VFS-ID-ESER-LAND-003

The Idaho National Laboratory Site Long-Term Vegetation Transects: Updates Through 2016

Environmental Surveillance,
Education and Research Program
September 2018

Cover photograph credits clockwise from the top: Alaysha Whitworth, Jackie Hafla, and Colby Kramer. All photographs are from Big Southern Butte. The friendly llama was residing near the base of the Butte in 2016 and the field crew adopted him as an honorary crew member. He was compensated for his efforts (which mostly consisted of greeting folks with curiosity and goodwill) with treats every Thursday throughout the summer.

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ACKNOWLEDGEMENTS

An incredible resource like the LTV is the result of contributions from numerous researchers, graduate students, field technicians, data managers, and DOE collaborators. We will always be grateful to Jay Anderson, Karl Holte, and Richard Inouye for recognizing the importance of this data set when it was only a few decades old. Their efforts allowed this data set to grow into one of the most comprehensive resources available for the sagebrush steppe and they used these data to make pivotal contributions to semi-arid plant ecology. For the 2016 sample period, we would like to recognize our cheerful and resilient field crew; Colby Kramer, Alaysha Whitworth, and Zane Stephenson. Kurt Edwards provided GIS support and tabular data management with great attention to detail. Jeremy Shive contributed maps and a very helpful review of the draft report. Alana Jensen designed a beautiful cover and Brande Hendricks masterfully handled all of the document formatting. We are also tremendously appreciative of Doug Halford and Kristin Kaser for providing reviews of the draft; their advice improved the report considerably.

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ACRONYMS

ANOVA	Analysis of Variance
CCA	Candidate Conservation Agreement
DOE	Department of Energy
ESER	Environmental Surveillance, Education, and Research
INL	Idaho National Laboratory
LTV	Long-Term Vegetation
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
PCBE	Protective Cap/Biobarrier Experiment
USFWS	United States Fish and Wildlife Service

EXECUTIVE SUMMARY

Vegetation abundance data have been collected periodically once every two to ten years since 1950 from plots located along two macro-transects that bisect the Idaho National Laboratory (INL) Site. The data generated from the Long-Term Vegetation (LTV) Project comprises one of the oldest, largest, and most comprehensive vegetation data sets for sagebrush steppe ecosystems in North America. Data from the LTV have been the basis for major milestones in understanding practical and theoretical ecology of sagebrush steppe. At the INL Site, the LTV continues to be used extensively to support National Environmental Policy Act (NEPA) processes, guide land management recommendations, develop site-specific revegetation guidelines, and for conservation management planning. The LTV plots were sampled for the thirteenth time in 2016. Analysis of the data collected during the 2016 sample period included updating functional group trends, which have now been reported for several decades. Trend analyses of non-native species abundance and distribution, first conduced in association with the 2006 sample effort, were also updated with the most current data set.

Notable changes between the 2011 and 2016 sample periods include decreases in shrub cover, particularly big sagebrush; increases in native grass cover; and declines in the densities of introduced annual grasses and forbs. In terms of long-term trends, big sagebrush cover is at its lowest point in the 66-year history of the data set. Native, perennial grasses are near the upper end of their historical range of variability. Although the abundance of introduced annuals has declined between the most recent two sampling efforts, introduced annuals remain much more abundant than native annuals across the LTV plots. Introduced annuals have also been exhibiting fluctuations with greater magnitudes of change from one sample period to the next over the past two decades when compared with earlier sample periods. Coincidentally, annual precipitation was below average for four of the five years prior to the 2016 sample period and the seasonal timing of precipitation has shifted away from wet spring periods to elevated precipitation in late-summer and fall over the past five to ten years.

Declines in big sagebrush cover are due to direct losses from wildland fire and possibly from reduced germination and establishment because of below average spring precipitation on the INL Site over the past decade. Changes in the seasonality of precipitation are likely also affecting the abundance of introduced annuals, especially with respect to the magnitude of change from one sample period to the next. Increased pressure from non-native species, including annuals like cheatgrass and perennials like crested wheatgrass, will undoubtedly persist over the next few decades. Some of the more recent changes in vegetation distribution and structure on the LTV plots may suggest the beginning of a shift to INL Site plant communities that are less resilient than they have been in the past. As sagebrush steppe management across the West faces increasing challenges, the LTV will continue to provide useful insight to local scientists and regional researchers alike.

1. INTRODUCTION

1.1 Background

The Long-Term Vegetation (LTV) Project and associated permanent vegetation plots (Figure 1) were established on what is now the Idaho National Laboratory (INL) Site in 1950 for the purpose of assessing the impacts of nuclear energy research and production on the surrounding ecosystem (Singlevich et al. 1951). Vegetation abundance data, including density and cover, have been collected periodically once every two to ten years from plots located along two macro-transects, which are perpendicular to one another and intersect near the center of the INL Site. The data generated from the LTV comprises one of the oldest, largest, and most comprehensive vegetation data sets for sagebrush steppe ecosystems in North America. A detailed account of the history of the LTV can be found in Forman et al. (2010).

Although early research confirmed that there were no significant impacts of radionuclides on vegetation across the INL Site landscape, the LTV continues to be used extensively to support the INL Site mission. For several decades, data from the permanent plots have been used to; support NEPA processes, make land management recommendations appropriate to the local ecosystem, and develop site-specific revegetation guidelines (e.g., Anderson and Shumar 1989, Blew et al. 2002). More recently, LTV data have also been used to support conservation management planning on the INL Site. Specifically, LTV data are utilized to provide longer-term context with which to compare and interpret sage-grouse habitat condition data (e.g., Shurtliff et al. 2018). Analyses of data from the LTV are important for understanding conservation threats like habitat fragmentation, climate change, and the effects of stressors on the resilience of native plant communities.

In addition to INL Site and mission-specific applications, data generated from the LTV have been the basis for major milestones in understanding practical and theoretical ecology of sagebrush steppe. Pertinent topics include; plant community classification and mapping, assessing effects of drought and livestock grazing, understanding fire history and recovery, characterizing species invasion patterns, testing theories of vegetation succession and change, and as a starting point for habitat suitability modeling for sensitive species. While these applications of the LTV data are not always specific to the INL Site, the knowledge gained certainly benefits land stewardship efforts at the INL Site.

Compared to sagebrush steppe across much of the western U.S., the LTV plots have historically had limited human impact due to their isolated location on the INL Site (Forman et al. 2010). However, disturbance is increasing in proximity to many LTV plots. They are also experiencing more variability in seasonal weather patterns than they have previously, as noted in the last LTV report (Forman et al. 2013). As direct disturbances on plant communities within the INL Site boundaries increase, and as disturbances across the region influence vegetation composition on the INL Site, plant communities will likely be affected as well. Incidentally, the LTV is becoming more important for understanding changes in native sagebrush steppe under increasing environmental stress. The LTV is particularly pertinent for monitoring change in vegetation condition, mechanisms driving local changes in species abundance and distribution, and understanding resistance and resilience inherent to local native plant communities.

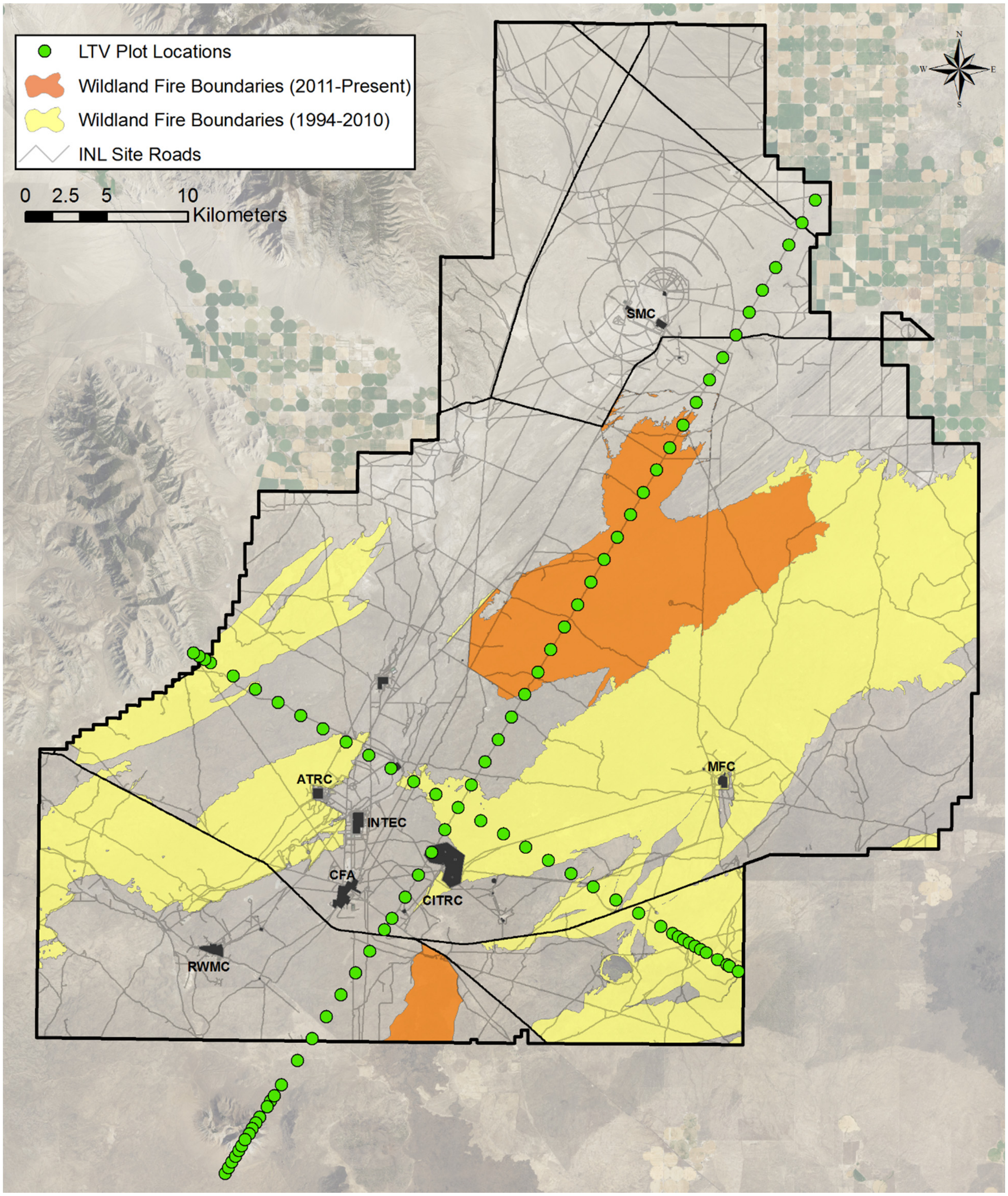

Figure 1. Long-Term Vegetation Plots on the Idaho National Laboratory Site. Wildland fires depicted are from 1994-2016.

1.2 Updates since the 2011 Sample Period

1.2.1 Summary of Recent Vegetation Monitoring and Applied Research

Updates regarding vegetation monitoring and research projects, independent of the LTV, are typically summarized in each iteration of this report because it is the most readily identified location for investigators searching for information on plant ecology at the INL Site. Between 2011 and 2016, there were two notable vegetation-based research and monitoring efforts. One was the initiation of a sage-grouse habitat monitoring project to support a Candidate Conservation Agreement (CCA) between the Department of Energy (DOE) and the U.S. Fish and Wildlife Service (USFWS; DOE and USFWS 2014). The other included publication of data from an ongoing ecohydrology study (e.g., McAbee et al. 2017; Campos et al. 2017).

The CCA for Greater Sage-grouse on the INL Site (DOE and USFWS 2014) was signed in 2014. The Agreement outlined several tasks to monitor sage-grouse populations and their habits that would be undertaken by the DOE through the Environmental Surveillance, Education, and Research (ESER) Program. Two tasks are specifically targeted at monitoring the condition, abundance, and distribution of sagebrush habitat, as well as the recovery trajectory of burned areas that had likely been sagebrush habitat prior to wildland fire. The habitat condition monitoring task entails the annual collection of species abundance data using sampling techniques similar to those used for the LTV. See Shurtliff et al. (2018) for more details on habitat condition monitoring. The habitat condition monitoring project and the LTV are excellent complementary data sets for exploring sagebrush steppe vegetation dynamics because together they provide the context of a relatively long timeline and the finer resolution offered by characterizing the variability of annually sampled plots.

The second sagebrush habitat monitoring task identified by the CCA tracks the abundance and distribution of sagebrush habitat across the INL Site. The habitat distribution task is used to incrementally update the INL Site Vegetation Map (Shive et al. 2011). Although it does not provide a mechanism for a comprehensive map update, this task does allow ESER to use aerial imagery to revise vegetation class delineations, especially for sagebrush-dominated classes that have changed due to disturbances like wildland fire or natural shifts in species composition due to invasive species pressure. See Shurtliff et al. (2017) for the most recent results from the habitat distribution monitoring task.

The ecohydrology study was conducted at an INL Site research location that was formerly developed for investigating alternative landfill capping design and was known at the Protective Cap/Biobarrier Experiment (PCBE; Anderson and Forman 2003). After the completion of the PCBE, many of the experimental treatments were continued and the data were used to compare the impacts of non-native grass invasion and shifts in precipitation timing on ecosystem function, and ultimately on resistance and resilience in sagebrush steppe. Specific research topics included characterization of the biogeochemistry and carbon storage potential of the experimental plots. Researchers have discontinued active treatments and annual data collection, but continue to publish results from the study (e.g., McAbee et al. 2017; Campos et al. 2017).

