Land Cover Change Within Wetland Complexes at Dixie Meadows, Churchill County, Nevada: 2015 – 2023

By Joshua J. Caster[1], Joel B. Sankey[1], Nathaniel D. Bransky[1,2]

[1]U.S. Geological Survey, Southwestern Biological Science Center, Flagstaff, AZ
[2]Northern Arizona University, Flagstaff, AZ

Contents

Abstract.....- 1 -

Introduction.....- 2 -

Background.....- 4 -

Objectives.....- 5 -

Methods.....- 5 -

Results.....- 10 -

Discussion and Conclusion.....- 15 -

References Cited.....- 17 -

Appendix 1: Tabular Summaries..... 19

Figures

Figure 1. The Dixie Meadows study area in Nevada……..3

Figure 2. Plot of the 146 satellite images used in analysis that were collected between October 2015 and November 2023……6

Figure 3. Example of land cover classification for a single date (June 21, 2018) within the Dixie Meadows study area……7

Figure 4. Temperature and precipitation records from 1949 – 2023 for the Lovelock Derby Field (USW00024172) NOAA COOP weather station……...10

Figure 5. Variability in area covered by each of the land cover classes from 2016 to 2023 summarized by land management……..12

Figure 6. Monthly and yearly variability in area covered by each of the land cover classes within the wetland complexes……...14

Acknowledgments

The authors acknowledge US Geological Survey colleagues Brian Halstead, Jonathan Rose, Patrick Kleeman, and Jessica Walker for helpful discussions and reviews that improved the report, as well as Meredith Hartwell with the USGS southwest region for formatting the final manuscript.

Prepared by the U.S. Geological Survey for the U.S. Fish and Wildlife Service, May 2025, under interagency agreement #4500165899.

Suggested citation

Caster, J.J., Sankey, J.B., and Bransky, N.D., 2025, Land cover change within wetland complexes at Dixie Meadows, Churchill County, Nevada—2015-2023: U.S. Fish and Wildlife Service, cooperator report prepared by the U.S. Geological Survey, Southwest Biological Science Center, 28 p.

Abstract

Dixie Meadows, Nevada, is a system of geothermal springs and seeps that feed a complex of marshes and wetland meadows that are located within lands managed by the Bureau of Land Management (BLM) and the Department of Defense (DOD). A previous U.S. Geological Survey report documented variability in satellite imagery-based land cover classifications for seven wetland complexes at near monthly time intervals between October 2015 and January 2022. This report presents additional data, extending analysis to November 2023. Land cover classifications between October 2015 and November 2023 demonstrated an association between vegetation cover characteristics and surface moisture, with Class 1 having dry, bare soil or sparse upland vegetation, Class 2 having moist, bare soil or sparse to small vegetation, Class 3 having dense green vegetation with potentially saturated soil conditions, Class 4 having a mix of shallow surface water, saturated soil, and dense green vegetation, and Class 5 having open surface water. Most of the wetland complexes occur close to spring outflows primarily within land managed by the DOD, though portions are also within BLM lands. The intervening and surrounding landscape outside of the wetland complexes assessed in this study are managed by the BLM. As a result, Class 1 land covers had the largest areal coverage for BLM managed lands. Classes 2 and 3 land covers were primarily mapped inside the wetland complexes and thus had the largest area coverage within DOD managed lands. Class 4 was almost exclusively mapped within the wetland complexes and thus was largely contained within DOD managed lands. Class 5 (open water) was exclusively mapped in and adjacent to a single wetland complex with catchment ponds on land managed by the BLM. The distribution of these land cover classes over the study period was seasonally and annually variable. Land cover areas of Classes 1 and 2 were larger during the spring months. Conversely, land cover areas of Classes 3 and 4 tended to be greatest during the summer or fall. These patterns might be influenced by differences in seasonal water sources and phenology.

Introduction

This introduction is largely taken from Sankey and others (2024).

Dixie Meadows, Nevada, is a system of springs and seeps of varying discharge volumes and temperatures that feed a complex of marshes and wetland meadows. Most of these springs and seeps are located along a steep scarp with flow generally following the topographic gradient towards an adjacent playa to the east (Huntington and others, 2014). The volume and temperature of water in the wetlands change seasonally and interannually due to surface water and geothermal groundwater interactions (Huntington and others, 2014; Garcia and others, 2015). The wetlands are habitat for a variety of plant and wildlife species, including *Anaxyrus williamsi* (Dixie Valley toad), which are endemic to this location (Forrest and others, 2017; Gordon and others, 2017; Halstead and others, 2021; Rose and others, 2022). The federal management of the wetlands and adjacent land is split by the Bureau of Land Management (BLM) and the Department of Defense (DOD) (Table 1, Figure 1).

Table 1. Area and relative proportions of the wetland complexes and area of interest (AOI) summarized by land management.

Land manager	Summary areas	Total *(m^2)*	Total *(acres)*	Percent of summary areas	Percent of all evaluated lands
U.S. Bureau of Land Management (BLM)	Wetland Complexes	459,300	113.50	29%	7%
	Area of Interest	2,808,700	694.04	53%	41%
U.S. Department of Defense (DOD)	Wetland Complexes	1,099,700	271.74	71%	16%
	Area of Interest	2,445,300	604.25	47%	36%

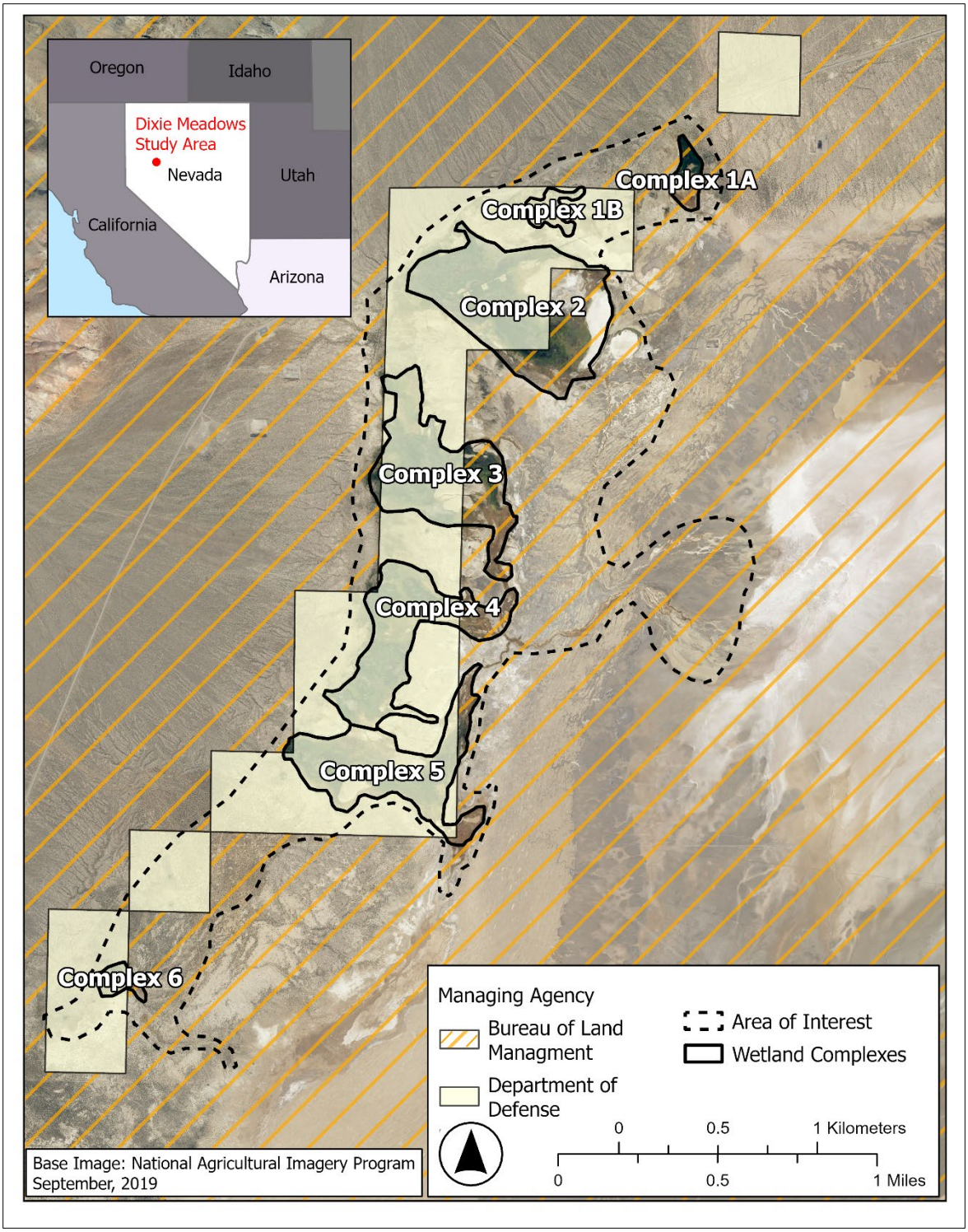


Figure 1. The Dixie Meadows study area in Nevada. The perimeters of wetland complexes 1A, 2, 3, 4, 5, 6 were defined by Halstead and others (2019) and Rose and others (2022). Perimeters of complex 1B and the more general area of interest were additionally defined within Sankey and others (2024). Background image is from the U.S. Department of Agriculture's (USDA) National Agriculture Imagery Program (NAIP), acquired September 1, 2019, courtesy of the USGS. BLM, U.S. Bureau of Land Management. DOD, U.S. Department of Defense.

