush lizards were present and absent .	59
<b>Figure 13:</b> Map of the Beverly quadrangle showing sandy soils, rocky soils, and other soils .....	61
<b>Figure 14:</b> Brewster sand flats with an adjacent orchard upslope of the study site .....	63
<b>Figure 15:</b> Map of all Washington sites color-coded for sagebrush lizard presence and absence .....	76
<b>Figure 16:</b> Map of all sagebrush lizard occurrences as indicated by the WDFW PHS database.....	77
<b>Figure 17:</b> Aerial Photos of the Sand Hollow Dunes in 1955 and 2017.....	78
<b>Figure 18:</b> Aerial photos of the Beverly Dunes in 1955 and 2017 .....	79
<b>Figure 19:</b> Overlay of estimated loose sand loss since 1955 in a portion of the Beverly Dunes .....	80
<b>Figure 20:</b> Aerial photos of Brewster in 1955 and 2017.....	81
<b>Figure 21:</b> Aerial photos of Pasco in 1955 and 2017.....	82
<b>Figure 22:</b> Aerial photos of Frenchman Coulee in 1961 and 2017.....	83
<b>Figure 23:</b> Sagebrush lizard ( <i>Sceloporus graciosus</i> ) basking on a mature greasewood .....	84
<b>Figure 24:</b> View of large dunes in the Alvord Basin .....	85
<b>Figure 25:</b> Aerial photograph of the Alvord Dunes from a DJI Phantom 3.....	86
<b>Figure 26:</b> View of a dune crest in the Catlow Valley.....	87
<b>Figure 27:</b> Burned section of the Catlow Valley dune fields.....	88
<b>Figure 28:</b> The only sagebrush lizard found in the Catlow Valley .....	89
<b>Figure 29:</b> View of the Catlow Valley approximately 1 km southwest from the surveyed dunes.....	90
<b>Figure 30:</b> View of Three-Lizard Buttes .....	91
<b>Figure 31:</b> View of the south-facing slope of the surveyed dune in the Juniper Dunes Wilderness.....	92
<b>Figure 32:</b> Beverly Dunes, facing west .....	93
<b>Figure 33:</b> Sagebrush lizard basking in the perimeter of a Russian thistle at the Beverly Dunes.....	94
<b>Figure 34:</b> Sentinel Butte Dunes, facing east.....	95
<b>Figure 35:</b> Sagebrush field near the Moses Lake Dunes .....	96

**Figure 36:** Wakefield Dunes with understory vegetation eliminated due to wildfire ..... 97  
**Figure 37:** Assistant Christian Olsen photographing a groundcover quadrat at the Sand Hollow Dunes ..... 98  
**Figure 38:** Partially cheatgrass-covered dune in Echo Basin, Frenchman Coulee ..... 99  
**Figure 39:** Long-nosed leopard lizard (*Gambelia wislizenii*) ..... 100  
**Figure 40:** Sagebrush lizard using a sagebrush as protection ..... 101

## INTRODUCTION

Much of the shrub-steppe and desert scrub ecosystems that historically covered most of the arid lowlands of the intermountain west of the USA are being lost or degraded. Irrigation has permitted large tracts of rangeland, croplands, and associated urban development to replace approximately 51–59% of these natural ecosystems in the Columbia Basin (Quinn 2004). In Washington alone, 48,000 acres of land had become irrigated by 1890 (Dobler et al. 1996).

Another important cause of change across arid landscapes is due to proliferation of invasive cheatgrass, an annual which is conducive grassland wildfires. Such fires facilitate the replacement of native shrubs with more cheatgrass. By 1999, over 25% of Great Basin shrub-steppe had been converted to cheatgrass monocultures (Epanchin-Niell et al. 2009). Once cheatgrass has invaded, there is a low chance of recovery for desert scrub and shrub steppe—landscapes that have persisted for centuries under natural periodic burns (Young and Evans 1978).

Moreover sandy soil and xeric ecosystems in proximity to major rivers and their tributaries are disappearing not only due to the pervasive effect of cheatgrass-fire disturbances but they also are being lost to dam reservoir expansion, the creation of irrigated agricultural lands, and altered floodplain and riparian flow dynamics (Graf 2006). Thus, what once were expansive xeric ecosystems are now diminished and fragmented, and many are being colonized by a variety of species of non-native plants, some of which have become invasive (Hallock et al. 2007, Francis et al. 2010). A common effect of the aforementioned disturbances includes loss of natural landscapes, reduction in areal extent of ecosystems,

fragmentation of vegetation types and degradation of their constituent animal communities or assemblages (Wilcox and Murphy 1985, Andrén 1994, Bender et al. 2003).

Species primarily comprising geographically isolated populations, wherein each population further comprises a small total area among fragments of formerly continuous habitat, are among those most at risk of local extinction. Therefore, habitat fragmentation continues to be a major factor driving the reduction in and loss of many species (Leavitt and Fitzgerald 2013). Whether the array of habitat fragments or patches can sustain a population depends not only on the suitability of habitat patches and fragments for individual survival, growth, and reproduction, but also on sufficient abilities of individuals to disperse among patches. Ecologically sensitive endemic species are being lost from much of their historical geographic ranges. Two famous examples of severe species declines are the number and sizes in sage grouse (*Centrocercus* spp.) populations (Crawford et al. 2004, Wisdom et al. 2011) and desert tortoise (*Gopherus agassizii*) populations (Esque et al. 2003).

In Washington and throughout the Pacific Northwest, federal agencies, such as Fish and Wildlife Services and the Bureau of Land Management, and state agencies have taken steps towards environmental conservation and preservation (*e.g.* see Wooten 2003, Haegen et al. 2004, Pellant et al. 2004, Hallock et al. 2007, Epanchin-Niell et al. 2009). Many state wildlife refuges and parks also are similarly maintained and monitored, with varying levels of success. Conservation initiatives, however, can be undermined if habitat disturbance, degradation, and loss further diminishes and isolates these relatively small ecosystem refugia. Failure to implement methods to monitor indications of organismal community integrity and species loss may waste funding and work. To achieve greater effectiveness in conservation initiatives, the study of a species that is considered an exemplar of how habitat loss and

fragmentation causes population declines or the loss of entire populations would be instructive. In central Washington, the northern sagebrush lizard (*Sceloporus graciosus*) is a native resident of desert-scrub environments within the shrub-steppe. Given the species has a wide, albeit patchy, geographic distribution in sandy locales in the Pacific Northwest and nearby regions, this species may be useful as a biological indicator of habitat loss and degradation. As ectotherms, lizards have been found to be sensitive to microhabitat composition in studies of ecological energetics, physiological ecology and biophysical ecology (Karasov and Anderson 1984, Irschick and Losos 1999, also see Angilletta 2001). Microhabitat features may strongly affect the ability of individual sagebrush lizard to thrive, survive, and reproduce. Moreover, because ever-smaller habitat patch sizes and increasing isolation of these habitat patches may reduce the viability of a lizard population to persist among the patches (see Hokit and Branch 2003), the apparent disappearance of *Sceloporus graciosus* throughout much of its former distribution in Washington has resulted in this species being placed on the WDFW's "Species of Concern" list as a candidate for designation as endangered in the state of Washington (Washington Department of Fish and Wildlife 2017b). Thus, *S. graciosus* is a good candidate as an indicator of community integrity in conservation surveys. In this study, I aim to assess the occurrence of sagebrush lizards in the northern extent of their Intermountain range and to determine which, if any, landscape variables correlate with residency in known habitats, both natural and altered.

### **The macrohabitat: shrub-steppe in Washington**

Shrub-steppe communities are composed of discontinuous woody shrub coverage with up to one or two layers of perennial grass. Prominent shrub cover includes big

sagebrush (*Artemisia tridentata*), antelope bitterbrush (*Purshia tridentata*), and greasewood (*Sarcobatus vermiculatus*). Grasses vary but include Indian ricegrass (*Oryzopsis hymenoides*) and various bunchgrasses. Historically, this environment characterized much of the Columbia Basin, which extends from central and eastern Washington into Oregon and western Idaho (Welch 2005). However, little remains of natural shrub-steppe in Washington. As much as fifty percent of natural communities have been lost to settlement (Welch 2005), and the Washington Department of Fish and Wildlife (1996) estimates that the Yakima Training Center, Hanford Nuclear Site, and the Yakama Indian Nation may hold the last large expanses (albeit in various stages of degradation) of this habitat type in the state.

Landscape conversion to pasture and croplands is the principal factor driving shrub-steppe disappearance and has been for many years. Agricultural conversion of shrub-steppe habitat in Washington began in the 1850s with the intention of converting much of the landscape to wheat fields. In a historical account published by the World's Fair Commission of the State of Washington, the land east of the cascades were viewed as the "...great wheat granary of the Pacific coast...and the time is not far distant when the great sage-brush plains will be as one vast field of waving grain" (Evans and Meany 1893, p. 103). The presence of the Columbia River and its tributaries enabled companies to invest millions of dollars in capital to irrigate the arid landscape for crops (Evans and Meany 1893). By the 1930s improved irrigation techniques allowed for stabilization and cultivation of sandy dune fields (Bunting et al. 2003, Hallock et al. 2007, Morris and Rowe 2014). Vegetation was mechanically and chemically removed to create pasture and crop fields, thereby completely removing large amounts of natural habitat (Morris and Rowe 2014; see Figure 1). By 1986,



**Figure 1:** A sand dune near Moses Lake recently cleared away for installment of a new crop field during the summer of 2016.

approximately 55% of all Washington shrub-steppe habitat was converted to agriculture (Cassidy and Grue 2000), and an estimated 33% of big sagebrush and bitterbrush cover in the Columbia Basin, which includes Oregon and parts of Idaho, have each been lost when compared to historical numbers (Quigley and Arbelbide 1997, Bunting et al. 2003). Additionally, 17% of the entire Columbia Basin has undergone direct agricultural conversion (Bunting et al. 2003).

Exotic annuals, including cheatgrass (*Bromus tectorum*), colonize disturbed regions of shrub-steppe habitat (Snell et al. 1997, Davies et al. 2011). Cheatgrass is an example of a pyrophilic (fire-adapted) plant that tends to increase the frequency of wildfires wherever it grows. The wildfires remove native shrubs and opens up large patches of disturbed habitat for the cheatgrass and other invasive species to colonize (Knick and Rotenberry 1997, Banks and Baker 2011). With most plants burned away, immigrant cheatgrass experience very little competition. Furthermore, cheatgrass also produces numerous seeds leading to large seed banks, which can enhance colonization of disturbed habitats (Banks and Baker 2011). Following the 24 Command Fire at Hanford Reach, big sagebrush (*Artemisia tridentata*) and spiny hopsage (*Grayia spinosa*) mostly disappeared while cheatgrass density increased (Evans and Lih 2005). Though native shrubs can outcompete cheatgrass, a span of at least 30 years without wildfire is required in some locales (Hanna and Fulgham 2015), and much longer time (*e.g.* 35–60 years) is needed in the drier locales (Baker 2006). Cheatgrass-dominated landscapes, however, have a fire return interval approximately four times higher than the moister locales of native sagebrush-dominated landscapes (Balch et al. 2013, Hanna and Fulgham 2015).

### **The mesohabitat: desert-scrub degradation in modified shrub-steppe landscapes**

Migratory sandy dunes historically have been a common feature in many shrub-steppe regions where large rivers can be found. Typically located along the leeward side of major rivers, active dunes comprise mostly soft quartz and basalt sand and derive their sand deposits from the eroded river banks. Over time, the sand is wind-blown to one side of the dune, which effectively migrates the individual dune (Petronne 1970). In addition to the dunes near active rivers, many dunes in the Intermountain West with shrub-steppe communities at higher elevations and desert scrub communities at lower elevations (*e.g.* see Van Devender and Spaulding 1979, Burgess 1995, Brooks and Matchett 2006), like those in the Catlow Valley, OR, were formed by deposits from pluvial lakes and rivers that have by now disappeared (Mehring Jr. and Wigand 1986). From an ecological perspective, active sand dunes are unique in that the unstable sandy substrate limits the amount of herbaceous cover while having less of an effect on the larger shrubs with durable root systems. As a result, sand dune mesohabitats have the physiognomy of shrub-dominated classic desert-scrub further south in the intermountain western USA, but in Washington these desert scrub habitats are more like islands embedded in the shrub-steppe biome (*e.g.* see Hallock et al. 2007).

In Washington, most large dune fields are largely located near the Columbia River. Primary examples of large dune fields are the Hanford Reach Dunes, Juniper Dunes, Wahluke Dunes, Crab Creek Dunes, and Beverly Dunes (Hallock et al. 2007). Many of these dunes, however, have been restricted by land development, and their natural migration patterns have been impeded. Large-scale conversion can be seen throughout the Columbia

Basin, especially around Moses Lake (Petrone 1970). As a result, these once prominent features of the Washington shrub-steppe are rapidly disappearing.

The construction of dams in Central Washington has greatly affected hydrologic dynamics in the soils surrounding or within dune fields. Petrone (1970) noted that the construction of the O'Sullivan Dam raised the water table in the Potholes Reservoir enough to stabilize the dunes there. While this is the only report of an altered water table affecting Columbia River Basin dunes, dams are known to affect surrounding water tables (see Francis et al. 2010). If dams along the Columbia River (such as the Bonneville Dam) have altered the water table in the nearby dune fields, it is likely that the dunes have been or will become stabilized, thus restricting natural sand migration.

Dune stabilization can result in a positive feedback in which a less ephemeral substrate can support a greater variety of plants, which then stabilizes the dunes further. The raised water table in the Potholes reservoir supports the growth of vegetation where water is more available (Harris 1954) and increases the accumulation of non-migratory soil and establishment of vegetative cover (Li et al. 2007). As a result, non-native plants can potentially spread to these altered dunes and the habitat can convert to one unsuitable to current organisms. Due to the stabilizing effects of herbaceous cover, the recent cheatgrass (*Bromus tectorum*) invasion has become a prominent contributor to the degradation of dunes and shrub-steppe in the intermountain West of North America (See Melgoza et al. 1990, Green et al. 2001, Ostoja et al. 2009, Banks and Baker 2011).

Collectively, disturbances to Washington dunes are reducing their area, fragmenting them, and eliminating potential habitat for species that can or only inhabit these dunes. State and federal land management departments, however, such as the Bureau of Land

Management and U.S. Fish and Wildlife Services, are interested in preserving these natural habitats. The Juniper Dunes Wilderness, Hanford Reach National Monument, and Moses Lake are examples of federal and state wildlife refuges or territories with the intention of preventing anthropogenic degradation. Unfortunately, little land is left that is characteristic of organismal communities that existed prior to the arrival of European-American settlers, so virtually all shrub steppe and desert scrub that does remain in Washington has suffered anthropogenic modification.

Sand dunes provide desert-scrub habitat with endemic species, some of which are threatened or endangered in the state of Washington. Ord's kangaroo rat (*Dipodomys ordii*), sagebrush voles (*Lemmiscus curtatus*), gray cryptantha (*Cryptantha leucophaea*), Northern wormwood (*Artemisia borealis* var. *wormskioldii*), and Columbia River tiger beetles (*Cicindela columbica*) are all examples of dune endemics (Hallock et al. 2007). The extent of the disturbance to these dune habitats is sparsely documented, and less is known about potential effects on resident organisms. For instance, the miner bee *Perdita similis pascoensis* was captured and documented only once at the Juniper Dunes in 1904 (Tepedino and Griswold 1995). The sagebrush lizard (*Sceloporus graciosus*) is another poorly studied dune organism, but because counts of individuals of this ecologically sensitive species are likely to be easier, cheaper, and faster than for the numerous other sensitive species, it may be an efficacious biological indicator—as a study substitute for other species—of habitat degradation, loss and isolation.

### **The microhabitat: relationship of sagebrush lizards to the dune ecosystem**

Because habitat loss increases the likelihood of population or species disappearance in that region (MacArthur and Wilson 1963, Andr n 1994), the viability of dune-dwelling populations would be at risk in areas of dune system degradation. The sagebrush lizard is one such psammophilous (sand-loving) resident, and thus habitat loss would strongly affect populations in its degraded range. In Washington, Oregon, and much of Nevada, the sagebrush lizard is the primary sceloporine lizard found in dune habitats with xeric sandy soil (Kerfoot 1968, Marcellini and Mackey 1970a), which permits greater oxygen availability in their underground burrows (Ferguson et al. 2014). Open sandy terrain with sparse patches of woody vegetation such as big sagebrush (*Artemisia tridentata*) and greasewood (*Sarcobatus vermiculatus*) characterize the desert-scrub mesohabitat in which *S. graciosus* thrives. These shrubs are used as perches from which *S. graciosus* will bask, and visually seek mates and prey (Rose 1976, Green et al. 2001). These large woody perennials also offer branch, leaf, litter, and burrow concealment from predators, and the surrounding open terrain is used for pursuing approaching prey, competitors, and mates (Green et al. 2001).

There is a paucity of conservation research on the dune habitats in Washington. Hallock and colleagues (2007) have provided the only treatise of the status of the state's natural dune systems at the request of the Bureau of Land Management. They estimate that 76% of original dune landscape has been lost since 1970 and that most of the remaining habitat is degraded and at risk of further degradation. They identify endemic species of concern based on information from the Washington DNR Natural Heritage Program, but reliable ecological data are lacking. In the White Sands region of New Mexico, the dune sagebrush lizard (*Sceloporus arenicolus*)—recently designated as a separate species from *S.*

*graciosus*— is an obligate resident of undisturbed sand dunes that has declined following dune disturbance and subsequent covering by vegetation (Snell et al. 1997, Walkup et al. 2017). Another population of *S. arenicolus* in the Arapaho Prairie declined by nearly half following an increase in vegetative cover (Ballinger and Watts 1995). Another desert scrub and shrub-steppe resident, the desert horned lizard (*Phrynosoma platyrhinos*), is similarly affected by cheatgrass-invaded habitat. Newbold (2005) measured a decrease in their sustained sprint speeds from 1.0 meter per second to approximately 0.2 meters per second in cheatgrass habitats, with the lizards moving in a zig-zag pattern to avoid clumps of cheatgrass. While little is known about the effects of exotic vegetation on *S. graciosus*, just from preliminary anecdotal observations alone, one may infer that sagebrush lizards tend to avoid areas heavily invaded by cheatgrass (also see Green et al. 2001).