1.2.2 Changes in Land Cover and Land Use Since 2011

Over the past few decades, the local INL Site and greater regional landscape have undergone some dramatic changes. Wildland fires have affected plant communities across about 38% (86.972 ha) of the INL Site since 1994 and about 10% (21,922 ha) has burned more than once (Figure 1). Several large fires have altered much of the sagebrush steppe vegetation to the south and to the east of the INL Site during the same time period. Two major fires have burned on the INL Site since the 2011 sample period. The T-17 Fire burned 17,505 ha in the central portion of the INL Site just a few weeks after LTV sampling was completed in 2011. The fire affected 11 LTV plots, and those plots were sampled each year for six years post-fire. Those data will eventually be used to assess the extent to which the post-fire plant community recovery is influenced by pre-fire vegetation conditions. The second large fire to burn since 2011 was the Midway Fire, which burned 1,755 ha along the southern INL boundary in 2012. This fire was largely contained to an exposed basalt outcropping and did not directly affect any LTV plots.

General use of remote backcountry locations of the INL Site has increased due to INL Site mission-related activities as well as use by non-DOE entities, like livestock permittees. The total extent of disturbed soil outside of facility footprints at the INL Site is greater now than it was a few decades ago and programmatic use of remote areas beyond facilities fences has also increased (Forman et al. 2013; Shurtliff et al. 2017). Anthropogenic impacts associated with livestock operations in grazing allotments, such as off-road travel, improvements to water tanks, and several new fences have increased as well. See Shurtliff et al. (2015 and 2017) for examples and discussion of disturbance, including linear features that have been mapped recently. The increase in anthropogenic disturbance on the INL Site is consistent with trends in land use across the western U.S.

1.3 The 2016 Sample Period

The LTV Plots were sampled for the thirteenth time in 2016. Analysis of the data collected during the 2016 sample period included updating functional group trends, which have been reported for several decades (Forman et al. 2013). Trend analysis of non-native species abundance and distribution, first conduced in association with the 2006 sample effort (Forman et al. 2010), were also updated with the most current data set and are discussed here.

2. METHODS

2.1 *Study Site*

The INL Site is positioned at the northern extent of the Great Basin and is characterized by cold desert sagebrush steppe vegetation. Over the past sixty years, plant communities on the INL Site have been classified into between eight and twenty-six distinct vegetation types (McBride et al. 1978, Anderson et al. 1996, Shive et al. 2011). Mean elevation of the INL Site is 1500 m. Surficial geology is strongly influenced by volcanic activity and soils include wind-blown sand or loess over basalt and a few alluvial deposits. Because soil movement patterns are influenced by abundant basalt outcrops and frequent windy conditions, transitions between soils types and textures may be quite abrupt. Shive et al. (2011) provides a more thorough description of the local environment.

Annual precipitation at the INL Site averages 207 mm (Figure 2), with May and June typically being the wettest months. Snow cover may persist from a few weeks to several months in the winter. Mean annual temperature for the INL Site (recorded at Central Facilities Area [CFA]) is 5.7 °C; however, high diurnal and seasonal temperature fluctuations are normal (Clawson et al. 2018). Wind direction is predominately from the southwest, but changes to the northeast for a few early morning hours daily (Anderson and Inouye 2001; Clawson et al 2018). Shive et al. (2011) and Forman et al. (2010) provide thorough discussions of the study site in terms of local biotic and environmental conditions.

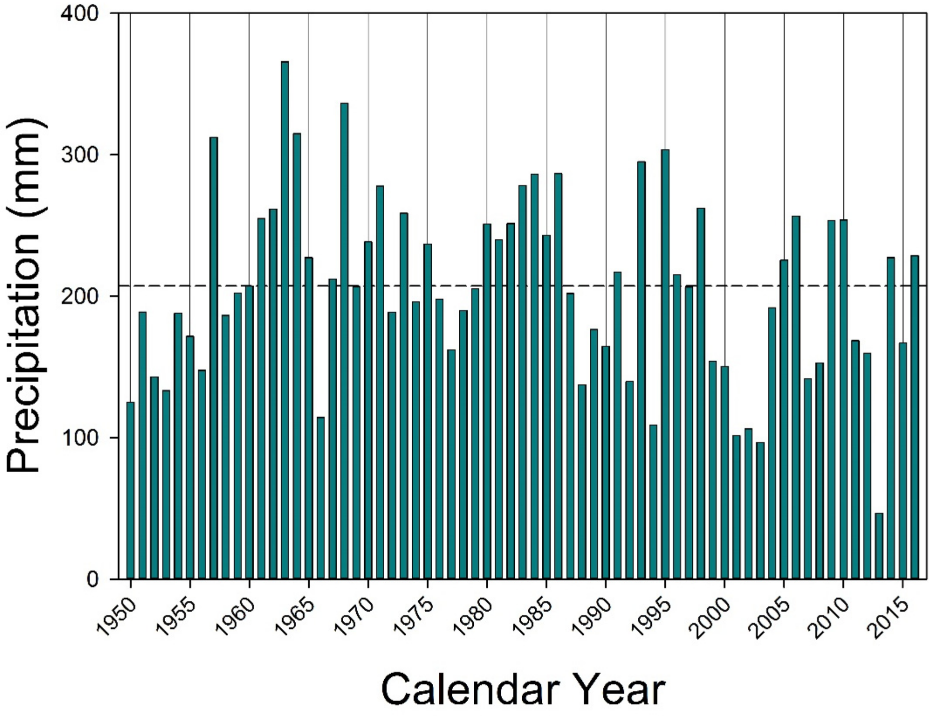

Figure 2. Total annual precipitation from 1950 through 2016 at the Central Facilities Area, Idaho National Laboratory Site. The dashed line represents mean annual precipitation.

2.2 Sample Design

All 89 active LTV plots were sampled between early June and mid-August of 2016. The plots are located along two macro-transects which bisect the INL Site (Figure 1). Plots are located approximately 1 mile apart, except on steep slopes, where they are in closer proximity to one another to capture the environmental gradient associated with changes in elevation. Forty-three plots, which are located in the centermost part of the INL Site, have been defined as "core plots" and have generally been considered to be representative of good-condition sagebrush steppe plant communities. The remainder of the plots are in vegetation types typically associated with sagebrush steppe, but communities are much more variable in the "peripheral plots" due to elevation, livestock grazing management, topography, soils, etc.

The original LTV plots consisted of two, 15.24 m transects that were placed parallel to one another and about 4.5 m apart. An additional transect, 20 m in length, was added to many of the plots in 1985; it was placed parallel to the original transects and about 4.5 m from the second transect. Cover, density, and frequency were measured on all of the accessible LTV plots in 1950, 1957, 1965, 1975, 1985, 1995, 2001, 2006, 2011, and most recently, 2016. A subset of plots and/or abundance metrics were sampled in 1978, 1983, and 1990.

Density and frequency were measured using twenty, 0.3 x 1.0 m quadrats located along the original two transects of each plot. Cover was estimated using line interception in all study years and point interception was used on most of the plots during the 1985 sample year and all sample periods thereafter. Line intercept data were collected along both original transects and point intercept data were collected using 50 point frames placed along all three transects. Density and frequency data and point interception data were collected for all taxa, and line interception data were collected for perennial grasses and shrubs. Line interception measurements follow guidelines suggested by Canfield (1941) and point interception data were collected using a method developed by Floyd and Anderson (1982). See Forman et al. (2010) for detailed sampling methodology.

2.3 Statistical Analysis and Data Presentation

Data were analyzed using one- and two-way ANOVAs (Zar 1999). Although a repeated measures design is the most appropriate statistical model given the permanent nature of the LTV plots, we were only able to use repeated measures ANOVAs for some of the analyses. Repeated measures tests are sensitive to balanced experimental designs. In many cases, data missing from the historical archives and inconsistencies in which plots were sampled from one sample period to the next led to unbalanced designs that were not amenable to repeated measures tests.

Updates to analyses characterizing trends in native species abundance and community composition were addressed using both point- and line-interception cover data on the core plots. An updated cover by species table for 2016 was compiled using the point-interception data, as it is the only cover metric that samples all taxa on a common scale. Long-term trends in functional groups of perennial species were characterized using line-interception data. Cover data for annual species were not collected prior to the initiation of point-interception methods in 1985, precluding cover analyses of those functional groups for the entire study period (1950-2016). The consistency with which line intercept data were collected in the core plots allowed us to analyze long-term trends of the perennial functional groups using repeated measures ANOVAs. Significance was determined at $\alpha = 0.05$ and the Holm-Sidak method (Sidak 1967) was used for multiple comparisons.

Analyses of non-native annual species' distribution and abundance patterns from 1950 through the current study period were conducted using density/frequency data on all of the LTV plots that were sampled during each of ten sample periods in which all available plots were sampled. The three sample periods during which only the core plots were sampled were omitted from the non-native species analyses. We used the entire data set rather than just the core plots for these analyses because we were interested in invasion patterns over as large a spatial extent as possible. The distribution of plots in which non-native species and functional groups occurred was mapped for the three most recent sample periods. We further analyzed changes in the density and frequency of annual species over the ten sample periods using one-way ANOVAs. Repeated measures designs could not be used due to inconsistencies among years in terms of which plots were sampled and represented in the historical data archives. The Holm-Sidak method was again used for multiple comparisons and significance was determined at $\alpha = 0.05$.

3. RESULTS

3.1 Cover by Species – Changes Since 2011

Point interception data from 2016 were used to summarize cover by species across the 43 core plots (Table 1). Compared with the 2011 data (Table 2), absolute total shrub cover decreased by nearly 4%. Big sagebrush (*Artemisia tridentata*) cover was about 2% lower in 2016 and green rabbitbrush (*Chrysothamnus viscidiflorus*) cover was slightly lower as well. These results were expected because 11 of the core plots burned in the T-17 Fire between the 2011 and 2016 sample periods and big sagebrush was abundant in most of those plots prior to the fire. In addition to the 11 plots that burned between the 2011 and 2016 sample periods, five core plots burned between the 2006 and 2011 sample periods. Because big sagebrush does not resprout after wildland fire, losses on the 16 core plots (about 37%) that were affected by fire in the past decade will likely be reflected in the LTV data summaries for several decades to come.

Table 1. Mean percent cover of vascular plants sampled on 43 Long-Term Vegetation plots using point-intercept methods during the 2016 sample period. Species are listed in order of descending cover values within each functional group. Cover is reported for each species having an absolute cover value > 0.1%. Constancy indicates the number of plots in which a species occurred. Cover normalized by constancy indicates the mean cover of a species averaged across only the number of plots in which it occurred.

Species	Absolute Cover (%)	Constancy	Cover (%) Normalized by Constancy
Shrubs			
Artemisia tridentata	7.32	25	12.58
Chrysothamnus viscidiflorus	6.41	38	7.25
Krascheninnikovia lanata	0.83	6	5.92
Grayia spinosa	0.44	4	4.68
Linanthus pungens	0.24	11	0.95
Tetradymia canescens	0.23	6	1.65
Others (n = 4)	0.20		
Total Shrub Cover	**15.67**		
Perennial Graminoids			
Hesperostipa comata	4.83	32	6.48
Elymus lanceolatus	3.78	31	5.24
Achnatherum hymenoides	2.08	39	2.29
Agropyron cristatum	1.48	8	7.94
Elymus elymoides	0.51	27	0.80
Poa secunda	0.31	18	0.75
Aristida purpurea	0.26	1	11.33
Pascopyrum smithii	0.16	3	2.3
Others (n = 4)	0.07		
Total Perennial Graminoid Cover	**13.48**		
Perennial Forbs			
Psoralidium lanceolatum	0.38	3	5.43
Sphaeralcea munroana	0.26	27	0.41
Eriogonum ovalifolium	0.18	12	0.64

Species	Absolute Cover (%)	Constancy	Cover (%) Normalized by Constancy
Descurainia pinnata	0.17	22	0.33
Astragalus filipes	0.16	8	0.87
Phlox hoodii	0.14	19	0.31
Pleiacanthus spinosus	0.12	4	1.25
Comandra umbellata	0.11	3	1.63
Others (n = 21)	0.28		
Total Perennial Forb Cover	**1.80**		
Succulents			
Opuntia polyacantha	**0.24**	23	0.44
Native Annuals and Biennials			
Mentzelia albicaulis	0.29	16	0.77
Chenopodium leptophyllum	0.19	26	0.31
Lappula occidentalis	0.17	16	0.45
Eriastrum wilcoxii	0.16	20	0.34
Others (n = 10)	0.23		
Total Native Annual/Biennial Cover	**1.04**		
Introduced Annuals and Biennials			
Alyssum desertorum	2.78	24	4.97
Salsola kali	1.56	22	3.05
Bromus tectorum	1.34	20	2.88
Halogeton glomeratus	1.06	8	5.72
Others (n = 4)	0.04		
Total Introduced Annual/Biennial Cover	**6.78**		
Total Vascular Plant Cover	**39.01**		

Table 2. Mean percent cover of vascular plants sampled on 43 Long-Term Vegetation plots using point-intercept methods during the 2011 sample period. Species are listed in order of descending cover values within each functional group. Cover is reported for each species having an absolute cover value > 0.1%. Constancy indicates the number of plots in which a species occurred. Cover normalized by constancy indicates the mean cover of a species averaged across only the number of plots in which it occurred.