Background

A previous study by the U.S. Geological Survey (USGS) Southwest Biological Science Center (SBSC), which was published in an Open-File Report (OFR) by Sankey and others (2024) and an associated data release by Bransky and others (2023), used aerial photography and satellite remote sensing data to map land cover within seven wetland complexes and the surrounding landscape (termed the area of interest; Figure 1) between October 2015 and January 2022. Five land cover types were mapped from the remote sensing imagery, spanning a gradient of soil moisture and vegetation conditions, termed Classes 1 – 5. Comparisons of Classes 1 – 5 with National Agricultural Imagery Program (NAIP) 60 cm-resolution aerial photographs and independent Stream Temperature, Intermittency, and Conductivity (STIC) sensor data published by Kleeman and Halstead (2022) showed that the classes corresponded to an environmental gradient of vegetation density and surface moisture, with Class 1 having the least photosynthetically active vegetation cover and driest conditions, Class 4 having dense vegetation cover and saturated soil conditions, and Class 5 representing open water. Specifically, areas were mapped as the following classes:

Class 1: Dry, bare soil or sparse upland vegetation.

Class 2: Moist, bare soil or sparse or small vegetation.

Class 3: Dense green vegetation, often with underlying surface water or saturated soil conditions.

Class 4: Mixed shallow surface water, saturated soil, and vegetation.

Class 5: Open water.

The mapped distribution of these classes varied by time, but Classes 2 and 3 consistently covered the largest proportion of the wetland complexes, representing a combined 72% on average (Sankey and others, 2024). These classes covered much of the wetland complexes and the adjacent landscape with Class 1 surrounding them along the outside edge, averaging about 20% of the wetland complexes. Classes 4 and 5 covered smaller areas, with Class 4 covering about seven percent of the wetland complexes, almost exclusively within the center of each, and Class 5 covering less than one percent of the wetland complexes within a pond in Complex 2 (Sankey and others, 2024; Figure 1).

Objectives

To better understand the dynamically changing water, vegetation, and soil conditions at Dixie Meadows, the U.S. Fish and Wildlife Service (USFWS) requested that USGS–SBSC extend the satellite remote sensing analysis and land cover classification (Bransky and others, 2023; Sankey and others, 2024) through December 2023 (Bransky and others, 2024). This report summarizes results of the full record of land cover classification from October 2015 through November 2023 based on the data published by Bransky and others (2023, 2024) and methods reported by Sankey and others (2024). Here we focus on the following objectives to summarize:

1) The distribution of land cover classes across lands managed by the Department of Defense (DOD) and the Bureau of Land Management (BLM), and

2) Variability in land cover classes over time within the wetland complexes.

Methods

Land cover classification

The methods used for land cover classification have been previously detailed by Sankey and others (2024) and are briefly summarized here. We analyzed 146 European Space Agency's Sentinel-2A satellite images acquired between October 2015 and November 2023 (Figure 2). The selected images were all atmospherically corrected (termed bottom of atmosphere; BOA) using the European Space Agency's Sen2Cor algorithm (https://step.esa.int/main/snap-supported-plugins/) and represent times with no apparent cloud cover over the study area. Although imagery was collected at sub-monthly intervals, cloud cover was a particularly limiting factor in analysis that resulted in a relatively small number of images collected in the months of January, February, and December compared to the other months of the year. No single year had data from all 12 months, but beginning in 2019, several months had more than one usable image (Figure 2).

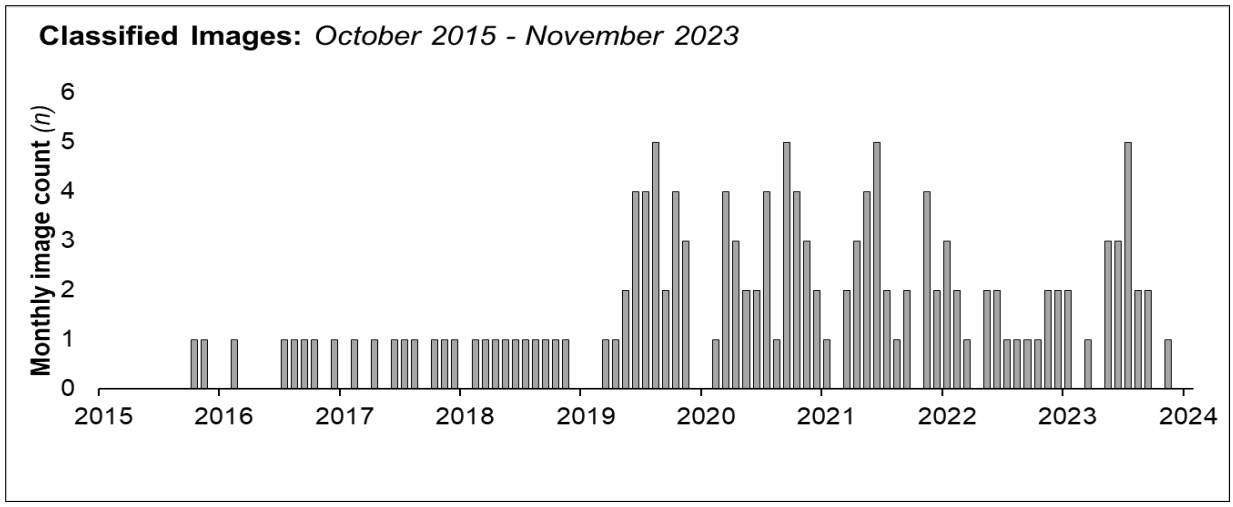


Figure 2. Plot of the 146 satellite images used in analysis that were collected between October 2015 and November 2023 summarized by month. Between 2017 and 2023, each year had images for at least 8 months representing at least one record for each global season (spring, summer, autumn, and winter). Between 2019 and 2023, several spring – winter months had multiple images that met the criteria for analysis.

The Sentinel-2A satellite acquires data within 12 spectral band widths of the electromagnetic spectrum at varying resolutions. Specific for this study, we used the green (542.5–577.5 nm) and near-infrared (777.6–892.6 nm) bands collected at 10-m pixel resolution to calculate the Green Normalized Difference Vegetation Index (gNDVI) and used this index for classification. gNDVI was originally proposed by Gitelson and others (1996), who showed that it is sensitive to variations in chlorophyll associated with land cover of green, photosynthetically active plant cover. gNDVI is calculated using the following equation:

$$gNDVI = \frac{NIR-G}{NIR+G} \quad (1)$$

where *G* is the green imagery band and *NIR* is the near-infrared imagery band. Notably for this study, the inverse of gNDVI is Normalized Difference Water Index (NDWI) originally proposed by McFeeters (1996) to identify open water. The mapped land cover classes were defined from gNDVI (Figure 3) as:

- Class 1: gNDVI > -0.1 and gNDVI <= 0.3
- Class 2: gNDVI > 0.3 and gNDVI <= 0.45
- Class 3: gNDVI > 0.45 and gNDVI <= 0.66
- Class 4: gNDVI > 0.66
- Class 5: gNDVI < -0.1

