



The Idaho National Laboratory Site Long-Term Vegetation Transects: Updates Through 2022

September 2024

Amy D. Forman



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ACRONYMS

ANOVA	Analysis of Variance
CCA	Candidate Conservation Agreement
DOE	Department of Energy
INL	Idaho National Laboratory
LTV	Long-Term Vegetation
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
USFWS	United States Fish and Wildlife Service

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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 fourteenth time in 2022. Analysis of the data collected during the 2022 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 conducted in association with the 2006 sample effort, were also updated with the most current dataset.

Notable changes between the 2016 and 2022 sample periods include decreases in shrub cover, particularly big sagebrush; decreases in native grass cover; and no significant changes in the densities of introduced annual grasses and forbs. With respect to long-term trends, big sagebrush cover is at its lowest point in the 72-year history of the data set. Native, perennial grasses are near the middle of their historical range of variability after near historic highs in 2016. The abundance of introduced annuals has remained relatively unchanged between the most recent two sampling efforts. However, introduced annuals remain much more abundant than native annuals across the LTV plots and the composition of the functional group has changed so that the most abundant introduced annual is Russian thistle rather than cheatgrass. 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, average annual precipitation has declined over the past two decades and seasonal timing of precipitation has shifted away from wet spring periods to elevated precipitation in late-summer and fall.

Declines in big sagebrush cover are due to direct losses from wildland fire and delayed natural post-fire recovery from reduced germination and establishment due to 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 across 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.

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1. INTRODUCTION

1.1 Background

The Long-Term Vegetation (LTV) Project and associated permanent vegetation plots 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 (Figure 1). 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 by providing longer-term context with which to compare and interpret sage-grouse habitat condition data (e.g., INL 2024). 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 wildland 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 has been 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 and Hafla 2018). Plant communities will likely be affected as direct disturbances increase and as disturbances across the region influence vegetation composition on the INL Site. Incidentally, the LTV is becoming more important for understanding changes in native sagebrush steppe under increasing environmental stress. The LTV is particularly relevant 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.

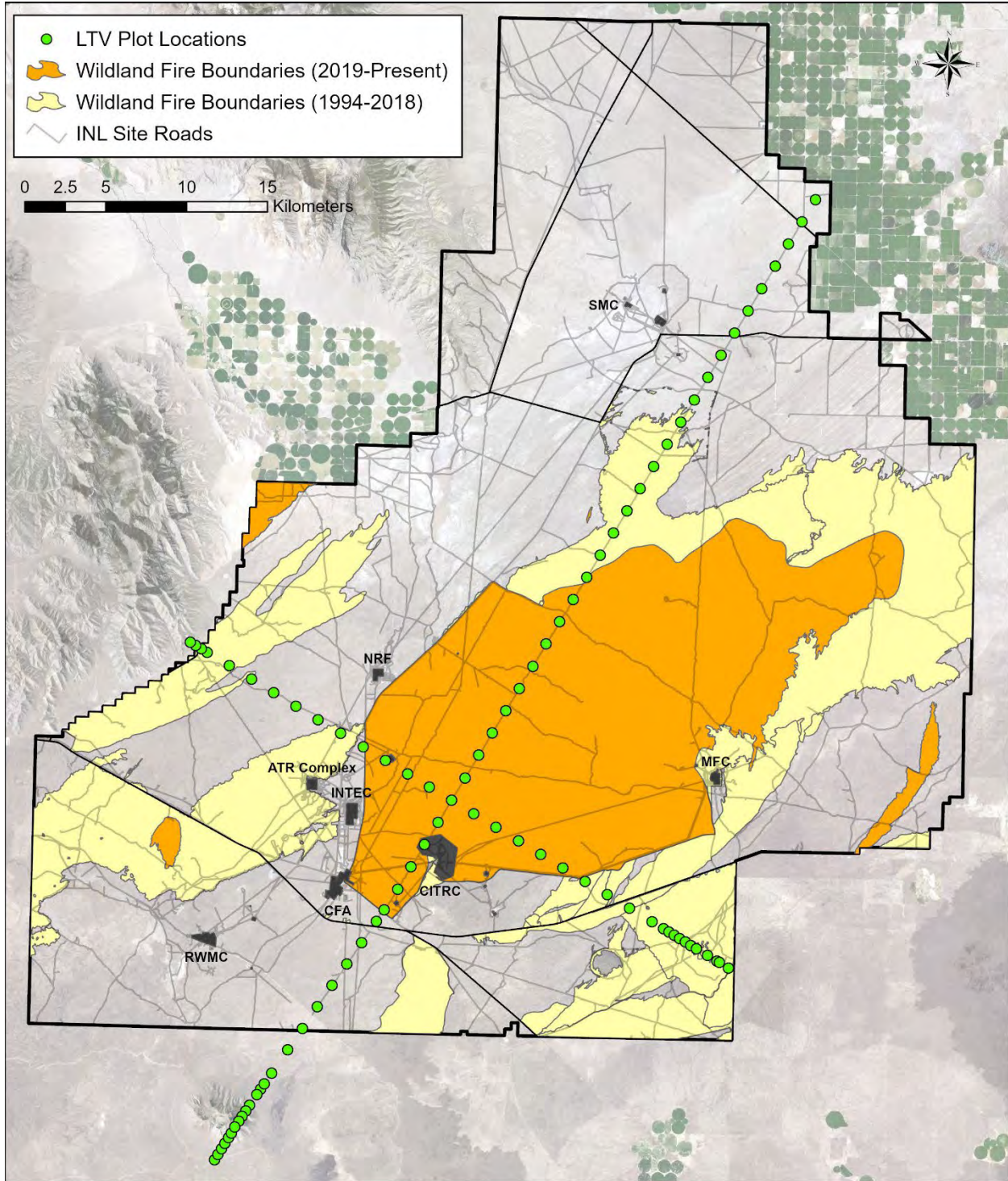


Figure 1. Long-Term Vegetation Plots on the Idaho National Laboratory Site. Wildland fires depicted are from 1994-2022.

1.2 Updates since the 2016 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 2016 and 2022, there were two notable vegetation-based research or monitoring efforts. One was the ongoing implementation of a sage-grouse habitat monitoring project to support a Candidate Conservation Agreement (CCA) between the DOE and the U.S. Fish and Wildlife Service (USFWS) (DOE and USFWS 2014). The other included a major revision the INL Site Vegetation Map (Shive et al. 2019).

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 Program, which transitioned in 2021 to the INL Natural Resources Group. 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 plant species abundance data using sampling techniques like those used for the LTV. See Shurtliff et al. (2018) for more details on habitat condition monitoring methodologies and INL (2024) for the most recent results from this task. 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 is used to track 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 the Natural Resources Group 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 INL (2024) for the most recent results from the habitat distribution monitoring task.

In addition to the smaller incremental updates to the INL Site Vegetation Map to support quantifying sagebrush habitat distribution for the CCA, more comprehensive updates are completed on five- to ten-year intervals. One such update was completed in 2019. This update involved three steps: (1) a plant community classification to define vegetation classes, (2) manual map delineations of those classes, and (3) an accuracy assessment of the completed map. The INL Site Vegetation Map is INL's most frequently utilized natural resources vegetation data set. It is used to support siting infrastructure expansion or development, for assessing wildlife habitat availability, to guide natural resource monitoring efforts, to establish habitat restoration priorities, and to inform other stewardship activities as they arise. Because this data set is so widely used, it is critically important to update it regularly and maintain it as current. See Shive et al. (2019) for the INL Site Vegetation Map and the details of the methodologies used for its development.

1.2.2 Changes in Land Cover and Land Use Since 2016

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 42% (97,620 ha) of the INL Site since 1994 and about 17% (38,739 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 period. One major wildfire and several smaller wildfires have burned on the INL Site since the 2016 sample period. The Sheep Fire burned 40,403 ha in the central portion of the INL Site in July of 2019. The fire affected 22 LTV plots, including 10 that have not been impacted by wildfire since data collection began in 1950. A total of 40 LTV plots have now been affected by wildland fire since comprehensive recordkeeping began in 1994. Four smaller wildfires burned during the summer of 2020 including the Howe Peak Fire, the Telegraph Fire, the Lost River Fire, and the Cinder Butte Fire. These wildfires burned between July 2 and August 18 and ranged in size from 11 ha to 678 ha. The 2020 wildfires did not affect any LTV plots. Wildland fire recovery plans were developed for the Sheep Fire and the 2020 fires (Forman et al. 2020, Forman et al. 2021). Wildfires smaller than 1 ha are generally not quantified for the purpose of implementing recovery actions. During the period between the 2016 and 2022 sampling efforts, there were several small, mostly roadside fires that fell into this category.

General use of remote backcountry locations of the INL Site has increased due to INL Site mission-related activities as well as use for non-DOE related activities, like livestock grazing. 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; INL 2023). Increased mission-related use of the backcountry over the past two decades has often been related to National and Homeland Security research. However future energy development initiatives like small modular reactor demonstration projects and wind and solar energy research are also being sited in the INL Site backcountry. Infrastructure development to support these programs as well as to support the Idaho Cleanup Project closure mission also impact previously undeveloped areas. Anthropogenic impacts associated with livestock operations in grazing allotments, such as off-road travel, improvements to water tanks, installation of water lines, and several new fences have increased as well. See INL (2023) for examples and discussion of disturbance, including linear features that have been recently mapped. The increase in anthropogenic disturbance on the INL Site is consistent with trends in land use across the western U.S.

1.3 The 2022 Sample Period

The LTV plots were sampled for the 14 time in 2022. Analysis of the data collected during the 2022 sample period included updating functional group trends, which have been reported for several decades (Forman and Hafla 2018). Trend analysis of non-native species abundance and distribution, first conducted in association with the 2006 sample effort (Forman et al. 2010), were also updated with the most current dataset and results 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 60 years, plant communities on the INL Site have been classified into between 8 and 26 distinct vegetation types (McBride et al. 1978, Anderson et al. 1996, Shive et al. 2011, Shive et al. 2019). 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 soil 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) 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.