Species	Absolute Cover (%)	Constancy	Cover (%) Normalized by Constancy
Shrubs			
Artemisia tridentata	9.55	33	12.45
Chrysothamnus viscidiflorus	7.88	39	8.68
Linanthus pungens	0.67	16	1.8
Grayia spinosa	0.6	6	4.28
Krascheninnikovia lanata	0.4	6	2.84
Tetradymia canescens	0.17	7	1.05
Others (n = 4)	0.22		
Total Shrub Cover	**19.49**		
Perennial Graminoids			
Hesperostipa comata	2.06	28	3.16
Elymus lanceolatus	1.58	31	2.2
Agropyron cristatum	1.13	6	8.07
Achnatherum hymenoides	0.45	29	0.66
Poa secunda	0.43	24	0.77
Pascopyrum smithii	0.31	5	2.63
Elymus elymoides	0.23	24	0.41
Pseudoroegneria spicata	0.15	5	1.32
Aristida purpurea	0.13	2	2.78
Others (n = 3)	0.07		
Total Perennial Graminoid Cover	**6.54**		
Perennial Forbs			
Crepis acuminata	0.34	11	1.32
Phlox hoodii	0.32	25	0.55
Astragalus filipes	0.22	13	0.71
Eriogonum ovalifolium	0.21	12	0.75
Comandra umbellata	0.21	4	2.24
Erigeron pumilus	0.14	13	0.47
Others (n = 30)	0.93		
Total Perennial Forb Cover	**2.37**		
Succulents			
Opuntia polyacantha	**0.17**	23	0.33
Native Annuals and Biennials			
Gayophytum diffusum	0.22	11	0.85
Cryptantha scoparia	0.18	12	0.65
Descurainia pinnata	0.14	13	0.47
Others (n = 11)	0.29		

Species	Absolute Cover (%)	Constancy	Cover (%) Normalized by Constancy
Total Native Annual/Biennial Cover	**0.83**		
Introduced Annuals and Biennials			
Alyssum desertorum	7.37	27	11.73
Bromus tectorum	4.61	30	6.61
Halogeton glomeratus	0.63	2	13.53
Descurainia sophia	0.11	12	0.41
Others (n = 3)	0.11		
Total Introduced Annual/Biennial Cover	**12.83**		

Between 2011 and 2016, total cover by perennial graminoids doubled. Needle and thread (*Hesperostipa comata*) was the most abundant perennial grass in both sample periods, and mean absolute cover of this species increased by two-fold over five years (Table 1 and Table 2). In 2016, crested wheatgrass (*Agropyron cristatum*), an introduced species, was the fourth most abundant perennial grass across the core LTV plots. It occurred in eight of the 43 core plots, an increase of two plots from 2011. Cover normalized by constancy values for this species indicate that it is very abundant in the plots where it occurs, much more so than any single native species (Table 1). Increases in crested wheatgrass are of particular concern because it has invaded the plots were it is found (it was historically planted in the vicinity of several plots, but was not planted directly on any plots), it continues to increase in the plots it occupies, and where it is present it occurs with much greater mean abundance than comparable native, perennial bunchgrass species.

Cover from native annuals and biennials were fairly comparable between the two sample periods, while introduced annuals and biennials decreased by half from 2011 to 2016. Desert alyssum (*Alyssum desertorum*) was the most abundant introduced annual in 2011 and 2016, but cover had decreased from about 7% in 2011 to under 3% in 2016. Cheatgrass (*Bromus tectorum*) was the second most abundant introduced annual, and mean cover from cheatgrass also decreased between the two sample periods. For the 2016 sample period, crested wheatgrass was slightly more abundant than cheatgrass. However, three species of native perennial grasses were all more abundant than either crested wheatgrass or cheatgrass; as a functional group, native perennial grasses were more abundant than introduced grasses.

In summary, total vascular vegetation cover was about 2% lower in 2016 than in 2011. Lower total cover was due to a decrease in both shrubs introduced annuals, but it was offset somewhat by a notable increase in native perennial grasses. About 1/3 of the total cover from herbaceous species across the core plots was from introduced grasses and forbs. Similar cover by species tables, summarized from the point interception data, were first presented using 1995 data (Anderson and Inouye 1999). Relative cover by introduced species decreased between the 1995 and 2006 sample periods. It was much higher during the 2011 growing season than in either 2006 or 1995, but declined again in 2016 and is once more consistent with historical values.

3.2 Cover by Perennial Functional Group – Trends Since 1950

Line interception data were used to update functional group trend analyses across the core LTV plots, which include all sample periods since 1950. Perennial grass cover from 2016 was within the historical range of variability for the 66 year-old data set (Figure 3). Mean perennial grass cover was significantly higher in 2016 than in the sample years with the five lowest means, and it was not significantly different than in 1975, the year with the highest reported mean perennial grass cover (Appendix A, Tables 1a and

1b). Shrub cover in 2016 was the lowest mean recorded since data collection began in 1950 and the difference between mean shrub cover in 2016 and mean shrub cover in its three highest years was significant (Appendix A, Tables 1a and 1b). Generally, shrub cover was down and perennial grass cover was up from the previous sample period, but neither difference was significant over the most recent five year period. The trends for mean shrub and perennial grass cover between the 2011 and 2016 sample periods were consistent between the point intercept (Tables 1 and 2) and the line intercept data sets (Figure 3).

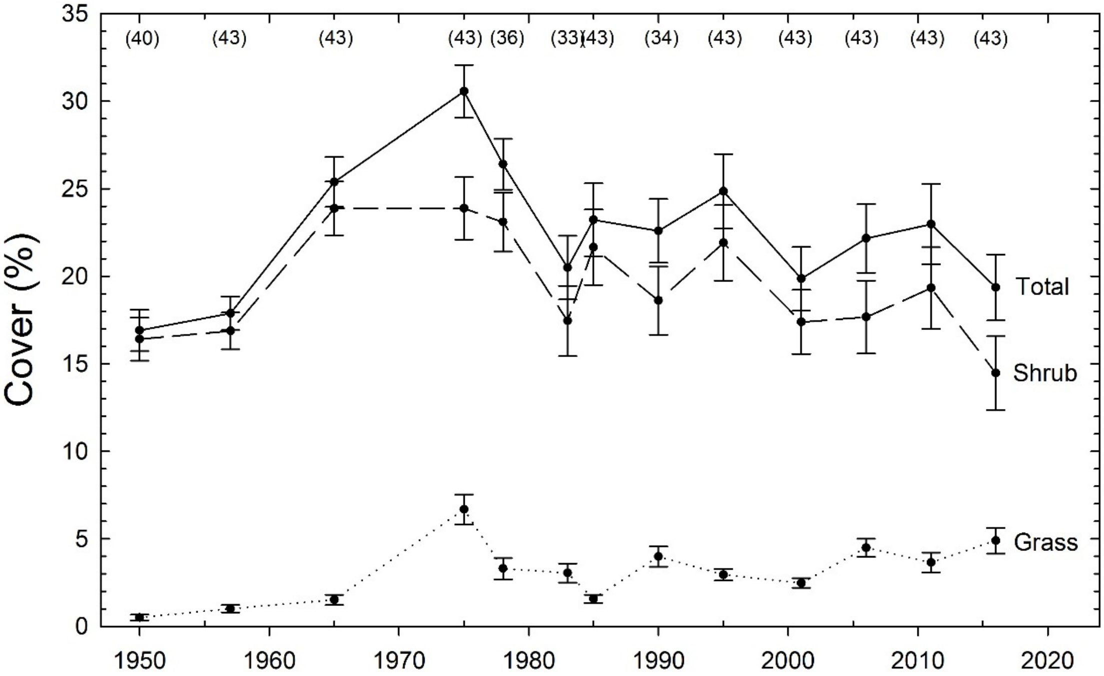

Figure 3. Trends in shrub cover, native perennial grass cover, and total combined perennial grass and shrub cover from 1950 to 2016 for the core subset of plots on the Long-Term Vegetation Project at the Idaho National Laboratory Site. Data were collected using line-interception methods and are represented here as means ± 1 SE. Numbers in parentheses at the top of the frame indicate the number of plots for which data were available in each sample year.

Within the shrub functional group, mean green rabbitbrush cover values for 2016 were lower than those reported for the 2011 sample period, but not significantly so. Green rabbitbrush cover values have generally been trending upward over the 66 year-old data set (Figure 4) and mean cover for the three highest, and more recent, sample periods (1995, 2006, and 2011) was statistically significantly higher than mean cover for the two earliest sample periods (1950 and 1957; Appendix A, Tables 2a and 2b). Big sagebrush cover decreased between the 2011 and 2016 sample periods (Figure 4). The decrease was not statistically significant (Appendix A, Tables 2a and 2b); 2016 represents one of several sample periods since 1965 for which big sagebrush cover declined over the mean from the previous sample period. Mean big sagebrush cover for 2016 was the lowest recorded mean for this species since data collection began in 1950 and it was significantly lower in 2016 than in 1995 and all previous sample periods. The precipitous decrease in big sagebrush over the last two decades is due, in large part, to losses from wildland fire. As noted in the previous section, 16 of the core LTV plots have burned in just the past decade. Although mean big sagebrush cover increased slightly between 2006 and 2011, the decrease from 2011 to 2016 contributes to an overall declining trend (Appendix A, Tables 2a and 2b). For the fourth consecutive sample period, mean green rabbitbrush cover and mean big sagebrush cover across the core plots were statistically indistinguishable from one another (Appendix A, Tables 2a and 2b).

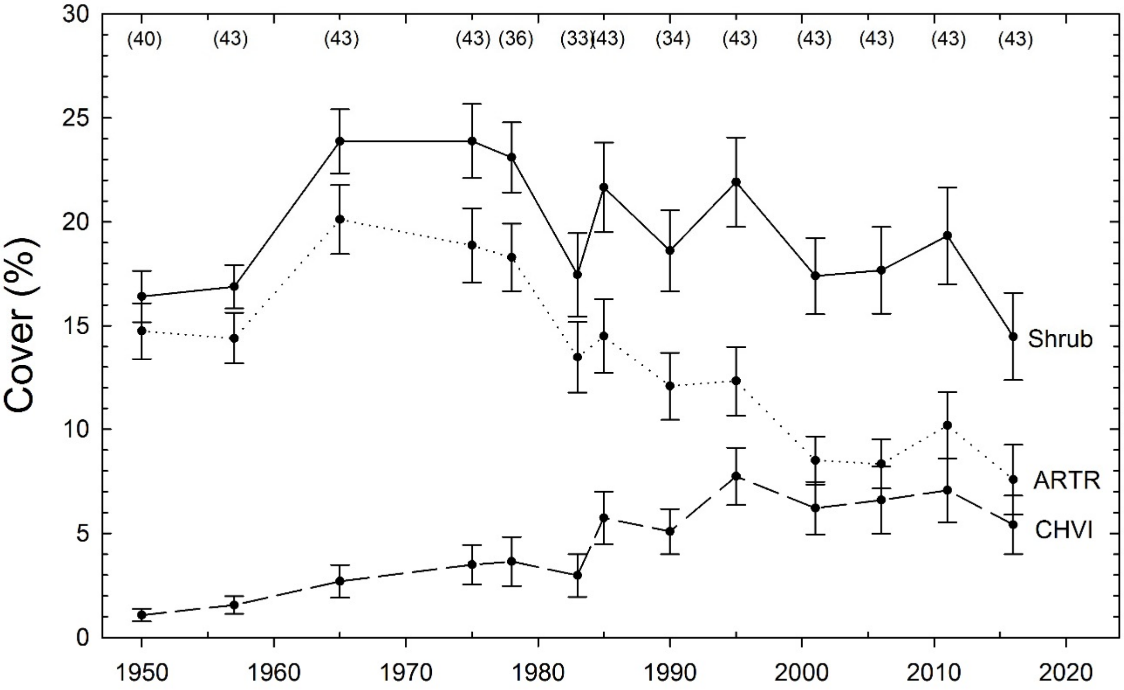

Figure 4. Trends in total shrub cover, *Artemisia tridentata* (ARTR) cover, and *Chrysothamnus viscidiflorus* (CHVI) cover from 1950 to 2016 for the core subset of plots on the Long-Term Vegetation Project at the Idaho National Laboratory Site. Data were collected using line-interception methods and are represented here as means ± 1 SE. Numbers in parentheses at the top of the frame indicate the number of plots for which data were available in each sample year.

Absolute cover of native grasses was near the upper end of its historic range of variability in 2016, with a mean of about 4% (Figure 5). Total grass biomass is typically underestimated by this cover value, as cover is sampled basally. Both bunchgrasses and rhizomatous grasses increased slightly since the last sample period (Figure 5), and the change in bunchgrass cover was statistically significant (Appendix A, Tables 3a and 3b). Compared to historical values, mean rhizomatous grass cover in 2016 was not significantly different from the highest or lowest reported values (Appendix A, Tables 3a and 3b). Bunchgrass cover was significantly higher in 2016 than it was in all sample periods prior to 2006, with the exception of 1975 (Figure 5). During the 2016 sample period, mean bunchgrass cover was significantly higher than mean rhizomatous grass cover, a trend which has been consistent since 1990 (Appendix A, Tables 3a and 3b).