With the combination of cheatgrass invasion and human land development, those sandy, desert scrub habitats that have not disappeared entirely are decreasing in total area and are prone to fragmentation (Hallock et al. 2007). For small populations of *S. graciosus*, fragmented patches are more likely to pose difficulty for movement, especially for dispersing juveniles (Chan et al. 2009). A good example of the difficulty in dispersal from patch to patch in lizards is found in the Coachella Valley, California, with the endemic fringe-toed lizard (*Uma inornata*); populations of these lizards were permanently isolated from each other once suburban communities covered most of the landscape (Barrows and Allen 2007). Habitat fragmentation has similarly affected other species of lizards (see Brown et al. 2008, Chan et al. 2009, Leavitt and Fitzgerald 2013).

Little is known about the current status of *S. graciosus* populations in Washington. There have been fewer reported sightings of this species in its range (Hallock et al. 2007),

and in some locations extensive habitat loss likely has eliminated or severely reduced population abundance. Both the states of Oregon and Washington have historical evidence of abundant and thriving populations (Kerfoot 1968, Goldberg 1975), but the current distribution of populations and population sizes of *S. graciosus* after decades of habitat loss and habitat degradation in both states are unknown. From a conservation perspective, it would be prudent to understand this species' relationship with changes in its habitat and its community composition.

### **Study overview**

Much essential information about sagebrush lizard populations and their habitats is needed:

1. the extent of sagebrush lizard residency in historically-occupied habitats,
2. the extent to which desert scrub and dune landscapes are degraded and/or fragmented, and the factors driving any habitat loss, and
3. which habitat factors correlate with sagebrush lizard patch occupancy and abundance.

This study focused on the following general question: *Are sagebrush lizard populations being eliminated from their habitat and, if so, what variables are the mostly likely causes?*

Because *S. graciosus* could be a herpetological and ecological exemplar as a denizen of a sand-and-shrub habitat and because the species has been ecologically understudied, knowledge of current spatial distribution of populations and population sizes of *S. graciosus* would be useful in identifying the ecological effects of habitat degradation or fragmentation in insular habitat within these increasingly threatened ecosystems.

## HYPOTHESES

### *Sceloporus graciosus* presence by site

H<sub>p1</sub>: *Null hypothesis of no temporal or spatial change*: Assuming essential habitat factors have not changed over the past century, *Sceloporus graciosus* now should be present and as abundant where they were known to have lived in the past several decades. In addition, given that 1) the Snake River drainage leading to the entire Columbia River Basin was the apparent pathway used by *Sceloporus graciosus* migration into the state of Washington, 2) populations of *S. graciosus* have been found as far as 50 km from the Columbia river in Washington, and 3) both sand and shrubs are habitat requirements for *S. graciosus*, it would be expected to find this species in the required habitat type within 50 km of the Columbia River and its major tributaries.

Withholding the possibility of stochastic extinction events, it should be reasonable for an established lizard population to be able to persist several decades. Thus, sagebrush lizard sightings from the mid-late 1990s and early 2000s should indicate habitats that presently hold resident populations.

### *Sceloporus graciosus* abundance as related to habitat disturbance

H<sub>a1</sub>: Sagebrush lizard abundance is inversely related to levels of habitat degradation, as measured by cheatgrass abundance, fire frequency, and scarcity of shrubs and open sand.

Prior studies have shown that conditions that remove or limit the possible microhabitats useable by a species will often reduce the possible number of individuals the habitat can sustain (*i.e.* see Hecnar and M.'Closkey 1998). Wildfire

and cheatgrass, for example, can remove the majority of suitable habitat for species like *S. graciosus* should their extent in the habitat be large. Localized disturbances, such as small isolated patches of cheatgrass, are not likely to remove as much, if any, suitable habitat. Assuming there is no rescue-effect from distant, nearest-neighboring metapopulations, *S. graciosus* abundance is expected to be lower in degraded habitat (*e.g.* abundant cheatgrass, few shrubs). Prior studies have shown inverse relationships between specialized species abundance and habitat disturbance (*i.e.* see Attum et al. 2006), so a similar relationship within *S. graciosus* populations would not be unexpected.

### ***Sceloporus graciosus* association with microhabitat**

H<sub>m1</sub>: Sagebrush lizards have been found in and among sagebrush in many studies; therefore, sagebrush lizards will be found most often associated with proximity to woody shrubs than to any other type of microhabitat.

The semi-arboreal lifestyle of *S. graciosus* requires shrubs to be large enough with thick stems or branches to be climbable. Sagebrush is the classic example of a suitable shrub that *S. graciosus* is often found climbing (giving the species its common name). Therefore, this lizard will be most encountered in close proximity to large woody shrubs for basking, foraging, and refugia.

### **Microhabitat relationship with disturbances**

H<sub>d1</sub>: Given that cheatgrass permits wildfire to destroy shrub steppe and desert scrub (*e.g.*, see Evans and Lih 2005), there will be an inverse relationship between disturbance variables—such as cheatgrass cover or bare ground caused by recent wildfire—and woody shrub coverage.

Many forms of habitat disturbance, such as wildfire, invasive species establishment, and general habitat loss, eliminate much of a landscape's habitability for shrubs and lizards. Perennial composition and abundance can go from high to non-existent in some circumstances (Evans and Lih 2005). The potential fragility of perennials like sagebrush under the context of disturbance will likely lead to changes in the availability of suitable microhabitat for *S. graciosus*.

### **Relationships between habitat disturbance and species similar to *S. graciosus***

H<sub>s1</sub>: Disturbances to any given habitat can potentially affect more than one inhabitant species, especially if multiple species fill similar niches; therefore, side-blotched lizards (*Uta stansburiana*) living in habitat suitable for *S. graciosus* should exhibit presence and abundance trends similar to that of sagebrush lizards due to habitat disturbances.

Sagebrush lizards often live alongside side-blotched lizards (*Uta stansburiana*) throughout their species range. Both species are members of the family Phrynosomatidae, are small-bodied, and live largely in the same biomes. Hence, these two species are similar enough in physiology that habitat changes strong enough to affect the populations of one may affect the other.

## Rationale for study and hypotheses

Understanding the relationship *S. graciosus* has with its environment requires an understanding of where populations appear to be robust. Apart from generalized distribution models (*e.g.* see Chan et al. 2013), there are few updated records regarding current populations in Washington. In fact, most studies involving this species were carried out in Utah or Idaho (*e.g.* Ferguson 1971, Tinkle 1973, Reynolds 1979). All information regarding the location of Washington populations are derived from historical sightings dating back to the turn of the 20<sup>th</sup> Century. While *S. graciosus* has been seen by members of the Bureau of Land Management (personal communications, Jason Lowe, 2016), there have not been any recent publications documenting their whereabouts. As such, a general survey of location and abundance is required for any ecological testing.

Furthermore, a general survey of population locations would be advantageous for determining any possible extirpations from past habitats. Much of the range of *S. graciosus* falls within redeveloped shrub-steppe surrounding the Columbia River (Dobler et al. 1996, Hallock et al. 2007). However, little is known regarding whether or not this species is still found in historic habitat that has been influenced by anthropogenic disturbance. Aside from landscape conversion, settlement in this environment often increases wildfire frequency, introductions of invasive species, and general fragmentation of continuous habitat, all of which have the capacity to diminish or eliminate constituent lizard populations. There are no known studies that have investigated these matters. Moreover, little is known about how much of which types of disturbances are strongly detrimental to *S. graciosus* populations. The fact that this species is a habitat specialist with specific community and landscape requirements is established (Woodbury and Woodbury 1945, Burkholder and Tanner 1974,

Adolph 1990, Green et al. 2001), but its tolerance for disturbance and of sub-optimal habitat (which is not quite defined) is not known. Species with narrow niche tolerances may be at risk even in cases of limited disturbance, and the presence and abundance of *S. graciosus* in habitats varying in types and severities of disturbances can lead to further insight into its habitat requirements.

If a species has narrow habitat requirements, it would be likely that it selectively uses certain portions of that habitat more than others; that is, a species may be specialized to use specific microhabitats within a general habitat type. For example, within a shrub-steppe environment (*i.e.*, the macrohabitat), abundance of individuals may vary among the constituent species due to shrub size, form, structure and location, such as slope, aspect, and proximity to edges or crests of dunes (*i.e.*, species-specific microhabitat features). For ectotherms that are relatively precise thermoregulators, microhabitat is important for regulating body temperature and maximizing metabolic (rate of food-processing and growth) potential (Adolph 1990). The capability of a shrub, for example, to provide refugia from wind or intense sunlight would be of use for lizards in this environment, especially if the benefits further match the species behavior and general life history. Thus, macrohabitat requirements for *S. graciosus* may predict presence, but precise microhabitat availability for feeding, thermoregulation, and refugia are more likely to be associated with lizard abundance.

It would not be unexpected for mesohabitats such as dunes to vary in shape and size in the shrub-steppe macrohabitat, and for the plant microhabitats also to vary with slope and aspect of a dune mesohabitat. For species that may rely on plant microhabitat (*e.g.*, species

and size of shrub), these differences may be important for determining the possible number of individuals present (*e.g.* see Ryberg et al. 2013).

Given the lack of current ecological knowledge of *S. graciosus* in Washington, a study investigating the foregoing questions, hypotheses, and unknowns would be of great use for state and private organizations with an interest for conserving what is left of the state's shrub-steppe and dune landscape, as well as the species inhabiting them. For instance, it is also unknown if the side-blotched lizard (*Uta stansburiana*), another denizen of the Columbia Basin that often lives in sympatry with the sagebrush lizard, may be affected likewise by the various sources of degradation in its habitat. Investigation of whether the presence and abundance of this species mirrors that of the sagebrush lizard under similar habitat conditions would be fruitful for identifying disturbances that have harmful implications beyond just a single species. Also, understanding any potential importance of microhabitat for target species would be useful in evaluating priority locations for protection, for it can be easy to overlook such differences at the macrohabitat perspective. Finally, this study will provide much needed information about *S. graciosus* in Washington, especially the locations of current populations and possible factors responsible for them.

## **METHODS**

### **General summary**

Sites within the Washington and Oregon geographic range for *Sceloporus graciosus* that may support populations were surveyed. These sites comprised 1) locales for which the WDFW and ODFW had records of sightings of sagebrush lizards sometime in the past six decades and 2) sandy locales with perennial plant physiognomy more typical of desert scrub, and thus conducive to the ecological needs of *S. graciosus* (Marcellini and MacKey 1970b, Adolph 1990, Green et al. 2001, also see Chan et al. 2009). Visual search at a standardized microhabitat-searching speed at each site was used to obtain data on number of lizards seen per minute. For each lizard, associated microhabitat and environmental data (*e.g.* lighting, air and ground temperatures) were also collected. The spatial pattern of vegetation at each locale was characterized by GIS classification of aerial images. A subset of sites included on-site, in-person field measures of cover and substratum using standard line-intercepts and transects-and-quadrats to assess accuracy of the GIS classification. General Linear Model statistics were used to test for differences between sites where sagebrush lizards were present and absent by comparing spatial distributions of woody shrubs, open sand, and annual grasses.

### **Study Sites**

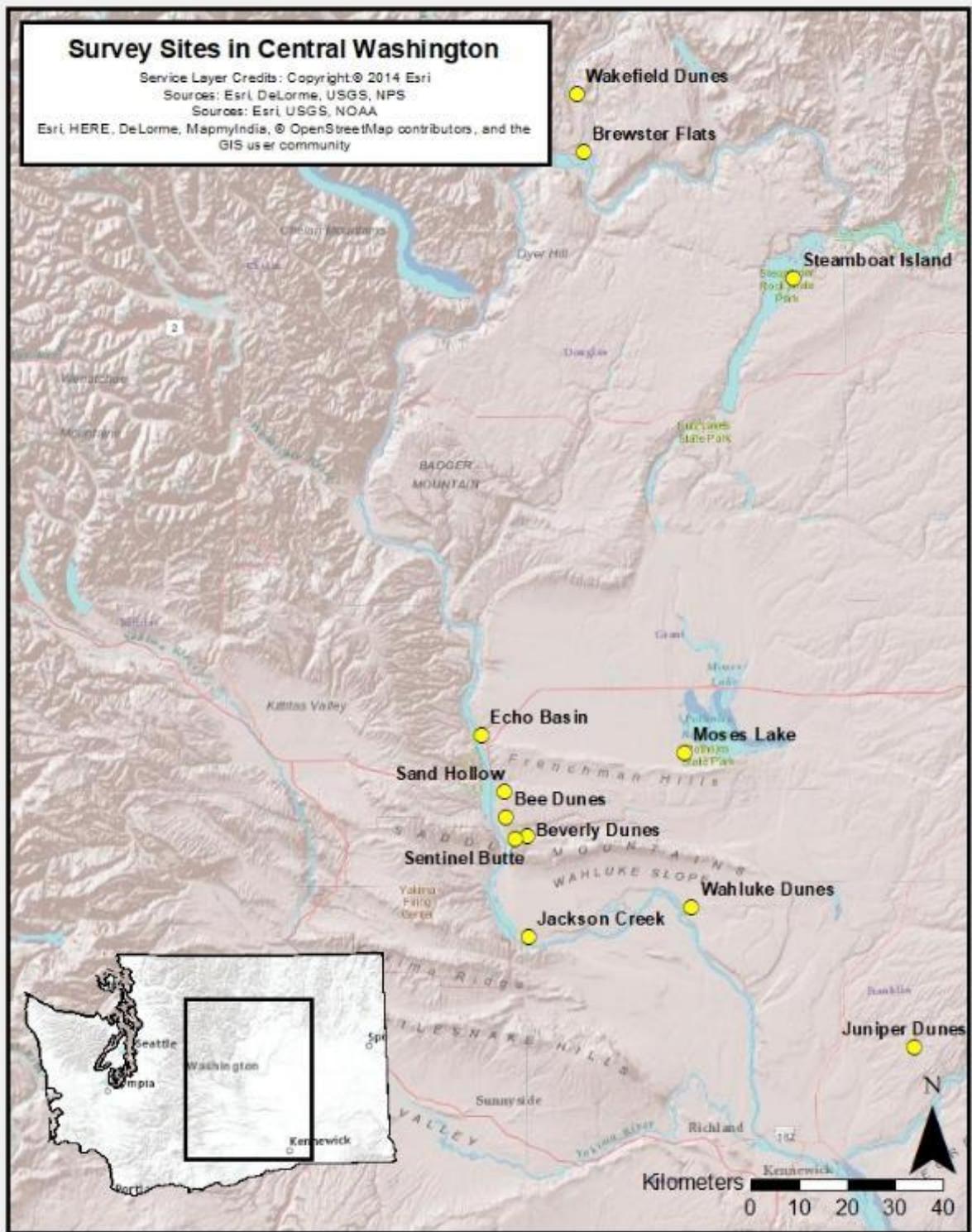
Sixteen sites were surveyed within the geographic range of *Sceloporus graciosus*; thirteen were in central Washington and three were in central and southeastern Oregon. Seven of the 13 Washington sites were known to have had at least one sagebrush lizard since 1900 based on point data from the Washington Department of Fish and Wildlife's Priority Habitats and Species database (2017a) and the remaining six were chosen due to apparent

suitability and/or close proximity to historical locations. Suitability was judged based on the following criteria: abundance of open spaces (*i.e.*, > 2 m) between adjacent woody shrubs or adjacent patches of woody shrubs, wherein the mature woody shrubs are commonly at least 1 m in diameter, and substratum is sand or loose/sandy loam. Data on study sites are listed in Table 1. Likewise, one of the three sites in Oregon was known to harbor sagebrush lizard populations, and the remaining two were chosen based on the suitability criteria.

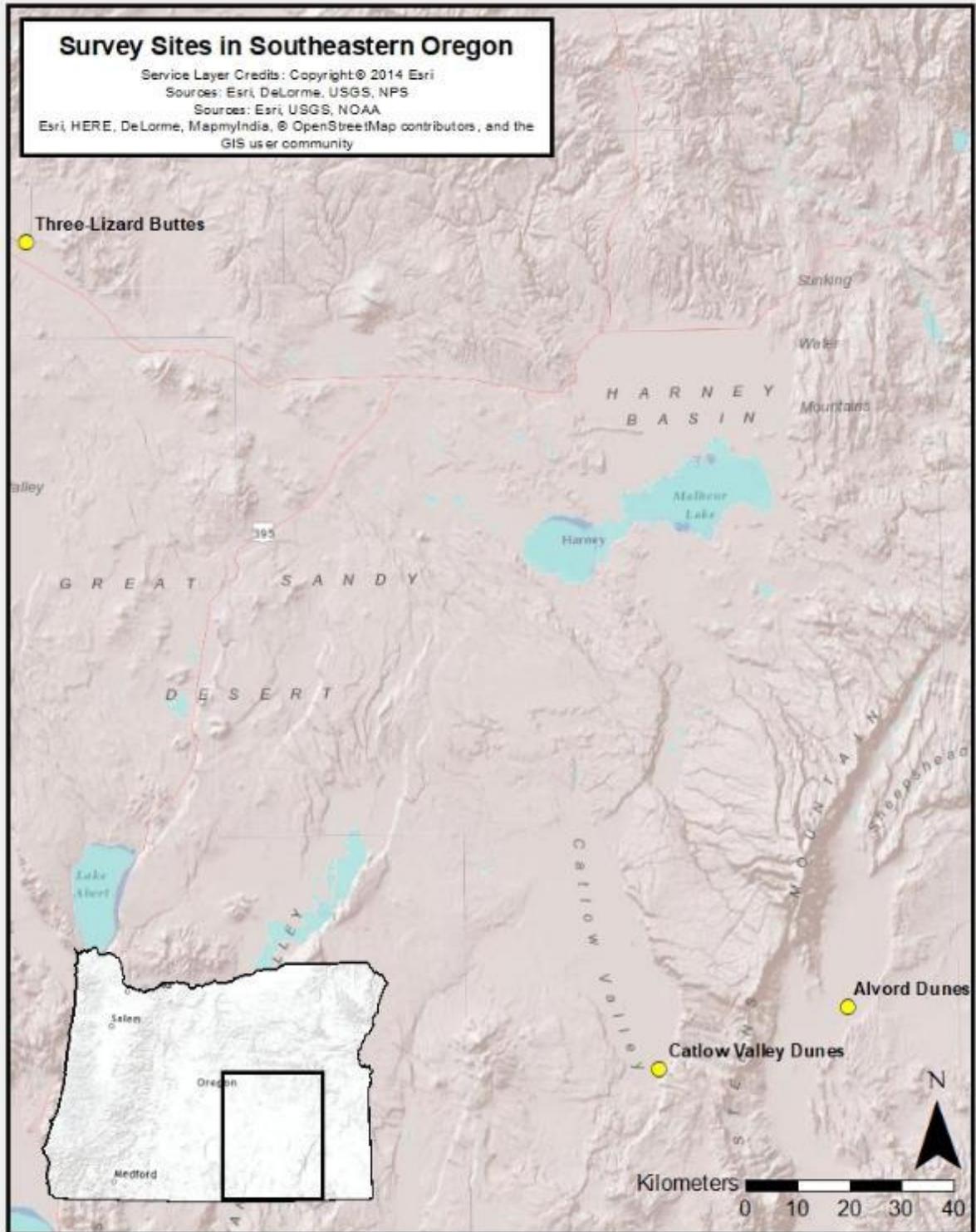
At the time of surveying, the exact location of the WDFW-confirmed sagebrush lizard occurrence at Steamboat Rock State Park could not be determined. It was later discovered that the surveyed area was just under a kilometer away from the location where at least one sagebrush lizard was found in 2002. A campground and recreational area surrounding the occurrence point was observed to be under active construction during surveys. It is uncertain whether lizards still persist there. For the purposes of this study, the lizard search data for this site were not used in general analyses to avoid erroneously skewing the results. Based on visual observations, the surveyed area had high grass cover and very little loose sandy substrate, and therefore did not seem consistent with sagebrush lizard habitat surveyed elsewhere. In contrast, the occurrence point was situated on a small, sandy beachhead with scattered sagebrush, so landcover summary statistics were created for this mesohabitat. No sagebrush lizards, however, were found in one-person, 20-minute survey of that site during the peak time of day and season for lizard activity in 2012 (personal communications, Roger Anderson, 2017). Based on these results and the small size of the available mesohabitat, sagebrush lizards were considered to be absent at this site.