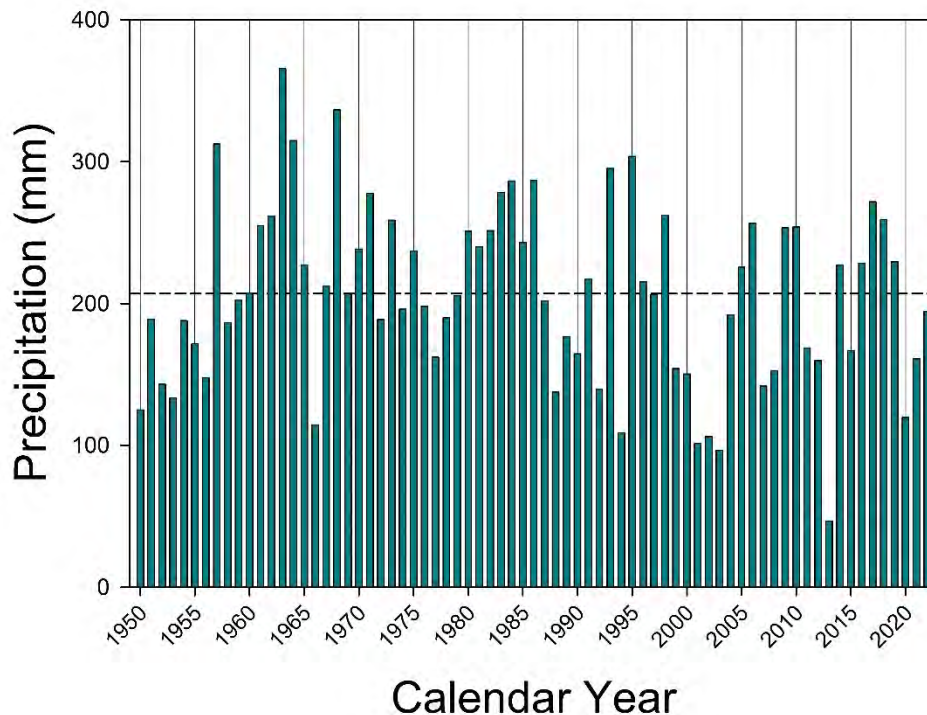


Figure 2. Total annual precipitation from 1950 through 2022 at the Central Facilities Area, Idaho National Laboratory Site, data are from the National Oceanic and Atmospheric Administration. The dashed line represents mean annual precipitation.

2.2 Sample Design

All 89 active LTV plots were sampled between early June and mid-August of 2022. 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 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 the accessible LTV plots in 1950, 1957, 1965, 1975, 1985, 1995, 2001, 2006, 2011, 2016, and most recently, 2022. 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.

Precipitation data were provided by the National Oceanic and Atmospheric Administration (NOAA) (NOAA 2023).

2.3 Statistical Analysis and Data Presentation

Data were analyzed using one- and two-way Analyses of Variance (ANOVAs; Zar 1999). Although a repeated measures design is the most appropriate statistical model given the permanent nature of the LTV plots, repeated measures ANOVAs were only used 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 2022 was compiled using the point-interception data, as it is the only cover metric for which all taxa are sampled 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 (1950-2022). 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 from each of 11 sample periods in which all accessible LTV plots were sampled. The three sample periods during which only the core plots were sampled were omitted from the non-native species analyses. The entire data set, rather than just the core plots, was used for these analyses to examine invasion patterns over as large a spatial extent as possible. The distribution of plots in which non-native functional groups occurred was mapped for the three most recent sample periods. Changes in the density and frequency of annual species over the 11 sample periods were further analyzed 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 $\alpha = 0.05$.

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3. RESULTS

3.1 Cover by Species – Changes Since 2016

Point interception data from 2022 were used to summarize cover by species across the 43 core plots (Table 1). Compared with the 2016 data (Table 2), absolute total shrub cover decreased by more than 5%. Big sagebrush (*Artemisia tridentata*) cover was about 3% lower in 2022 and green rabbitbrush (*Chrysothamnus viscidiflorus*) cover was lower by nearly 2%. These results were expected because 10 core plots that had not previously burned were affected by the 2019 Sheep Fire and big sagebrush was abundant in most of those plots prior to the fire. Of the 43 core plots, only ten have not been affected by wildland fire between 1994 and the 2022 sample period. Because big sagebrush does not resprout after wildland fire, losses on the 33 core plots (about 77%) that have been affected by wildfire over the past three decades will be reflected in the LTV data summaries for several decades to come. Between the two sample periods, big sagebrush cover was slightly higher on the plots where it still occurred, as indicated by the cover normalized by constancy metric. However, across all core plots green rabbitbrush replaced big sagebrush as the most abundant shrub species during the 2022 sample period.

Table 1. Mean percent cover of vascular plants sampled on 43 Long-Term Vegetation plots using point-intercept methods during the 2022 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			
<i>Chrysothamnus viscidiflorus</i>	4.57	35	5.61
<i>Artemisia tridentata</i>	4.17	13	13.80
<i>Krascheninnikovia lanata</i>	0.57	7	3.49
<i>Tetradymia canescens</i>	0.22	7	1.36
<i>Grayia spinosa</i>	0.21	2	4.53
<i>Linanthus pungens</i>	0.21	9	0.98
Others (n = 3)	0.05		
Total Shrub Cover	9.99		
Perennial Graminoids			
<i>Hesperostipa comata</i>	2.09	32	2.81
<i>Achnatherum hymenoides</i>	1.30	37	1.51
<i>Elymus lanceolatus</i>	1.26	35	1.55
<i>Agropyron cristatum</i>	1.02	12	3.66
<i>Poa secunda</i>	0.65	23	1.22
<i>Elymus elymoides</i>	0.42	29	0.63
<i>Aristida purpurea</i>	0.17	1	7.11
Others (n = 6)	0.26		
Total Perennial Graminoid Cover	7.17		
Perennial Forbs			
<i>Psoraleidum lanceolatum</i>	0.16	3	2.35

Table 1. continued.

Species	Absolute Cover (%)	Constancy	Cover (%) Normalized by Constancy
<i>Pleiacanthus spinosus</i>	0.12	4	1.28
<i>Comandra umbellata</i>	0.12	3	1.67
<i>Arenaria franklinii</i>	0.11	3	1.61
Others (n = 23)	0.46		
Total Perennial Forb Cover	0.97		
Succulents			
<i>Opuntia polyacantha</i>	0.18	14	0.54
Native Annuals and Biennials			
<i>Descurainia pinnata</i>	0.35	30	0.50
<i>Mentzelia albicaulis</i>	0.19	15	0.54
Others (n = 10)	0.14		
Total Native Annual/Biennial Cover	0.68		
Introduced Annuals and Biennials			
<i>Salsola tragus</i>	3.71	27	5.92
<i>Alyssum desertorum</i>	1.52	25	2.61
<i>Bromus tectorum</i>	1.14	30	1.64
<i>Sisymbrium altissimum</i>	0.84	17	2.13
<i>Halogeton glomeratus</i>	0.62	11	2.42
<i>Descurainia sophia</i>	0.26	14	0.81
Others (n = 3)	0.05		
Total Introduced Annual/Biennial Cover	8.16		
Total Vascular Plant Cover	27.16		

Table 2. 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			
<i>Artemisia tridentata</i>	7.32	25	12.58
<i>Chrysothamnus viscidiflorus</i>	6.41	38	7.25
<i>Krascheninnikovia lanata</i>	0.83	6	5.92
<i>Grayia spinosa</i>	0.44	4	4.68
<i>Linanthus pungens</i>	0.24	11	0.95
<i>Tetradymia canescens</i>	0.23	6	1.65
Others (n = 4)	0.20		
Total Shrub Cover	15.67		
Perennial Graminoids			
<i>Hesperostipa comata</i>	4.83	32	6.48
<i>Elymus lanceolatus</i>	3.78	31	5.24
<i>Achnatherum hymenoides</i>	2.08	39	2.29
<i>Agropyron cristatum</i>	1.48	8	7.94
<i>Elymus elymoides</i>	0.51	27	0.80
<i>Poa secunda</i>	0.31	18	0.75
<i>Aristida purpurea</i>	0.26	1	11.33
<i>Pascopyrum smithii</i>	0.16	3	2.3
Others (n = 4)	0.07		
Total Perennial Graminoid Cover	13.48		
Perennial Forbs			
<i>Psoralidium lanceolatum</i>	0.38	3	5.43
<i>Sphaeralcea munroana</i>	0.26	27	0.41
<i>Eriogonum ovalifolium</i>	0.18	12	0.64
<i>Descurainia pinnata</i>	0.17	22	0.33
<i>Astragalus filipes</i>	0.16	8	0.87
<i>Phlox hoodii</i>	0.14	19	0.31
<i>Pleiocanthus spinosus</i>	0.12	4	1.25
<i>Comandra umbellata</i>	0.11	3	1.63
Others (n = 21)	0.28		
Total Perennial Forb Cover	1.80		
Succulents			
<i>Opuntia polyacantha</i>	0.24	23	0.44
Native Annuals and Biennials			
<i>Mentzelia albicaulis</i>	0.29	16	0.77
<i>Chenopodium leptophyllum</i>	0.19	26	0.31
<i>Lappula occidentalis</i>	0.17	16	0.45

Table 2. continued.

Species	Absolute Cover (%)	Constancy	Cover (%) Normalized by Constancy
<i>Eriastrum wilcoxii</i>	0.16	20	0.34
Others (n = 10)	0.23		
Total Native Annual/Biennial Cover	1.04		
Introduced Annuals and Biennials			
<i>Alyssum desertorum</i>	2.78	24	4.97
<i>Salsola kali</i>	1.56	22	3.05
<i>Bromus tectorum</i>	1.34	20	2.88
<i>Halogeton glomeratus</i>	1.06	8	5.72
Others (n = 4)	0.04		
Total Introduced Annual/Biennial Cover	6.78		
Total Vascular Plant Cover	39.01		

In 2022, total cover by perennial graminoids declined to nearly half of its 2016 value. Needle and thread (*Hesperostipa comata*) was the most abundant perennial grass in both sample periods and mean absolute cover of this species decreased by about 2.5% over six years (Table 1 and Table 2). In both 2016 and 2022, crested wheatgrass (*Agropyron cristatum*), an introduced species, was the fourth most abundant perennial grass across the core LTV plots. Crested wheatgrass cover did decrease slightly between the two sample periods, but constancy increased from eight plots to 12 plots. Cover normalized by constancy values for this species indicate that it is very abundant in the plots where it occurs, more so than any single native species (Table 1). Increases in crested wheatgrass are of particular concern because it has invaded the plots where 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 decreased slightly between the two sample periods, while introduced annuals and biennials increased by a little more than 1% mean absolute cover from 2016 to 2022. During the 2022 sample period, cover from introduced annuals and biennials was 12 times higher than cover from native annuals and biennials. Desert allyssum (*Alyssum desertorum*) was the most abundant introduced annual in 2016 and absolute cover from this species decreased by almost half in 2022. Absolute cover from Russian thistle (*Salsola tragus*) more than doubled between the 2016 and 2022 sample periods, making it the most abundant introduced annual species across the core LTV plot in 2022. Cheatgrass (*Bromus tectorum*) was the third most abundant introduced annual in 2022 and it decreased slightly between the two sample periods, with a mean absolute cover value of just over 1%. For the 2022 sample period, crested wheatgrass and cheatgrass abundance were comparable to one another. However, three species of native perennial grasses were all more abundant than either crested wheatgrass or cheatgrass; as a functional group, native perennial grasses remained more abundant than introduced grasses.

In summary, total vascular vegetation cover was about 10% lower in 2022 than in 2016. Lower total cover was due to a decrease in both shrubs and perennial grasses. The only functional group with an increase in absolute cover between the two sample periods was introduced annuals and biennials, which

was due to increases in Russian thistle abundance. About 1/3 of the total cover vascular plant cover 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, or cover normalized by constancy, by introduced annual and biennial species was much higher and relative cover by native annual and biennial species was much lower in 2022 when compared with the 1995 sample period. The species contributing the greatest amount of cover to the introduced annual and biennial functional group changed from cheatgrass and tall tumblemustard (*Sisymbrium altissimum*) in 1995 to Russian thistle and desert alyssum (*Alyssum desertorum*) in 2022.