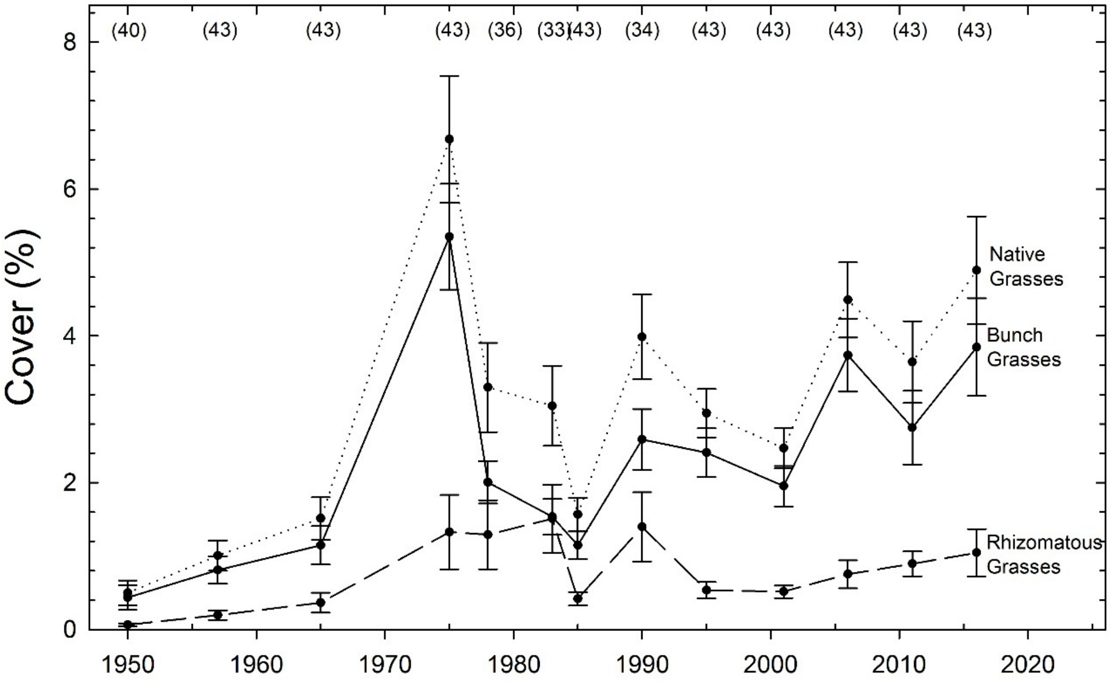

Figure 5. Trends in total native perennial grass cover, native bunchgrass cover, and native perennial rhizomatous grass cover from 1950 to 2016 for the core subset of plots on the Long-Term Vegetation Project at the Idaho National Laboratory Site. Data were collected using line-interception methods and are represented here as means ± 1 SE. Numbers in parentheses at the top of the frame indicate the number of plots for which data were available in each sample year.

Both native grass cover and crested wheatgrass cover have increased since 2001 (Figure 6). Unlike native grass cover, which fluctuates from one sample period to the next, crested wheatgrass cover has been increasing in a very linear fashion since about 1990 (Figure 6). As mentioned in the previous section, this trend is driven by only eight of the 43 core plots in which crested wheatgrass currently occurs, and it was not planted in any of those plots. The risk of crested wheatgrass introduction to a local area via seed dispersal is high, as evidenced by the addition of two plots with crested wheatgrass occurrence in 2016, and the subsequent increases in abundance appear to be highly predictable. Although native perennial grass cover is still significantly greater than introduced perennial grass cover (Appendix A, Tables 4a and 4b), a downward fluctuation in native grass cover coupled with continued increases in crested wheatgrass could eliminate the difference very abruptly.

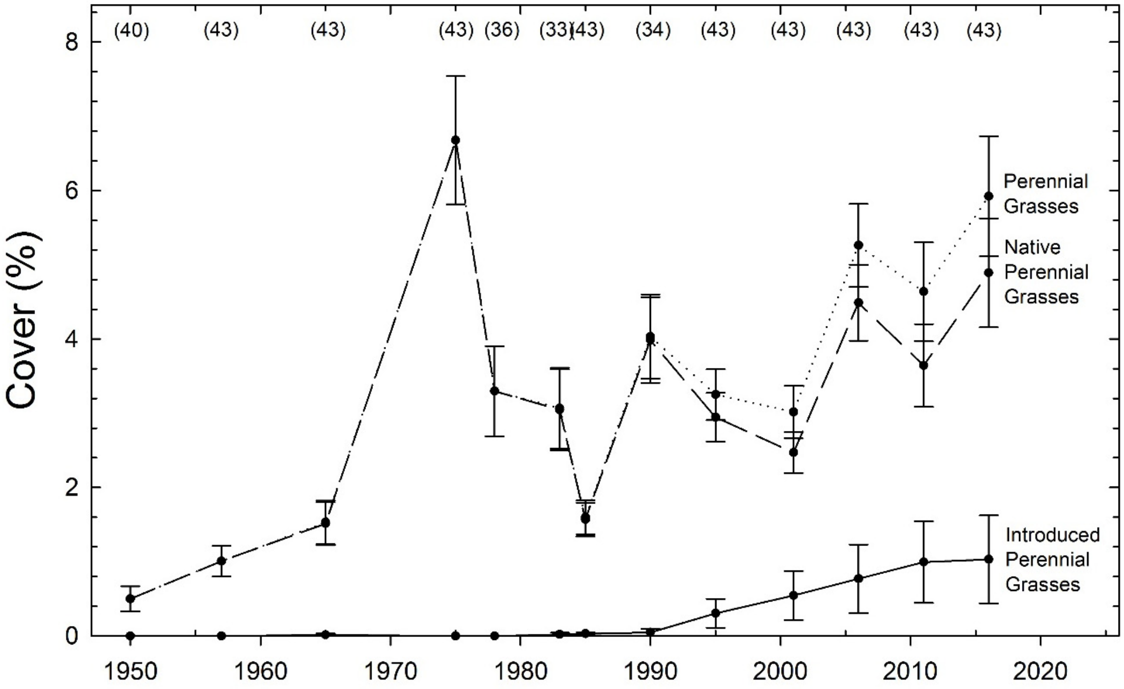

Figure 6. Trends in total perennial grass cover, native perennial grass cover, and introduced perennial grass cover from 1950 to 2016 for the core subset of plots on the Long-Term Vegetation Project at the Idaho National Laboratory Site. Data were collected using line-interception methods and are represented here as means ± 1 SE. Numbers in parentheses at the top of the frame indicate the number of plots for which data were available in each sample year.

3.3 Density/Frequency by Annual Functional Group – Trends Since 1950

Trend analyses of abundance and distribution of annual species were first conducted subsequent to the 2006 sample period (Forman et al. 2010) and are updated here with the 2016 data. Density/frequency data are used for long-term analyses of annual species because it is the only subset of data from the LTV with annual species abundance prior to 1985. During the 2016 sample period, cheatgrass was detectable in 40 out of 89 active plots (Figure 7a), which is a decrease from the 2011 sample period when cheatgrass was detectable in a total of 56 plots (Figure 7b). The overall macro-scale distribution of cheatgrass is more limited in 2016 than it was in 2006 (Figure 7c) as well. It is notable that cheatgrass distribution and abundance did not appear to increase after the 2011 T-17 Fire (Figure 7a). At the scale of an individual plot, it remains difficult to predict whether density will increase or decrease from one sample period to the next based solely on historical trends in cheatgrass abundance, but the general trend for most plots has been a decrease in 2016 from the two prior sample periods.

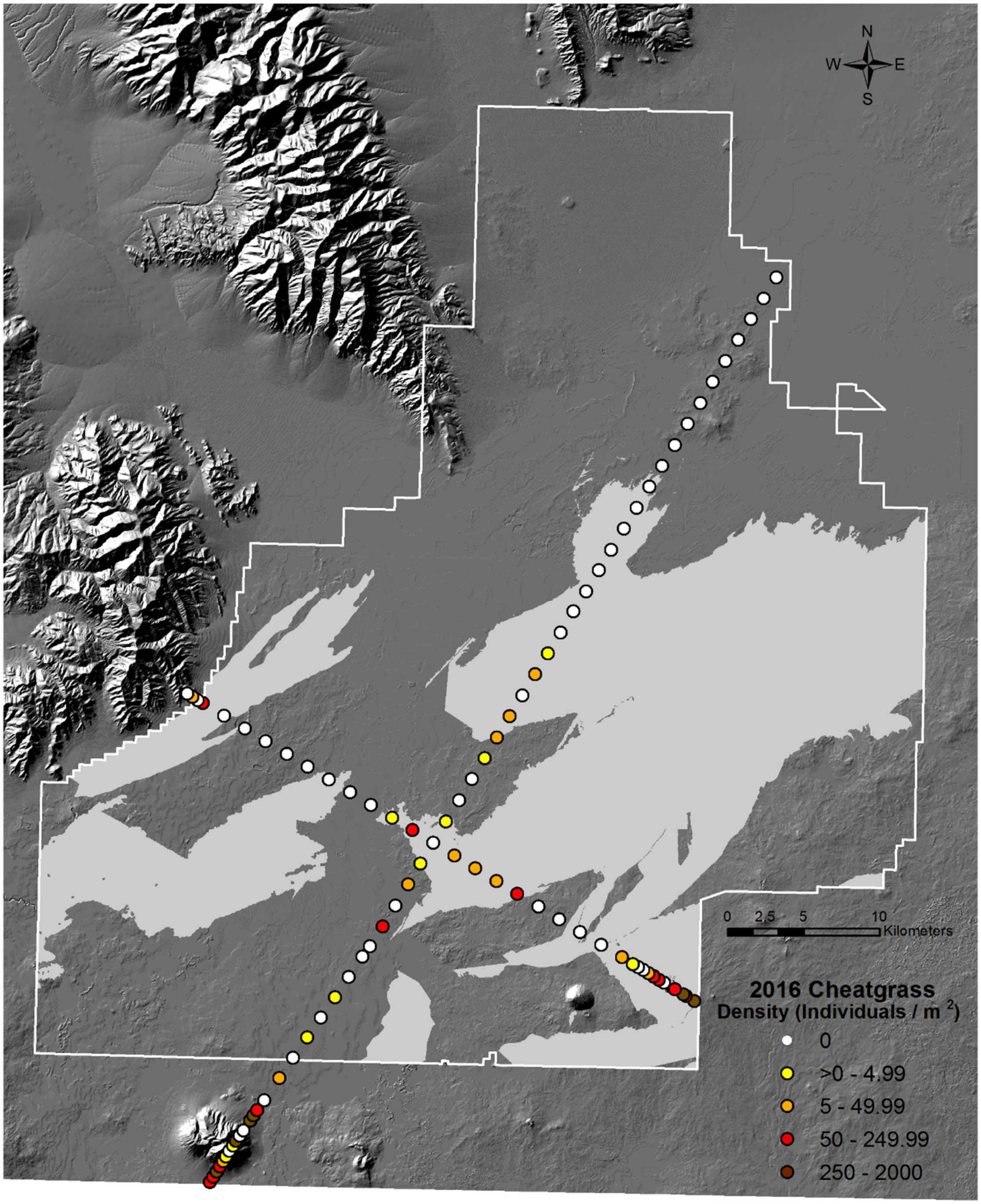

Figure 7a. ***Bromus tectorum*** **distribution by density class on the Long-Term Vegetation Project permanent plots at the Idaho National Laboratory Site in 2016. Light gray depicts fires occurring between 1994 and 2016.**

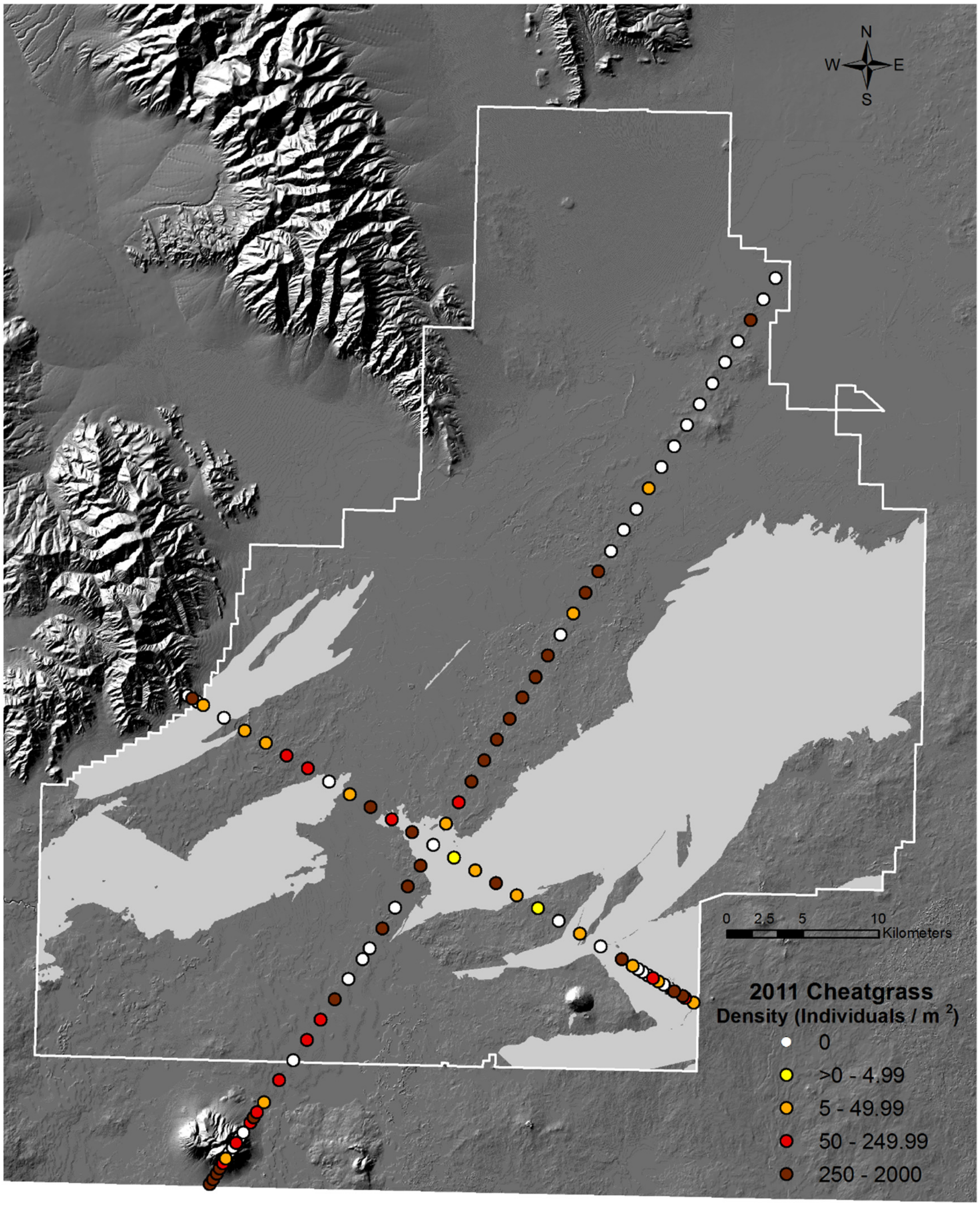

Figure 7b*. Bromus tectorum* **distribution by density class on the Long-Term Vegetation Project permanent plots at the Idaho National Laboratory Site in 2011. Light gray depicts fires occurring between 1994 and 2011.**