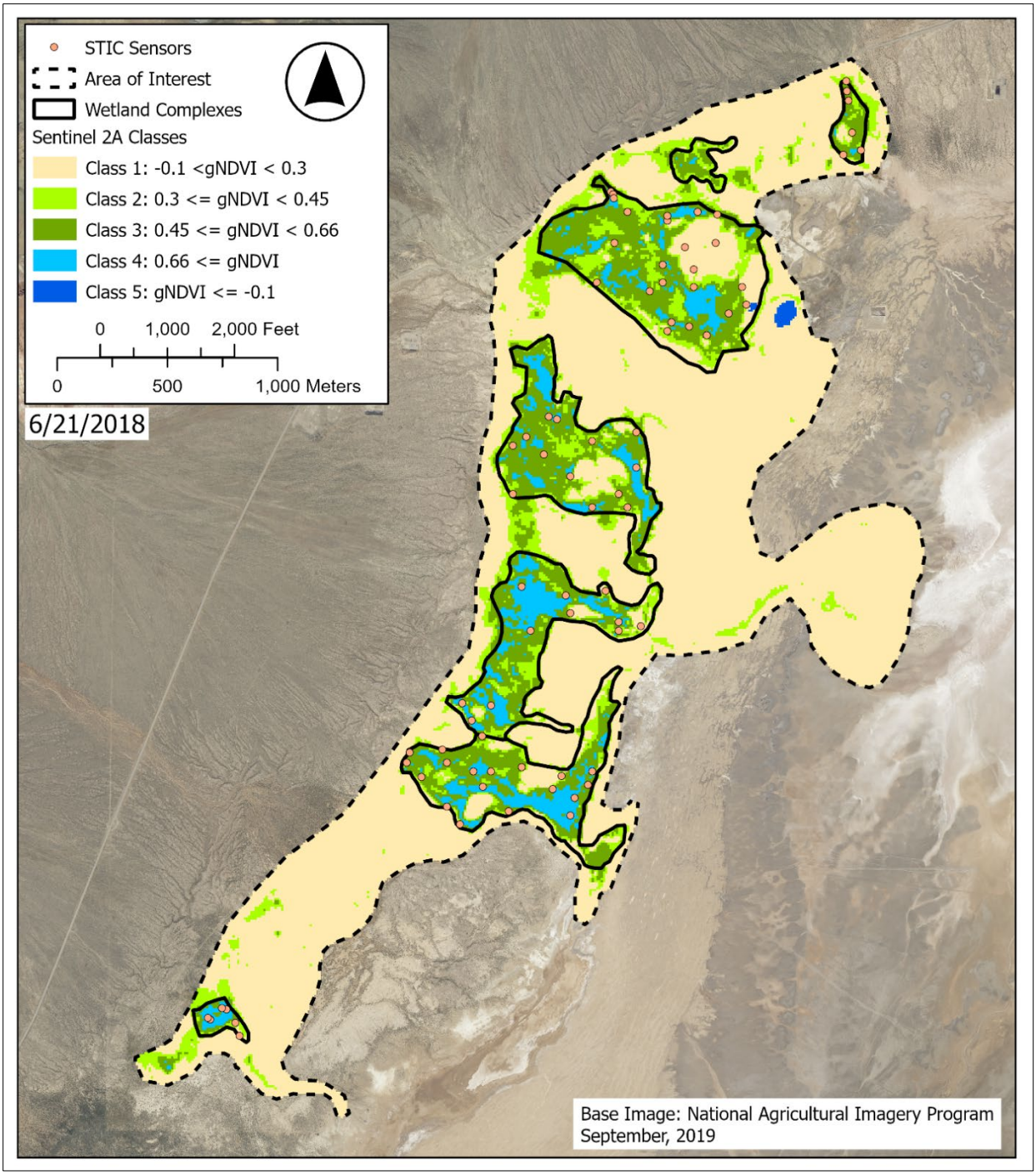


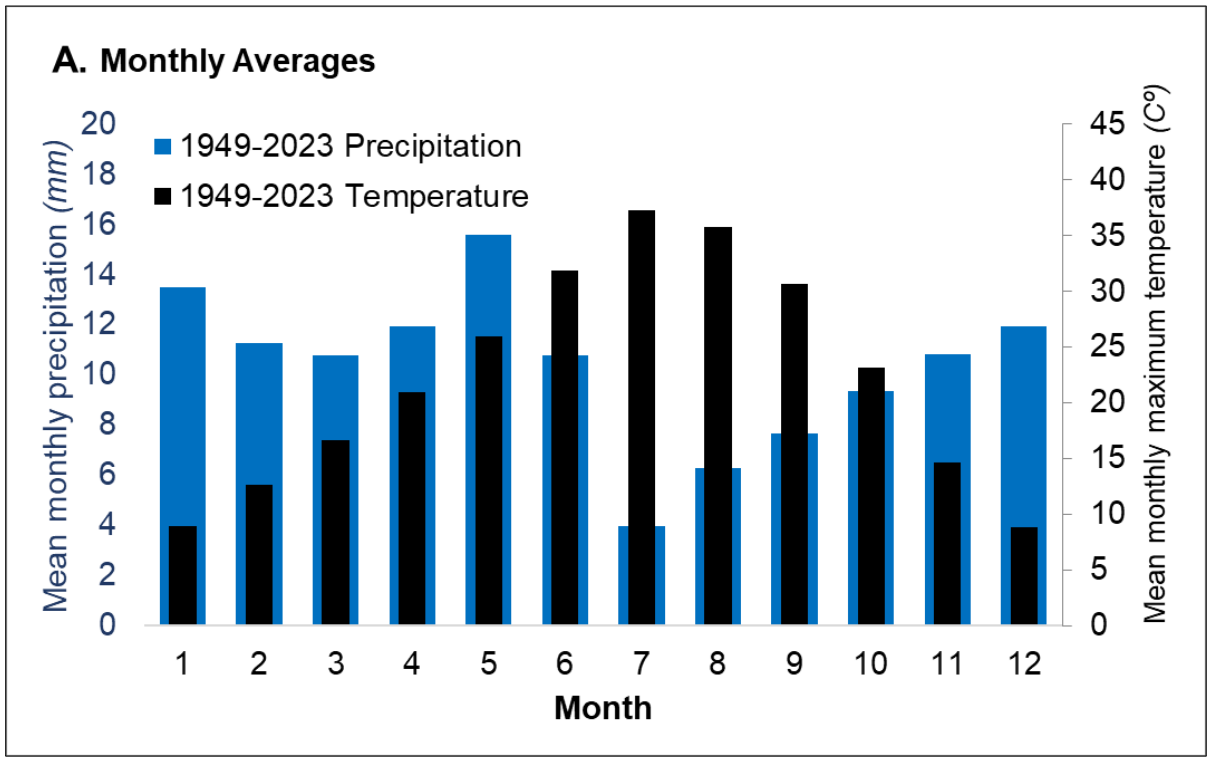
Figure 3. Example of land cover classification for a single date (June 21, 2018) within the Dixie Meadows study area from Sankey and others (2024). Class 1 (tan; -0.1 < gNDVI < 0.3) represents dry, bare soil or sparse upland vegetation; Class 2 (light green; 0.3 <= gNDVI< 0.45) represents moist, bare soil or sparse or small upland vegetation; Class 3 (dark green; 0.45 <= gNDVI< 0.66) represents dense green vegetation, often with underlying surface water or saturated soil conditions; Class 4 (light blue; 0.66 <= gNDVI) represents mixed shallow surface water, saturated soil, and vegetation; Class 5 (dark blue; gNDVI <= -0.1) represents open water. Stream Temperature, Intermittency, and Conductivity (STIC) sensor data were used for class validation by Sankey and others (2024). Sensor locations are provided for reference.

Climate and weather

There were no known long-term, on-site weather observations at the wetland complexes study area. Prior to the study period, there were two National Oceanographic and Atmospheric Administration (NOAA) Cooperative Observer (COOP) stations within the Dixie Valley region with more than five years precipitation and temperature data: 1) Dixie Valley Anderson, NV (USC00262315, operational between 1973-1979) located 7 miles south-southwest of the study area and 2) Brinkerhoff Ranch (USC00261160, operational between 1967-1980) located approximately 18 miles northeast of the study area. At a farther geographic radius, there were at least three stations (hereafter "long-record stations") continuously operated between 1949 – 2024; 1) Lovelock Derby Field (USW00024172) located approximately 30 miles northwest of the study area on the opposite side of the Stillwater Mountains, 2) Fallon Experiment (USC00262780) located approximately 42 miles southeast of the study area, and 3) Austin No. 2 (USC00260507) located approximately 56 miles to the west of the study area on the opposite side of the Clan Alpine Mountains. Comparing the three long-record stations to the period of operations for the two closer Dixie Valley stations, we found that the Lovelock Derby Field station provided the closest approximation to weather conditions within Dixie Valley. Specifically, monthly average temperatures were linearly correlated to Dixie Valley Anderson and Brinkerhoff Ranch with an r^2 of 0.99 and 0.92, respectively. Monthly totals of precipitation were less well correlated (Dixie Valley Anderson r^2=0.59 and Brinkerhoff Ranch r^2=0.42), but still significantly (95% confidence) related. As such, we describe climate and weather trends for the study area based on the Lovelock Derby Field NOAA COOP station records.