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 2022 was within the historical range of variability for the 72-year-old data set (Figure 3). Mean perennial grass cover was significantly higher in 2022 than in the sample years with the five lowest means (1950, 1957, 1965, 1985, and 2001), and it was significantly lower than in 1975, the year with the highest reported mean perennial grass cover (Appendix A, Tables 1a and 1b). Shrub cover in 2022 was the lowest mean recorded since data collection began in 1950 and the difference between mean shrub cover in 2022 and mean shrub cover in its six highest years (1950, 1957, 1990, 2001, 2006, and 2011) was significant (Appendix A, Tables 1a and 1b). Generally, shrub cover was down, and perennial grass cover was about the same compared to the previous sample period, but neither difference was significant between the most recent six-year period. The trend for mean shrub cover between the 2016 and 2022 sample periods was consistent between the point intercept (Tables 1 and 2) and the line intercept datasets (Figure 3), but the point intercept data indicated a greater decrease in grass cover than the line intercept dataset over the same period.

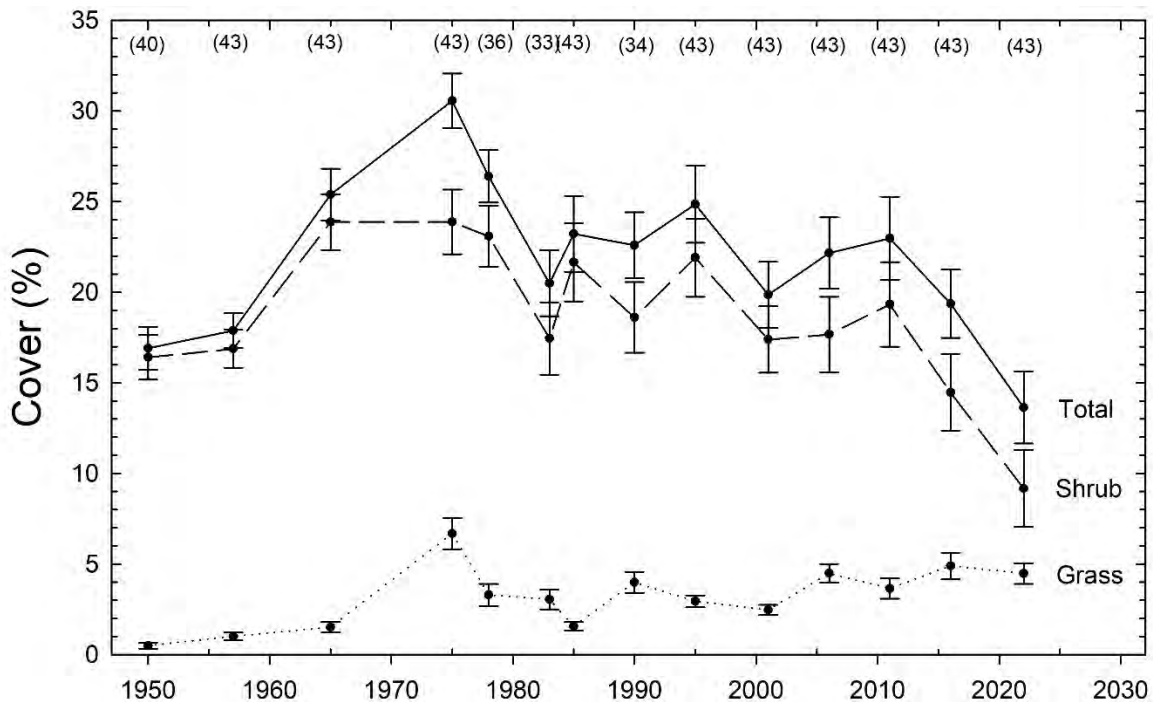


Figure 3. Trends in shrub cover, native perennial grass cover, and total combined perennial grass and shrub cover from 1950 to 2022 for the core subset of plots on the Long-Term Vegetation Project at the Idaho National Laboratory Site. Data were collected using line-interception methods and are represented here as means \pm 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 2022 were lower than those reported for the 2016 and 2011 sample periods, but not significantly so. Green rabbitbrush cover was generally trending upward from the beginning of data collection through 2011 (Figure 4) and mean cover for the three highest sample periods (1995, 2006, and 2011) was significantly higher than mean cover for the two earliest sample periods (1950 and 1957; Appendix A, Tables 2a and 2b). Although green rabbitbrush cover has declined since 2011, it was within the range of historical variability in the 2022 sample period and did not significantly differ from years with the lowest or highest values. Big sagebrush cover decreased between the 2016 and 2022 sample periods (Figure 4). Though the decrease was not statistically significant (Appendix A, Tables 2a and 2b), 2022 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 2022 was the lowest recorded value for this species since data collection began in 1950 and it was significantly lower in 2022 than in all other sample periods except 2016 and 2006. 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, most of the core LTV plots have burned in the past three decades. For the fifth consecutive sample period, mean green rabbitbrush cover and mean big sagebrush cover across the core plots were statistically indistinguishable from one another in the line interception dataset (Appendix A, Tables 2a and 2b).

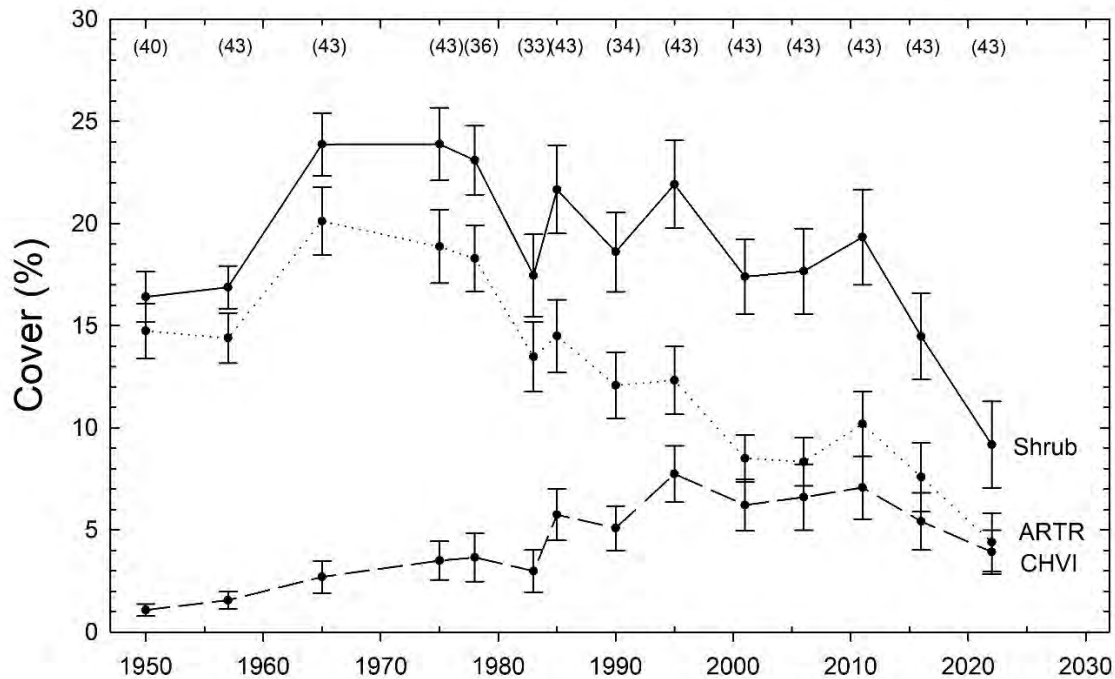


Figure 4. Trends in total shrub cover, *Artemisia tridentata* (ARTR) cover, and *Chrysothamnus viscidiflorus* (CHVI) cover from 1950 to 2022 for the core subset of plots on the Long-Term Vegetation Project at the Idaho National Laboratory Site. Data were collected using line-interception methods and are represented here as means \pm 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 remained near the upper end of its historic range of variability in 2022, with a mean of about 5% (Figure 5). Total grass biomass is typically underestimated by this cover value, as cover is sampled basally. Both bunchgrasses and rhizomatous grasses decreased slightly since the last sample period (Figure 5), but the change was not statistically significant for either functional group (Appendix A, Tables 3a and 3b). Compared to historical values, mean rhizomatous grass cover in 2022

was not significantly different from the highest or lowest reported values (Appendix A, Tables 3a and 3b). Bunchgrass cover was significantly higher in 2022 than it was in the seven sample periods with the lowest mean values (Figure 5). During the 2022 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).

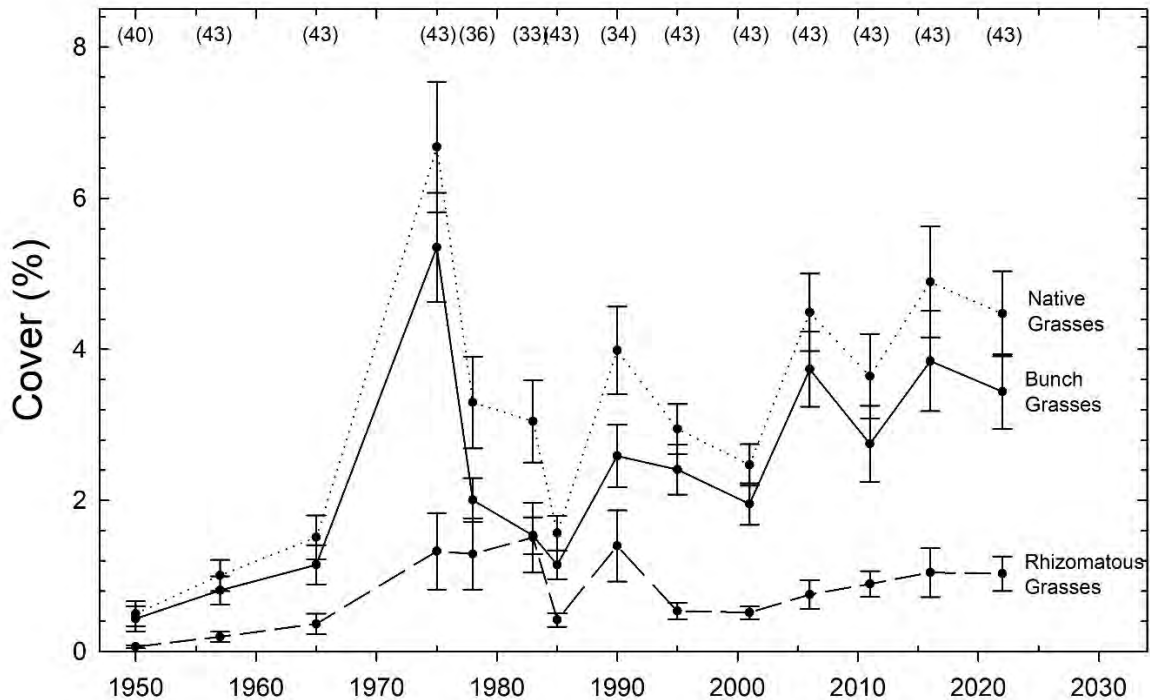


Figure 5. Trends in total native perennial grass cover, native bunchgrass cover, and native perennial rhizomatous grass cover from 1950 to 2022 for the core subset of plots on the Long-Term Vegetation Project at the Idaho National Laboratory Site. Data were collected using line-interception methods and are represented here as means \pm 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 decreased slightly between 2016 and 2022 (Figure 6), but the change was not significant for either functional group (Appendix A, Tables 4a and 4b). Unlike native grass cover, which fluctuates from one sample period to the next, crested wheatgrass cover appears to exhibit a more stable abundance pattern. Crested wheatgrass has been increasing in a very linear fashion since about 1990, and the 2022 cover values indicate the first small, but nonsignificant decrease during this period (Figure 6). As mentioned in the previous section, the number of plots in which crested wheatgrass occurs continues to expand from one sample period to the next, 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 four plots with crested wheatgrass occurrence in 2022, and the subsequent increases in abundance appear to be relatively predictable. Although native perennial grass cover is still significantly greater than introduced perennial grass cover (Appendix A, Tables 4a and 4b), the impacts of crested wheatgrass invasion on native plant communities remain a concern.