**Table 1:** Locations of study sites, including the latitude and longitude coordinates. Also indicated is if sagebrush lizard populations have been previously found at the site, either by the WDFW or personal observation, and temperature ranges during surveys.

Location	State	Documented Historical Occurrence	Days Surveyed	Temperature Range	Lat.	Long.
Bee Dunes	WA	-	2	26–35°C	46.8647	-119.8975
Beverly Dunes	WA	Y	1	18–29°C	46.8308	-119.8689
Brewster Sand Flats	WA	-	1	-	48.1074	-119.6936
Chicken Creek	WA	Y	2	21–27°C	48.0937	-119.6656
Echo Basin	WA	-	2	26–28°C	47.0180	-119.9864
Jackson Creek	WA	-	1	27–29°C	46.6410	-119.8674
Juniper Dunes Wilderness	WA	Y	2	28–27°C	46.4250	-118.8244
Potholes State Park	WA	-	1	27–28°C	46.9824	-119.4310
Sandhollow Dunes	WA	-	2	27–29°C	46.9144	-119.9258
Sentinel Butte	WA	Y	1	26–27°C	46.8233	-119.9011
Steamboat Island	WA	Y	1	-	47.8648	-119.1190
Wahluke Dunes	WA	Y	1	-	46.6841	-119.4236
Wakefield Dunes	WA	Y	1	-	48.2127	-119.7132
Alvord Basin	OR	Y	7	20–33°C	42.4400	-118.4763
Catlow Valley	OR	-	2	27–28°C	42.3348	-118.9162
Three-Lizard Buttes	OR	-	2	23–33°C	43.7785	-120.3890



**Figure 2:** Map of survey sites in central Washington. The Brewster Flats point represents both the sand flats near Anderson Field and the Chicken Creek boat launch flats.



**Figure 3:** Map of survey sites in southeastern Oregon.

Because *Sceloporus graciosus*, along with other denizens of sandy and dune habitat, may be becoming uncommon-to-rare in Washington (Hallock et al. 2007), sites from Oregon were added to this study to increase the number of sites investigated and to compare differences among mesohabitats with an abundance of lizards versus those with a paucity of lizards. In southeastern Oregon, at least one of the sites chosen was known to have relatively undisturbed habitat which contained “thriving” sagebrush lizard populations (P. Zani and R. Anderson, 2016, personal communication). Any latitudinal difference as a causal factor in site-to-site sagebrush lizard abundance—apparently low in Washington versus high in Oregon—is inferred to be unlikely for two reasons. First, altitude and latitude trends were in opposite relationship among sites. Frost-free seasons are about 1–2 months longer among the Washington sites than at the Oregon sites, and daylength is likewise slightly longer in Washington (Plantmaps.com 2018). Mean annual temperature decreases by about 0.5°C for every degree latitude (Trøjelsgaard and Olesen 2013), and also decreases by about 6.5°C for each kilometer in elevation (International Civil Aviation 2002). Since the survey sites in Washington were 4–6 degrees higher in latitude and about 1.6 km lower in elevation than the Oregon sites, one would expect the Washington sites to be only about 3°C warmer. This is supported by mean monthly summer temperatures being 2–3°C warmer and less than 2 mm difference in precipitation between Beverly, WA and Fields, OR (Western Regional Climate Center 2016). The habitat range for sagebrush lizards ends near the Canadian border as both latitude and elevation increases. Second, because A) sagebrush lizards and side-blotched lizards (*Uta stansburiana*) commonly are found either in sympatry or in similar habitat across much of their geographic range (Jones and Lovich 2009), B) the high abundance of side-blotched lizards in higher latitudes of the species’ geographic distribution has been

attributed to sufficiently long activity seasons, high food availability, and low predation pressure in the northern regions (Wilson 1991), then I expect 1) that the non-anthropogenic factors affecting survivorship, growth, and reproduction should be similar in these two species of small lizards, and 2) the populations of *S. graciosus* in Washington should be robust in the absence of anthropogenic disturbance. Nonetheless, it remains possible that other latitudinally-relevant environmental factors unaccounted for in this study could influence the demographics of this species.

### **Timing of field surveys**

Because lizards in Idaho and California are known to begin to emerge from hibernacula between March and May (Goldberg 1975, Guyer and Linder 1985, Martins 1993), potential study sites were visited March through June of 2016. Data collection began in June 2016 at the Alvord Basin in southeastern Oregon: the Alvord and Catlow Valley Dunes were surveyed from mid-June to mid-July. Three-Lizard Buttes—the site expected to have high lizard abundance—was studied in late July. The 12 Washington sites were surveyed between late July and early October, which corresponds with the post-reproductive portion of the activity season of the species.

Hibernation does not begin until sometime in October for *Uta stansburiana*, *Sceloporus graciosus* and *Sceloporus occidentalis* (Goldberg 1975, P. Zani and R. Anderson, 2016, personal communication) in Oregon and Washington so all surveys completed during summer and early autumn 2016 occurred while sagebrush lizards were still active.

## Weather

All lizard surveys were conducted under weather conditions that are known to correspond to high lizard activity (Grant and Dunham 1988, Grant 1990). Surveys were done between mid-morning and late afternoon (approximately 0900–1500) when lizards are typically most active (Grant and Dunham 1988, Ferguson et al. 2014) during summer at higher latitudes and higher altitudes. That is, searches for lizards occurred when air temperatures were between 22 and 30°C, primarily on days when air temperature was approximately 28°C in early afternoon. When I was in the field, air temperature at 2 m from ground level was collected using an HH81A digital thermometer (OMEGA Engineering) and surface temperatures were collected using a non-contact infrared thermometer (Digi-Sense model WD-20250-07). Wind speed was measured with a hand-held anemometer (Kestrel 1000), but surveys were conducted when maximum wind speed was less than 10 m/s, because there is some evidence that lizard activity does not seem to be as high on windy days, perhaps because thermoregulation and hearing may be compromised (*e.g.* see Castilla and Bauwens 1991, Maia-Carneiro et al. 2012). Moreover, lizard surveys were not done under overcast or rainy conditions. Thus, surveys were contingent upon clear skies or partly cloudy skies and dry weather. By only conducting surveys when conditions were close to optimal for lizard activity (Adolph and Porter 1993), I maximized the chance of encountering lizards while surveying a given site.

## Lizard surveys

For all sites, the frequency of encounter was collected using standard Visual Estimation Surveys (VES; Dodd 2010, Crump and Scott Jr. 2014). This method of search comprises a largely one-directional walk to avoid resighting the same lizard, and uses the number of lizards spotted within a recorded period of time as a proxy for population abundance. Like other phrynosomatid lizards, sagebrush lizards conspicuously move if a person approaches within a few meters. This species uses vision to detect prey, conspecifics and predators, so when the searcher approaches closely to identify the sex and size of the lizard, the searcher can successfully identify the lizard if the searcher moves head and arms slowly and avoids direct eye-contact.

Measuring actual population density would require enormous effort by comparison to VES. Moreover, other methods, such as random quadrat survey also requires enormous time investment and there is potential to count individuals twice if searching nearby quadrats, unless they are captured and marked (also time-consuming). Also, like any small area which has large perimeter-to-area ratio, small search areas increase the likelihood that one may count an individual lizard that may not be a resident in that quadrat (some portion of a hectare, for example)—rather, it may be a visitor of that quadrat, having entered from offsite during the survey. The result could be an overestimation of population density. There is consensus across several herpetological studies that VES accurately captures species presence when compared to traditional plot or transect surveys (see Doan 2003, Flint and Harris 2005, Grover 2006, Hutchens and DePerno 2009).

Search effort for *Sceloporus graciosus* was standardized on a microhabitat basis, with time spent searching corresponding with the number of microhabitats surveyed. For every

minute of search, each surveyor searched approximately 12 microhabitats. For shrubs averaging 1 m in diameter and generally spherical in shape, each has a sunlit side and shaded side that could be used by a lizard throughout the day (*i.e.* two microhabitats). For a distribution of shrubs at least 1 m apart, the walking speed is about 5–6 m/min. Walking speed was adjusted according to the vegetation structure of the landscape to maintain a 12 microhabitat/min survey rate. The time it takes to survey the mesohabitat (*e.g.* a sand dune) will correlate with the number of microhabitats present if equal search effort is given for every microhabitat. Because they are ambush predators, sagebrush lizards are sedentary during most of their foraging time (*i.e.*, cryptic), searching visually for approaching prey, where they are predictably close to shrubs-as-refugia. A human searcher can focus on shrub proximity to enable a robust estimate of lizard abundance by recording the number of encounters with lizards per minute for any shrub-abundant mesohabitat.

VES transects were performed along dunes or similar sandy substrate for each study site. The number of days spent at each site depended on the spatial extents of suitable shrubs (microhabitats) in the mesohabitat (see Table 1). For the Alvord Dunes, which were the largest sampled, 50 m-long transects were stretched parallel along the leeward side of the dune where shrubs and lizards were sheltered from playa winds. For this site, 50 m transects were usually long enough to sample the entire dune. For all other non-Alvord sites where dunes were much smaller, transects were either 30 m long or the length of the dune if it was less than 30 m. Sampling involved walking along the transect at a regular pace as previously described and searching for lizard presence. Assistant surveyors were spread out 5 m from each other in a line parallel to the length transect. Stopwatches were used to record the amount of time spent searching and the time of encountering a lizard. Stopwatches were

started at the beginning of the survey, and then were all paused at the moment a lizard was encountered. Data on the lizard's species, behavior, mesohabitat, microhabitat, substrate, lighting conditions, and the time on the stopwatch (used to later calculate encounter rate) were immediately recorded. Following data collection, stopwatches were started again and the searches were resumed normally. Encountered lizards were not recorded more than once, and since evading lizards hide in the nearest shrub, most individuals were located and identified. The few that completely evaded identification were classified as "unknown" and excluded from analysis.

Since the utility of VES is contingent upon the visual detection of lizards, several assumptions were made: (1) search efficacy was constant among surveys and searchers, (2) lizards were equally detectable among shrub types, (3) lizards would exhibit predictable basking or perching behavior during surveys, (4) weather conditions during surveys would be suitable for lizard activity. To meet these assumptions, (1) all assistant searchers were trained to properly search for lizards and identify their species and behavior, (2) shrubs that could potentially conceal lizards were thoroughly searched, moving branches aside as needed, resulting in conspicuous movement by lizards (3) searcher body movements were slowed to avoid triggering evasive lizard behavior, and (4) surveys were completed under weather and temperature conditions suggested in herpetological literature. These assumptions are further addressed in association with Figure 5.

## GIS image classification

Site landscape composition was characterized using image mosaics taken by an Autel X-Star Premium quadcopter with a 12 megapixel  $4000 \times 3000$  resolution camera. All flights were done with myself as FAA-certified remote pilot in command under 14 CFR Part 107 (certification number: 4039244) and one assistant spotter. For each of these sites, aerial images were taken at approximately 100 ft (30.48 m) in altitude with the camera facing down at a  $0^\circ$  angle where lizard surveys were conducted. The number of images taken were consistent with the area needed for classification with enough overlap for later reference. Weather conditions during photography were generally overcast with wind speeds of less than 10 mi/hr (4.5 m/s).

A  $-15$  lens distortion filter was applied to all photographs in GIMP 2.8 to correct the barrel-eye effect common in sUAS cameras. The corrected photographs were then imported into ArcMap v. 10.3 (ESRI), geo-referenced, and mosaicked. The Mosaic-to-New Raster tool was then used to create a new raster image composed of all individual photographs for each site. Prior to image classification, all extraneous features that were not to be sampled (*e.g.* roads, vehicles, trees) were manually cut from the raster images. Boulders were also removed from analyses due to misclassifications with shrubs and because sagebrush lizards were not observed to use rock-like structures. Thus, all images only included shrubs, sand, and grasses typical of natural sagebrush lizard habitat. Finally, all prepared images were standardized to a  $0.1 \times 0.1$  cell resolution (*i.e.* 1 cell =  $10 \text{ cm}^2$ )

Supervised image classifications were done with the following possible classes: shrub, sand, grass, other. All sites had the primary shrub, sand, and grass classes, while the other class was used as needed for landcover types not known to be used by sagebrush lizards

(*e.g.* dung, compact soil). A minimum of 20,000 pixels per class were used in photographed sites, and a minimum of 10,000 pixels per class were used in sites where Google NAIP imagery was used. For each class in each site, the total pixels were randomly divided in half in order to generate two uniquely classified rasters. These were used in the Tabulate Area tool to create a confusion matrix for the purposes of assessing the precision of the classification model. The results from these analyses would indicate inconsistent class sampling or classification inaccuracy.

### **Shrub-cover transects**

Point-line intercepts and photoquadrats on transect lines were used for the Alvord Dunes, Bee Dunes, Catlow Dunes, Juniper Dunes, Sand Hollow Dunes, and Three-Lizard Buttes. These studies became supplemental data that were used in cross-assessing sUAS-derived landscape classifications. For these point-line intercepts, a minimum of three 20 m lines were arbitrarily placed along the area used for VES. The point-line intercept method of surveying shrub coverage (see Canfield 1941) was used by measuring every shrub that crossed the transect line. Procedure of this survey included walking along the transect from 0 m to 20 m and stopping to measure every shrub interception. Crossing-points (where any part of the shrub crossed the meter tape) was recorded for cover analysis. Size and species were also recorded for every shrub that intercepted the transect line. A minimum of three point-intercept surveys were conducted per location, with the exception of the large Alvord Dunes, in which there was enough space to do three surveys per dune, the Three-Lizard Buttes, where I had the time to do only two surveys.

Once point-line intercepts were established, a belt-line transect comprising  $1 \times 1$  m quadrats with  $20 \times 20$  cm grids was systematically placed along the same line, with a quadrat being measured at every other meter, alternating sides each time. Thus, out of 40 possible quadrat surveys on a 20 m transect, 20 were collected (10 quadrats on either side of the line). For every placement of the quadrat, an aerial photograph at a  $0^\circ$  angle (*i.e.* top-down) was taken approximately 1 m above the quadrat. These photographs were then analyzed in the lab for percent herbaceous cover by species. Coverage was visually approximated using a rapid count for each photograph with enhanced precision since every  $20 \times 20$  cm square contributed to a constant 4% of the area. Rapid counts using quadrats has shown in many previous studies to provide accurate representations of vegetation cover (Stohlgren et al. 1998, Kent 2011), although recounts were made to check and avoid approximation error. Since a minimum of three transects were made per site, at least 60 photoquadrats were collected and analyzed for each site.

### **Statistical analysis**

FRAGSTATS v. 4.2 (University of Massachusetts, Amherst) was used for spatial referencing and analysis. The following class statistics were calculated from each classified experimental raster: percent shrub, percent sand, percent grass, percent of shrubs  $\geq 1$  m (PLS), percent core area (PCA), and a grass-proximity index (GPI). PCA is the summed areas  $a$  ( $m^2$ ) of shrub and sand patches  $ij$  based on edge depths of 0.5 m for shrubs and 1 m for sand, as a percent of the total landscape area (TA), expressed as

$$PCA = \frac{\sum_{j=1}^n a_{ij}}{TA} (100) \quad \text{Equation 1}$$

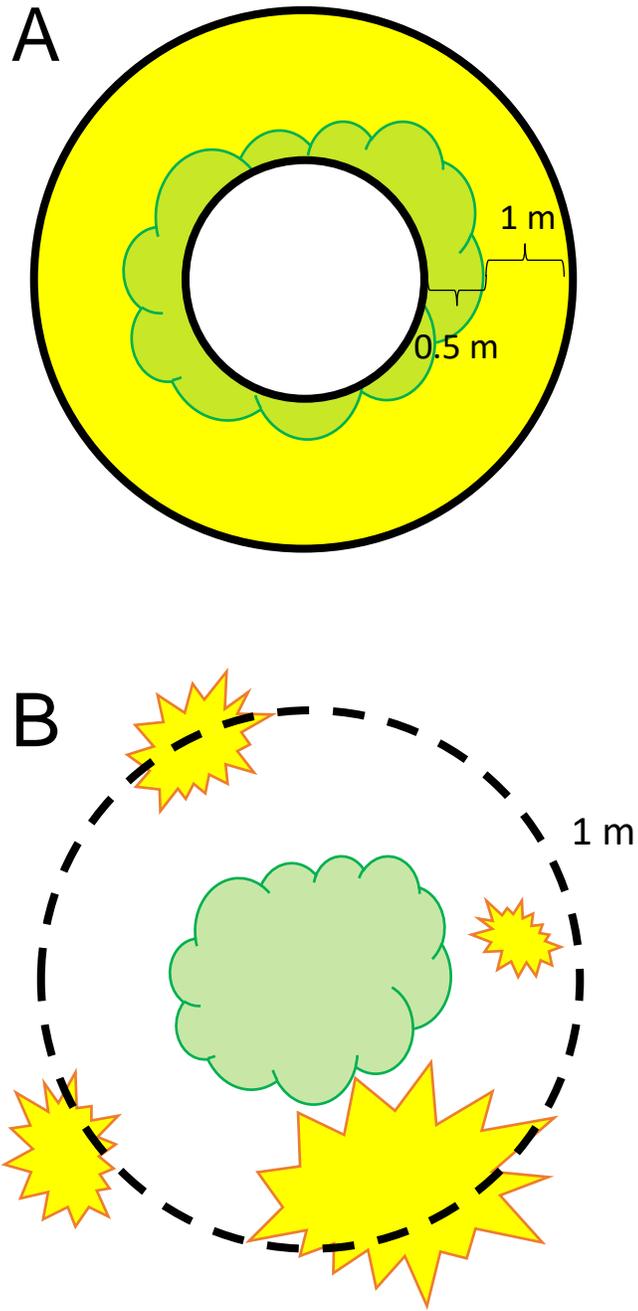
Equation 1 is an estimate of the total shrub-sand edge habitat available for sagebrush lizards extending 1 m into open sand and 0.5 m into shrub refugia. Conversely, GPI is the similarity index between shrubs and grasses at a distance of 1 m apart, where the shrub-to-grass similarity coefficient was assigned a value of 1 and all other inter-class coefficients 0, divided by total landscape area and expressed in log<sub>10</sub>. The similarity index from which this metric is designed, is the “sum, over all neighboring patches with edges within a specified distance (m) of the focal patch, of neighboring patch area (m<sup>2</sup>) times a similarity coefficient between the focal patch type and the class of the neighboring patch (0-1), divided by the nearest edge-to-edge distance squared (m<sup>2</sup>) between the focal patch and the neighboring patch” (McGarigal 2014, pg. 139). Thus, GPI can be expressed as

$$SIMI = \sum_{s=1}^n \frac{a_{ijs} \cdot d_{ik}}{h_{ijs}^2}$$

$$GPI = \log_{10} \left( \frac{SIMI}{TA} \right) \quad \text{Equation 2}$$

where  $a_{ijs}$  is the area of the patch within the neighborhood of patch  $ij$ ,  $d_{ik}$  is the similarity coefficient between patch types  $i$  and  $k$ , and  $h_{ijs}$  is the edge-to-edge distance between patch  $ijs$  and patch  $ij$  (McGarigal 2014). Illustrative models for PCA and GPI can be found in Figure 4.