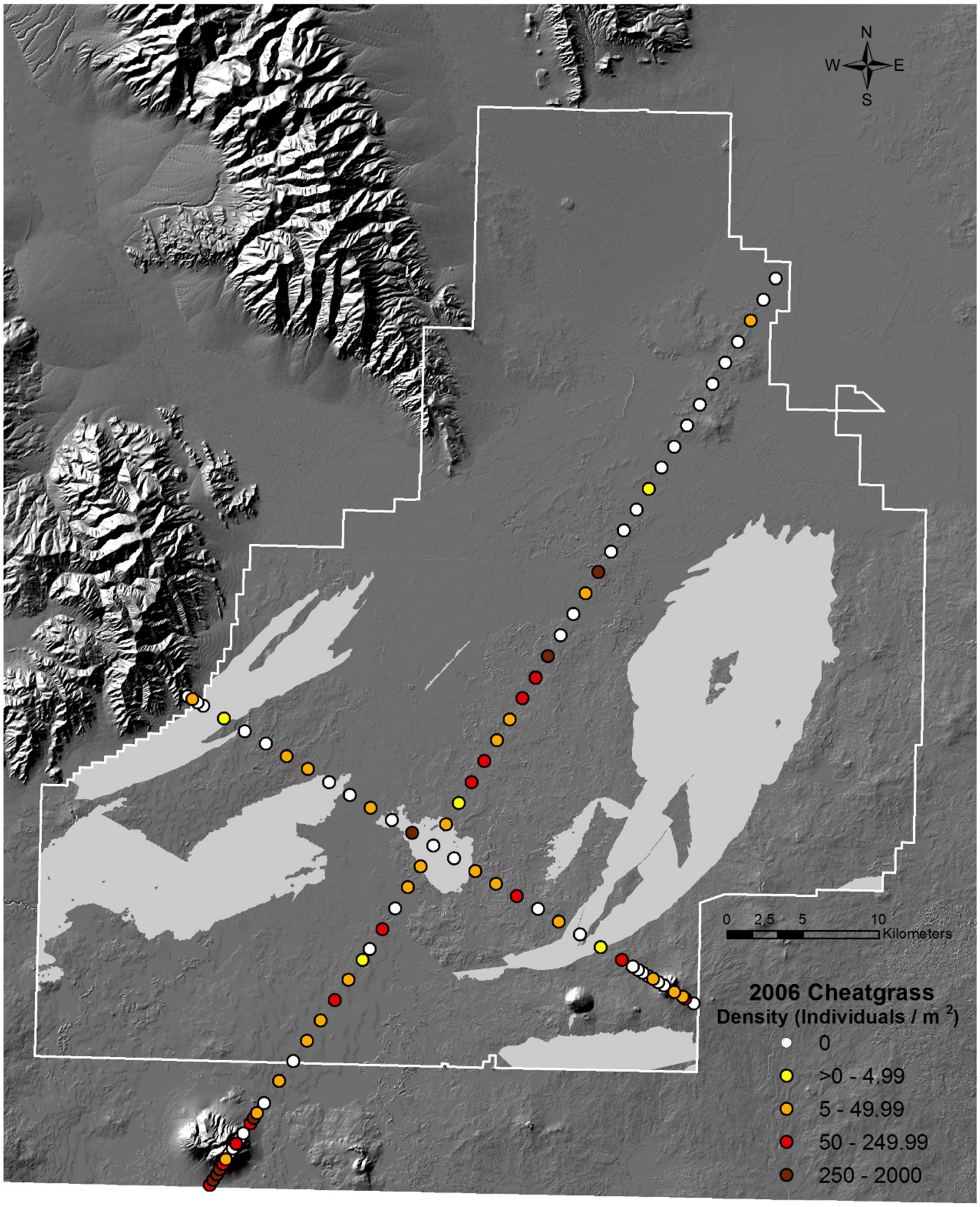

Figure 7c. *Bromus tectorum* distribution by density class on the Long-Term Vegetation Project permanent plots at the Idaho National Laboratory Site in 2006. Light gray depicts fires occurring between 1994 and 2006.

Mean cheatgrass density during the 2016 sample period was much lower than in 2011 and was similar to 2006 mean density (Figure 8). When compared to every other sample period, mean cheatgrass density was significantly higher in 2011 (Appendix A, Tables 5a and 5b). For every sample year except 2011, mean cheatgrass density does not significantly differ from one sample period to another or from that of the earliest sample period in 1950. Between the 2011 and 2016 sample periods, cheatgrass frequency also decreased and mean frequency was significantly higher in 2011 than all but the 2001 sample period

(Appendix A, Tables 5a and 5b). Frequency is calculated as the percentage of density frames per plot in which cheatgrass is present; therefore, a decrease in this metric indicates a decrease in the plot-scale, or local, distribution of the species.

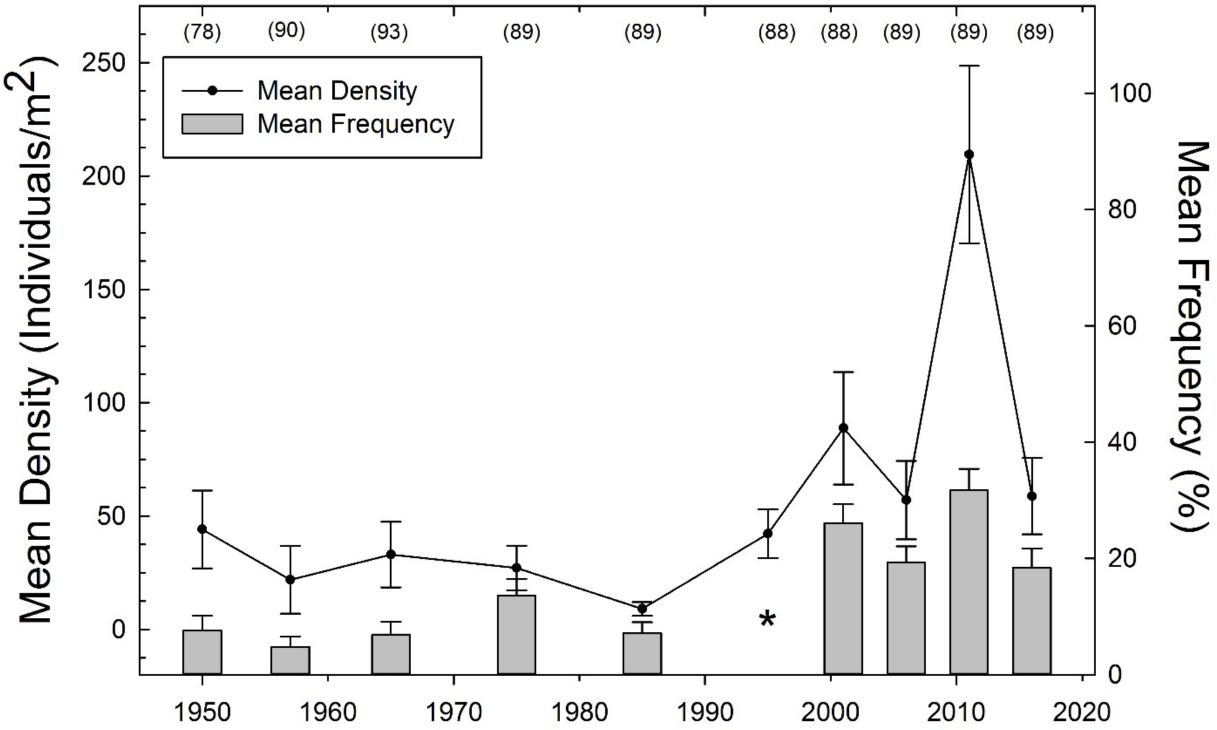

Figure 8. Density and frequency trends for Bromus tectorum on the Long-Term Vegetation Project permanent plots at the Idaho National Laboratory Site from 1950 to 2016. Data are means ± 1 SE. *Frequency data are missing from the 1995 data archives.

The introduced annual forbs functional group is generally dominated by desert alyssum, but other species from the mustard family like *Descurainia sophia* and *Sisymbrium altissimum*, and chenopods like *Salsola kali* and *Halogeton glomeratus* may also be abundant. Introduced annual forbs were detectable in density frames of 53, or more than half, of the active LTV plots during the 2016 sample period (Figure 9a). This is an increase of eight plots between 2011 (Figure 9b) and 2016. The distribution of plots where introduced annual forbs were detected in 2016 is comparable to the plot distribution in 2006 (Figures 9a and 9c). Although the overall distribution of plots with detectable densities of introduced annual forbs increased over the past five years, densities largely decreased in plots were introduced annual forbs had occurred in 2011. Compared with previous sample periods, introduced chenopods were relatively more abundant and introduced mustards were relatively less abundant in 2016 than they were in previous sample periods (e.g., Table 1 and Table 2).

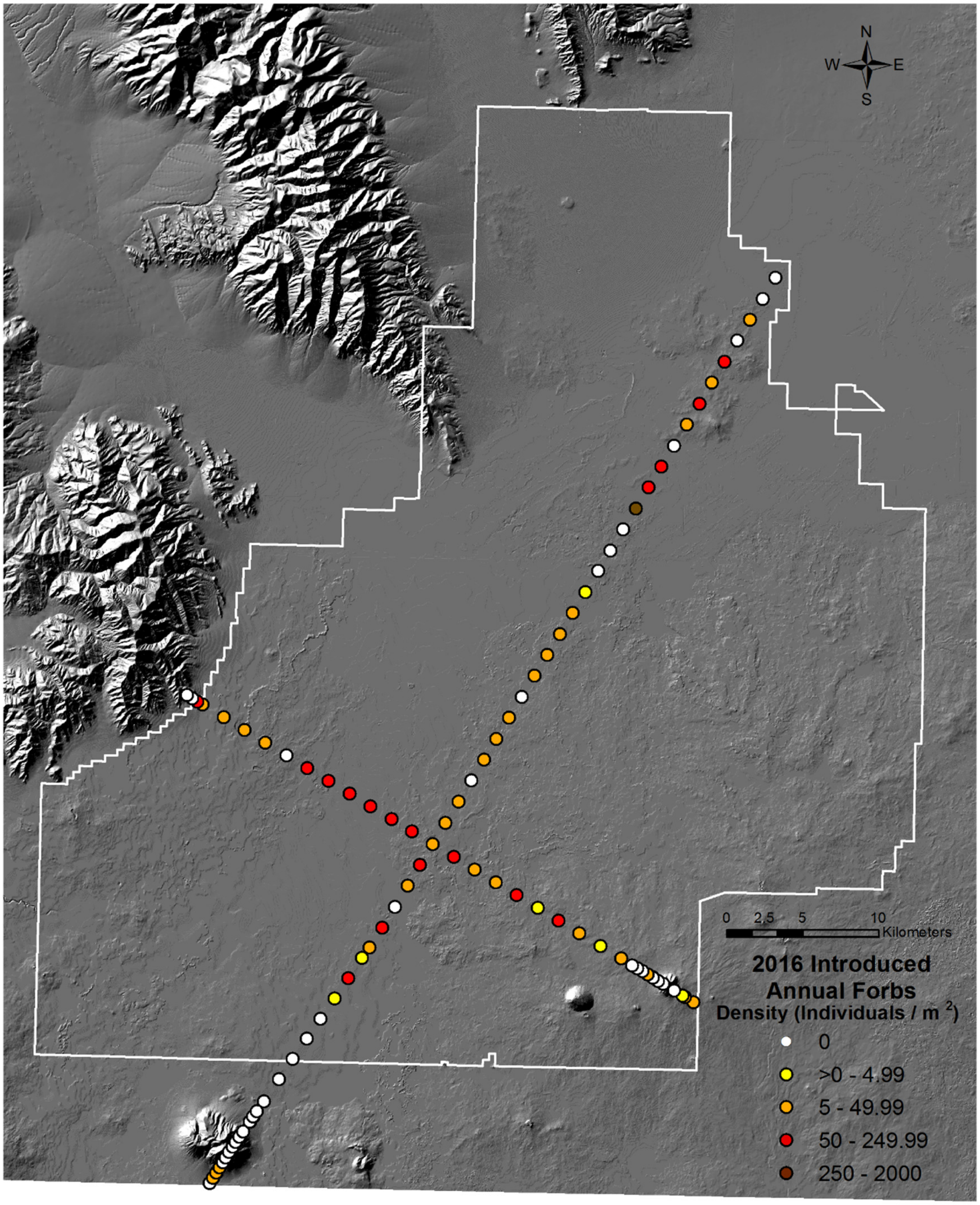

Figure 9a. Introduced annual forb distribution by density class on the Long-Term Vegetation Project permanent plots at the Idaho National Laboratory Site in 2016.