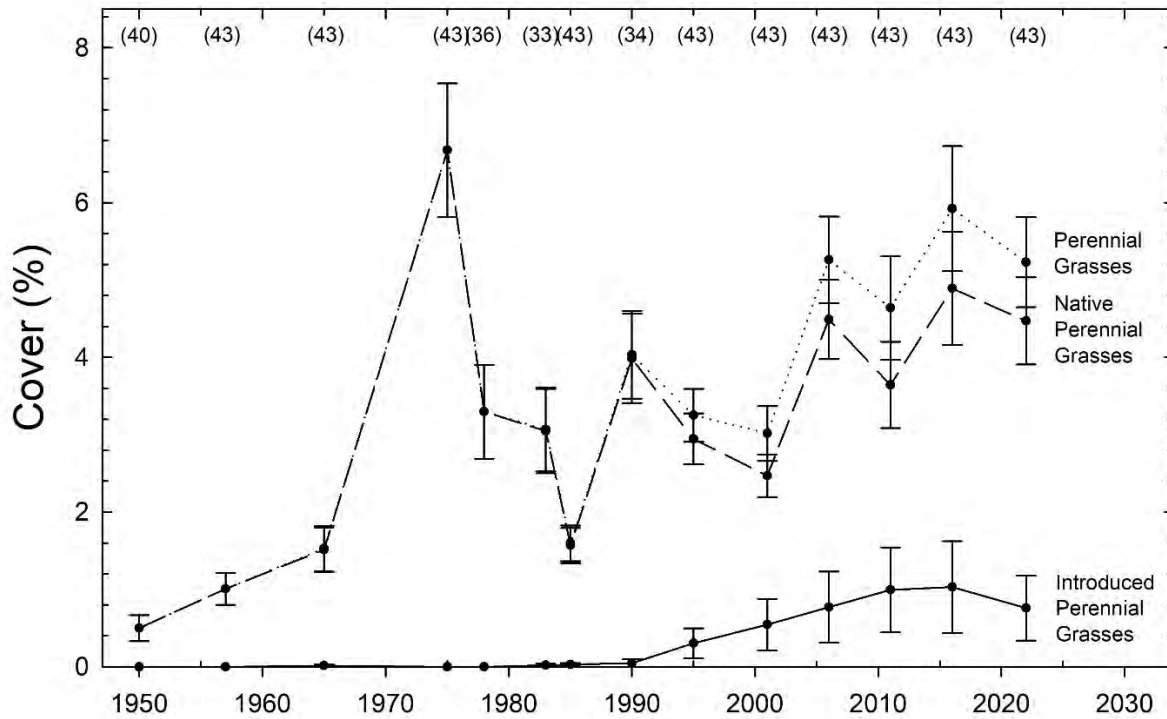


Figure 6. Trends in total perennial grass cover, native perennial grass cover, and introduced perennial grass cover from 1950 to 2022 for the core subset of plots on the Long-Term Vegetation Project at the Idaho National Laboratory Site. Data were collected using line-interception methods and are represented here as means \pm 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 after the 2006 sample period (Forman et al. 2010) and are updated here with the 2022 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/biennial species abundance prior to 1985. During the 2022 sample period, cheatgrass was detectable in 57 out of 89 active plots (Figure 7a), which is an increase from the 2016 sample period when cheatgrass was detectable in a total of 40 plots (Figure 7b). The overall macro-scale distribution of cheatgrass in 2022 was like that of 2011 (Figure 7c). It is notable that cheatgrass distribution and abundance did not appear to increase after the 2011 T-17 Fire (Figure 7b) or the 2019 Sheep 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 or the disturbance history of the plot.

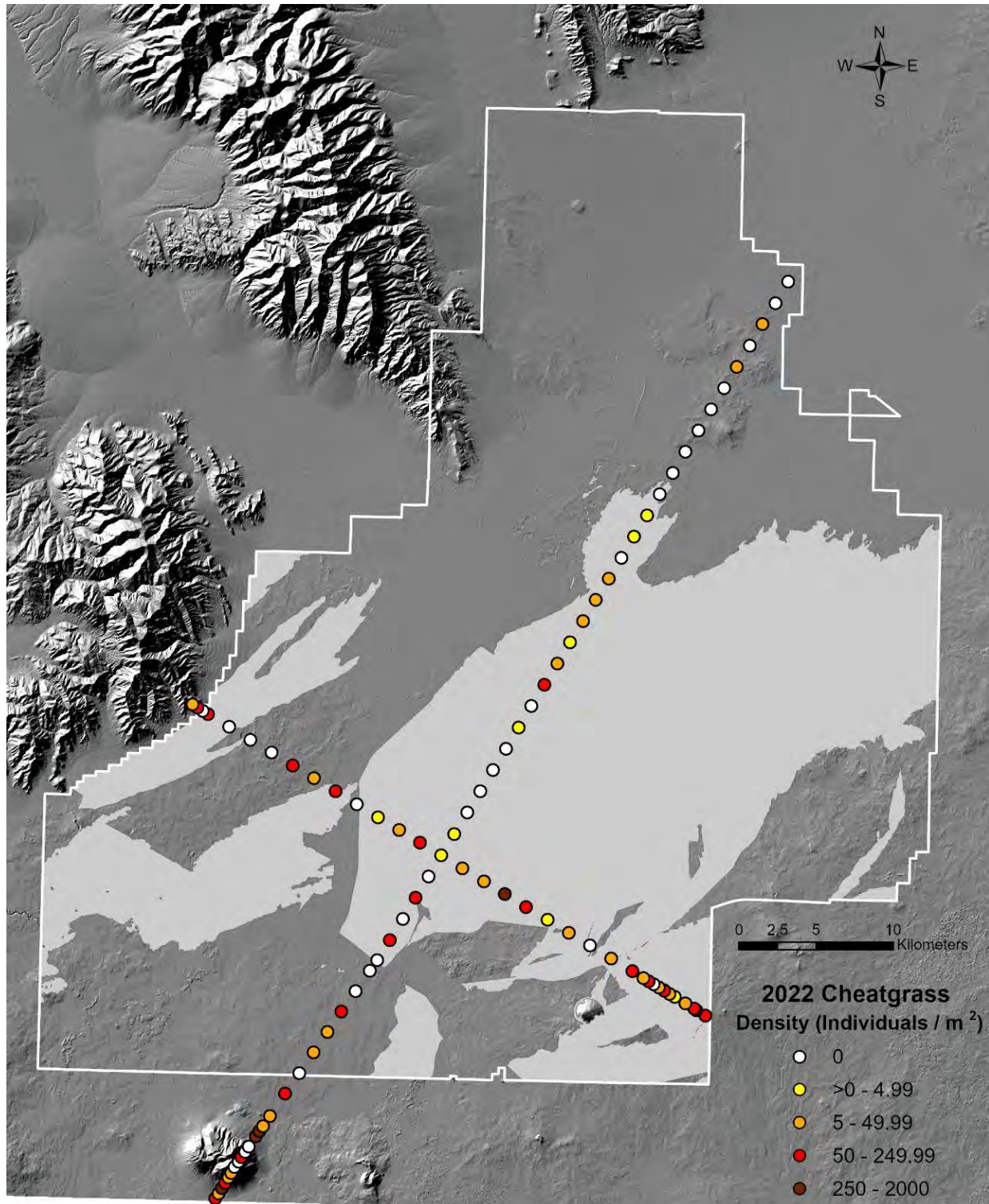


Figure 7a. *Bromus tectorum* distribution by density class on the Long-Term Vegetation Project permanent plots at the Idaho National Laboratory Site in 2022. Light gray depicts fires occurring between 1994 and 2022.

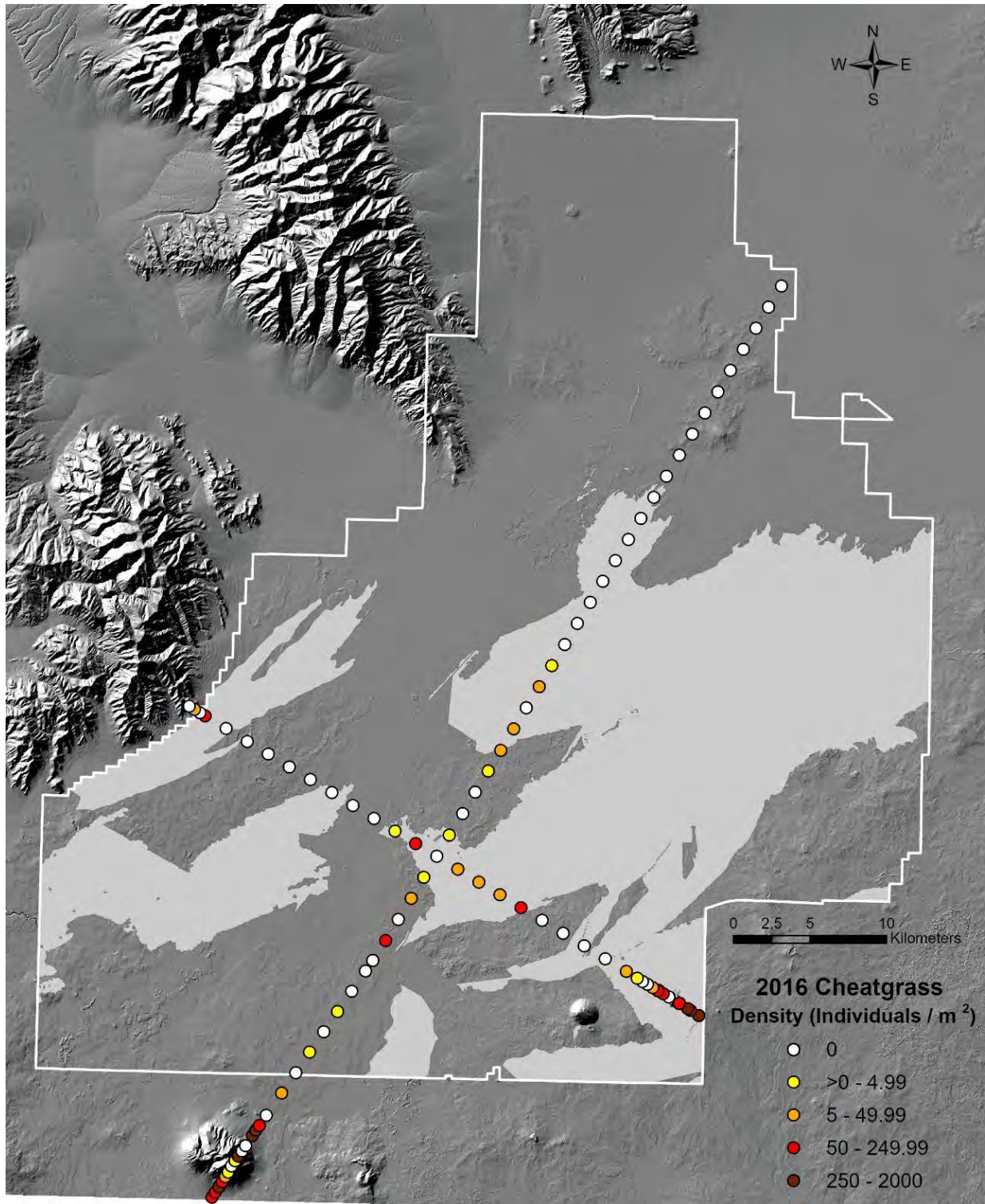


Figure 7b. *Bromus tectorum* distribution by density class on the Long-Term Vegetation Project permanent plots at the Idaho National Laboratory Site in 2016. Light gray depicts fires occurring between 1994 and 2016.