With R v. 3.3.2 (R Development Core Team), image classification landcover data were tested against transect and quadrat-derived data with an analysis of similarities



**Figure 4:** Illustrative models showing (A) the yellow area defining PCA, and (B) the grass patches within 1 m of a shrub included in GPI.

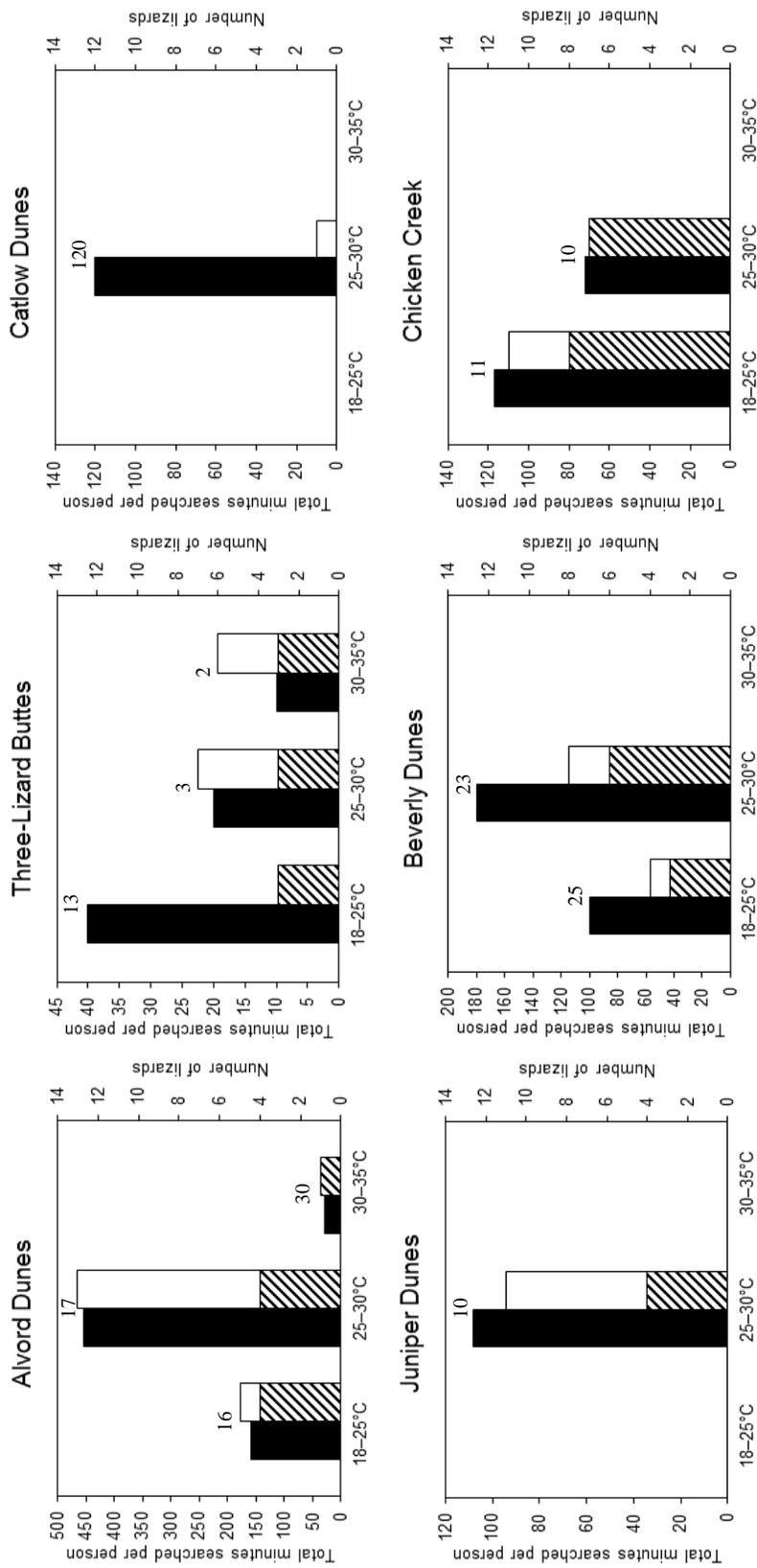
(ANOSIM). Contingent upon failure to find differences between sampling methods at  $\alpha = 0.05$ , image classification-derived landcover data were used for further analysis. Sagebrush lizard encounter frequencies were tested for correlations with the aforementioned class statistics using Pearson's product moment correlation coefficient. Tests for correlations among class statistics were done in the same fashion. ANOSIM was used to test for differences in class statistics between sites where sagebrush lizards were present and sites where they were absent, and similarity percentages were calculated to determine the class statistics contributing the most to presence/absence differences. Since the grass proximity index is represented as a unitless value and could not be used in ANOSIM with other data, an independent-samples t-test was used separately to assess differences between sagebrush lizard-present and absent sites. These tests were repeated for side-blotched lizards as well.

Finally, chi-square tests were used to test for differences among certain microhabitats in the frequency of sightings of all lizards for both sagebrush lizards and side-blotched lizards. Shrub association was tested using the frequency lizards were found either within 1 m of a shrub or in an open sand patch. For lizards found near shrubs, the frequency of occurrence underneath the shrub, against the center stem, on shrub surfaces, and outside perimeter (*i.e.* the nanohabitat) was similarly tested. Significance for comparative differences in lizard habitat use was based on  $\alpha = 0.05$ . Furthermore, the standardized residuals for each lizard-habitat association were used to determine where differences lie. Residuals greater than  $\pm 2.00$  were considered to have significant contribution (see Agresti 2007) to differences in microhabitat use.

## RESULTS

### Weather during surveys

The assumption that visual surveys were performed when lizards were likely to be active and detectable was tested by documenting that searches were performed during sunny, warm weather, with air temperatures sufficiently close to the optimum range for lizard activity of 24-28°C (Pianka 1970). Lizards were found at mean air temperature of 26.2°C and median of 27.1°C. Air temperatures during lizard searches ranged 18°C to 35°C (Table 1). In contrast, searching for lizards near the extremes of activity-prone ambient temperatures revealed the efficacy of searching when lizards are likely to be active. For example, one survey was attempted in a morning when air temperature was less than 18°C, but no lizards were seen until closer to midday when air temperature approached 20°C. Moreover, during searches when air temperatures exceeded 30°C, when lizards were likely to have retreated from the heat of the day to avoid critical body temperatures (*e.g.* see Angilletta et al. 2002, Scheffers et al. 2014), fewer lizards were found, and those were in deep shade (seven found in 80 person-searching minutes, compared to an average of 11 in 80 person-searching minutes between 24°C and 28°C). Given that lizards were detectable both in cool (18–25°C) and warm temperatures (25–30°C), and that the majority of lizards at cooler temperatures were actively trying to bask and conspicuous to the human eye, the ability to spot a lizard regardless of activity should not have been hindered by cooler temperatures (see Figure 5). Furthermore, sagebrush lizards were detectable even in the two sites when temperatures reached 30–35°C. Thus, I verified that I searched for lizards when lizards have been found to be most active and that the potential influence of temperature on encounter data was eliminated (Pianka 1970).



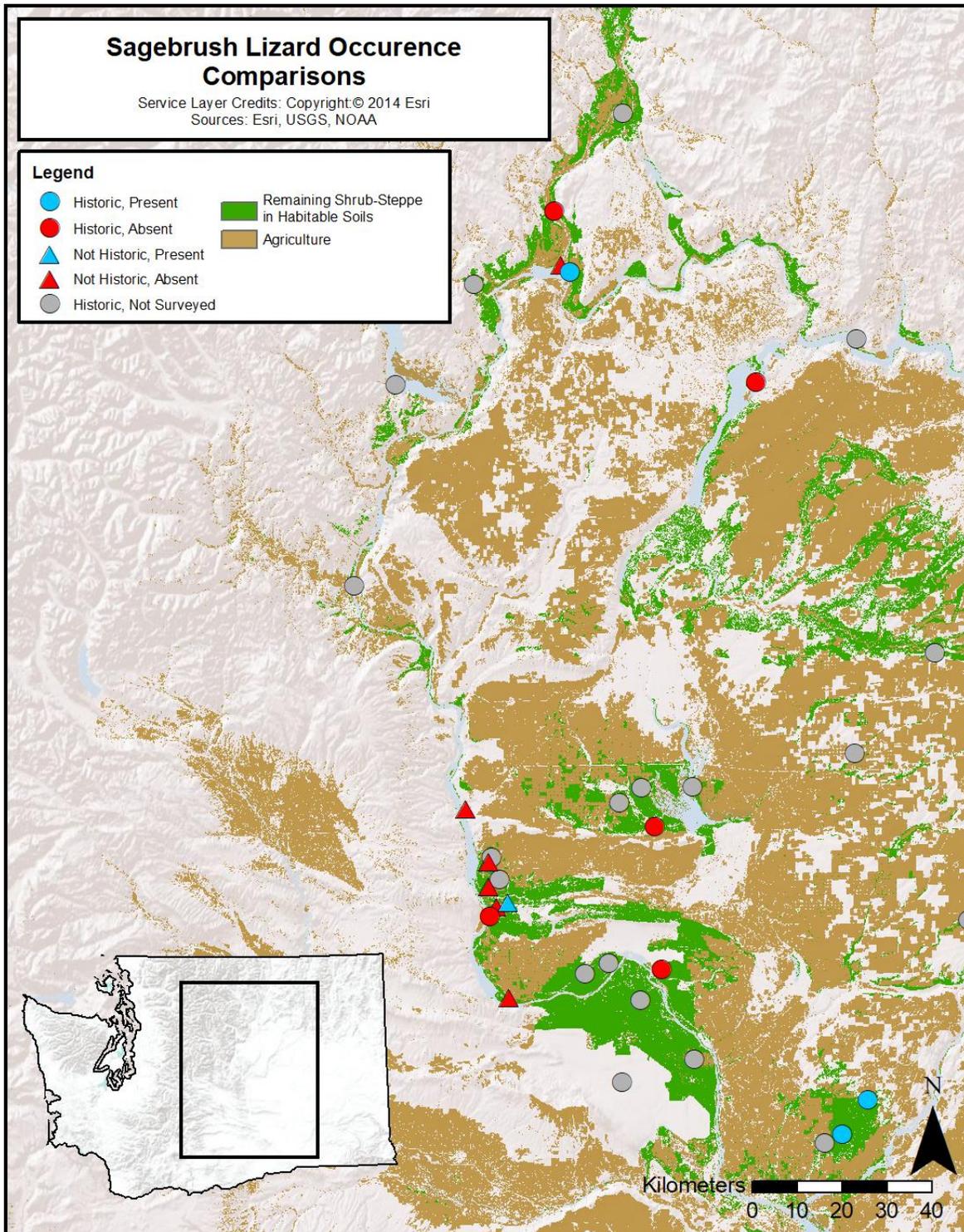
**Figure 5:** Total number of sagebrush lizards in all 6 sites where they were present, and sorted by the air temperature range in which they were spotted. Black bars indicate total person searching minutes for each temperature range. White bars indicate the total amount of sagebrush lizards, with the hatched subset indicating those of which were basking when spotted. Numbers above bars indicate the average number of person search minutes to spot a sagebrush lizard.

## Lizard encounters

A total of 105 sagebrush lizards were found across all sites with a search effort of 3,055 person-search minutes across 56 independent searches. Other lizards found during these searches were 99 side-blotched lizards, 35 western whiptail lizards, and 8 leopard lizards, all of which are active in ambient conditions similar to those when *Sceloporus graciosus* are active. Whiptails and leopard lizards were only found in Oregon, but sagebrush and side-blotched lizards were found in both Oregon and Washington. Twelve small-bodied lizards were not identified to species after having escaped from view, but were clearly either sagebrush lizards or side-blotched lizards. Of these twelve, ten were from the Alvord Basin, one was from the Beverly Dunes, and the last was from Echo Basin.

Among sagebrush lizards, 2 of the 39 (5 %) in Oregon and 24 of the 66 (36 %) in Washington were young-of-the-year (YOY). The difference in age-ratios is assumed to be due to surveying the Washington sites later in the breeding season. Likewise, 15 of the 99 (15%) side-blotched lizards were YOY, with only one of these found in Oregon. Hence, 79 adult sagebrush and 84 adult side-blotched lizards were found in this study, upon which analyses were done to avoid inflated encounter rates due to the presence of new hatchlings later in the activity season. Lizards of all other species were adults.

Of the 16 sites surveyed, I encountered sagebrush lizards in only six sites: Alvord Basin, Beverly Dunes, Catlow Dunes, Chicken Creek, Juniper Dunes, and Three-Lizard Buttes (Figure 6). I did not find sagebrush lizards or evidence that they were present in nine (69%) of the surveyed Washington sites, but all three Oregon sites had at least one resident sagebrush lizard. Two of the Washington sites, the Wakefield Dune and Wahluke Dunes, were verified to have sagebrush lizard populations with GPS point data in 2002 and 1995,



**Figure 6:** Map of survey sites in WA indicating sites with WDFW-documented sagebrush lizard occurrences, and additional sites surveyed for this study. Sagebrush lizard presence (blue) and absence (red) is also indicated, along with areas of suitable habitat and surrounding agriculture.

respectively (Washington Department of Fish and Wildlife 2017a). Likewise, the dunes at Sentinel Butte were also confirmed to have sagebrush lizards in 1995. However, no sagebrush lizards were found at or nearby (< 2 km) these marked locations during my surveys.

Sagebrush lizards were most common at Three-Lizard Buttes in Oregon, with an encounter rate of 0.243 adults per person-search minute (Table 2). The lowest encounter rate of all sites was in the Catlow Valley with only one adult sagebrush lizard found in 150 person-search minutes (0.007 adults/min). I encountered one sagebrush lizard in approximately the same location days before during a reconnaissance survey, and thus it is highly likely that it was the same individual counted in the recorded survey. This lends support that search thoroughness was not an issue for lizard detection in the Catlow Valley, and that the extreme low abundance at this site is likely due to other factors. To reflect this, sagebrush lizards were considered to be statistically and ecologically absent at this site. Encounter rates in the remaining sites ranged from 0.016 adults/min in the Alvord Basin to 0.097 adults/min at Chicken Creek.

In sites where any lizard was present, I did not find a relationship between the presence of sagebrush lizards and side-blotched lizards (Pearson's chi-squared test,  $\chi^2 = 2.86$ ,  $p = 0.09$ ). Further, there were no differences in overall encounter rate between sagebrush lizards and side-blotched lizards (one-way ANOVA,  $p = 0.60$ ,  $df = 11$ ), which is supportive of a consistent search effort between sites since the number of microhabitats searched was held constant among sites.

**Table 2:** Comparisons among sites for search effort and frequency of sightings of the lizards *Sceloporus graciosus* and *Uta stansburiana*.

Site	Minutes Searched	Survey Area (h)	<i>S. graciosus</i>			<i>U. stansburiana</i>		
			Total Adults	Total Recruits	Encounter Rate (adults/min)	Total Adults	Total Recruits	Encounter Rate (adults/min)
Alvord Dunes	1164	3	19	0	0.016	16	1	0.013
Bee Dunes	240	0.88	-	-	-	11	4	0.067
Beverly Dunes	210	1.7	12	11	0.110	3	-	0.014
Brewster Sand Flats	60	0.5	-	-	-	-	-	-
Catlow Dunes	150	1.2	1	0	0.007	-	-	-
Chicken Creek	195	0.96	19	5	0.133	-	-	-
Echo Basin	91	3	-	-	-	5	1	0.077
Jackson Creek	60	1	-	-	-	13	-	0.217
Juniper Dunes	163	0.5	11	8	0.117	-	-	-
Moses Lake	110	3	-	-	-	-	-	-
Sand Hollow Dunes	242	1.1	-	-	-	14	9	0.095
Sentinel Butte	120	3.1	-	-	-	21	-	0.175
Steamboat Island (Shore)	60	1.5						
Steamboat Island (Camp)								
Three Lizard Buttes	70	1	17	2	0.271	1	-	0.043
Wahluke Dunes	60	1	-	-	-	-	-	-
Wakefield Dunes	60	0.78	-	-	-	-	-	-
<b>Total</b>	<b>3055</b>	<b>24.22</b>	<b>79</b>	<b>26</b>	<b><math>\bar{x} = 0.109</math></b>	<b>84</b>	<b>15</b>	<b><math>\bar{x} = 0.088</math></b>

Whiptails were present only in the Alvord Basin, and leopard lizards were present only in the Alvord Basin and Catlow Valley. Interestingly, encounter rates for both sagebrush lizards and side-blotched lizards were the lowest in the Alvord and Catlow. Of all the lizards encountered in the Alvord, whiptails were the most abundant. Sagebrush and side-blotched lizards were similar in abundance, but in greater abundance than were leopard lizards. The larger and more abundant perennials on the large dunes tend to restrict the line-of-sight for this visual predator (see Eason and Stamps 1992) and may have been responsible for the low rate of leopard lizard encounters, despite the high abundance of this species in the Alvord Basin (Steffen and Anderson 2006). The desert horned lizard, *Phrynosoma platyrhinos*—a species well known to be cryptic (Newbold 2005, Steffen and Anderson 2006, also see Cooper Jr. and Sherbrooke 2012)—was also encountered in the Alvord, but at a low frequency (approximately 0.2/hr).