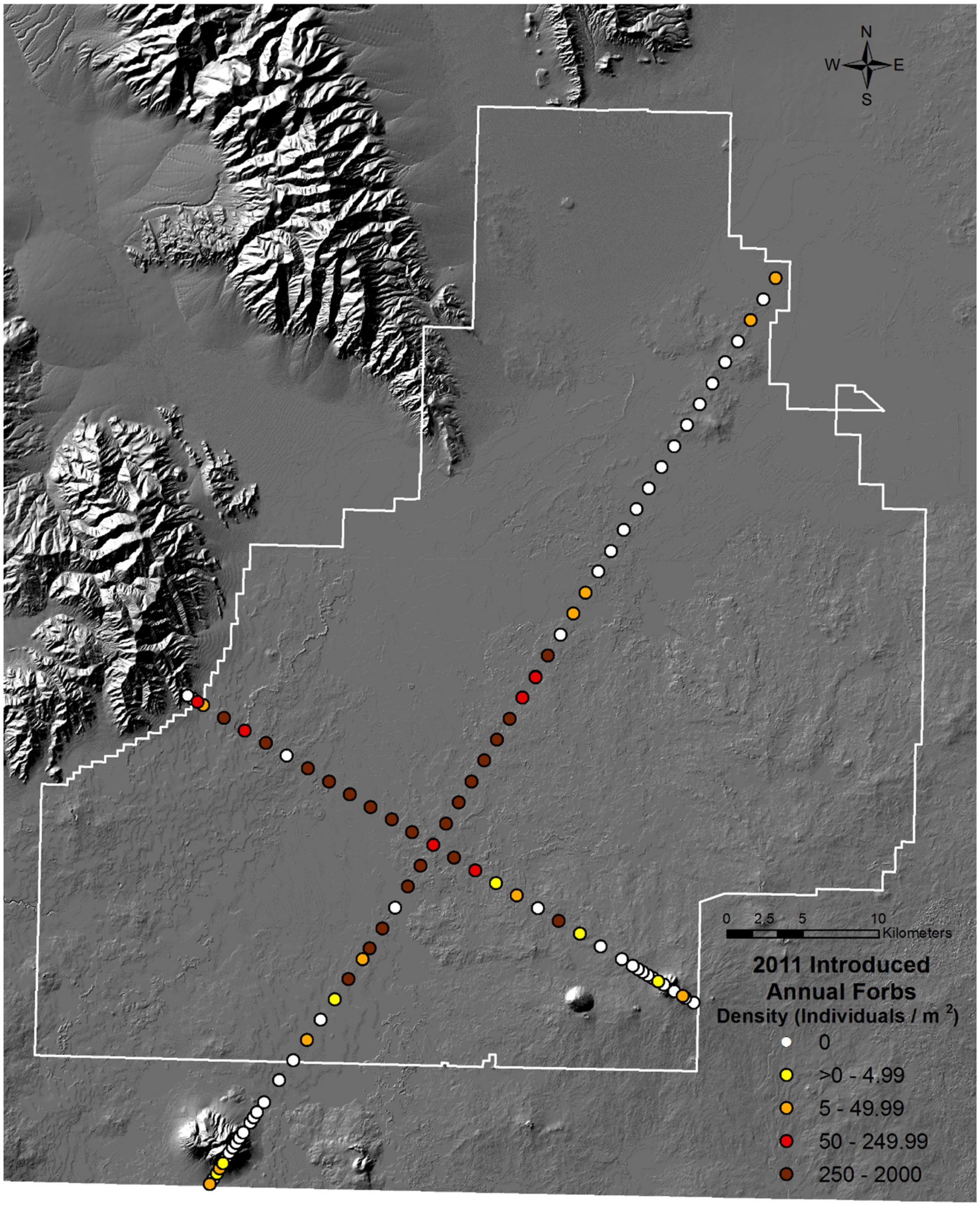

Figure 9b. Introduced annual forb distribution by density class on the Long-Term Vegetation Project permanent plots at the Idaho National Laboratory Site in 2011.

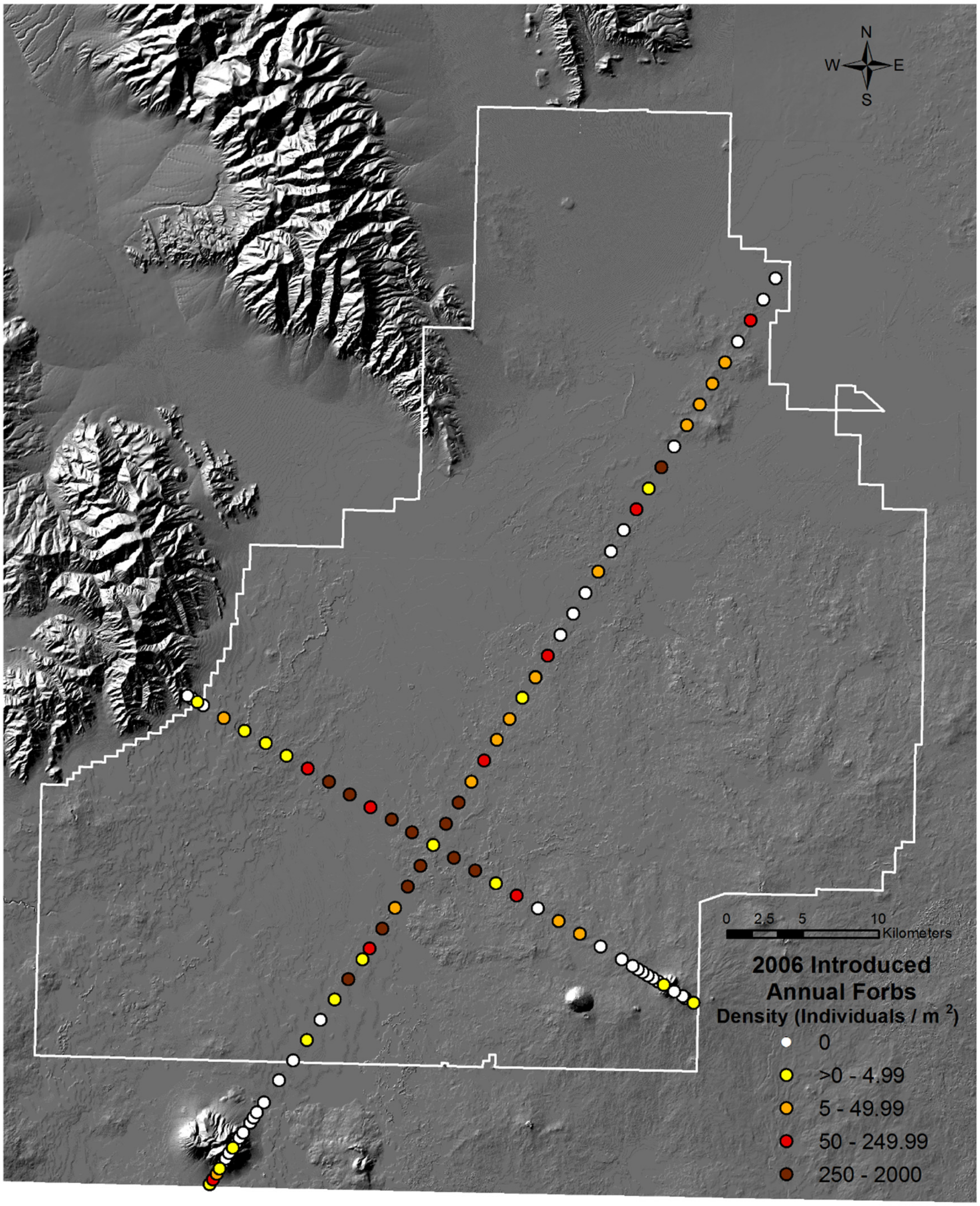

Figure 9c. Introduced annual forb distribution by density class on the Long-Term Vegetation Project permanent plots at the Idaho National Laboratory Site in 2006.

From 1995 through 2011, introduced annual forbs exhibited a dramatic, exponential increase in abundance (Figure 10). Density of introduced annual forbs averaged nearly 340 individuals/m^2 across the 89 active LTV plots in 2011 and mean density was significantly greater in 2011 than in all prior sample periods (Appendix A, Tables 6a and 6b). In 2016, introduced annual forb density decreased to its lowest mean since 1995 and the decrease was statistically significant (Appendix A, Tables 6a and 6b). Mean frequency decreased slightly between 2011 and 2016, but the difference was not significant. Mean frequency of introduced annual forbs has been statistically indistinguishable from one sample period to another from 2001 through 2016, and it is significantly greater from 2001 to 2016 than all sample periods prior to 1995 (Appendix A, Tables 6a and 6b). It appears as though the within plot-level, or small-scale distribution of species represented by this functional group, has been similar over the past two decades but has increased over early sample periods.

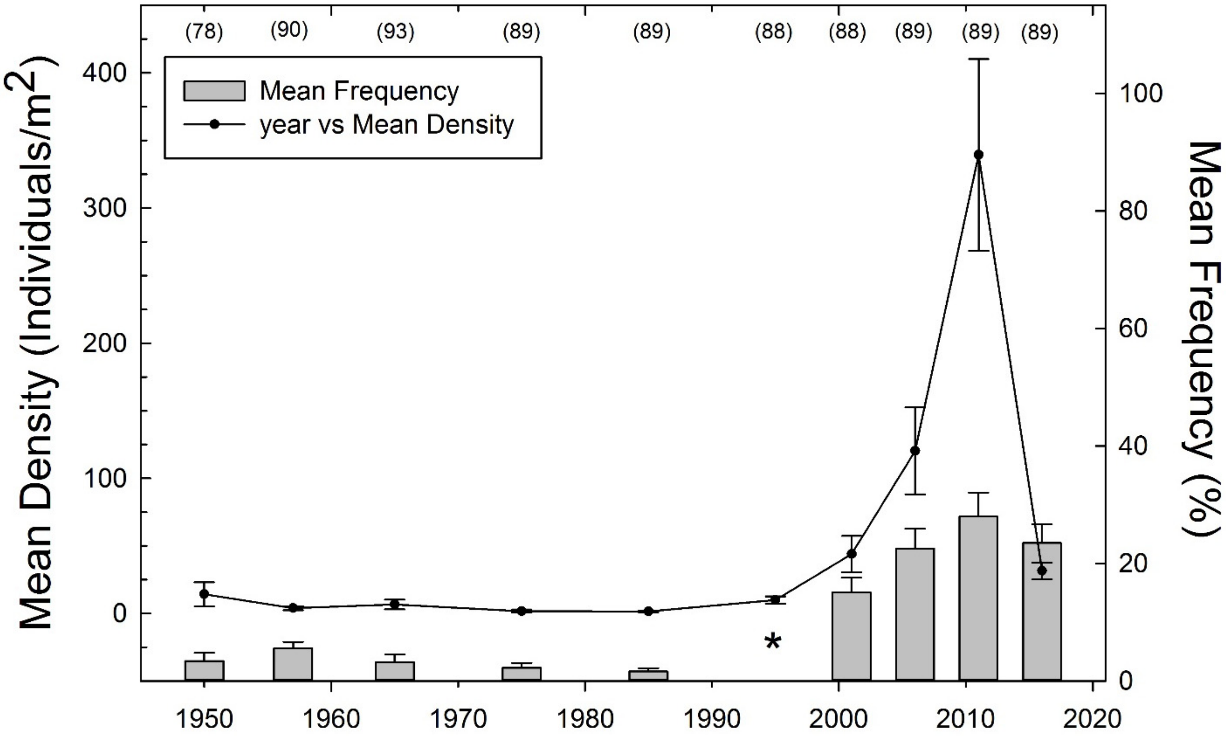

Figure 10. Density and frequency trends for introduced annual forbs on the Long-Term Vegetation Project permanent plots at the Idaho National Laboratory Site from 1950 to 2016. Data are means ± 1 SE. *Frequency data are missing from the 1995 data archives.

Density and frequency data for native annual forbs are included here so that abundance patterns between introduced and native functional groups may be compared. Mean density of individuals in this functional group decreased, but was not significantly lower in 2016 than in 2011 (Figure 11). In general, a few sample years with the highest means are significantly different than a few sample years with the lowest means, for both density and frequency (Appendix A, Tables 7a and 7b). The trend is not directional. In contrast to density and frequency data for cheatgrass and introduced annual forbs, means for native annual forbs are no more likely to be high in recent years than in early sample periods. In terms of fluctuation from one sample period to the next, abundance trends for introduced species have similar patterns, but years with high and low mean values are not always coincident between native and introduced annual functional groups. In 2016, mean frequencies were comparable between native annual forbs and introduced annual forbs and mean density of the introduced functional group was about double that of the native functional group (Appendix A, Tables 6a and 7a).

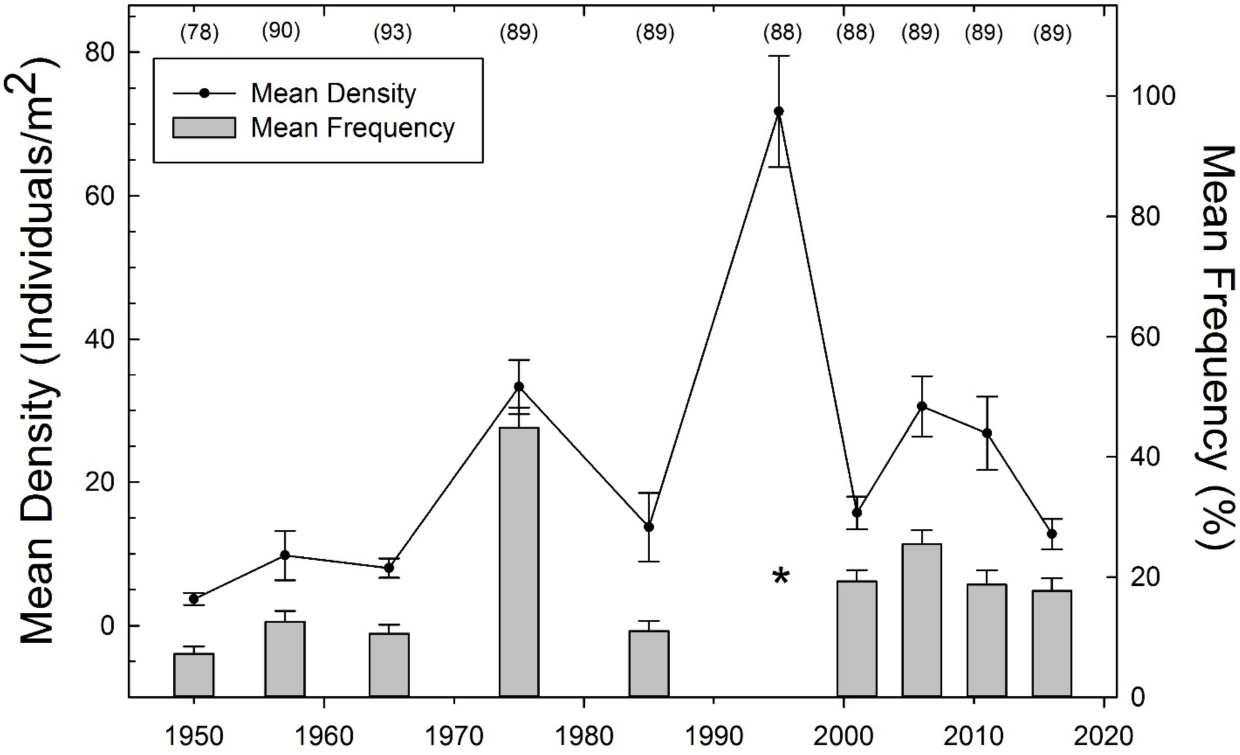

Figure 11. Density and frequency trends for native annual forbs on the Long-Term Vegetation Project permanent plots at the Idaho National Laboratory Site from 1950 to 2016. Data are means ± 1 SE. *Frequency data are missing from the 1995 data archives.