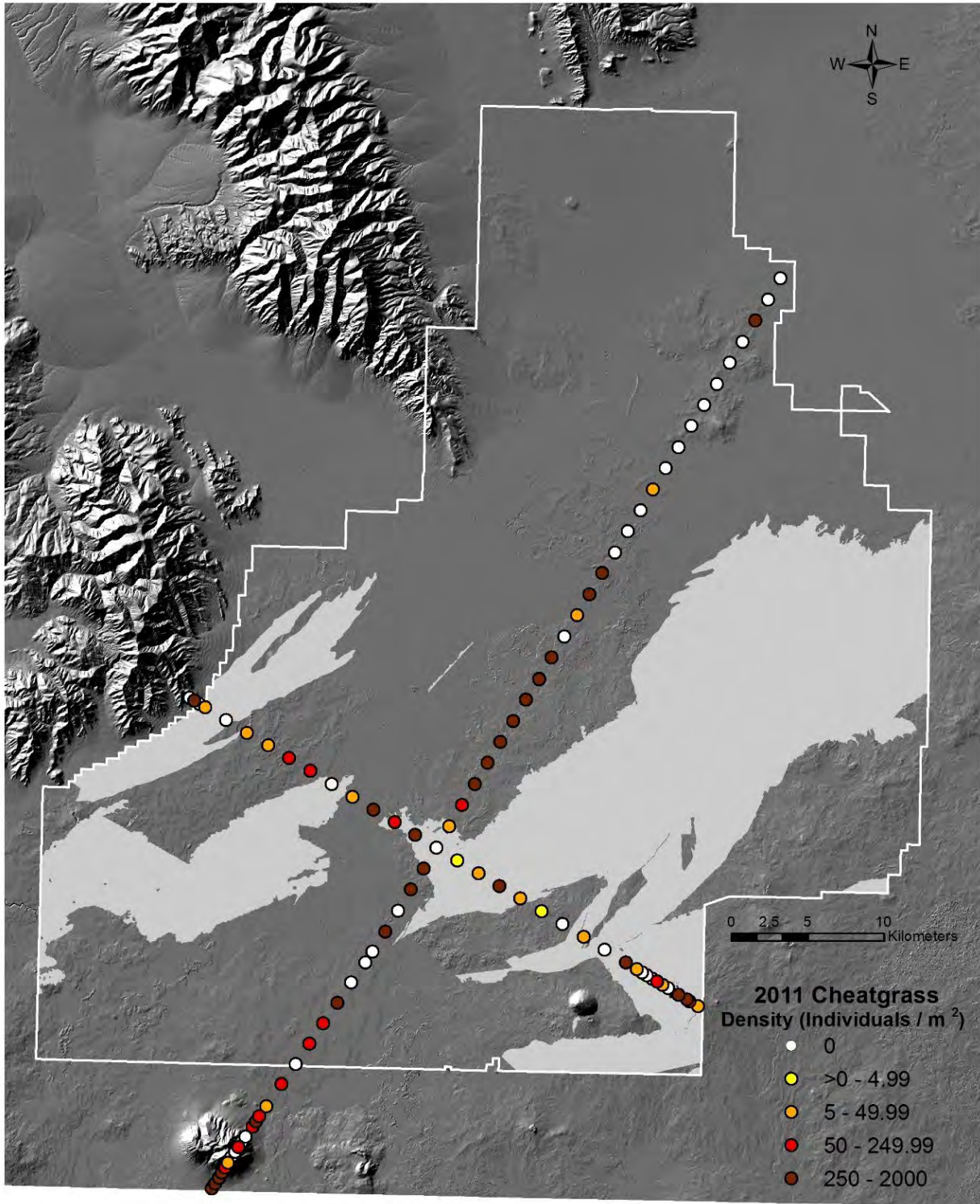


Figure 7c. *Bromus tectorum* distribution by density class on the Long-Term Vegetation Project permanent plots at the Idaho National Laboratory Site in 2011. Light gray depicts fires occurring between 1994 and 2011.

Mean cheatgrass density during the 2022 sample period was nearly the same as during the 2016 sample period (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 2016 and 2022 sample periods, cheatgrass frequency increased slightly, but the change was not significant. Overall, mean frequency tends to be significantly higher in years with the highest mean values than in years with the lowest mean values and the years with the highest mean values tend to occur within the past 25 years, whereas the years with the lowest mean values tend to occur near the beginning of the 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, an increase in this metric indicates an increase in the plot-scale, or local, distribution of the species.

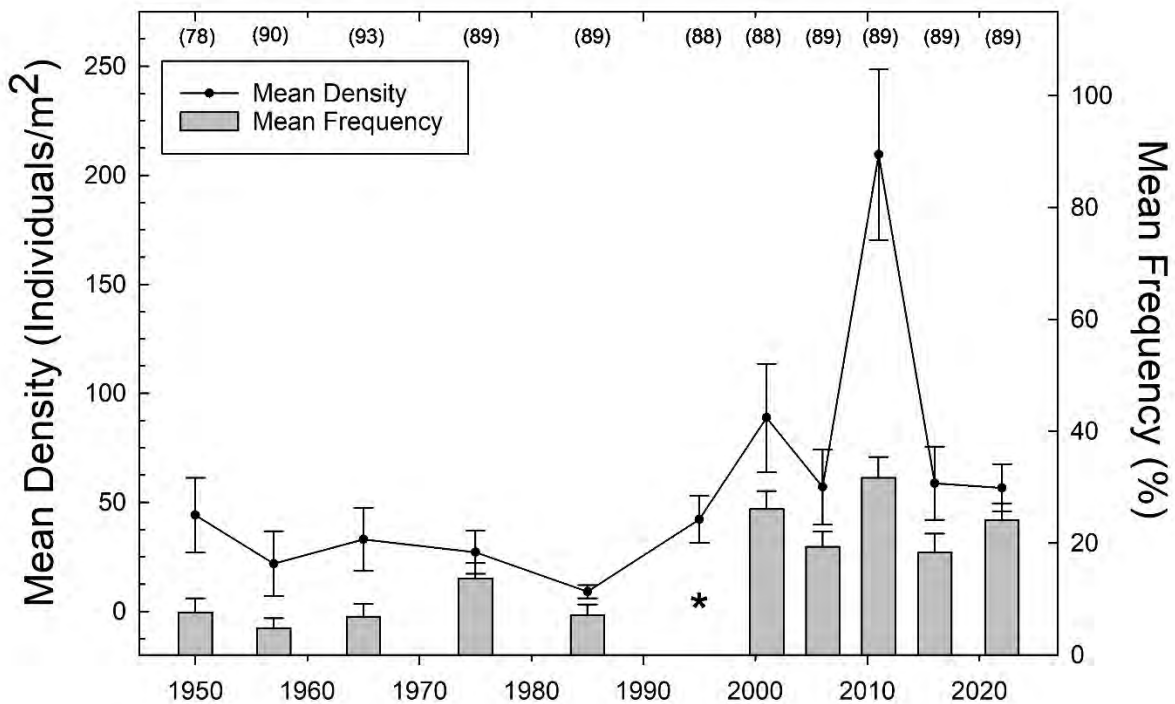


Figure 8. Density and frequency trends for *Bromus tectorum* on the Long-Term Vegetation Project permanent plots at the Idaho National Laboratory Site from 1950 to 2022. Data are means \pm 1 SE. *Frequency data are missing from the 1995 data archives.

The introduced annual forbs functional group has historically been dominated by desert alyssum, but other species from the mustard family like herb sophia (*Descurainia sophia*) and tall tumbled mustard were also abundant. Compared with previous sample periods, introduced chenopods like Russian thistle and saltlover (*Halogeton glomeratus*) were relatively more abundant and introduced mustards were relatively less abundant than they were in previous sample periods (e.g., Table 1 and Table 2). Introduced annual forbs were detectable in density frames of 53, or more than half, of the active LTV plots during the 2022 sample period (Figure 9a). The distribution of plots where introduced annual forbs were detected in 2022 is comparable to the plot distribution of the same functional group in 2016 (Figures 9a and 9b). The number of plots with introduced annual forbs in 2016 and 2022 was an increase of eight plots over the number of plots with introduced annual forbs in 2011 (Figure 9c). Although the overall distribution of plots with detectable densities of introduced annual forbs was higher in the last two sample periods,

within plot comparisons indicate that densities of those species largely decreased between 2011 and 2016. Densities in 2022 were somewhat higher than in 2016 but were also lower when compared to 2011.