### **Lizard habitat use**

Despite occupying much of the same mesohabitat, sagebrush lizards and side-blotched lizards used the same microhabitats (*e.g.* shrubs) differently. However, there were no apparent differences in shrub use by lizards, even though shrub species composition differed between sites. Also, shrub species did not affect search effort and lizard detectability, since branches were easily moved aside, which prompted any cryptic lizards to move and reveal their presence. Thus, the assumption that lizards could be equally detected in different shrub types was met. Woody shrub microhabitats were occupied most by both lizards: 68% of all encountered sagebrush lizards and 43% of all side-blotched lizards were associated with similar shrub microhabitats. Observed microhabitat use, however,

significantly differed from expected use when comparing the two species (Pearson's chi-squared test,  $\chi^2 = 11.87$ ,  $p < 0.01$ ). Sagebrush lizards were negatively associated with non-woody shrubs or annuals, whereas side-blotched lizards were positively associated with them. Side-blotched lizard use of non-woody shrubs contributed the most (26.4%) to the  $\chi^2$  score. Although the majority of side-blotched lizards were found near woody shrubs, there were approximately 25% fewer found near these microhabitats than would be expected if the microhabitat distribution of this species had conformed to that of *Sceloporus graciosus*. Interestingly, there was little contribution from either species' open terrain use to the  $\chi^2$  score, indicating similarity to expected values.

When comparing woody shrub nanohabitat use (*i.e.*, which parts of the shrub microhabitat were used and how often they were used), sagebrush lizards tended to utilize the different parts of the shrub, whereas side-blotched lizards were found more frequently at the perimeter of the plant (Pearson's chi-squared test,  $\chi^2 = 9.23$ ,  $p = 0.02$ ). Although both sagebrush lizards and side-blotched lizards were most often found along shrub perimeters, 17% fewer sagebrush lizards and 25% more side-blotched lizards were associated with perimeters than expected under the null assumption that both lizards use each nanohabitat at the same frequencies. The frequency of using the center stems and outer surface of the shrubs were similar to expected values, with 52% of sagebrush and 28% of side-blotched lizards found using these nanohabitats.

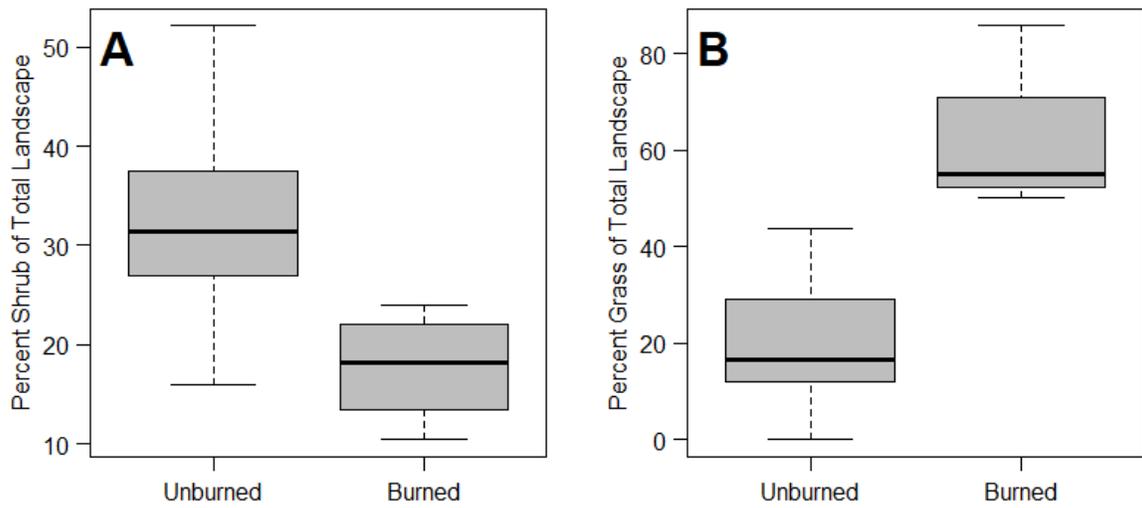
## Accuracy analysis of image classification

Images acquired with sUAS were very high in resolution with a cell size of 0.1 m per image, resulting in the capability for classifying even small (*e.g.* < 0.5 m in diameter) plants and plant patches. Classification accuracy overall was high for sites where sUAS photography was collected. The mean total accuracy for these sites was 89.1%. The producer's accuracy, which is related to errors of omission, averaged 88%. Similarly, the average user's accuracy, which is related to errors of commission, was 87.8%. When they occurred, misclassifications were often a result of similarities in color for sand and grasses, since the boundaries between sand and cheatgrass patches are not always clearly delineated from an aerial perspective. Classification accuracy, however, was high (> 80%) across all sites. Furthermore, the average  $\hat{k}$  value was 0.83 and ranged from 0.78 to 0.90; models with values > 0.80 are typically considered very strong and those with values > 0.70 are considered good (Landis and Koch 1977). Also, for sites where both aerial and transect/quadrat measurements were taken, there were no paired differences for shrubs ( $p = 0.06$ ,  $df = 5$ ), sand ( $p = 0.93$ ,  $df = 5$ ), or grass ( $p = 0.14$ ,  $df = 5$ ), though the power for these comparisons was low. Given the high accuracy, few errors, high  $\hat{k}$ , and similarity between sampling methods, the image classification models performed on the sUAS imagery were considered to be appropriate for landscape cover analysis. Due to the low resolution of Google Earth's NAIP imagery and the small mesohabitat scale, I was not able to create contingency tables with a minimum of 5000 pixels in each class for accuracy assessment. This inability, however, only affects the three sites for which I was unable to collect sUAS imagery. Given the success of the prior classifications, these general models were used for further analysis under careful interpretation.

## Landcover class results

Surveyed sites had a wide variety and amounts of landcover. Amounts of cover by shrub, sand, and grass all varied among sites, with values as low as 0–3% and as high as 85% cover per class. Sites with a recent history of wildfire (*i.e.* in past two decades), such as the Wahluke and Catlow Dunes either had high cover by annual grasses—more than 50% or very little vegetation at all (Wakefield dune, which last burned in 2001). Conversely, unburned sites had significantly lower grass cover averaging roughly 19% (ANOSIM,  $R = 0.79$ ,  $p < 0.01$ ) and contributed the greatest (46%) to the Bray-Curtis dissimilarity index. An additional 37% of the differences was contributed by unburned sites having 35% more open sand compared to burned sites. Percent shrub cover was significantly lower in burned sites (one-way ANOVA,  $p = 0.02$ ,  $df = 13$ ) with about 15% less cover (Figure 7A), but these differences contributed the least (17%) of the Bray-Curtis dissimilarity between burned and unburned sites. Also, there was a negative correlation ( $R = -0.61$ ,  $p = 0.02$ ) between percent shrub and grass cover (Figure 8A). It should also be noted that a strong inverse correlation ( $R = -0.89$ ,  $p < 0.01$ ) was found between percent grass and sand cover (Figure 8B) and a strong positive correlation ( $R = 0.96$ ,  $p < 0.01$ ) was found between percent grass and GPI (Figure 8C). All sites with a history of wildfire formed a single group with 60% similarity, and sites that have never been burned likewise formed a separate group with 60% similarity (Figure 9). There was no correlation between shrub and sand cover.

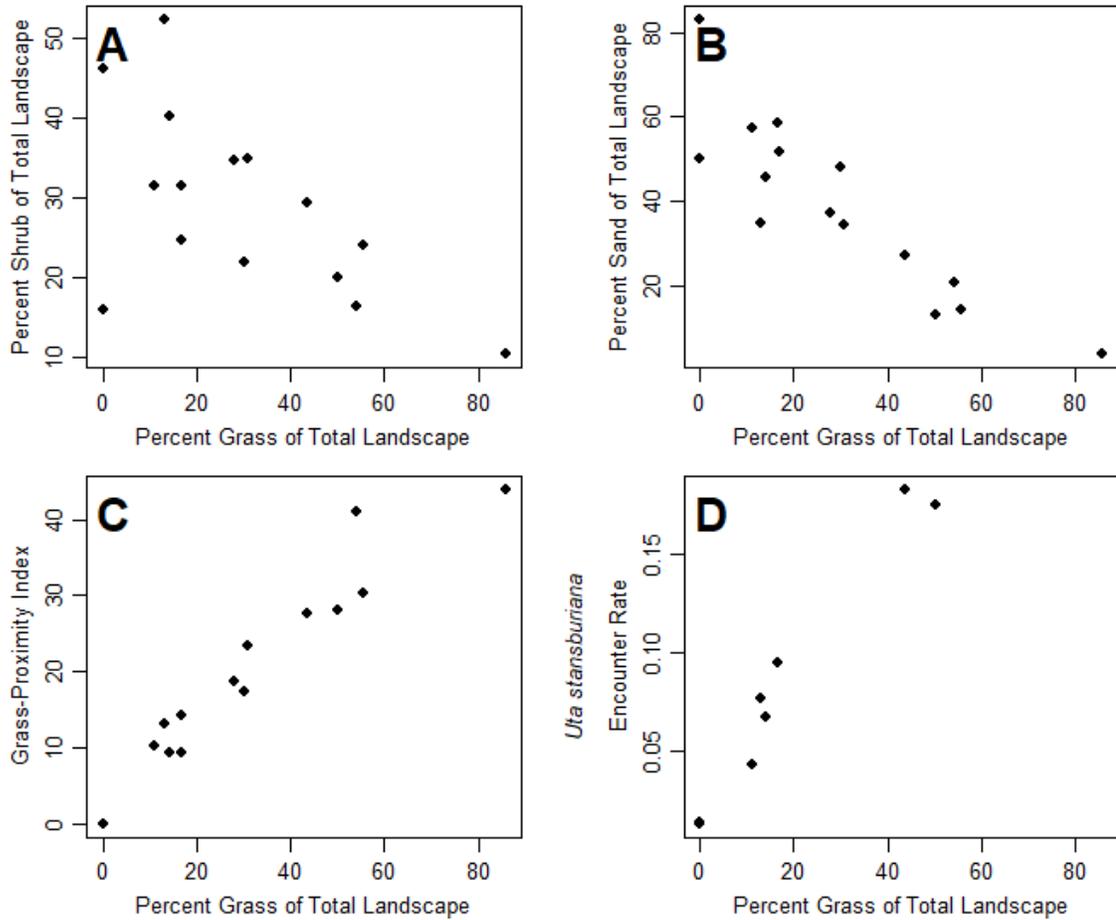
While landcover differed between sites when they were categorized based on the historical presence of wildfire, there were no differences when categorized by sagebrush lizard presence (ANOSIM,  $R = 0.15$ ,  $p = 0.13$ ). Sites where sagebrush lizards were present did not have any separation from those that did not have sagebrush lizards. Thus, the only



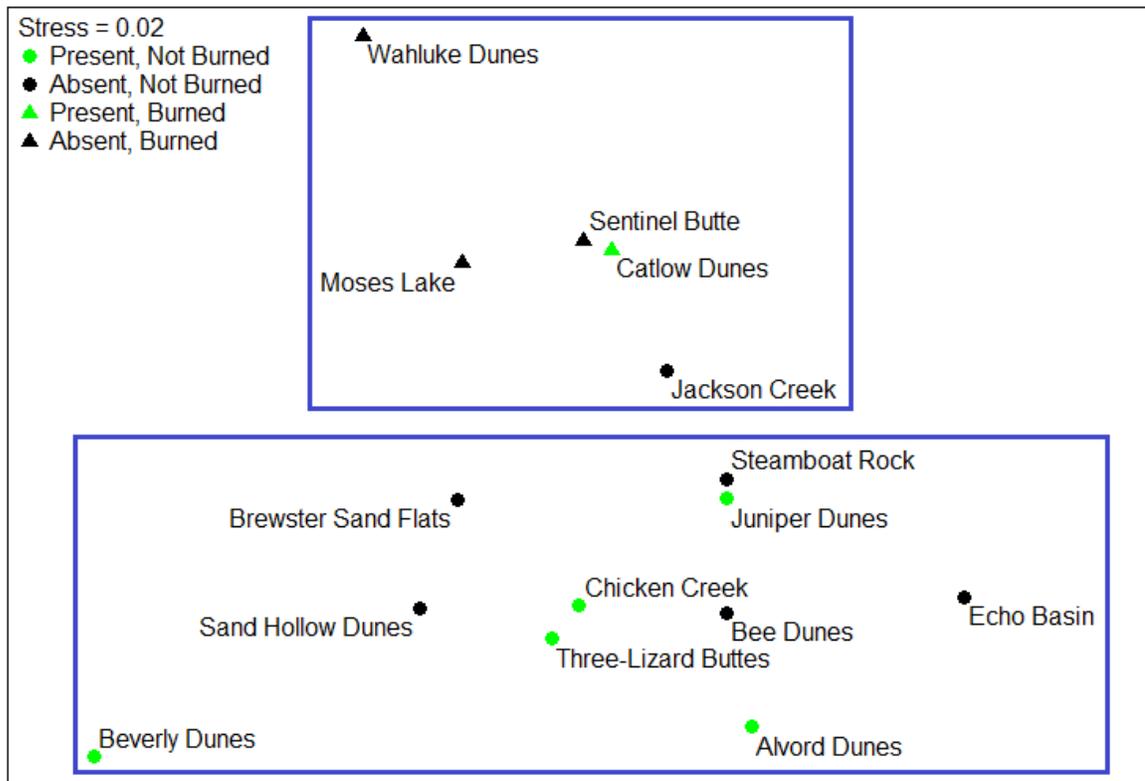
**Figure 7:** Bar plots showing the percent shrub (A) and grass cover (B) in unburned and burned sites.

difference found between sites using MDS and ANOSIM concerned whether or not the site had been previously burned. No differences were found between sites where side-blotched lizards were present versus where they were absent (ANOSIM,  $R = 0.06$ ,  $p = 0.18$ ).

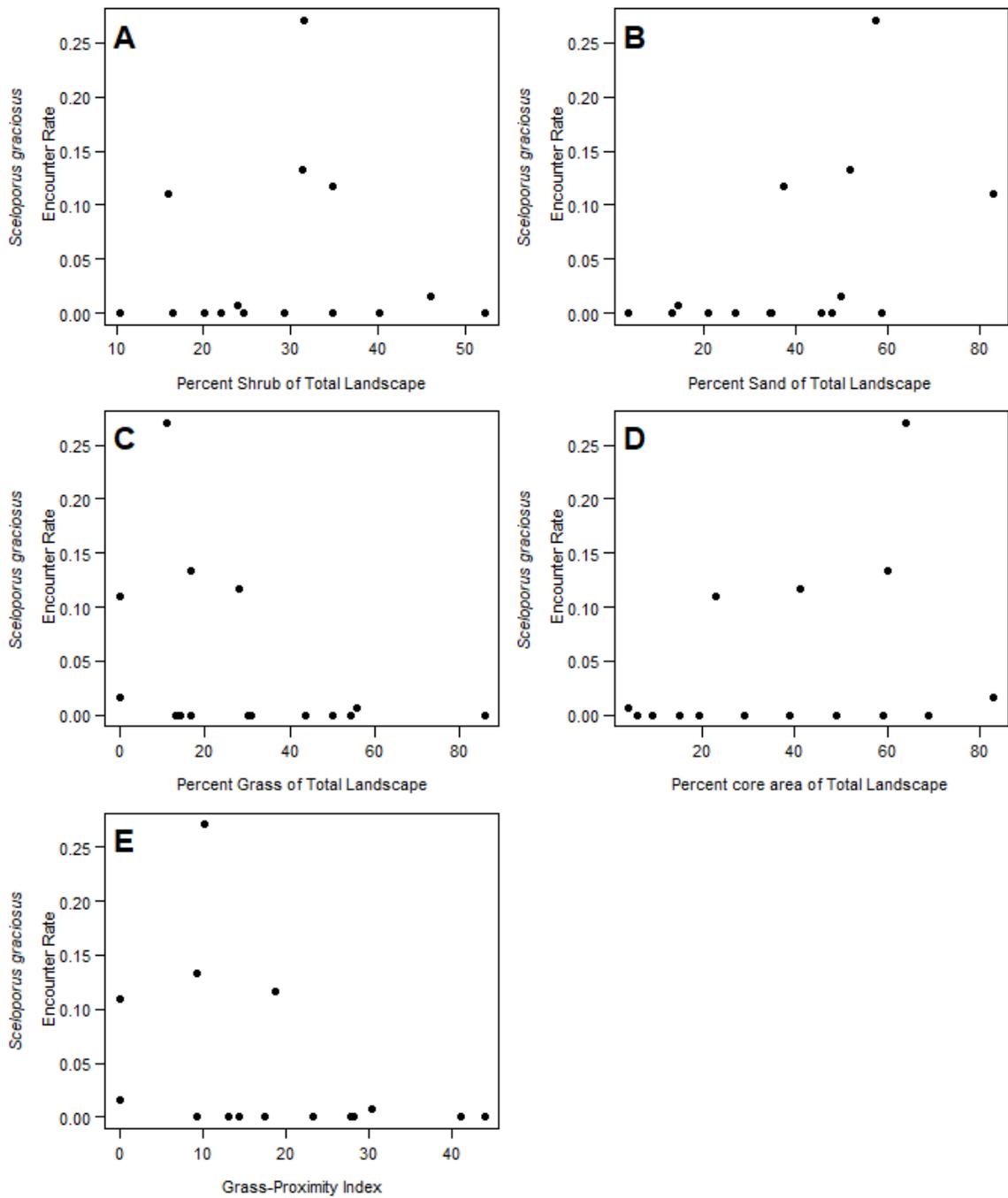
The encounter rate for sagebrush lizards did not correlate with any landcover variable collected (Figure 10), although there was a strong positive correlation ( $R = 0.98$ ,  $p < 0.01$ ,  $N = 13$ ) between side-blotched lizards and percent grass cover (Figure 8D). However, this correlation, as well as all other correlations, are lost when sites where they are absent are included in the analysis (Figure 11). Of the 8 sites where side-blotched lizards were found, only one of them—Sentinel Butte—had been burned in the last 10 years. No sagebrush lizards were found in any of the sites that had been burned with the exception of the Catlow Dunes, where only one remaining individual was found.