Precipitation at the Lovelock Derby Field NOAA COOP station is generally highest in late spring, averaging over 20 mm (~0.8 in) during the month of May (Figure 4A). Temperatures peak during summer in July or August with an average maximum daily temperature over 35º C (~95◦ F). Precipitation is lowest, averaging less than 10 mm per month (~0.4 in), during the hot summer months of June, July, and August (Figure 4A). Precipitation and temperature summarized from 2013 to 2023 generally follow a similar interannual pattern as the long-term record summarized from 1949 to 2023. However, the average precipitation values appear to be slightly smaller for some winter, spring, and fall months, and average temperatures appear to be slightly warmer for summer months for 2013–2023 compared to 1949–2023 (Figure 4A).

The annual record of precipitation and temperature from 1949 to 2023 is highly variable. However, there is a possible correspondence between temperature and precipitation, where years with warmer average temperatures tend to have below average precipitation and years with lower average temperatures tend to have relatively above average precipitation (Figure 4B). Over our remote sensing study period from 2015 to 2023, precipitation was near the long-record average (123 mm) with one notable dry year, 2020, that coincided with higher-than-average temperatures (Figure 4B).



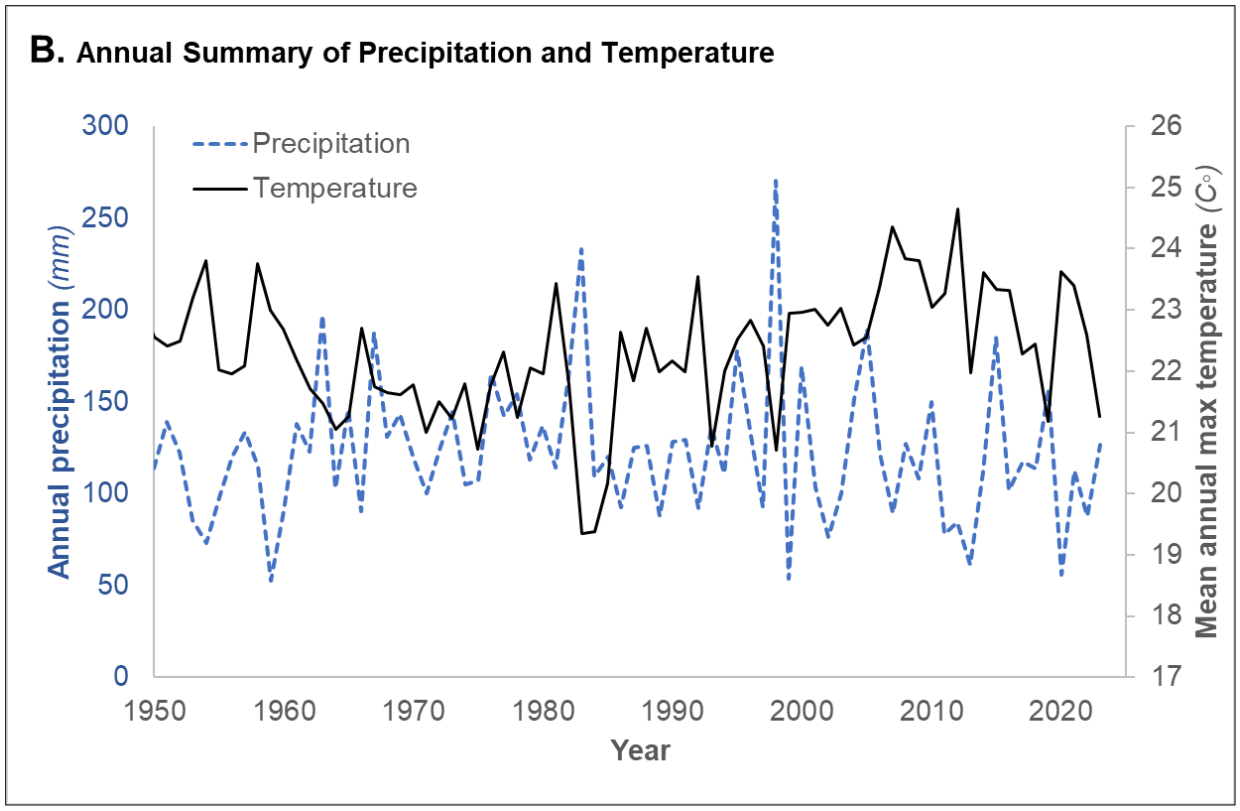


Figure 4. Temperature and precipitation records from 1949 – 2023 for the Lovelock Derby Field (USW00024172) NOAA COOP weather station, representative of conditions within Dixie Valley, Nevada. **A.** Monthly summaries of the average maximum daily temperature and total precipitation for the period of record (1949 – 2023) and the most recent 10-year observations (2013 – 2023). **B.** Annual summary of the average maximum daily temperature and total precipitation between 1949 and 2023. For visualization, a missing portion of the station's records between 1983 and 1988 have been synthesized using the Fallon Experiment (USC00262780) and Austin No. 2 (USC00260507) stations.

Results

Summary of land cover classifications

The extended analysis of land cover was consistent with the previous results by Sankey and others (2024) showing Class 1 covered the largest area within the area of interest and Classes 2 and 3 covered the largest areas within the wetland complexes. Here we summarized the results from 2015 to 2023 by land management for the wetland complexes and area of interest in Figure 5.

Class 1, representing dry, bare soil or sparse upland vegetation, covers the largest area (~70%) within the combined area of interest and wetlands complexes (Figure 5B). Almost 2/3rd (65%) of the average Class 1 area occurs on BLM lands within the area of interest.

Nine percent of the total Class 1 area occurs within the wetland complexes and is roughly split between BLM and DOD managed lands. The largest coverage was mapped in March 2023 at 1,107 acres. The smallest coverage was mapped in December 2016 at 613 acres.

Areas mapped as Class 2 are moist, bare soil or sparse, small upland or senescent vegetation. Class 2 averages approximately 16% of the total combined area of interest and wetland complexes. Approximately 70% of the average Class 2 area is mapped on DOD managed lands. A majority (67%) of Class 2 is mapped within the wetland complexes and of the Class 2 cover within wetland complexes, approximately 69% is on DOD managed lands (Figure 5C). The largest coverage was mapped in March 2018 at 403 acres. The smallest coverage was mapped in July 2016 at 115 acres.

Areas mapped as Class 3 are dense green vegetation, often with underlying surface water or saturated soil conditions. Class 3 averages approximately 12% of the total combined area of interest and wetland complexes (Figure 5D). Most (93%) of Class 3 is mapped within the wetland complexes and of the Class 3 cover within wetland complexes, approximately 80% is on DOD managed lands. The largest coverage was mapped in February 2017 at 311 acres. The smallest coverage was mapped in February 2022, January 2023, and March 2023 at 0 acres (no Class 3 present).

Areas mapped as Class 4 are mixed shallow surface water, saturated soil, and vegetation. Class 4 averages approximately 2% of the total combined area of interest and wetland complexes (Figure 5E). Almost all (98%) of Class 4 is mapped within the wetland complexes and of the Class 4 cover within wetland complexes, approximately 87% is on DOD managed lands. The largest coverage was mapped in November 2015 at 149 acres. The smallest coverage was 0 acres (no Class 4), occurring in 37 of the 146 image classifications, most of which were in the cooler months (October – March).

Areas mapped as Class 5 are open water. Open water covers a very small area relative to the other classes, making up less than one percent of the total combined area of interest and wetland complex areas (Figure 5F). A little over half (58%) of Class 5 is mapped within the wetland complexes and of the Class 5 cover within wetland complexes, all (100%) is on BLM managed lands, primarily within Wetland Complex 2 (Figure 1). The largest coverage was mapped in March 2023 at 13 acres. The smallest coverage was 0 acres (no Class 5), occurring in 67 of the 146 image classifications.