3.4 Precipitation Patterns

Total annual precipitation in 2016 was slightly above average (about 20mm), but four of the five years prior to the 2016 sample period were drier than average (Figure 2). In fact, 2013 was the driest year in the 66-year precipitation data record with only about ¼ average total precipitation. In contrast, total annual precipitation in 2011 was about 40mm below average, but precipitation was at least 40 mm greater than average during three of the five years prior to the 2011 sample period. Over the two decades prior to, and including the 2016 sample period, precipitation was below average during 13 of the twenty years. The mean departure from average was more than 65mm/year for drier years and only about 37mm/year for wetter years (National Oceanic and Atmospheric Administration [NOAA] 2018).

During the five years prior to the 2016 sample period, the seasonality of precipitation appears to deviate from historical monthly means (Figure 12). Long-term monthly means indicate that about 60% of the annual precipitation generally occurs by the end of June. In four of the five years prior to the 2016 sample period, less than half of the annual precipitation fell during the first half of the year. Only slightly more than half (50.3%) occurred before June in 2013, the driest year on record. Precipitation prior to LTV sampling in June 2016 was also well-below average. Whereas May and June have typically been the wettest months of the year at the INL Site, late summer and fall months have been more likely to be the wettest months in recent years. Over 100mm of rain fell in August of 2014; average precipitation for this month is about 13mm. September and October precipitation have also been substantially above average several times in the last decade.

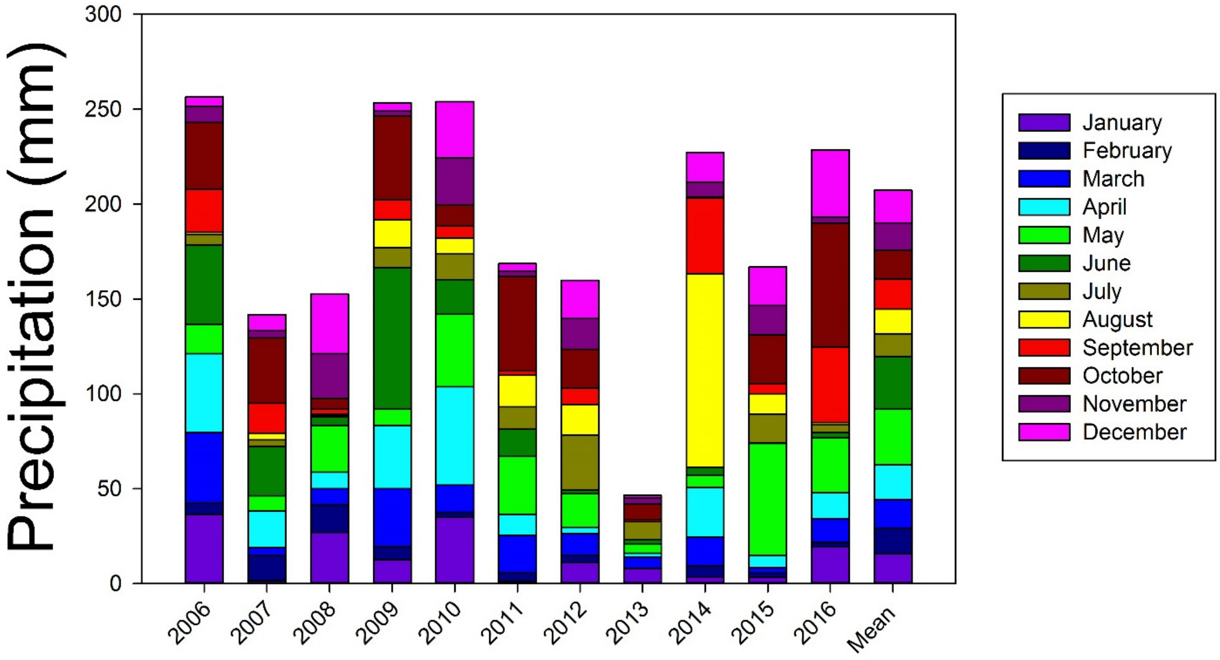

Figure 12. Annual precipitation by month from the Central Facilities Area, Idaho National Laboratory Site. Mean monthly precipitation includes data from 1950 through 2016.

4. DISCUSSION AND CONCLUSIONS

Anderson and Inouye (2001) argued that native plant communities on the INL Site have the capacity to undergo compositional changes based on environmental fluctuations, but those changes are reversible and represent the extent of variation possible for healthy, native plant communities. However, the most recent analysis of trends in native functional groups on the LTV plots indicates that vegetation composition across the INL Site is approaching the limits of, and even beginning to deviate from historical ranges of variability. Non-native functional groups are also exhibiting notable changes in abundance trends. Results from analysis including the 2016 dataset show that the current distribution and abundance of introduced species have undergone a dramatic reversal when compared to the 2011 data set. Whether 2011 cover was anomalously high or 2016 cover was a deviation from an emerging trend remains to be determined.

Trend analyses through the 2016 sample period indicate that in terms of total vegetative cover, natives have not yet been noticeably impacted by environmental stress and/or high-magnitude changes in the abundance of non-natives. However, some species like big sagebrush, continue to follow a trajectory of decline. Other species, like many of those in the native, perennial grass functional group are near historical highs. Both of these results signify departures from historical means for species composition and abundance and may be an indication of changes in vegetation condition moving forward. The factors most likely causing changes to species composition at the INL Site over the past few and potentially the next few decades are changing precipitation patterns, pressure from invasive species, and wildland fire.

4.1 Effects of Precipitation on Vegetation

Each of the sagebrush steppe functional groups has evolved a different set of adaptations for responding to local precipitation patterns. Though mature sagebrush may be able to survive prolonged drought periods, seeds require wetter than average conditions to germinate and establish (Meyer and Monson 1992). Thus, only a few years out of every decade may be conducive for large-scale successful recruitment. Sagebrush recruitment may be even more limited in burned areas, possibly because of limited seed availability (Chambers 2000) and harsher microsite conditions (Blew and Forman 2010). Spring and summer precipitation were well above average in 2009 and 2010, which may have improved big sagebrush recruitment in those years and resulted in slightly higher cover values in 2011 when compared to the two prior sample periods. Between the 2011 and 2016 sample periods sagebrush cover declined to its lowest value in the history of the data set. Though some of this decline results from loss to wildland fire, some is probably related to unfavorable reestablishment conditions as well. Cumulative annual precipitation through June for each of the years between the 2011 and 2016 sample period was below average, which could contribute to poor sagebrush establishment.

Mean cover of native perennial grasses decreased between the 2006 and 2011 sample periods, but increased to one of the highest means in the 66-year old data set in 2016. Grasses are thought to be much more immediately responsive to precipitation than shrubs. However, cumulative precipitation through May (plot sampling began in June) during the 2016 sample period was below average. Spring and early summer precipitation were below average in the years immediately prior to the current sample period as well. Anderson and Inouye (2001) suspected grass cover may experience a lag in response to precipitation; they were unable to definitively identify a lag period for most species, and it is unclear from these data how long the lag period may be. The increase in native, perennial grasses in 2016 may also result from other factors, such as response after wildland fire. As with natives, the mean cover of introduced perennial grasses, entirely from crested wheatgrass, did not track precipitation between the two most recent sample periods, and crested wheatgrass does not appear to track precipitation on the INL Site at all (Forman et al. 2013).

Abundance of native annual and biennial forbs during recent sample periods were reflective of gross precipitation patterns in the year prior to and in the year of sampling. We generally find that the sample periods with the highest densities and frequencies of native annuals are also some of the wettest on record (Forman et al. 2013). Introduced annual forbs do not respond to precipitation as predictably, and they are currently more abundant than native annual forbs by a factor of three to six, depending on the abundance metric (cover or density) considered. Whereas the mean density of natives appears to fluctuate annually, or at least from one sample period to the next with no discernable trend, introduced forbs exhibited an exponential increase in density from about 1995 to 2011 then experienced a sharp decline from 2011 to 2016. Native annual forbs tend to function as ephemerals, where the pattern of fluctuation is much more similar to the fluctuation in annual precipitation than that of introduced forbs.

Precipitation is not likely the sole factor driving abundance trends for introduced annual forbs; however, specific precipitation events can produce notable responses. The elevated abundance values of two late-season introduced, annual forbs *Salsola kali* and *Halogeton glomeratus*, are probably a vestige of the extremely wet period in August 2014. In the months following the wet period, individuals of both species were observed to grow much larger than normal and likely produced much more seed than they would in a more typical year. From the CCA habitat monitoring project where vegetation abundance data are collected annually, we observed a substantial increase in cover from 2014 to 2015 for both of these species and cover values remained somewhat elevated in 2016 (Shurtliff et al. 2017).

As with introduced annual forbs, the abundance and distribution trends of cheatgrass are not easily interpreted within the context of seasonal precipitation patterns. Theoretically, the shift toward late summer/fall precipitation that has been occurring on the INL Site over the past decade would favor an increase in cheatgrass abundance because of its winter annual growth cycle. In other INL Site data sets, such as the habitat monitoring data set mentioned above, we have documented large increases in cheatgrass following years with higher than average late season precipitation. Yet these patterns are not consistent with the current sample period for the LTV data set. At this time, it is unclear as to why these data sets are inconsistent with one another, aside from sampling different locations with different plant community potentials.

The semi-arid West has been becoming both hotter and drier and trends are predicted to continue along the same general trajectory (Karl et al. 2009). The spatial and temporal variability of precipitation is also projected to continue to increase (Katz and Brown 1992). In a semi-arid environment, specific precipitation events can impact vegetation composition as much, or more than average values (Smith et al. 1997). Declines in total precipitation coupled with changes in the seasonal timing, as well as increases in the potential for notable precipitation events could lead to less stability in plant communities at the INL Site. We are already observing higher magnitudes of changes in annual species from one sample period to another. Longer-term, a shift to a warmer, drier climate may eventually favor a shift away from sagebrush steppe; declines in local sagebrush cover certainly support this possibility.

4.2 Non-native Species Invasion Patterns

There are two non-native grasses that are of particular concern on the INL Site. Cheatgrass is widely recognized as an invasive annual that currently impacts much of the semi-arid West (D’Antonio et al. 2009). Crested wheatgrass is an introduced perennial that has been planted across the sagebrush steppe for a variety of reasons including post-fire soil stabilization and to control other weeds (Pellant and Lysne 2005). Although crested wheatgrass was not historically considered invasive, it has been found to encroach on and displace native vegetation locally (Gunnell et al. 2010). Each of these species appear to have a very different invasion pattern on the INL Site; cheatgrass abundance is fluctuating more dramatically over time while crested wheatgrass is steadily increasing in spatial distribution and is methodically replacing natives once established. Cheatgrass seems to be strongly influenced by precipitation and crested wheatgrass does not appear to respond to precipitation at all.

The surge in cheatgrass abundance between the 2006 and 2011 sample periods marks a departure from historical patterns, which are generally characterized by fluctuations from one sample period to another. The sharp decline from 2011 to 2016 was also much greater than any previously recorded decline, but resulted with cheatgrass abundance values again within the historical range of variability. The current abundance values from the LTV data set should be interpreted with caution. As mentioned in the section above, other vegetation data sets at the INL Site indicate increasing cheatgrass abundance values and the potential for even greater annual fluctuations (Shurtliff et al. 2017).

Based on cheatgrass distribution analyses, Forman et al. (2010) concluded that cheatgrass is widely distributed and seed is likely available across the INL Site. Because cheatgrass is so widely distributed, susceptible plant communities are at greater risk of cheatgrass dominance in the future. Rather than a true invasion into an area where the species did not previously exist, the recent increase in variability may instead reflect the increasing dominance of cheatgrass in susceptible plant communities, particularly in years with weather patterns that favor cheatgrass. Increases in the variability of cheatgrass abundance from one year and one data set to another may indicate that the resistance of native plant communities to dominance by cheatgrass may be decreasing. Decreases in the resistance of native sagebrush steppe plant communities could be attributed to any number or combination of biotic and/or abiotic factors. They include increased soil disturbance, changes in the frequency and intensity of land use, short-term losses of shrubs from plant communities due to wildland fire, and large fluctuations in the seasonality of precipitation. Other potential contributing factors, which may be a little more difficult to evaluate, involve biotic interactions, weather-based fluctuations in species' competitive abilities, and changes in water and/or nutrient balance which negatively impact the ability of native species to function optimally.