**Figure 8:** Scatterplots with significant correlations between (A) total shrub and total grass as percentages of the landscape, (B) total sand and total grass as percentages of the landscape, (C) the grass-proximity index and total grass as a percentage of the landscape, and (D) the encounter rate (count of individuals per minute) for side-blotched lizards (*Uta stansburiana*) and the total grass as a percentage of the landscape.



**Figure 9:** Multidimensional scaling plot of all surveyed sites. Sixty percent similarity boxes are drawn surrounding similar sites based on percent landcover composition. Symbols refer to a history of wildfire (triangle) or no wildfire (circle). Point colors correspond to the presence (green) and absence (black) of sagebrush lizards. Factors used include percent core habitat, shrub, sand, and grass cover.



**Figure 10:** Scatterplots of non-significant ( $p > 0.05$ ) relationships between sagebrush lizard encounter rate and measures of habitat cover. Sites where sagebrush lizards were absent are included.



## DISCUSSION

### **Sagebrush lizard presence within their WA and OR ranges**

The estimated range and distribution of sagebrush lizards in the intermountain west has remained largely the same for the past several decades. Chan et al. (2013) offered the most recent map, but it largely concerned the distribution of distinct genotypes across the American West and didn't take into consideration range reductions due to habitat fragmentation and loss. Also, the current most detailed distribution model in Washington was made in 1997 (NatureMapping Foundation) and was based on sagebrush-dominant shrub-steppe landcover regardless of soil substrate. Since the sagebrush lizard is an understudied species and much of its northern range has been lost, the pressing question of how this species is responding to habitat loss, which has not been previously investigated, is important for determining the appropriate response for biodiversity conservation.

My field research has revealed the absence of sagebrush lizards at formerly occupied sites in much of its former range in the state of Washington. All 13 sites in WA should have had sagebrush lizard populations under the null hypothesis that known habitats should continue to sustain populations under natural (*i.e.* excluding anthropogenic influence) conditions. Furthermore, given the dramatic loss of historic habitat in the last century, these remaining sites were chosen expecting that that should hold larger, healthier populations than any of the other scattered fragments in the state. Because sagebrush lizards were found only in three WA surveys, there is a lack of evidence to support the aforementioned null hypothesis. Rather, the 69% absenteeism suggests some degree of disappearance from mesohabitat that formerly sustained, or historically should have been capable of sustaining, sagebrush lizard populations. This is especially true for populations known to have once been

present in 5 of these sites, but were not found during this study. Sagebrush lizards were found at only 2 of the 7 historical sites. It is important to note that much of the sandy habitat required by the sagebrush lizard is no longer as abundant as it had been in pre-settlement times. The surveyed habitats in Washington were among the few that should still have been representative of natural conditions before the influence of the variables hypothesized to affect sagebrush lizard abundance. In other words, there is little remaining viable habitat for this species, and of that much less is expected to have some semblance of “pristine” conditions. It would not be unreasonable to suggest that among formerly known locales for the sagebrush lizard, the lizard is now extinct in at least 50% of them in Washington.

Given that surveys were not repeated and capture-mark-recapture methods were not employed due to time constraints, there is some uncertainty as to whether or not sagebrush lizards have been extirpated from these locales. For some sites, however, the inability to detect individuals may be due to their extreme rarity, especially in sites where no lizards of any species could be detected. If lizards are so few that they are not detected in the available habitat searched at optimal times, then their extinction is imminent. The absence of this species in some of the best remaining habitat should be of grave concern for anyone interested in the conservation of biological diversity in Washington.

At the Bee Dunes and Sand Hollow Dunes, the side-blotched lizard—which is commonly sympatric with the sagebrush lizard—was easily detected and in abundance, but there were no sagebrush lizards present. These sites had mesohabitat and microhabitat that look very suitable for sagebrush lizards, but it is possible that sagebrush lizards may not have been able to migrate to those sites if a path from the original shoreline was not available. At other locales without sagebrush lizards, but with similarly suitable habitat and where there

appears to have been no barrier to migration to sagebrush lizards; however, I consider it more likely that the sagebrush lizards may have gone extinct. When sympatric, sagebrush lizards and side-blotched lizards are typically found in approximately equal abundance (Tinkle 1967). Thus, the presence of the diminutive side-blotched lizard should not preclude sagebrush lizards from these sites. Moreover, my inability to find neither a presence-absence nor encounter rate relationship between these two species lends further support that the presence of side-blotched lizards should not affect the presence of sagebrush lizards. Hence, in these environs characteristic of sagebrush lizard habitats, sagebrush lizards should have been detected if side-blotched lizards were present.

In contrast, sagebrush lizards were detected in all three sites within the Oregon range. Both the Alvord Dunes and Three-Lizard Buttes had evidence of stable communities of multiple species which included sagebrush lizards. Even in the presence of known predators and competitors, sagebrush lizards were still detectable at regular rates in the Alvord Basin. An interesting finding from the surveys in OR is the presence of one sagebrush lizard at the Catlow Valley Dunes. This site, as were all others, was selected based on the presence of pluvial sand dunes within the lizard's geographic range, and the presence of this individual is indicative of historical occupation of this mesohabitat by this species. Despite equivalent search effort, no additional sagebrush lizards were found. While historical abundance at this location is unknown, it is unlikely that the paucity of individuals at this site is suggestive of former numbers. It is also unlikely that the presence of leopard lizards would be a causal factor for low detectability of sagebrush lizards, because leopard lizards were found at both the Catlow and Alvord Dunes in similar numbers, and sagebrush lizards were routinely detected in the Alvord Dunes. Instead, the near-absence of sagebrush lizards at the Catlow

Dunes, and the apparent absence in many of the sites in the WA range may be explained by differences in land cover composition and the variation of microhabitats within the mesohabitat.

### **Differences in landscape composition among sites**

All sixteen sites had similar characteristics of sandy substratum and or sandy dunes with mosaics of woody shrub patches. Dominant shrubs were big sagebrush (*Artemisia tridentata*), greasewood (*Sarcobatus vermiculatus*), and antelope bitterbrush (*Purshia tridentata*), all of which sagebrush lizards were observed to use as refugia. Invasive cheatgrass was usually the most common grass species; where present, bunchgrasses comprised 2–8% of these sandy sites.

There was much variability in mesohabitat composition among sites: the percent of the habitat covered by a given class (*e.g.* cheatgrass) was dominant in some and nearly non-existent in others. At the Wakefield Dunes and Wahluke Dunes almost all shrubs were eliminated by wildfires; surviving shrub cover was low (0% and 10%, respectively). The Wahluke Dunes were a part of a 19,000 acre burn in 2007 (Northwest Interagency Coordination Center 2017). At the other sites with wildfire burns (Catlow Dunes, Sentinel Butte), there were some unburned patches of mesohabitat and other large areas with remains of scorched shrub stems, with either abundant cheatgrass or no vegetation (if the burn had happened within the past year). These burned sites were expected to have a lower proportion of shrubs than at sites with no history of fire in recent decades, and indeed my analyses revealed 15% percent less mature shrub cover in burned sites compared to unburned sites

(Figure 3). However, this difference contributed to the least (17%) to the Bray-Curtis dissimilarity for these two groups, which indicates differences in shrub cover were less pronounced than differences in other cover types.

Other differences in land cover, however, were apparent, such as the 33% greater grass and 32% less sand coverage in burned sites. These findings are consistent with previous studies showing that wildfire burns facilitate colonization by cheatgrass (Knick and Rotenberry 1997, Banks and Baker 2011). For desert scrub and dune mesohabitats, the strong inverse correlation between grass and sand cover also supports Hallock et al.'s (2007) evidence for an increasing amount of grass-stabilized dune systems. Among the sites in WA, the Juniper Dunes site exemplified dune-system stabilization by cheatgrass: surrounding the sandy dune crest where sagebrush lizards were found were dune slopes and troughs between dunes that were densely covered with cheatgrass, and the ground resembled a compact soil instead of what appeared to originally be loose sand. The only animals encountered in these areas stabilized by cheatgrass were arthropods.

### **Relationship between sagebrush lizard presence and habitat composition**

#### *Presence/absence analysis*

Given that sagebrush lizards were absent in multiple locations in their geographic range that were likely to have held populations in the past, and that there have been changes in patch composition within these sites, it was expected there may be relationships between the alteration of the habitat and the absence of this species. However, the lack of any differences between landcover characteristics of sites where sagebrush lizards were present

and absent was very surprising. The grouping of all 4 burned sites, which had more overall grass coverage, into the same 60% similarity group with Jackson Creek, another site with high grass coverage, was representative of the original hypothesized patterns considering that all of these sites did not have detectable sagebrush lizard populations. While all sites with sagebrush lizard populations were indeed contained within the second 60% similarity group, the presence of 5 other sagebrush-lizard absent sites in this group suggests no effect of the measured variables of landcover as principal drivers of abundance.

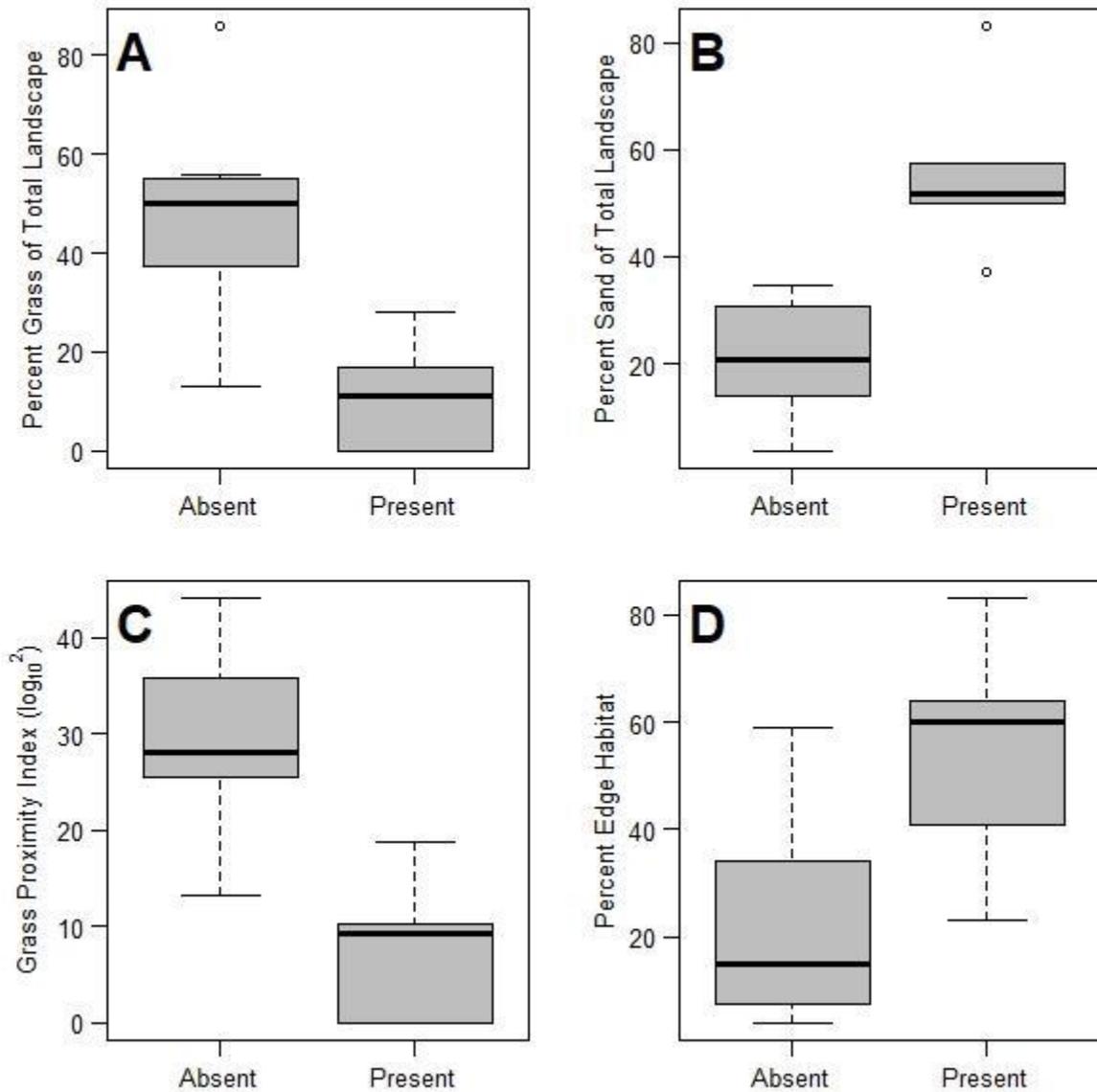
Of the aforementioned 5 sagebrush-lizard absent sites, 3—the Brewster sand flats, Bee Dunes, and Sand Hollow Dunes—were within 200 m of a crop field or orchard, and 1—Steamboat Rock State Park—was actively being converted into a recreational campground. Thus, I realized 4 out of these 5 sites were likely to have strong direct anthropogenic influences that could have an effect on resident lizard populations. The absence of sagebrush lizards at Steamboat Rock is almost certainly a result of total habitat loss due to reservoir inundation and building development, but whether or not the proximity to agriculture has an effect on lizard abundance is uncertain. However, when these three near-agriculture sites are grouped together as a third independent class in ANOSIM, grass cover was higher in lizard-absent sites (Figure 12) and contributed the greatest (43%) to differences between sites (ANOSIM,  $R = 0.22$ ,  $p = 0.05$ ). Conversely, sand abundance was higher in lizard-present sites. Also, GPI (grass-proximity index) was nearly four times higher in lizard-absent sites than in lizard-present sites (one-way ANOVA,  $p < 0.01$ ,  $df = 10$ ). There were no differences between lizard-present sites and agricultural sites ( $p = 0.44$ ).

Shrub cover and percent favorable edge-habitat contributed the least to differences between sites (16.7% and 0.46%, respectively). During surveys, it appeared as though lizards

were less likely to occur in patches with grass present, so these data corroborate these observations, especially given that all sagebrush-lizard present sites are grouped with 60% similarity (Figure 9).

Under this new model, there is a strong dissimilarity between all sites where sagebrush lizards were detected and the five other sites that fell outside of this group. In these outgrouped sites, the high amount of grass and low amount sand likely indicates a mesohabitat composition that is unfavorable to sagebrush lizards. The Catlow Valley, Western Moses Lake, and Wahluke Dunes have high cheatgrass coverage that has completely stabilized these dunes with no evidence of active sand input, and the Jackson Creek and Sentinel Butte sites are in a semi-stabilized state. From prior studies showing *Sceloporus* and related species' aversion to cheatgrass (*e.g.* Green et al. 2001, Newbold 2005, Hall et al. 2009, Bozanich 2015) I infer that an abundance of grass limits the suitability of habitat for *Sceloporus graciosus*.

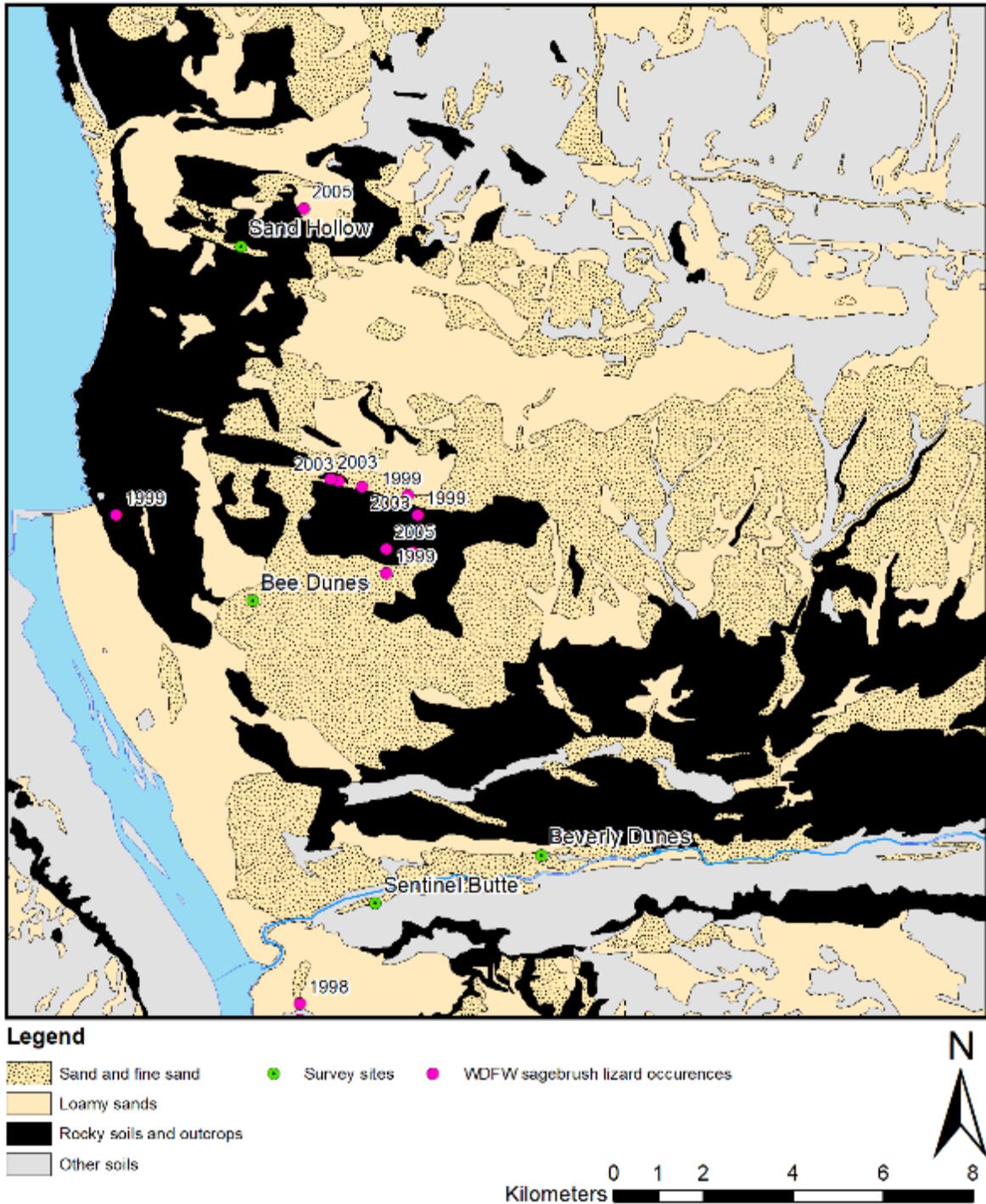
Of particular interest is that the amount of shrub cover contributed to only about 17% of the dissimilarity index between sites where sagebrush lizards were present and sites where these lizards were absent (about 32% and 26% shrub cover, respectively). Thus both site categories appear to have sufficient shrub cover based on Green et al.'s (2001) suggestion that approximately 25% cover is optimal for this species. Because sagebrush lizards are known to actively use the periphery of shrubs that were surrounded by sand (Rose 1976, Green et al. 2001), it was surprising to find that the availability of core edge-microhabitats (PCA) contributed the least to lizard-presence versus absence. Holding the number of shrubs



**Figure 12:** Box plots showing data spread of various landscape measures for sites where sagebrush lizards were present and absent when near-agriculture sites are removed. The amount of grass present (**A**) and nearby shrubs (**C**) are on average higher in sites where sagebrush lizards are absent, whereas the availability of open sandy terrain (**B**) and edge habitat (**D**) is higher in sites where sagebrush lizards are present.

constant, an interspersed mosaic of shrubs-and-sand would have a higher proportion of edge-habitat than aggregated shrubs, and thus would have more occupiable microhabitats. Given these results, I infer that factors relating to the immediate vicinity of the shrubs are instead more important for habitat quality. For instance, the proximity of grass to shrub microhabitat may be a more important factor than shrub or edge-habitat availability. If grasses surround a given shrub, when a lizard is on or near the ground with shrub foliage above, the lizard's visual field would be severely limited and hinder its ability to watch for food, mates, and predators. I infer from the greater GPI in lizard-absent sites that annual grasses are commonly found in close proximity to shrubs and degrade the utility of those shrubs for sagebrush lizards. If GPI were equivalent between sites with lizards and sites without lizards, then annual grasses would be aggregated away from shrubs. Instead, because both grass cover and GPI are high in lizard-absent sites, the grasses are interspersed with shrubs and are likely to limit the usefulness of shrub edge-habitat.