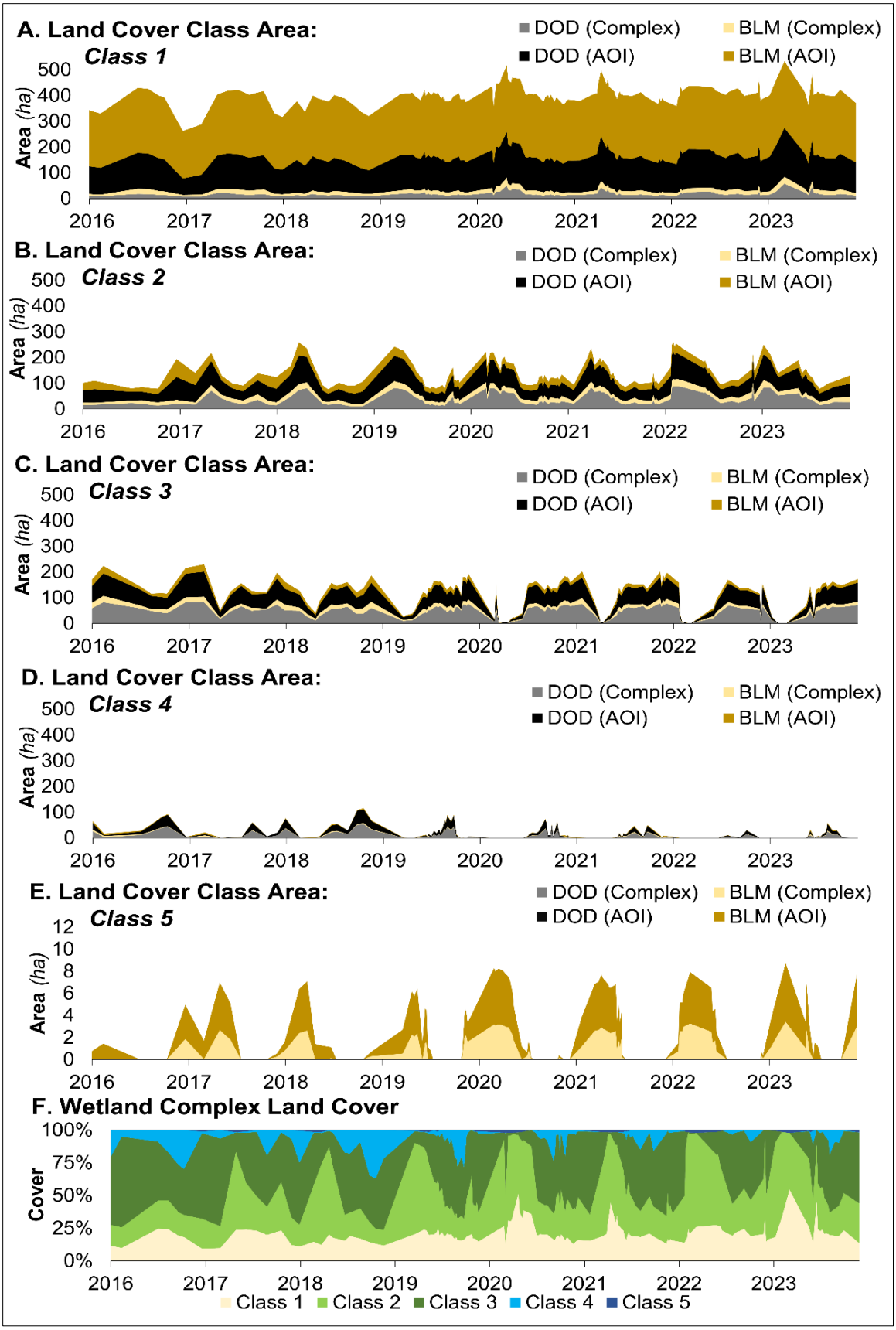

A. Land Cover Class Area:
Class 1
DOD (Complex)
BLM (Complex)
DOD (AOI)
BLM (AOI)
Area (ha)
500
400
300
200
100
0
2016
2017
2018
2019
2020
2021
2022
2023
B. Land Cover Class Area:
Class 2
C. Land Cover Class Area:
Class 3
D. Land Cover Class Area:
Class 4
E. Land Cover Class Area:
Class 5
12
10
8
6
4
2
0
F. Wetland Complex Land Cover
Cover
100%
75%
50%
25%
0%
Class 1
Class 2
Class 3
Class 4
Class 5

Figure 5. Variability in area covered by each of the land cover classes from 2016 to 2023 summarized by land management (Bureau of Land Management, BLM; U.S. Department of Defense, DOD) for the wetland complexes and area of interest (AOI). **A.** Variability in area covered by Class 1 (dry, bare soil or sparse upland vegetation). **B.** Variability in area covered by Class 2 (moist, bare soil or sparse or small upland vegetation). **C.** Variability in area covered by Class 3 (dense green vegetation, often with underlying surface water or saturated soil conditions). **D.** Variability in area covered by Class 4 (mixed shallow surface water, saturated soil, and vegetation). **E.** Variability in area covered by Class 5 (open water). Note the change in axis scale from the previous land cover classes. **F.** Variability of land cover class summarized as a percentage of areal cover of all wetland complexes.

Variability in land cover classes over time

The extended analysis of land cover within the wetland complexes appeared to highlight patterns in monthly (intra-annual) and yearly (interannual) variability in areal cover for the five classes (Figure 6). We note several distinct differences in monthly patterns of classified area that likely represent seasonal variance in moisture and phenology (Figure 6). Class 1 covers the largest area in the spring months (March – May) compared to other months, with relatively consistent coverage for the rest of the year. Class 2 has larger areal coverage and high variance in areal coverage early in the year (January – February). Class 2 cover area remains large through spring and decreases into the summer and fall months (May – November). Similarly, Class 3 has high variance in areal coverage during January and February but differs from Class 2, as areal coverage increases through the rest of the year (April – December). Class 4 has a similar, but temporally offset, pattern from Class 1, covering the largest areas in the late summer and early fall months (e.g., August and September) with consistently lower coverage area during the rest of the year. Class 5 follows a similar pattern as Class 2, with large coverage areas and high variance early in the year (January and February) and large coverage in the spring declining into the summer months (Figure 6).

Trends in mean annual areal coverage from 2017 to 2023 within the wetland complexes were less definitive than the monthly patterns (Figure 6). In general, the largest annual coverages of the dry or sparsely vegetated land cover classes (Classes 1 and 2) tended to occur later within the study period (2022 – 2023), while land covers with greater moisture content and vegetation density (Classes 3 and 4) tended to have larger coverage early during the study period (2017 – 2020). For example, the smallest mean annual area cover for Classes 1 and 2 occurred in 2018, whereas the largest mean annual area cover for those classes occurred in 2023 and 2022, respectively. Conversely, the smallest mean annual area covered by Classes 3 and 4 occurred in 2022, whereas the largest mean annual area covered occurred in 2020 and 2018, respectively. Annual trends within Class 5 were complicated by its relatively small coverage area. The maps presented by Bransky and others (2023, 2024; example Figure 3) show that Class 5 trends reflect changing water conditions within a single ephemeral pond downslope of Wetland Complex 2 that generally follows observed temporal patterns for land cover Class 2.