Crested wheatgrass hasn't been planted on any of the LTV plots but has invaded eight plots as of the 2016 sample period. Additionally, it has become the most abundant herbaceous species on most of the plots where it has established. Crested wheatgrass is likely invading and displacing natives in a similar manner everywhere it occurs across the INL Site. In the past, crested wheatgrass was planted across the West (and on the INL Site) and was considered to be a naturalized species with little risk to the surrounding native ecosystem (Pellant and Lysne 2005). However, it is becoming increasingly recognized as an invasive species (Hansen and Wilson 2006) that has the potential to impact the function of native plant communities (Gunnell et al. 2010). The ability to control the spread and dominance of crested wheatgrass has not been studied long enough to produce any effective control mechanisms with long-term, repeatable results. Until such management approaches have been developed, crested wheatgrass will likely continue to expand in distribution and increase in cover at its current rate on the INL Site.

4.3 Wildland Fire

Although there have historically been large fires on the INL Site, such as the fires documented from the mid-1800's (Anderson et al. 1996) and the early 1900's (Colket and Bunting 2003), they were likely infrequent. Average fire rotation intervals were probably on the order of 200 to 350 years (Baker 2011). Until recently, post-fire vegetation recovery was characterized by rapid re-establishment of native herbaceous species within two to three years following fire (Buckwalter 2002, Blew and Forman 2010). Generalizations from fire ecology studies on the INL Site and from other southeast Idaho locations suggested that the plant community after a fire was a reflection of the community present before the fire, with the exception of the loss big sagebrush (Ratzlaff and Anderson 1995, Buckwalter 2002, Blew and Forman 2010). Conventional wisdom has been that native plant communities in good pre-burn ecological condition will return to diverse, native plant communities within a few growing seasons post-burn and can resist invasion by non-native species.

As described in the introduction, nearly 40% of the INL Site has burned since 1994 and almost 10% of the INL Site has burned more than once during the same time period. Large fires have been more frequent in the last two decades than they were in the prior two centuries. Some of the fires since 1994 have been caused by lightning strikes, while others were caused by accidental human ignition, particularly along public highways. Risk of impacts to native vegetation from fire are much greater now than they were in the past. Pressure from invasive species like cheatgrass also continue to increase. The cumulative loss of sagebrush directly from each fire is increasing and the potential for natural sagebrush reestablishment appears to be becoming more limited by changing weather patterns. There have also been greater fluctuations in non-native annual species abundance from one sample period to another recently. All of these trends may portend a future condition where the native ecosystem become less resilient.

The LTV remains an important data set for documenting and understanding vegetation changes across the INL Site. Its value as a resource for understanding current changes within the context of long-term processes is invaluable. As sagebrush steppe management across the West faces increasing challenges, the LTV data set will continue to provide powerful insight to local scientists and regional researchers alike.

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APPENDIX A

SUMMARY STATISTICS TABLES

ANOVA RESULTS TABLES

Table 1a. Estimates of mean cover for native perennial functional groups from the line-interception data on the "core" Long-Term Vegetation Project plots at the Idaho National Laboratory Site from 1950 to 2016. Minimum significant difference indicates the value at which means of pairwise comparisons between two sample years within each functional group becomes significant.

Total		Shrub		Grass	
Year	**Mean**	**Year**	**Mean**	**Year**	**Mean**
1950	16.91	1950	16.41	1950	0.50
1957	17.89	1957	16.88	1957	1.01
1965	25.39	1965	23.88	1965	1.51
1975	30.56	1975	23.89	1975	6.68
1978	26.39	1978	23.10	1978	3.30
1983	20.50	1983	17.45	1983	3.05
1985	23.22	1985	21.66	1985	1.57
1990	22.60	1990	18.61	1990	3.99
1995	24.86	1995	21.91	1995	2.95
2001	19.86	2001	17.39	2001	2.47
2006	22.16	2006	17.67	2006	4.49
2011	22.98	2011	19.33	2011	3.64
2016	19.36	2016	14.47	2016	4.89
Minimum Significant Difference	**6.31**		**7.00**		**1.94**

Table 1b. Results tables for one-way repeated measures ANOVAs comparing mean cover for native perennial functional groups from the line-interception data on the "core" Long-Term Vegetation Project plots at the Idaho National Laboratory Site from 1950 to 2016.

Total, One-way Repeated Measures ANOVA Results					
Source of Variation	**DF**	**SS**	**MS**	**F**	**P**
Plot	42	30072.07	716.00		
Year	12	7071.50	589.29	7.71	<0.001

Shrub, One-way Repeated Measures ANOVA Results					
Source of Variation	**DF**	**SS**	**MS**	**F**	**P**
Plot	42	36290.37	864.06		
Year	12	4930.86	410.91	5.05	<0.001

Grass, One-way Repeated Measures ANOVA Results					
Source of Variation	**DF**	**SS**	**MS**	**F**	**P**
Plot	42	1705.61	40.61		
Year	12	1529.21	127.43	17.32	<0.001

Table 2a. Estimates of mean cover for *Artemisia tridentata* (ARTR) and *Chrysothamnus viscidiflorus* (CHVI) from the line-interception data on the "core" Long-Term Vegetation Project plots at the Idaho National Laboratory from 1950 to 2016. Minimum significant difference indicates the value at which means of pairwise comparisons between two sample years within each species becomes significant. The significance column indicates whether the mean cover difference between each species was significant for a given sample period.

Year	ARTR	CHVI	Significant
1950	16.57	0.99	Yes
1957	15.90	1.15	Yes
1965	22.90	2.37	Yes
1975	21.68	3.48	Yes
1978	18.40	3.70	Yes
1983	13.48	2.98	Yes
1985	16.24	5.76	Yes
1990	11.79	4.69	Yes
1995	13.63	7.61	Yes
2001	8.88	6.38	No
2006	8.33	7.43	No
2011	10.12	7.05	No
2016	6.60	6.10	No
Minimum Significant Difference	**5.43**	**5.90**	

Table 2b. Results table for two-way repeated measures ANOVA comparing mean cover for *Artemisia tridentata* (ARTR) and *Chrysothamnus viscidiflorus* (CHVI) from the line-interception data on the "core" Long-Term Vegetation Project plots at the Idaho National Laboratory from 1950 to 2016.

Two-way Repeated Measures ANOVA Results					
Source of Variation	**DF**	**SS**	**MS**	**F**	**P**
Plot	32	13884.71	433.90	0.93	0.59
Species	1	19787.37	19787.37	40.16	<0.001
Species x Plot	32	15768.72	492.77		
Year	12	3076.24	256.35	7.81	<0.001
Year x Plot	384	12612.15	32.84		
Species x Year	12	9139.84	761.65	13.27	<0.001

Table 3a. Estimates of mean cover for native perennial bunch grasses and native perennial rhizomatous grasses from the line-interception data on the "core" Long-Term Vegetation Project plots at the Idaho National Laboratory from 1950 to 2016. Minimum significant difference indicates the value at which means of pairwise comparisons between two sample years within each functional group becomes significant. The significance column indicates whether the mean cover difference between each functional group was significant for a given sample period.

Year	Bunch	Rhizomatous	Significant
1950	0.27	0.07	No
1957	0.60	0.20	No
1965	0.78	0.37	No
1975	4.11	1.46	Yes
1978	1.92	1.41	No
1983	1.54	1.51	No
1985	0.90	0.47	No
1990	2.64	1.44	Yes
1995	2.47	0.47	Yes
2001	2.07	0.58	Yes
2006	3.95	0.70	Yes
2011	2.90	0.94	Yes
2016	4.09	1.23	Yes
Minimum Significant Difference	**1.45**	**1.44**	

Table 3b. Results table for two-way repeated measures ANOVA comparing mean cover for native perennial bunch grasses and native perennial rhizomatous grasses from the line-interception data on the "core" Long-Term Vegetation Project plots at the Idaho National Laboratory from 1950 to 2016.

Two-way Repeated Measures ANOVA Results					
Source of Variation	**DF**	**SS**	**MS**	**F**	**P**
Plot	32	664.21	2076	1.04	0.46
Growth Form	1	383.92	383.92	19.28	<0.001
Growth Form x Plot	32	637.0.8	19.91		
Year	12	574.42	47.87	14.68	<0.001
Year x Plot	384	1252.18	3.26		
Growth Form x Year	12	244.88	20.41	6.32	<0.001

Table 4a. Estimates of mean cover for native perennial grasses and introduced perennial grasses from the line-interception data on the "core" Long-Term Vegetation Project plots at the Idaho National Laboratory from 1950 to 2016. Minimum significant difference indicates the value at which means of pairwise comparisons between two sample years within each functional group becomes significant. The significance column indicates whether the mean cover difference between each functional group was significant for a given sample period.

Year	Native	Introduced	Significant
1957	1.01	0.00	No
1965	1.51	0.02	Yes
1975	6.68	0.00	Yes
1985	1.57	0.03	Yes
1995	2.95	0.31	Yes
2001	2.47	0.55	Yes
2006	4.49	0.77	Yes
2011	3.64	1.00	Yes
2016	4.89	1.03	Yes
Minimum Significant Difference	**1.49**	**N/A**	

Table 4b. Results table for two-way repeated measures ANOVA comparing mean cover for native perennial grasses and introduced perennial grasses from the line-interception data on the "core" Long-Term Vegetation Project plots at the Idaho National Laboratory from 1950 to 2016.

Two-way Repeated Measures ANOVA Results					
Source of Variation	**DF**	**SS**	**MS**	**F**	**P**
Plot	42	837.74	19.95		
Nativity	1	1554.65	1554.65	45.26	<0.001
Nativity x Plot	42	1442.70	34.35		
Year	8	734.82	91.85	20.76	<0.001
Year x Plot	336	1487.02	4.43		
Nativity x Year	8	522.96	65.37	10.63	<0.001

Table 5a. Estimates of mean density and frequency for *Bromus tectorum* from the density/frequency data on the all of the Long-Term Vegetation Project plots for which data were available in each sample year at the Idaho National Laboratory from 1950 to 2016. Minimum significant difference indicates the value at which means of pairwise comparisons between two sample years within either density or frequency becomes significant. *Frequency data were not available for 1995.

Density		Frequency	
Year	**Mean**	**Year**	**Mean**
1950	44.08	1950	7.63
1957	21.85	1957	4.78
1965	33.01	1965	6.88
1975	27.07	1975	13.65
1985	9.04	1985	7.14
1995	42.14	1995	*
2001	88.73	2001	26.08
2006	56.99	2006	19.33
2011	209.49	2011	31.69
2016	58.71	2016	18.37
Minimum Significant Difference	**120.76**		**12.19**

Table 5b. Results tables for one-way ANOVAs comparing mean density among sample periods and mean frequency among sample periods for *Bromus tectorum*. Data are from all of the Long-Term Vegetation Project plots for which data were available in each sample year at the Idaho National Laboratory from 1950 to 2016.

Density, One-way ANOVA Results					
Source of Variation	**DF**	**SS**	**MS**	**F**	**P**
Year	9	2636116.35	292901.82	9.02	<0.001

Frequency, One-way ANOVA Results					
Source of Variation	**DF**	**SS**	**MS**	**F**	**P**
Year	8	63689.91	7961.24	11.73	<0.001

Table 6a. Estimates of mean density and frequency for introduced annual forbs from the density/frequency data on the all of the Long-Term Vegetation Project plots for which data were available in each sample year at the Idaho National Laboratory from 1950 to 2016. Minimum significant difference indicates the value at which means of pairwise comparisons between two sample years within either density or frequency becomes significant. *Frequency data were not available for 1995.

Density		Frequency	
Year	**Mean**	**Year**	**Mean**
1950	14.15	1950	3.40
1957	3.90	1957	5.61
1965	6.68	1965	3.23
1975	1.68	1975	2.25
1985	1.44	1985	1.63
1995	9.91	1995	*
2001	43.92	2001	15.11
2006	120.22	2006	22.53
2011	339.29	2011	27.98
2016	31.44	2016	23.48
Minimum Significant Difference	**113.54**		**11.71**

Table 6b. Results tables for one-way ANOVAs comparing mean density among sample periods and mean frequency among sample periods for introduced annual forbs. Data are from all of the Long-Term Vegetation Project plots for which data were available in each sample year at the Idaho National Laboratory from 1950 to 2016.

Density, One-way ANOVA Results					
Source of Variation	**DF**	**SS**	**MS**	**F**	**P**
Year	9	8895515.27	988390.59	17.30	<0.001

Frequency, One-way ANOVA Results					
Source of Variation	**DF**	**SS**	**MS**	**F**	**P**
Year	8	79767.75	9970.97	20.26	<0.001

Table 7a. Estimates of mean density and frequency for native annual forbs from the density/frequency data on the all of the Long-Term Vegetation Project plots for which data were available in each sample year at the Idaho National Laboratory from 1950 to 2016. Minimum significant difference indicates the value at which means of pairwise comparisons between two sample years within either density or frequency becomes significant. *Frequency data were not available for 1995.

Density		Frequency	
Year	**Mean**	**Year**	**Mean**
1950	3.70	1950	7.24
1957	9.79	1957	12.56
1965	8.02	1965	10.59
1975	33.31	1975	44.83
1985	13.72	1985	11.01
1995	71.72	1995	*
2001	15.72	2001	19.261
2006	30.58	2006	25.449
2011	26.82	2011	18.71
2016	12.75	2016	17.70
Minimum Significant Difference	**18.80**		**10.45**

Table 7b. Results tables for one-way ANOVAs comparing mean density among sample periods and mean frequency among sample periods for native annual forbs. Data are from all of the Long-Term Vegetation Project plots for which data were available in each sample year at the Idaho National Laboratory from 1950 to 2016.

Density, One-way ANOVA Results					
Source of Variation	**DF**	**SS**	**MS**	**F**	**P**
Year	9	312043.43	34671.49	23.55	<0.001

Frequency, One-way ANOVA Results					
Source of Variation	**DF**	**SS**	**MS**	**F**	**P**
Year	8	89957.10	11244.64	28.35	<0.001