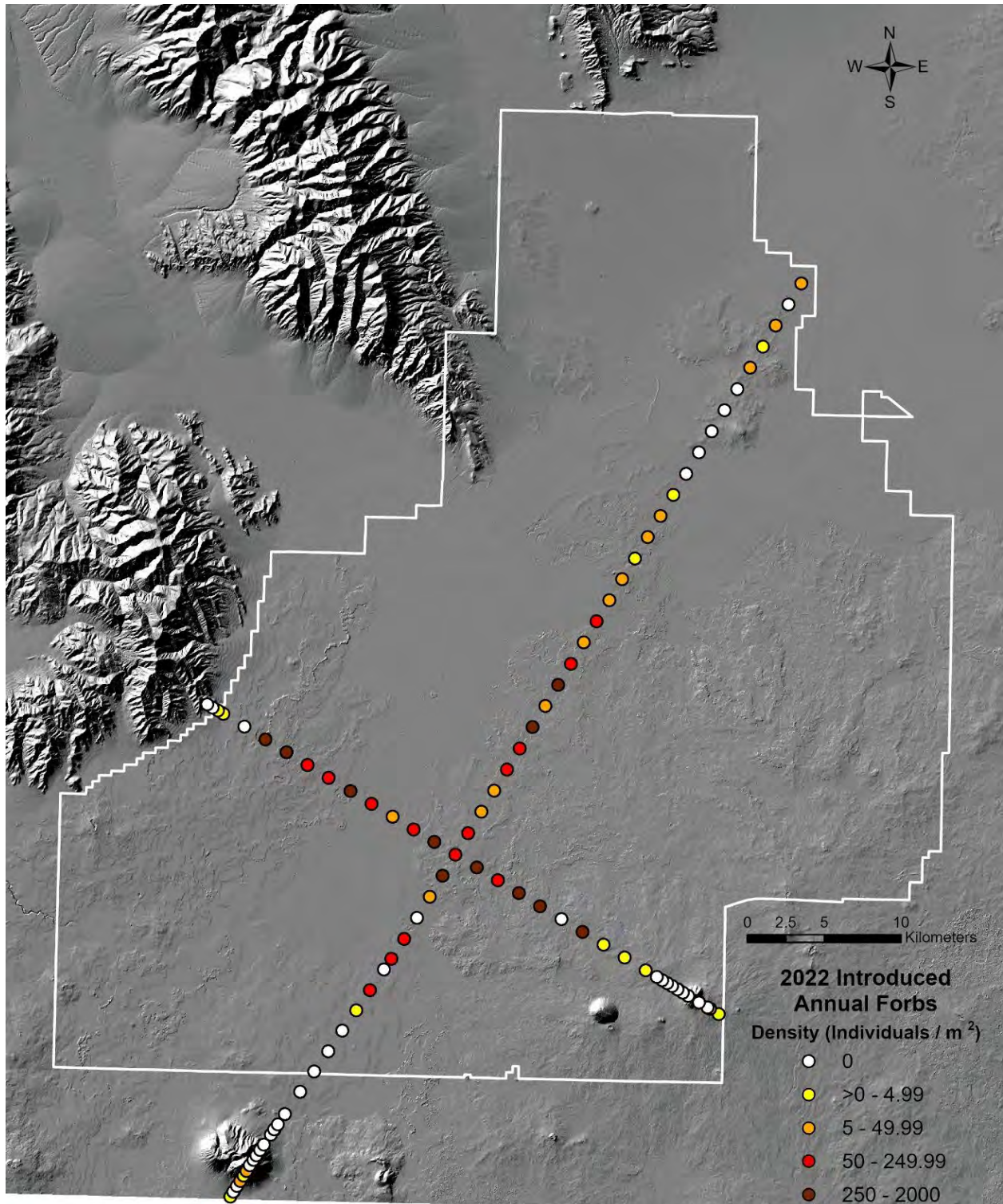


Figure 9a. Introduced annual forb distribution by density class on the Long-Term Vegetation Project permanent plots at the Idaho National Laboratory Site in 2022.

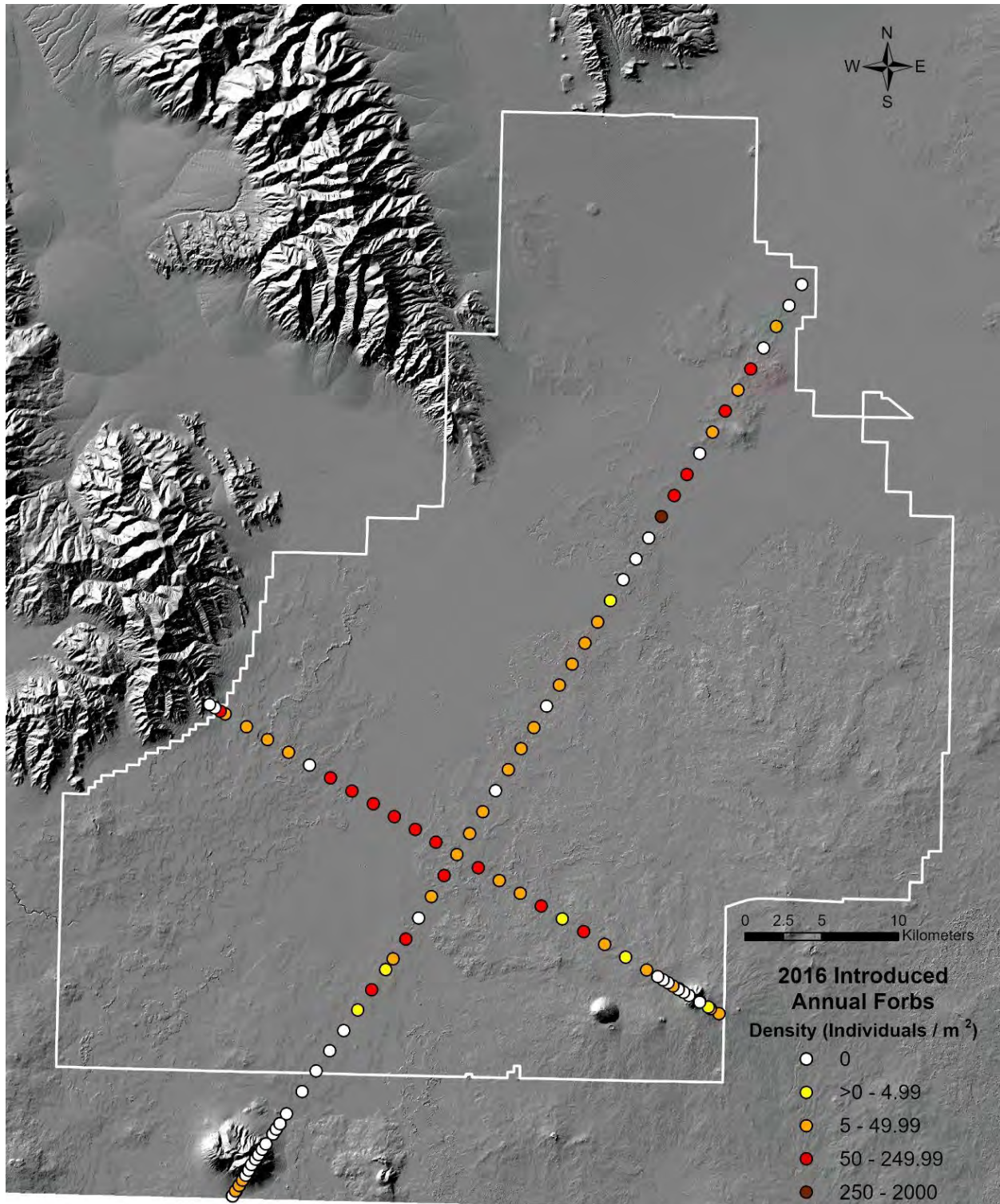


Figure 9b. Introduced annual forb distribution by density class on the Long-Term Vegetation Project permanent plots at the Idaho National Laboratory Site in 2016.

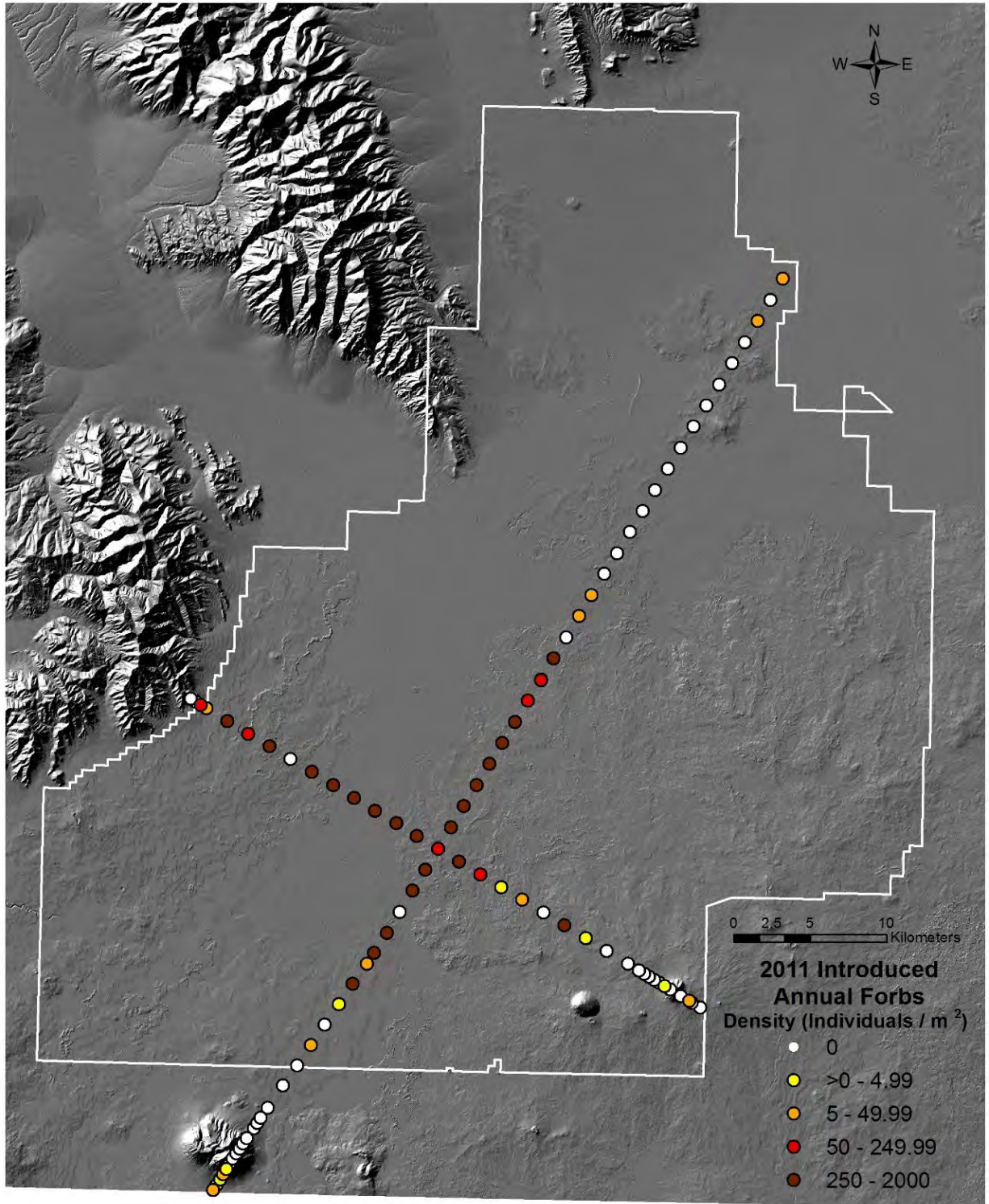


Figure 9c. Introduced annual forb distribution by density class on the Long-Term Vegetation Project permanent plots at the Idaho National Laboratory Site in 2011.

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/m² 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, but it increased again between the 2016 and 2022 sample periods. Mean 2022 density values were comparable to those in 2006, but they were not significantly different from any other year except 2011 (Appendix A, Tables 6a and 6b). Mean introduced annual forb frequency increased slightly between 2016 and 2022, but the difference was not significant. Mean frequency has been statistically indistinguishable from one sample period to another from 2006 through 2022 but mean introduced annual frequency is often statistically higher in more recent sample periods when compared to sample periods from the 1990s or earlier. Generally, 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.