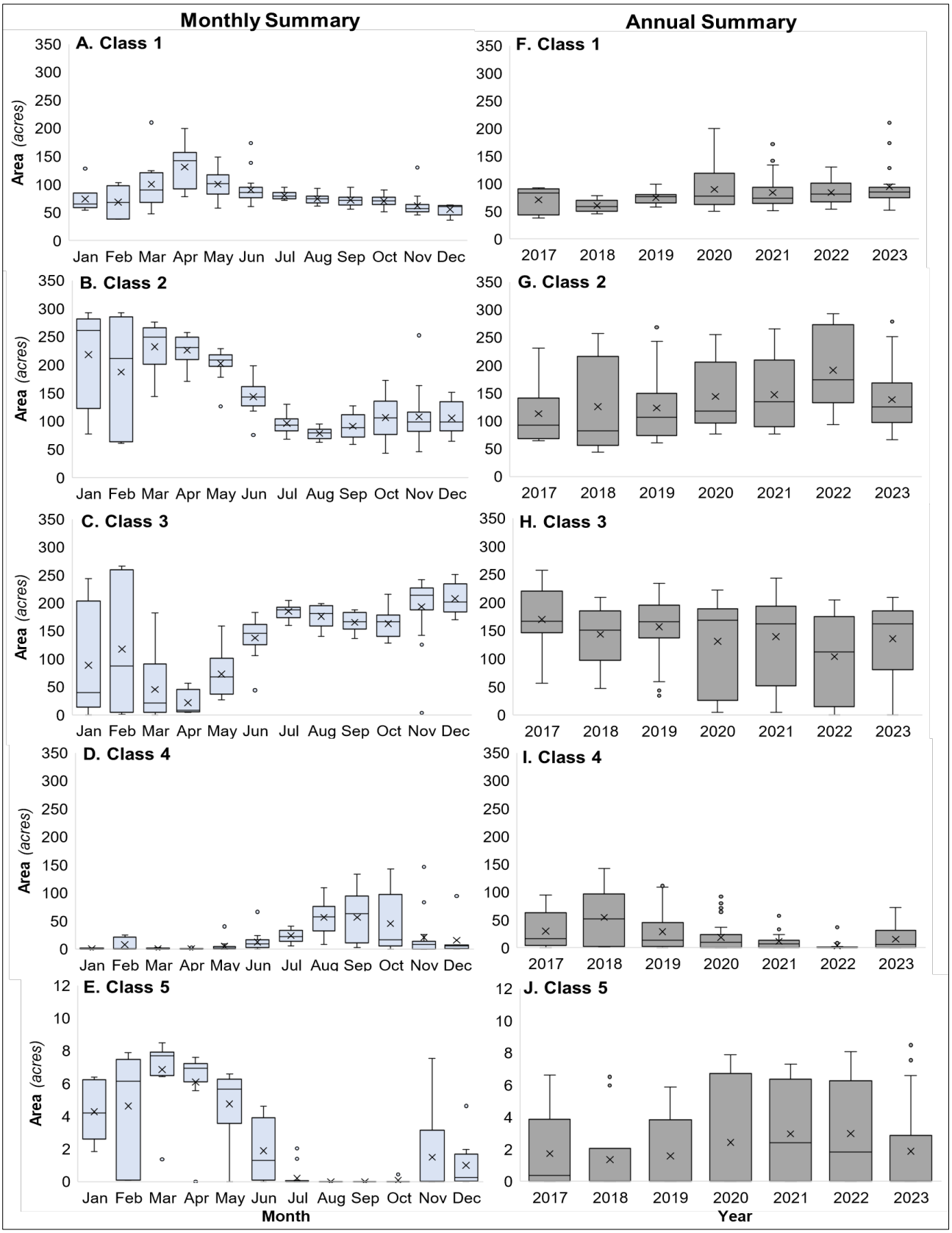

Monthly Summary
Annual Summary
A. Class 1
B. Class 2
C. Class 3
D. Class 4
E. Class 5
F. Class 1
G. Class 2
H. Class 3
I. Class 4
J. Class 5
Area (acres)
Month
Year
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
2017 2018 2019 2020 2021 2022 2023

Figure 6. Monthly (A – E) and yearly (F – J) variability in area covered by each of the land cover classes within the wetland complexes. Six or fewer monthly land cover observations were possible in 2015 and 2016 due to operational limitations and cloud cover and so were excluded from the annual summaries (F – J). Note the difference in scale between Class 5 (E and J) and the other land cover classes.

Discussion and Conclusion

The results in this report detail variability in the coverage of five land cover classes between October 2015 and November 2023 for seven mapped wetland complexes (Complex 1A, 1B, 2 – 6) and the surrounding area of interest within Dixie Meadows, Nevada on land managed by the DOD and BLM (Figure 1; Figure 5; Appendix 1). The spatial distribution of land cover classes within and around the wetland complexes and management areas appeared to be governed by proximity to a series of warm springs located along a northeast-southwest oriented scarp at the western extent of the area of interest and the general topographic gradient dipping towards the playa in the east (Huntington and others, 2014).

A majority of the wetland complexes occur close to these spring outflows within land managed by the DOD, though a portion is also within BLM lands. Most of the intervening and surrounding landscape outside of the wetland complexes assessed in this study is managed by the BLM. As a result, Class 1 (dry, bare soil or sparse upland vegetation), which was primarily mapped outside the wetland complexes, had the largest areal coverage for BLM managed lands. Classes 2 (moist, bare soil or sparse or small upland vegetation) and 3 (dense green vegetation, often with underlying surface water or saturated soil conditions) were primarily mapped inside the wetland complexes and thus had the largest area coverage within DOD managed lands. Class 4 (mixed shallow surface water, saturated soil, and vegetation) was almost exclusively mapped within the wetland complexes and was largely contained within DOD managed lands. Class 5 (open water) was exclusively mapped in and adjacent to Wetland Complex 2 within catchment ponds and land managed by the BLM.

The distribution of land cover classes over the study period was seasonally and annually variable, though the seasonal patterns of coverages were somewhat counterintuitive to precipitation and temperature patterns. Land cover areas of Classes 1 (dry) and 2 (sparsely vegetated), were larger during the spring months when rainfall was relatively high. Conversely, land cover areas of Classes 3 and 4 (relatively wetter soil and denser vegetation), tends to be greatest during the summer or fall months when rainfall was relatively low, and temperatures were relatively high.

These patterns might be influenced by differences in seasonal water sources and phenology. For example, Classes 3 and 4 covers a greater extent of the interior of the wetland complexes that are sourced by groundwater-fed seeps and springs with vegetation that appeared to have relatively greater photosynthetic activity (higher gNDVI; Gitelson and others, 1996) during months with longer daylight hours.

Class 1 largely occurred in areas adjacent to, but outside of the wetland complexes, where surface runoff, precipitation, or other factors might play a more direct role in supplying water to these areas, likely influencing the vegetation community and timing of photosynthetic activity. Class 2 covered much of the exterior edge of the wetland complexes between Classes 1 and 3 (see for example Figure 3). Its coverage area was likely complicated by seasonal weather and groundwater that also influenced the fill volume within the ephemeral ponds that make up Class 5.

There were no definitive interannual patterns in land cover area for the five classes over the study period from October 2015 – November 2023, though Classes 1 and 2 tended to be mapped over a larger proportion of the study area in more recent years than the wetter and more densely vegetated Classes 3 and 4. For example, the largest average annual land cover areas for Classes 1 and 2 occurred in 2023 and 2022, respectively. Conversely, the largest average annual land cover areas for Classes 3 and 4 occur in 2020 and 2018, respectively.

Annual weather patterns for the seven years from 2017 to 2023 shown in Figure 6 do not appear to directly relate to observed land cover, as there is no significant relationship between land cover, precipitation, or temperature. Mean annual precipitation was larger in the first half of the study period (2015 – 2019; 135 mm yr^{-1}) than the second half (2020 – 2023; 96 mm yr^{-1}), consistent with potentially drier conditions in more recent years. Cattle grazing also occurs within Dixie Valley (Huntington and others, 2014) and variability in its intensity, in combination with weather variability, might further complicate quantifying and interpreting land cover changes. Analysis of land cover change that extends longer than seven years would likely provide better evidence for linking weather, land use, and environmental conditions to land cover variability.

This investigation, and the previously published results (Bransky and others, 2023; Sankey and others, 2024), used land cover changes classified from remote sensing datasets. These data and interpretations are specific to the 146 classified Sentinel-2 satellite images (10-m resolution). These observations were validated using 60-centimeter (cm) to 1-m pixel resolution USDA NAIP multispectral aerial images acquired in 2015, 2017, and 2019. Additionally, we incorporated previously published observations by Kleeman and Halstead (2022) documenting the presence or absence of wet or dry soil surface conditions from relative conductivity measured at 79 Stream Temperature, Intermittency, and Conductivity (STIC) loggers from April 2019 to September 2021. We used the Green Normalized Difference Vegetation Index (gNDVI; Gitelson and others, 1996) and its inverse relationship to the Normalized Difference Water Index (NDWI; McFeeters, 1996) to define the five land cover classes. Site visits by the authors were not feasible during the study period and so we did not collect additional ground truth observations beyond the published STIC observations (Kleeman and Halstead, 2022).

Different results might be obtained for the land cover assessments of the wetland complexes conducted over other time periods, using different remotely sensed imagery, image processing, analysis methods, ground observations of surface water and soil moisture conditions, and (or) if

study site visits and ground truth data collection were logistically and financially feasible to implement. Future investigations of land cover in the wetland complexes at Dixie Valley that build on the results presented here, as well as in the report by Sankey and others (2024) and other environmental monitoring data (for example, Halstead and others, 2019; Halstead and Kleeman, 2020; Kleeman and Halstead, 2022), could help inform important habitat characteristics (for example, Rose and others, 2022) of the wetlands. Specifically, these data could be used to aid in understanding the unique wetland habitat characteristics of the different wetland complexes, the areas of the landscape adjacent to the wetland complexes, or the different DOD and BLM land management units. This information might also provide the framework for both monitoring land cover changes with differing management strategies and investigating factors that might influence changes within these wetland complexes and adjacent lands.