Prior to the inclusion of agricultural proximity as a potential factor, the absence of sagebrush lizards was puzzling at the three sites grouped with lizard-present sites because the mesohabitat generally appeared to be prime habitat for this species (*e.g.* plentiful sand and shrubs), and the sites were located along the Columbia River where corridors of sandy substrate would have permitted migration prior to anthropogenic development (see Figure 13). Furthermore, in two of these three sites (Bee and Sand Hollow Dunes) I encountered side-blotched lizards at moderately high frequencies (see Table 2). These two species are often sympatric and in nearly equivalent numbers (Tinkle 1967), so it was expected to find sagebrush lizards where side-blotched lizards were present, and in sites where landscape composition was similar those presently supporting sagebrush lizards. Because these three



**Figure 13:** Map of the Beverly quadrangle showing sandy soils, rocky soils, and other soils. Sites surveyed in this study are indicated as green points and locations of WDFW-documented occurrences are indicated as purple points with the year of sighting. Note that most point-locations are connected via sandy-soil corridors. Soil data courtesy of the U.S. Geological Survey.

surveyed locations were within 200 m from an alfalfa or orchard field where chemical overspray may have been possible. Although the presence of agricultural fields adjacent to ostensibly suitable habitat islands for sagebrush lizards where the lizards are absent nonetheless is speculative, I offer this relationship as a correlation-based, alternative hypothesis to the null model that assumes sagebrush lizards were never at these sites (see Figure 6) or that they went extinct without human influence. DuRant et al. (2007) found the pesticide carbaryl to impair locomotion in *Sceloporus occidentalis*, and other compounds have been found to be harmful to reptiles in multiple studies (see Hopkins and Winne 2006, Buono et al. 2007, Cakici and Akat 2012, Cardone 2015). Although Holem et al. (2006) did not find any negative effects on *S. occidentalis* from exposure to the pesticide Malathion, the physiological and ecological effects of most modern pesticides, such as organophosphorus and carbamate variants, have not been extensively studied (Campbell and Campbell 2002). It is unknown whether these, or similar, pesticides and herbicides are sprayed near these sites, but given evidence in prior studies of potential health effects on lizards due to pesticide and herbicide exposure, as well as the absence of ants and the paucity of other invertebrates at a seemingly lizard-suitable site downslope and directly across the road from an orchard at the sand flats approximately 6 km northeast of Brewster (Figure 14), prompts the question of agricultural influence. Given that the inclusion of these agriculturally-proximate sites masks all differences between sites if not independently classified, the absence of sagebrush lizards in occupiable habitat near crop fields is indicative of an extinction factor related to agriculture. Entomological surveys and testing for chemical accumulation in prey arthropods should be further investigated (also see Weir et al. 2016).



**Figure 14:** Brewster sand flats near Anderson Field with an adjacent orchard upslope of the study site. No evidence of lizards, insects, or rodents was found.

As for the sympatric side-blotched lizard, the usefulness of edge-habitat may not be as important for survival and might offer an alternative explanation for their presence in sites where sagebrush lizards were not detected. Side-blotched lizards were found more often in open landscapes than under shrubs, which they were observed to use more as vision-disrupting obstacles while fleeing from the surveyor. Using vegetation as a means to avoid detection from a potential predator (especially by juveniles) has been previously described (Tinkle et al. 1962, Germano and Lawhead 1986, Peterson and Whitford 1987) and may further explain the strong correlation with side-blotched lizard encounter rate and grass cover. Side-blotched lizards can also be considered a habitat generalist in that they have a wide distribution in a variety of ecotypes in the American West (Tinkle 1967, Hibbitts et al. 2013). A lack of preferential association with vegetation type would improve survivorship in a changing landscape, thereby promoting the odds of a generalist species like *Uta stansburiana* persisting in a habitat were a specialist species like *Sceloporus graciosus* would be driven to extirpation.

#### *Correlation analysis using rate of encounter*

The encounter rate of sagebrush lizards was anticipated to correlate with varying degrees of environmental composition, especially those suggestive of habitat degradation. The presence of wildfire and annual grasses were two prominent sources of desert scrub/dune degradation identified during surveys, so a lack of correlation between sagebrush lizard encounter rate and these two variables was initially surprising. Likewise, the lack of correlation between encounter rate and any habitat variable, including shrub cover, did not support the initial hypotheses. Given that these lizards are well known to associate with

sagebrush, then a greater amount of shrub cover was expected to correlate with more frequent encounters or even a higher chance the species was present at a given site.

With the absence of any correlation with sagebrush lizard encounter rate, these results may be indicative of either 1) a too small sample size with sagebrush lizards or 2) the inability for VES in this study to detect a response below the mesohabitat level. There was a total of five sites where apparently sustainable sagebrush lizard populations were present (*i.e.* excluding the Catlow Dunes), so a sample size of five may have made correlations with encounter rate difficult, and thus may be prone to type-II error. Given that samples are collected at the site (mesohabitat) level, however, the results are likely insensitive to any ecological relationships at the patch/microhabitat level. During surveys, sagebrush lizards were never observed in proximity to cheatgrass; while it remains possible that grass or shrub composition at the scale of 5 m, for example, may allow for a detectable correlation with encounter rate, the overall results at the site-level would fail to detect it. Now that mesohabitat with and without sagebrush lizards in their historic range have been identified, a more suitable method to determine scaling effects of habitat composition on sagebrush lizards may be to employ a repeated capture-mark-recapture study at one or two sites where the mesohabitat is spatially heterogenous (Grant and Doherty 2007, Smolensky and Fitzgerald 2010).

## **Conclusions**

*Sceloporus graciosus* is an understudied species with few relevant publications in the last few decades. As more of the Intermountain West is altered by expanding infrastructure,

agriculture, and invasive species, further understanding the implications these changes have for the health and stability of natural communities would be of use for conservation strategies. Reptiles like *Sceloporus graciosus* that are microhabitat specialists are excellent model organisms to observe the effects of habitat change.

Based on the results of this study, it is clear that much of the sagebrush lizard's historical range is now much narrower, with mesohabitats scattered into fragments and degraded to varying degrees. In particular, the gradual development of Washington's remaining dune and desert scrub landscapes is of grave concern because what is left of these semi-stable fragments are threatened by a combination of anthropogenic and environmental disturbances. Much of this landscape has been directly redeveloped and lost, with potential plans for further conversion. For instance, the Crab Creek drainage (an area where sagebrush lizards are present) was identified as a viable location to install an irrigation reservoir that would reshape the landscape and destroy all remaining dune habitat (Washington Dept. of Ecology and U.S. Bureau of Reclamation 2007). Where the landscape is not actively being developed, cheatgrass is becoming more established and perpetuating wildfire in sagebrush lizard habitat. The expansion of invasive cheatgrass is likely undermining the utility of shrub-edge microhabitat used by these lizards and degrading the overall quality of the mesohabitat.

More importantly, sagebrush lizards appear to now be extinct in parts of their former range with implications that the aforementioned scope of habitat degradation is a causal factor. I did not find a single site in Washington free from any form of anthropogenic influence, thus I consider state-wide extinction of this species possible, especially considering that cheatgrass is firmly established in two of the three sites where this lizard is present. There may be remnant individuals in some of the sites I surveyed—the WDFW has

published occurrences of sagebrush lizards in the Wahluke Dunes and near Sand Hollow within the last 10–15 years—but the persistent threat of habitat loss and fragmentation is still applicable to them. The relationship between habitat degradation and sagebrush lizard presence should be alarming to anyone interested in preserving what is left of this species in the state. The last population found at the Beverly Dunes has a small habitat (approximately 2.5 hectares) routinely used by dune-buggies and other recreational ORVs. These vehicles may be helping to prevent the sand from stabilizing and suppressing cheatgrass, but this small population seems to be isolated and can be strongly affected by changes to the number of individuals. In general, detailed population surveys, recruitment information, and mesohabitat connectivity analyses would be necessary to determine requirements for viability in these fragmented landscapes. Habitat characteristics that promote population sustainability or metapopulations in these environments would be of use when assessing the survivability of increasingly suboptimal habitat, especially if contrasted against generalist species such as *Uta stansburiana*.

Holistic community ecology studies are desperately needed for these disappearing dune and desert-scrub habitat, as well as for the general shrub-steppe that is characteristic of most of the Intermountain West. Although in this study I present evidence of sagebrush lizard rarity or absence where it was once common and the factors likely degrading its habitat, other residents of the desert-scrub and shrub-steppe are likely influenced as well. For instance, I noticed a surprising lack of small mammal presence during my Washington surveys. Pocket mice and kangaroo rats, among others, are often found in these arid landscapes, so their possible absence in sites like these may reflect unknown consequences at the community level. Likewise, I never encountered the pygmy short-horned lizard

*(Phrynosoma douglasii)* during surveys in their Washington range. Given phrynosomatid sensitivity to cheatgrass (Newbold 2005), this species may be affected by desert-scrub degradation like the sagebrush lizard. While as concerning these changes to the shrub-steppe and desert-scrub environment are from a conservation aspect, the ecological response to widespread habitat loss and fragmentation presents major research opportunities in not only the states of Washington and Oregon, but across the entire Intermountain West as well.

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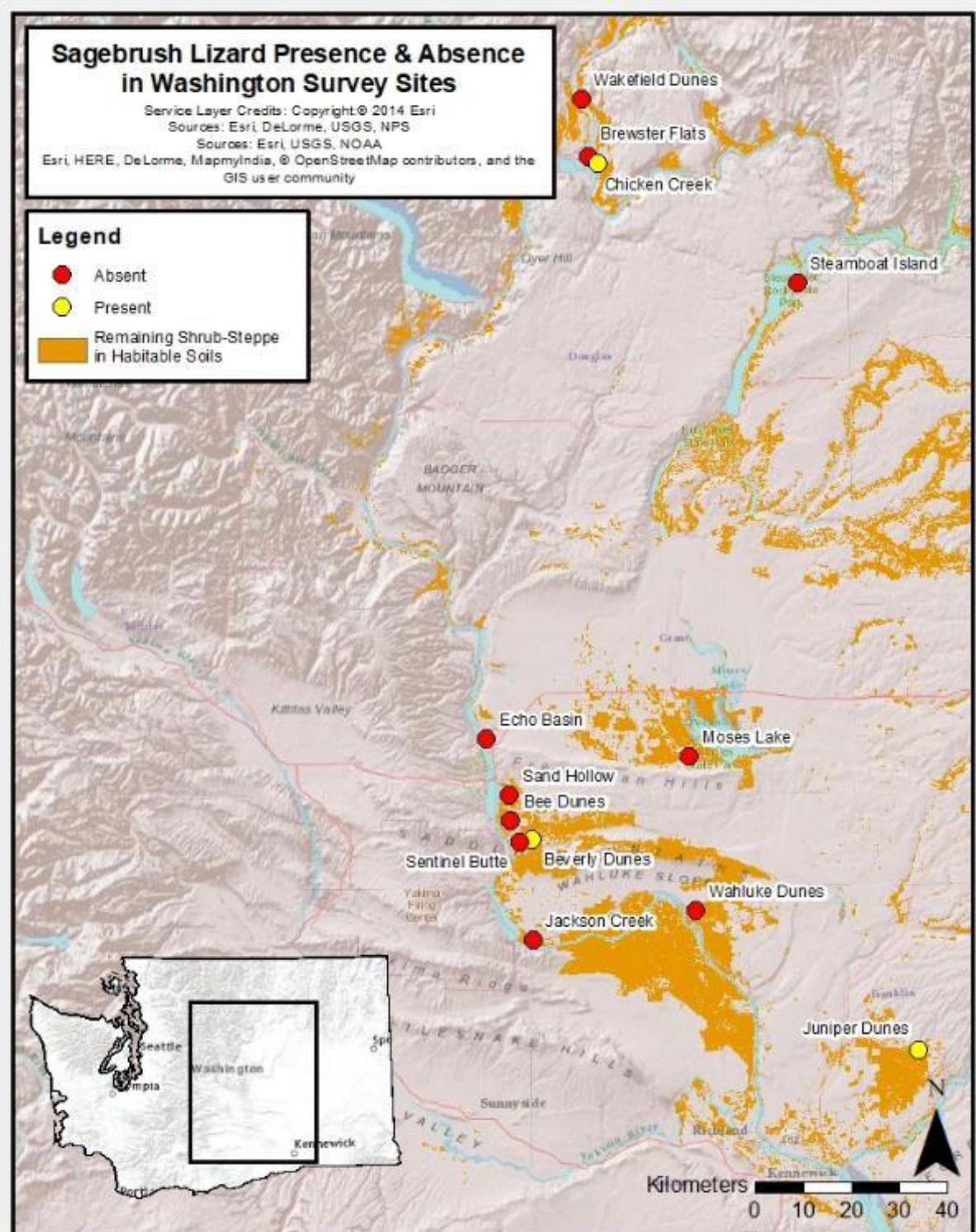
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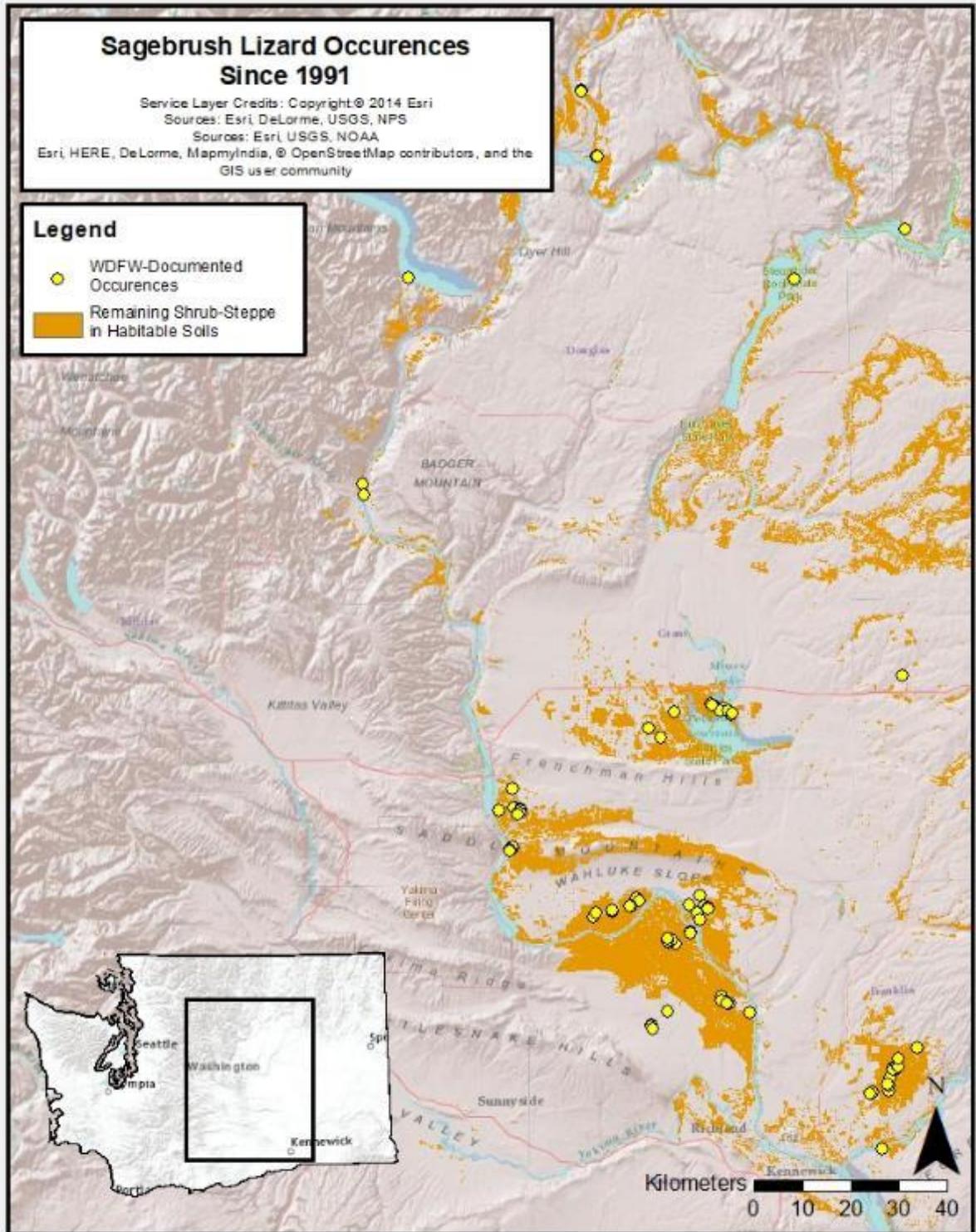
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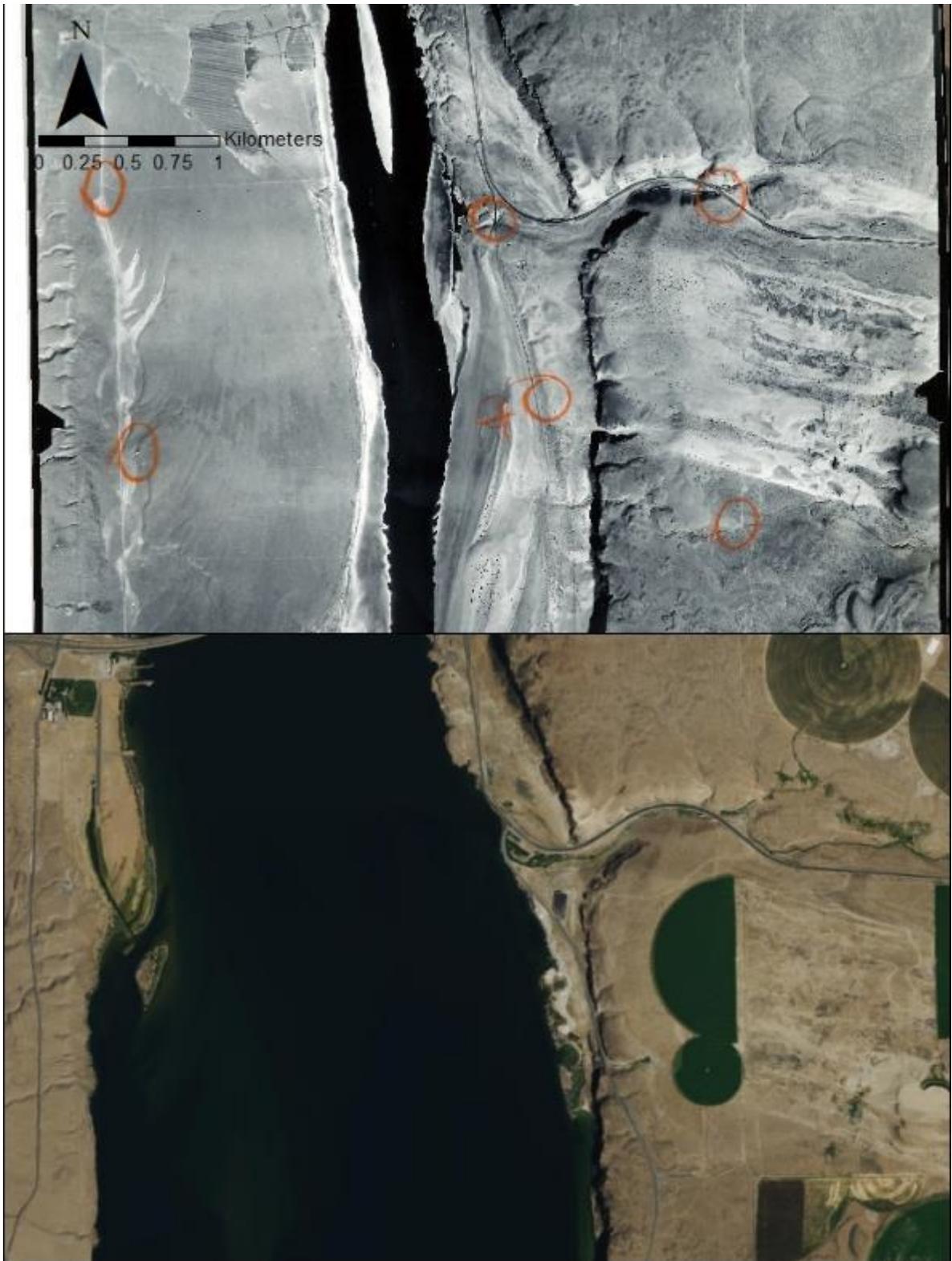
## APPENDIX