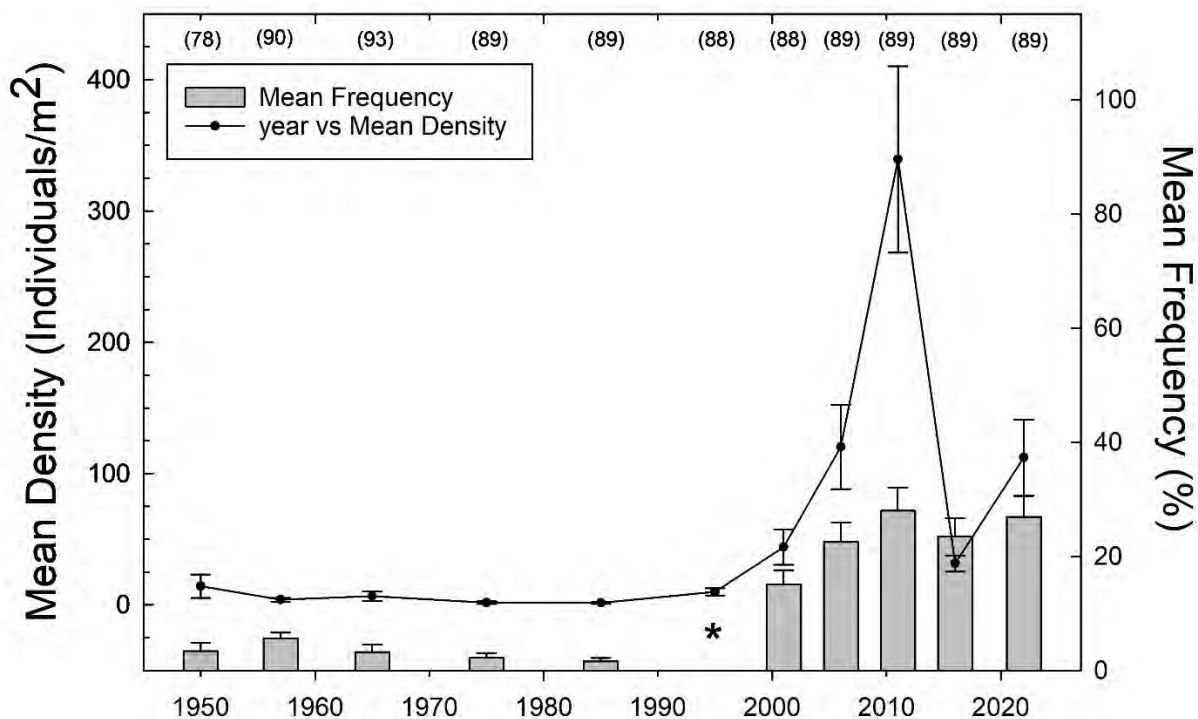


Figure 10. Density and frequency trends for introduced annual forbs on the Long-Term Vegetation Project permanent plots at the Idaho National Laboratory Site from 1950 to 2022. Data are means \pm 1 SE. *Frequency data are missing from the 1995 data archives.

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 2022 than in 2016 (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 frequency data for introduced cheatgrass and annual forbs, mean frequency 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 2022, mean densities and frequencies were higher for introduced annual forbs than

native annual forbs and mean density of introduced annual forbs was about double that of the cheatgrass (Appendix A, Tables 5a, 6a, and 7a).

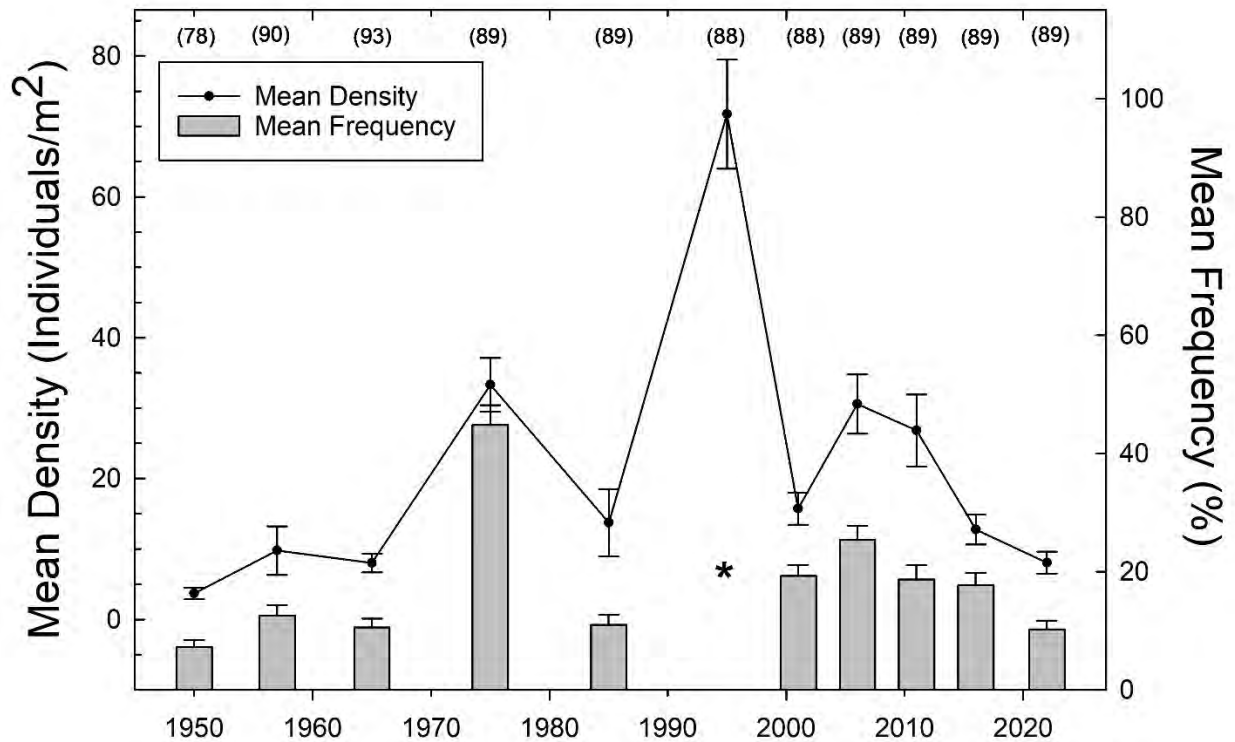


Figure 11. Density and frequency trends for native annual forbs on the Long-Term Vegetation Project permanent plots at the Idaho National Laboratory Site from 1950 to 2022. Data are means \pm 1 SE. *Frequency data are missing from the 1995 data archives.

3.4 Precipitation Patterns

Total annual precipitation in 2022 was slightly below average (about 10mm), and the two years prior to the 2022 sample period were also drier than average (Figure 2). Total precipitation in 2020 was only about 1/2 of annual precipitation, averaged since 1950. Total annual precipitation was also below average in four of the five years prior to the 2016 sample period, including 2013 which was the driest year on record with only about 1/4 of average annual precipitation. Over the two decades prior to, and including the 2022 sample period, precipitation was below average during twelve of the twenty years. The mean departure from average was about 65mm/year for drier years and only about 38 mm/year for wetter years.

During the five years prior to the 2016 sample period, the seasonality of precipitation appeared to deviate from historical monthly means (Figure 12). Long-term monthly means indicate that about 60% of the annual precipitation on the INL Site 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. Although the seasonal precipitation patterns in 2017-2020 were more typical, in that May and June were some of the wetter months of the year, the wettest months in the two years prior to the 2022 sample period were October and August. Over the past two LTV sample periods, late summer and fall months

have been the wettest months of the year more often than would be expected. September and October precipitation have also been substantially above average several times in the last decade.

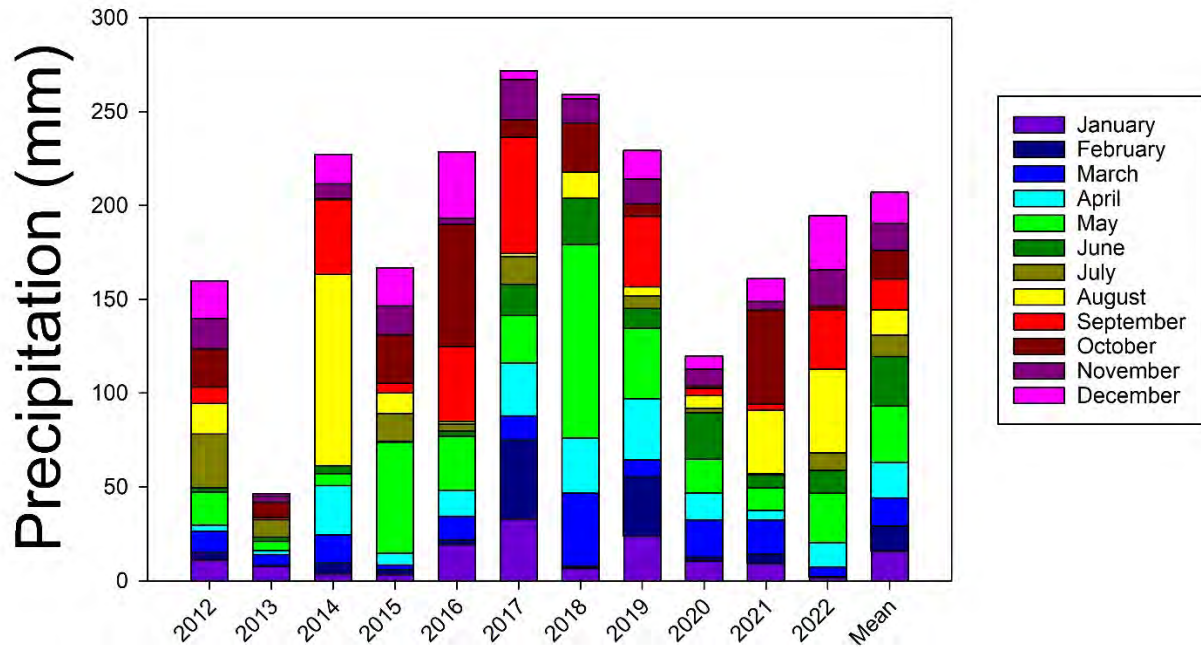


Figure 12. Annual precipitation by month from the Central Facilities Area, Idaho National Laboratory Site; data are from the National Oceanic and Atmospheric Administration. Mean monthly precipitation includes data from 1950 through 2022.

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. The most recent analysis of trends in vegetation composition on the LTV plots indicates that the abundance of some functional groups across the INL Site may be approaching the limits of, and even beginning to deviate from historical ranges of variability. For example, cover and density of native functional groups like shrubs and annual forbs have been declining and are now as low as they have been within the 72-year dataset. Conversely, some results from analyses through the 2022 dataset indicate just how extensive the capacity for change and the how wide the fluctuating range of variability in some functional groups, particularly non-natives, may be. Results through 2016 showed that the distribution and abundance of introduced species underwent a dramatic reversal when compared to the 2011 dataset. Data from the 2022 sample period are consistent with those from 2016 indicating that although values from 2011 were high, the reversal in trend was not an anomaly.