References Cited

Bransky, N., Caster, J., Sankey, J.B., 2023, Land cover classification data for wetland complexes at Dixie Meadows, Nevada from October 2015 to January 2022: U.S. Geological Survey data release, accessed September 28, 2023, https://doi.org/10.5066/P90U1VAM.

Bransky, N., Sankey, J.B., and Caster, J., 2024, Land cover classification data for wetland complexes at Dixie Meadows, Nevada from January 2022 to November 2023: U.S. Geological Survey data release, accessed September 28, 2023, https://doi.org/10.5066/P14GNRTE.

Forrest, M.J., Stiller, J., King, T.L., and Rouse, G.W., 2017, Between hot rocks and dry places—The status of the Dixie Valley toad: Western North American Naturalist, v. 77, no. 2, p.162–175, accessed September 28, 2023, at https://doi.org/10.3398/064.077.0204.

Garcia, C.A., Huntington, J.M., Buto, S.G., Moreo, M.T., Smith, J.L., and Andraski, B.J., 2015, Groundwater discharge by evapotranspiration, Dixie Valley, west-central Nevada, March 2009–September 2011 (ver. 1.1, April 2015): U.S. Geological Survey Professional Paper 1805, 90 p., accessed September 28, 2023, at https://doi.org/10.3133/pp1805.

Gitelson, A.A., Kaufman, Y.J., and Merzlyak, M.N., 1996, Use of a green channel in remote sensing of global vegetation from EOS-MODIS: Remote Sensing of Environment, v. 58, no. 3, p. 289–298, accessed September 28, 2023, at https://doi.org/10.1016/S0034-4257(96)00072-7.

Gordon, M.R., Simandle, E.T., and Tracy, C.R., 2017, A diamond in the rough desert shrublands of the Great Basin in the Western United States—A new cryptic toad species (Amphibia—Bufonidae, *Bufo* (*Anaxyrus*)) discovered in Northern Nevada: Zootaxa, v. 4290, no. 1, p. 123–139, accessed September 28, 2023, at https://doi.org/10.11646/zootaxa.4290.1.7.

Halstead, B.J., and Kleeman, P.M., 2020, Site and survey data for Dixie Valley toads in Churchill County, Nevada, 2019: U.S. Geological Survey data release, accessed September 28, 2023, https://doi.org/10.5066/P9BT38WU.

Halstead, B.J., Kleeman, P.M., Duarte, A., Rose, J.P., Urquhart, K., Mellison, C., Guadalupe, K., Cota, M., Van Horne, R., Killion, A., and Ruehling, K., 2019, Monitoring protocol development and assessment for narrowly endemic toads in Nevada, 2018: U.S. Geological Survey Open-File Report 2019–1067, 28 p., accessed September 28, 2023, at https://doi.org/10.3133/ofr20191067.

Halstead, B.J., Kleeman, P.M., Rose, J.P., and Fouts, K.J., 2021, Water temperature and availability shape the spatial ecology of a hot springs endemic toad (*Anaxyrus williamsi*): Herpetologica, v. 77, no. 1, p. 24–36, accessed September 28, 2023, at https://doi.org/10.1655/HERPETOLOGICA-D-20-00047.

Huntington, J.M., Garcia, C.A., and Rosen, M.R., 2014, Hydrogeologic framework and occurrence, movement, and chemical characterization of groundwater in Dixie Valley, west-central Nevada: U.S. Geological Survey Scientific Investigations Report 2014–5152, 60 p., accessed September 28, 2023, at https://doi.org/10.3133/sir20145152.

Kleeman, P.M, and Halstead, B.J., 2022, Temperature and relative conductivity at sampling locations in the Dixie Valley, Churchill County, Nevada, 2019–2021: U.S. Geological Survey data release, accessed September 28, 2023, at https://doi.org/10.5066/P95BHQXT.

McFeeters, S.K., 1996, The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features: International Journal of Remote Sensing, v. 17, no. 7, p. 1425–1432, accessed September 28, 2023, at https://doi.org/10.1080/01431169608948714.

Rose, J.P., Kleeman P.M., and Halstead B.J., 2022, Hot, wet and rare—Modelling the occupancy dynamics of the narrowly distributed Dixie Valley toad: Wildlife Research, v. 50. no. 7, p. 552–567, accessed September 28, 2023, at https://doi.org/10.1071/WR22029.

Sankey, J.B., Bransky, N.D., Caster, J.J., 2024, Investigation of land cover within wetland complexes at Dixie Meadows, Churchill County, Nevada, from October 2015 to January 2022: U.S. Geological Survey Open-File Report 2024-1029, accessed September 28, 2023, at https://doi.org/10.3133/ofr20241029.

Appendix 1: Tabular Summaries

Appendix Table 1.1: Land Manager Summary

Cover Class	Land Manager	Extent	Average *(m^2)*	Min *(m^2)*	Max *(m^2)*	Average *(Acres)*	Min *(Acres)*	Max *(Acres)*
1	All	Area of Interest	3,697,540	2,479,000	4,479,500	913.68	612.57	1,106.91
2	All	Area of Interest	837,729	466,200	1,630,700	207.01	115.20	402.95
3	All	Area of Interest	608,602	0	1,257,100	150.39	0.00	310.64
4	All	Area of Interest	95,266	0	602,500	23.54	0.00	148.88
5	All	Area of Interest	14,862	0	53,300	3.67	0.00	13.17
1	All	Wetland Complexes	329,541	145,400	850,300	81.43	35.93	210.11
2	All	Wetland Complexes	562,557	176,600	1,183,900	139.01	43.64	292.55
3	All	Wetland Complexes	564,260	0	1,077,200	139.43	0.00	266.18
4	All	Wetland Complexes	93,947	0	593,000	23.21	0.00	146.53
5	All	Wetland Complexes	8,696	0	34,300	2.15	0.00	8.48
1	BLM	Area of Interest	2,398,383	1,845,400	2,595,900	592.65	456.01	641.46
2	BLM	Area of Interest	259,325	135,100	700,800	64.08	33.38	173.17
3	BLM	Area of Interest	123,074	0	295,800	30.41	0.00	73.09
4	BLM	Area of Interest	13,056	0	78,500	3.23	0.00	19.40
5	BLM	Area of Interest	14,862	0	53,300	3.67	0.00	13.17
1	BLM	Wetland Complexes	151,944	61,400	301,200	37.55	20.83	74.11
2	BLM	Wetland Complexes	173,220	84,300	299,900	42.80	0.00	63.18
3	BLM	Wetland Complexes	113,213	0	255,700	27.98	0.00	18.53
4	BLM	Wetland Complexes	12,227	0	75,000	3.02	0.00	8.48
5	BLM	Wetland Complexes	8,696	0	34,300	2.15	113.50	113.50
1	DOD	Area of Interest	1,299,158	633,600	1,890,800	321.03	76.50	273.17
2	DOD	Area of Interest	578,405	309,600	1,105,500	142.93	0.00	238.68
3	DOD	Area of Interest	485,528	0	965,900	119.98	0.00	131.93

4	DOD	Area of Interest	82,210	0	533,900	20.31	0.00	0.00
5	DOD	Area of Interest	0	0	0	0.00	0.00	0.00
1	DOD	Wetland Complexes	177,597	71,800	575,200	43.89	22.81	220.10
2	DOD	Wetland Complexes	389,337	92,300	890,700	96.21	0.00	203.00
3	DOD	Wetland Complexes	451,047	0	821,500	111.46	0.00	203.00
4	DOD	Wetland Complexes	81,719	0	530,200	20.19	0.00	131.02
5	DOD	Wetland Complexes	0	0	0	0.00	0.00	0.00

Appendix Table 1.2: Summary Complex 1A

Cover Class	Land Manager	Extent	Average (m^2)	Min (m^2)	Max (m^2)	Average (Acres)	Min (Acres)	Max (Acres)
1	All	Complex 1A	5,210	1,600	18,000	1.29	0.4	4.45
2	All	Complex 1A	12,497	3,800	32,100	3.09	0.94	7.93
3	All	Complex 1A	17,464	0	30,400	4.32	0	7.51
4	All	Complex 1A	3,429	0	18,000	0.85	0	4.45
5	All	Complex 1A	0	0	0	0	0	0
1	BLM	Complex 1A	5,210	1,600	18,000	1.29	0.4	4.45
2	BLM	Complex 1A	12,497	3,800	32,100	3.09	0.94	7.93
3	BLM	Complex 1A	17,464	0	30,400	4.32	0	7.51
4	BLM	Complex 1A	3,429	0	18,000	0.85	0	4.45
5	BLM	Complex 1A	0	0	0	0	0	0
1	DOD	Complex 1A	0	0	0	0	0	0
2	DOD	Complex 1A	0	0	0	0	0	0
3	DOD	Complex 1A	0	0	0	0	0	0
4	DOD	Complex 1A	0	0	0	0	0	0
5	DOD	Complex 1A	0	0	0	0	0	0