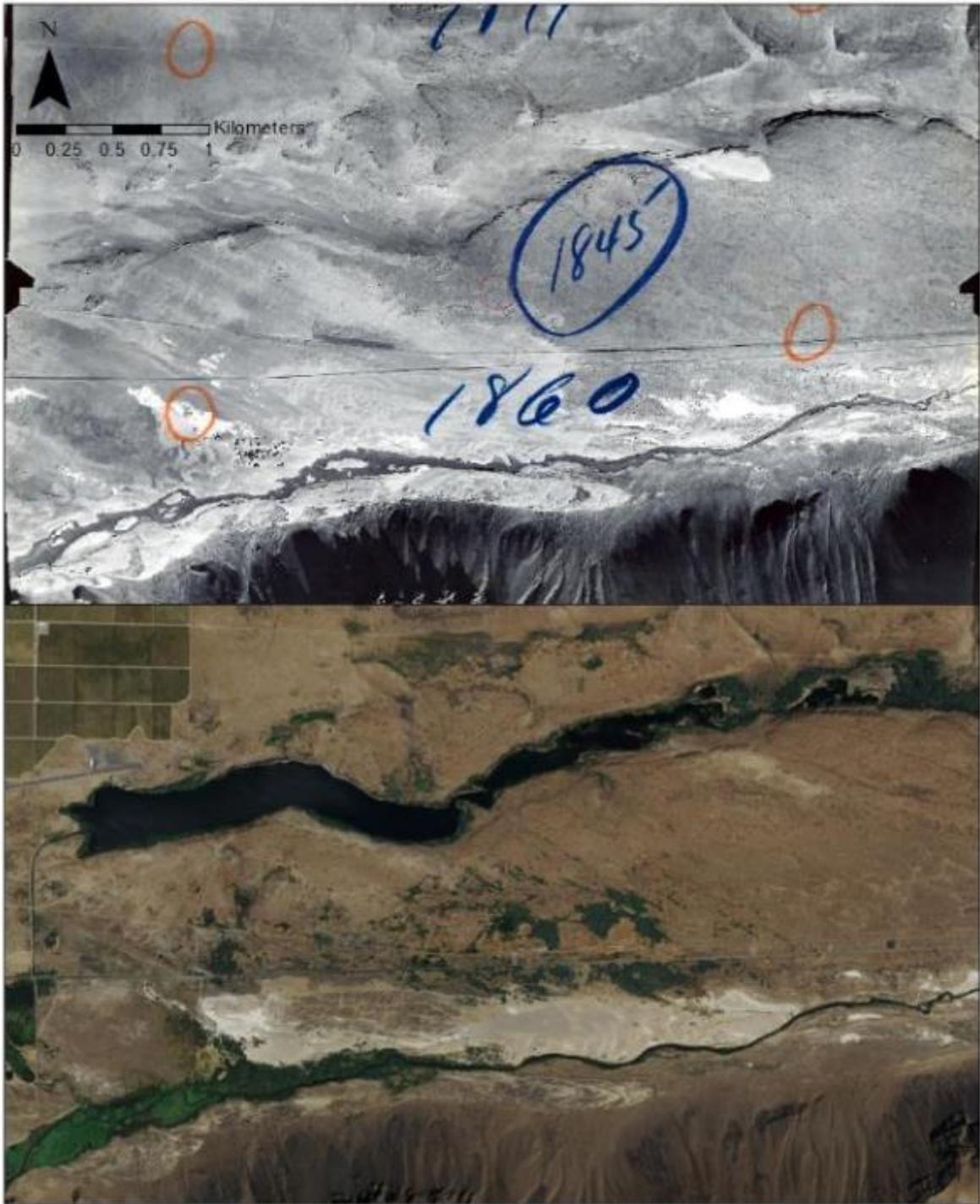
**Figure 15:** Map of all Washington sites color-coded for sagebrush lizard presence and absence. USGS soils and land-use data were used to isolate both soils on which sagebrush lizards had been documented, and a combination of shrub-steppe shrubland and grassland.



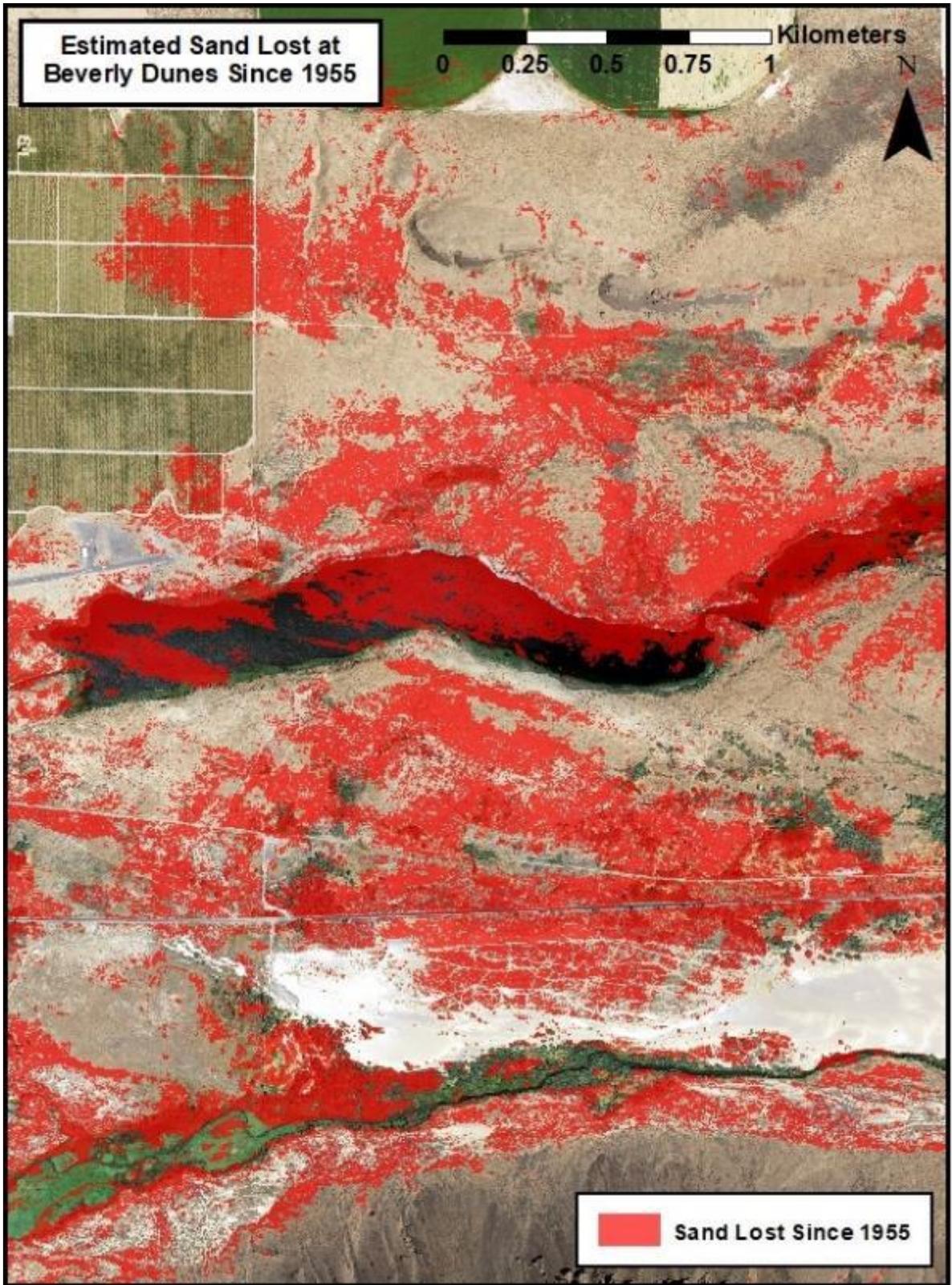
**Figure 16:** Map of all sagebrush lizard occurrences as indicated by the WDFW Priority Habitat and Species database. Remaining shrub-steppe was derived using the same data in Figure 15.



**Figure 17:** Aerial Photos of the Sand Hollow Dunes in 1955 (top) and 2017 (bottom).



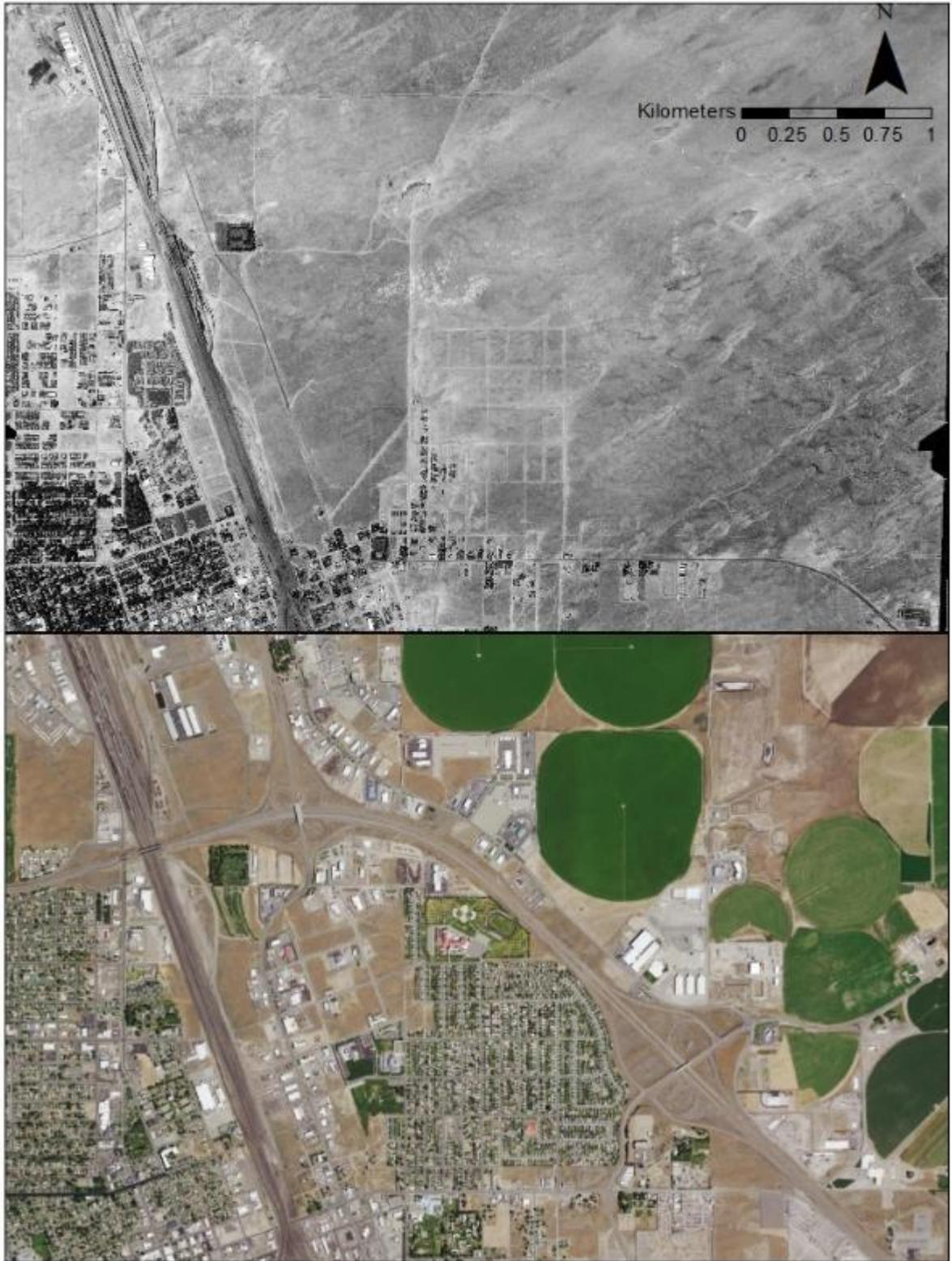
**Figure 18:** Aerial photos of the Beverly Dunes in 1955 (top) and 2017 (bottom).



**Figure 19:** Overlay of estimated loose sand loss since 1955 in a portion of the Beverly Dunes.



**Figure 20:** Aerial photos of Brewster in 1955 (top) and 2017 (bottom). Note the sandy landmass no longer present.



**Figure 21:** Aerial photos of Pasco in 1955 (top) and 2017 (bottom). Note the northeastern dunes in 1955. This sand eventually migrated into the Juniper Dunes.



**Figure 22:** Aerial photos of Frenchman Coulee in 1961 (top) and 2017 (bottom). Hatch marks indicate location of 1961 shoreline.



**Figure 23:** Sagebrush lizard (*Sceloporus graciosus*) basking on a mature greasewood.



**Figure 24:** View of large dunes in the Alvord Basin.

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**Figure 25:** Aerial photograph of the Alvord Dunes from a DJI Phantom 3. Photo credits: Steve Martin.



**Figure 26:** View of a dune crest in the Catlow Valley. Note the high density of cheatgrass.



**Figure 27:** Burned section of the Catlow Valley dune fields.



**Figure 28:** The only sagebrush lizard found in the Catlow Valley. This individual fled into the limbs for cover. Bush was situated at the edge of a dune adjacent to open hardpan.



**Figure 29:** View of the Catlow Valley approximately 1 km southwest from the surveyed dunes. This location likely burned and all vegetation succeeded by cheatgrass.



**Figure 30:** View of Three-Lizard Buttes.



**Figure 31:** View of the south-facing slope of the surveyed dune in the Juniper Dunes Wilderness. Sagebrush lizards were only found on the sandy crest surrounded by cheatgrass.



**Figure 32:** Beverly Dunes, facing west. Note the large greasewood complexes to the right and the sand blowing in from the western edge of the dunes.



**Figure 33:** Sagebrush lizard basking in the perimeter of a Russian thistle at the Beverly Dunes.



**Figure 34:** Sentinel Butte Dunes, facing east. Note the fire line in the foreground. The unburned section below is infested with cheatgrass.



**Figure 35:** Sagebrush field near the Moses Lake Dunes. Notice the packing of Russian thistle diaspores around the sagebrush and bitterbrush in the foreground.



**Figure 36:** Wakefield Dunes. Most understory vegetation was eliminated due to wildfire.



**Figure 37:** Assistant Christian Olsen photographing a groundcover quadrat at the Sand Hollow Dunes.



**Figure 38:** Partially cheatgrass-covered dune in Echo Basin, Frenchman Coulee.



**Figure 39:** Long-nosed leopard lizard (*Gambelia wislizenii*) held by Dr. Roger Anderson. This is a major predator of sagebrush lizards in the Alvord Basin.



**Figure 40:** Sagebrush lizard avoiding me by using a sagebrush as protection.