Trend analyses through the 2022 sample period indicate that perennial grass cover is near the middle of its range of variability and native grasses have not yet been noticeably impacted by environmental stress and/or high-magnitude changes in the abundance of non-natives. Over the span of the dataset, there have been notable increases in non-native annual frequency and an increasing magnitude of fluctuation in density. Both results signify departures from historical means for species composition and abundance and may be an indication of changes in vegetation condition moving forward. Some of 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

Species in each of the sagebrush steppe vegetation 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. The drier departure from the annual precipitation mean over the past few decades and the shift in seasonality to more precipitation in the late summer and fall months and less in the spring and early summer are likely to have a negative impact on sagebrush germination and establishment. Sagebrush recruitment may be even more limited in burned areas because of limited seed availability (Chambers 2000) and harsher microsite conditions (Blew and Forman 2010). Though much of the decline in sagebrush cover across the INL Site since 1995 is due to losses from wildland fire, unfavorable re-establishment conditions may delay recovery, extending the naturally slow recovery process. Even without additional losses, sagebrush cover will remain low across the LTV plots for decades to come, and the recovery trajectory of sagebrush will continue to reflect changing precipitation patterns.

Grasses are thought to be much more immediately responsive to precipitation than shrubs. Mean cover of native perennial grasses declined between the 2016 and 2022 sample periods, following two drier than average years. However, native perennial grasses increased to one of the highest means in the 72-year-old dataset in 2016, but 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 2016 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 changes in native,

perennial grasses over the past decade suggest that the relationship between cover and precipitation is multifaceted and other abiotic or biotic factors may influence perennial grass cover. As with natives, the mean cover of introduced perennial grasses (crested wheatgrass), did not track precipitation directly over the past decade, 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. In general, 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 far more abundant than native annual forbs. Whereas the mean density of natives appears to fluctuate annually, or at least from one sample period to the next with no directional trend, introduced forbs exhibited an exponential increase in density from about 1995 to 2011 then experienced a sharp decline from 2011 to 2016 and a slight increase between 2016 and 2022. Native annual forbs tend to function as ephemerals, where the pattern of fluctuation appears to much more closely tied to the fluctuation in annual precipitation than that of introduced forbs.

Precipitation does not appear to be the sole factor driving abundance trends for introduced annual forbs; however, specific precipitation events can produce notable responses. The elevated abundance values of two introduced, annual forbs, Russian thistle and saltlover, over the last two sample periods are probably a response to the unusual wet periods that occurred late in the growing season during the years prior to the 2016 and 2022 sample periods. The wettest August on record occurred in 2014 and August and October precipitation in 2021 were about three times greater than average. In the months following these late season wet periods, individuals of both species were observed to grow much larger than normal and produced much more seed than they would in a more typical year. Increased seed production along with favorable late season growing conditions are conducive for continued increases in these species.

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 few decades would favor an increase in cheatgrass abundance because of its winter annual growth cycle. In other INL Site datasets, such as the CCA Habitat Condition Monitoring dataset (INL 2024), large increases in cheatgrass have been documented following some years with higher-than-average late season precipitation, but it does not occur consistently after all years with above average fall precipitation. Relationships between higher cheatgrass abundance and elevated fall precipitation are also not consistent across all sample periods within the LTV dataset. Interactions with other species like native grasses or introduced annual forbs may be influencing cheatgrass responses to precipitation timing.

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 either total precipitation or effective soil moisture availability (Palmquist et al. 2016) 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. Higher magnitudes of changes are observed in annual species from one sample period to another, as well as higher abundance values for species that favor late season precipitation. Longer-term, a shift to a warmer, effectively drier climate may eventually favor a shift away from sagebrush steppe.

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. In 2022, cheatgrass abundance remained statistically unchanged from 2016 values. The current cheatgrass abundance values from the LTV dataset should be interpreted and used with caution with respect to land management and stewardship decisions. The risk of cheatgrass dominance to sagebrush steppe ecosystems remains high and this risk should be considered when planning weed management, restoration, and wildfire planning and protection activities on the INL Site.

Based on cheatgrass distribution analyses, Forman et al. (2010) concluded that cheatgrass is widely distributed and seed has been in the seedbank across the INL Site for many decades. The increase in cheatgrass variability from one sample period to the next may indicate that the resistance of some native plant communities to dominance by cheatgrass is 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, 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.

Results from earlier LTV analyses demonstrated that the abundance and composition of species in intact sagebrush plant communities are generally very stable over time (Anderson and Inouye 2001). More recent information from a comparable dataset further suggest that total vegetative cover has much greater annual fluctuations in recovering post-fire communities than in communities dominated by sagebrush (INL 2024). These combined results indicate that wildland fire is one factor that has the potential to decrease the stability and the resistance of plant communities across the INL Site. However, native herbaceous cover remains within historical ranges of variability and cheatgrass remains as likely to decrease as to increase from one sample period to another, suggesting that post-fire communities continue to maintain some capacity for resilience.

Crested wheatgrass has not been planted on any of the LTV plots but has invaded 12 plots as of the 2022 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 on the INL Site. In the past, crested wheatgrass was planted across the West (and on the INL Site) and was considered 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 reflected the community present before the fire, apart from 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, more than 40% of the INL Site has burned since 1994 and more than 15% of the INL Site has burned more than once during the same period. Large fires have been more frequent in the last three decades when compared to the prior two centuries (Forman et al. 2024). 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 re-establishment 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 for more recent sample periods. All these trends point to the importance of limiting ignitions of human caused wildfires and limiting the size of all wildfires on the INL Site to the extent possible. Because pre-fire vegetation conditions are changing, active post-fire treatments may become increasingly necessary to reduce the risk of dominance by non-native species and to restore sagebrush habitat. INL recently completed a framework for prioritizing and facilitating post-fire recovery actions to address natural resource recovery objectives (Forman et al. 2024).

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 land stewards and regional researchers alike.

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Appendix A

Summary Statistics Tables

ANOVA Results Tables

Table A-1a. Estimates of mean cover for native perennial functional groups from the line-interception data on the “core” Long-Term Vegetation Transect plots at the Idaho National Laboratory Site from 1950 to 2022. 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
2022	13.64	2022	9.17	2022	4.47
Minimum Significant Difference	6.97		7.40		2.00

Table A-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 Transect plots at the Idaho National Laboratory Site from 1950 to 2022.

Total, One-way Repeated Measures ANOVA Results						
Source of Variation	DF	SS	MS	F	P	
Plot	42	32133.83	765.09			
Year	13	10118.40	778.34	9.72	<0.001	

Shrub, One-way Repeated Measures ANOVA Results						
Source of Variation	DF	SS	MS	F	P	
Plot	42	38489.63	916.42			
Year	13	8978.91	690.69	8.02	<0.001	

Grass, One-way Repeated Measures ANOVA Results						
Source of Variation	DF	SS	MS	F	P	
Plot	42	1791.05	42.64			
Year	13	1604.10	123.39	16.02	<0.001	

Table A-2a. Estimates of mean cover for *Artemisia tridentata* (ARTR) and *Chrysothamnus viscidiflorus* (CHVI) from the line-interception data on the “core” Long-Term Vegetation Transect plots at the Idaho National Laboratory from 1950 to 2022. 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
2022	4.39	3.92	No
Minimum Significant Difference	5.44	5.90	

Table A-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 Transect plots at the Idaho National Laboratory from 1950 to 2022.

Two-way Repeated Measures ANOVA Results					
Source of Variation	DF	SS	MS	F	P
Plot	32	14640.87	457.53	1.01	0.49
Species	1	18282.38	18282.38	38.24	<0.001
Species x Plot	32	15299.63	478.11		
Year	13	5184.91	398.84	11.85	<0.001
Year x Plot	416	14005.17	33.67		
Species x Year	13	10646.43	818.96	14.05	<0.001

Table A-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 Transect plots at the Idaho National Laboratory from 1950 to 2022. 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
2022	3.44	1.03	Yes
Minimum Significant Difference	1.58	N/A	

Table A-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 Transect plots at the Idaho National Laboratory from 1950 to 2022.

Two-way Repeated Measures ANOVA Results					
Source of Variation	DF	SS	MS	F	P
Plot	32	694.50	21.70	0.94	0.57
Growth Form	1	464.08	464.08	20.27	<0.001
Growth Form x Plot	32	732.61	22.89		
Year	13	626.29	48.18	13.81	<0.001
Year x Plot	416	1451.61	3.49		
Growth Form x Year	13	263.88	20.29	6.23	<0.001

Table A-4a. Estimates of mean cover for native perennial grasses and introduced perennial grasses from the line-interception data on the “core” Long-Term Vegetation Transect plots at the Idaho National Laboratory from 1950 to 2022. 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
2022	4.47	0.76	Yes
Minimum Significant Difference	1.53	N/A	

Table A-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 Transect plots at the Idaho National Laboratory from 1950 to 2022.

Two-way Repeated Measures ANOVA Results					
Source of Variation	DF	SS	MS	F	P
Plot	42	896.18	21.34		
Nativity	1	1836.05	1836.05		<0.001
Nativity x Plot	42	1731.37	41.22		
Year	9	782.88	86.99		<0.001
Year x Plot	378	1733.02	4.59		
Nativity x Year	9	537.87	59.76		<0.001

Table A-5a. Estimates of mean density and frequency for *Bromus tectorum* from the density/frequency data on all the Long-Term Vegetation Transect plots for which data were available in each sample year at the Idaho National Laboratory from 1950 to 2022. 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
2022	56.57	2022	24.10
Minimum Significant Difference	120.76		12.36

Table A-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 the Long-Term Vegetation Transect plots for which data were available in each sample year at the Idaho National Laboratory from 1950 to 2022.

Density, One-way ANOVA Results					
Source of Variation	DF	SS	MS	F	P
Year	10	2636642.33	263664.23	8.65	<0.001

Frequency, One-way ANOVA Results					
Source of Variation	DF	SS	MS	F	P
Year	9	70181.90	7797.99	11.26	<0.001

Table A-6a. Estimates of mean density and frequency for introduced annual forbs from the density/frequency data on all the Long-Term Vegetation Transect plots for which data were available in each sample year at the Idaho National Laboratory from 1950 to 2022. 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
2022	112.15	2022	26.91
Minimum Significant Difference	118.55		11.72

Table A-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 the Long-Term Vegetation Transect plots for which data were available in each sample year at the Idaho National Laboratory from 1950 to 2022.

Density, One-way ANOVA Results					
Source of Variation	DF	SS	MS	F	P
Year	10	9136288.38	913628.84	15.57	<0.001

Frequency, One-way ANOVA Results					
Source of Variation	DF	SS	MS	F	P
Year	9	98159.31	10906.59	19.39	<0.001

Table A-7a. Estimates of mean density and frequency for native annual forbs from the density/frequency data on all the Long-Term Vegetation Transect plots for which data were available in each sample year at the Idaho National Laboratory from 1950 to 2022. 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
2022	8.05	2022	10.23
Minimum Significant Difference	17.60		10.45

Table A-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 the Long-Term Vegetation Transect plots for which data were available in each sample year at the Idaho National Laboratory from 1950 to 2022.

Density, One-way ANOVA Results					
Source of Variation	DF	SS	MS	F	P
Year	10	329436.91	32943.69	24.27	<0.001

Frequency, One-way ANOVA Results					
Source of Variation	DF	SS	MS	F	P
Year	9	95709.41	10634.38	28.21	<0.001