Appendix Table 1.3: Summary Complex 1B

Cover Class	Land Manager	Extent	Average (m^2)	Min (m^2)	Max (m^2)	Average (Acres)	Min (Acres)	Max (Acres)
1	All	Complex 1B	7,866	1,300	32,500	1.94	0.32	8.03
2	All	Complex 1B	20,545	4,500	28,100	5.08	1.11	6.94
3	All	Complex 1B	8,402	0	24,000	2.08	0	5.93
4	All	Complex 1B	186	0	2,800	0.05	0	0.69
5	All	Complex 1B	0	0	0	0	0	0
1	BLM	Complex 1B	0	0	0	0	0	0
2	BLM	Complex 1B	0	0	0	0	0	0
3	BLM	Complex 1B	0	0	0	0	0	0
4	BLM	Complex 1B	0	0	0	0	0	0
5	BLM	Complex 1B	0	0	0	0	0	0
1	DOD	Complex 1B	7,866	1,300	32,500	1.94	0.32	8.03
2	DOD	Complex 1B	20,545	4,500	28,100	5.08	1.11	6.94
3	DOD	Complex 1B	8,402	0	24,000	2.08	0	5.93
4	DOD	Complex 1B	186	0	2,800	0.05	0	0.69
5	DOD	Complex 1B	0	0	0	0	0	0

Appendix Table 1.4: Summary Complex 2

Cover Class	Land Manager	Extent	Average (m^2)	Min (m^2)	Max (m^2)	Average (Acres)	Min (Acres)	Max (Acres)
1	All	Complex 2	138,538	61,000	319,400	34.23	15.07	78.93
2	All	Complex 2	166,266	50,000	358,100	41.09	12.36	88.49
3	All	Complex 2	157,874	0	335,800	39.01	0	82.98
4	All	Complex 2	34,242	0	220,100	8.46	0	54.39
5	All	Complex 2	8,579	0	33,800	2.12	0	8.35
1	BLM	Complex 2	81,960	31,300	143,500	20.25	7.73	35.46
2	BLM	Complex 2	58,875	22,000	111,100	14.55	5.44	27.45
3	BLM	Complex 2	39,968	0	98,000	9.88	0	24.22
4	BLM	Complex 2	5,618	0	38,800	1.39	0	9.59
5	BLM	Complex 2	8,579	0	33,800	2.12	0	8.35
1	DOD	Complex 2	56,577	25,500	204,500	13.98	6.3	50.53
2	DOD	Complex 2	107,392	17,600	255,800	26.54	4.35	63.21
3	DOD	Complex 2	117,906	0	237,800	29.14	0	58.76
4	DOD	Complex 2	28,625	0	193,800	7.07	0	47.89
5	DOD	Complex 2	0	0	0	0	0	0

Appendix Table 1.5: Summary Complex 3

Cover Class	Land Manager	Extent	Average (m^2)	Min (m^2)	Max (m^2)	Average (Acres)	Min (Acres)	Max (Acres)
1	All	Complex 3	64,177	23,400	212,600	15.86	5.78	52.53
2	All	Complex 3	130,005	31,600	275,500	32.12	7.81	68.08
3	All	Complex 3	128,827	0	231,400	31.83	0	57.18
4	All	Complex 3	17,492	0	124,500	4.32	0	30.76
5	All	Complex 3	0	0	0	0	0	0
1	BLM	Complex 3	30,477	11,100	77,500	7.53	2.74	19.15
2	BLM	Complex 3	53,580	18,000	94,800	13.24	4.45	23.43
3	BLM	Complex 3	35,712	0	79,200	8.82	0	19.57
4	BLM	Complex 3	2,130	0	18,400	0.53	0	4.55
5	BLM	Complex 3	0	0	0	0	0	0
1	DOD	Complex 3	33,699	12,300	138,800	8.33	3.04	34.3
2	DOD	Complex 3	76,425	13,600	180,700	18.88	3.36	44.65
3	DOD	Complex 3	93,114	0	168,300	23.01	0	41.59
4	DOD	Complex 3	15,362	0	112,000	3.8	0	27.68
5	DOD	Complex 3	0	0	0	0	0	0

Appendix Table 1.6: Summary Complex 4

Cover Class	Land Manager	Extent	Average (m^2)	Min (m^2)	Max (m^2)	Average (Acres)	Min (Acres)	Max (Acres)
1	All	Complex 4	38,864	11,800	122,900	9.6	2.92	30.37
2	All	Complex 4	106,472	26,100	252,000	26.31	6.45	62.27
3	All	Complex 4	125,494	0	234,800	31.01	0	58.02
4	All	Complex 4	22,770	0	118,700	5.63	0	29.33
5	All	Complex 4	0	0	0	0	0	0
1	BLM	Complex 4	16,482	4,500	37,000	4.07	1.11	9.14
2	BLM	Complex 4	23,622	10,300	40,000	5.84	2.55	9.88
3	BLM	Complex 4	8,014	0	29,900	1.98	0	7.39
4	BLM	Complex 4	182	0	6,400	0.05	0	1.58
5	BLM	Complex 4	0	0	0	0	0	0
1	DOD	Complex 4	22,382	7,100	87,900	5.53	1.75	21.72
2	DOD	Complex 4	82,850	11,100	218,800	20.47	2.74	54.07
3	DOD	Complex 4	117,480	0	206,400	29.03	0	51
4	DOD	Complex 4	22,588	0	118,100	5.58	0	29.18
5	DOD	Complex 4	0	0	0	0	0	0

Appendix Table 1.7: Summary Complex 5

Cover Class	Land Manager	Extent	Average (m^2)	Min (m^2)	Max (m^2)	Average (Acres)	Min (Acres)	Max (Acres)
1	All	Complex 5	71,964	28,000	185,400	17.78	6.92	45.81
2	All	Complex 5	117,183	38,700	231,300	28.96	9.56	57.16
3	All	Complex 5	112,661	0	217,100	27.84	0	53.65
4	All	Complex 5	13,976	0	110,400	3.45	0	27.28
5	All	Complex 5	116	0	1,300	0.03	0	0.32
1	BLM	Complex 5	15,425	4,700	37,700	3.81	1.16	9.32
2	BLM	Complex 5	21,684	7,800	32,100	5.36	1.93	7.93
3	BLM	Complex 5	10,284	0	30,000	2.54	0	7.41
4	BLM	Complex 5	690	0	10,000	0.17	0	2.47
5	BLM	Complex 5	116	0	1,300	0.03	0	0.32
1	DOD	Complex 5	56,538	19,900	148,100	13.97	4.92	36.6
2	DOD	Complex 5	95,499	30,900	203,000	23.6	7.64	50.16
3	DOD	Complex 5	102,377	0	193,000	25.3	0	47.69
4	DOD	Complex 5	13,286	0	107,300	3.28	0	26.51
5	DOD	Complex 5	0	0	0	0	0	0

Appendix Table 1.8: Summary Complex 6

Cover Class	Land Manager	Extent	Average (m^2)	Min (m^2)	Max (m^2)	Average (Acres)	Min (Acres)	Max (Acres)
1	All	Complex 6	2,922	0	10,400	0.72	0	2.57
2	All	Complex 6	9,589	3,400	24,500	2.37	0.84	6.05
3	All	Complex 6	13,538	0	20,900	3.35	0	5.16
4	All	Complex 6	1,851	0	11,900	0.46	0	2.94
5	All	Complex 6	0	0	0	0	0	0
1	BLM	Complex 6	2,388	0	6,400	0.59	0	1.58
2	BLM	Complex 6	2,963	600	6,000	0.73	0.15	1.48
3	BLM	Complex 6	1,771	0	5,500	0.44	0	1.36
4	BLM	Complex 6	177	0	2,000	0.04	0	0.49
5	BLM	Complex 6	0	0	0	0	0	0
1	DOD	Complex 6	534	0	4,800	0.13	0	1.19
2	DOD	Complex 6	6,626	1,100	19,500	1.64	0.27	4.82
3	DOD	Complex 6	11,767	0	17,000	2.91	0	4.2
4	DOD	Complex 6	1,673	0	10,700	0.41	0	2.64
5	DOD	Complex 6	0	0	0	0	0	0