Effects of Precipitation Variation on Secondary Plant Succession in the Sagebrush Steppe Ecosystem of Southern Idaho over 80 Years

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Authorization to Submit Thesis

This thesis of Holly E. Cunningham, submitted for the degree of Master of Science with a Major in Natural Resources and titled "Effects of Precipitation Variation on Secondary Plant Succession in the Sagebrush Steppe Ecosystem of Southern Idaho over 80 Years," has been reviewed in final form. Permission, as indicated by the signatures and dates below, is now granted to submit final copies to the College of Graduate Studies for approval.

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Abstract

Precipitation patterns can provide details and information related to historical and present-day vegetation variation within the sagebrush steppe. There is a critical gap in what we know about long-term shifts in plant communities, including the effects precipitation has on secondary plant succession. It is important to understand shifts in dominance between invasive annual grasses and native perennial grasses in sagebrush steppe ecosystems; especially after a fire or other disturbance occurs. This study was conducted on two 16-ha study sites in southern Idaho that were tilled for farming but abandoned in the early 1930s. Species densities data collected in 1933-1947, 1954, 1961, 1992 and 2015 were categorized into plant functional groups and examined over time. Long-term datasets evaluating plant community composition relative to precipitation patterns can increase understanding in how plant communities respond to precipitation influence in the sagebrush steppe ecosystem on the Snake River plain.

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Dedication

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CHAPTER 1: History of the Piemeisel Study Sites

INTRODUCTION

The Snake River Plain, located primarily in southern Idaho, is a 644-km stretch of unique landscape, boasting vast fields of crop production, sagebrush steppe rangeland, and clusters of urban settlements (Axelrod, 1968). The Snake River Plain is unique, in that it offers irrigation water in a semi-arid desert region. Water is collected by damming up the Snake River, the largest tributary of the Columbia River (Plummer et al., 2000). The Magic Valley area is within the Snake River Plain and is a prime example of how water has transformed land use from desert rangeland to irrigated farmland creating more than 608,000-ha of agriculture production (USDA Census of Agriculture, 2012; Tasumi & Allen, 2007).

BURLEY AND CASTLEFORD STUDY SITES

During the 1930s, about 13% of southern Idaho's sagebrush steppe rangeland was disturbed by unrestricted livestock grazing, repeated human-influenced burning, and vegetation removal to implement crop production (Piemeisel & Chamberlin, 1936). Following these disturbances, drought and declining wheat prices contributed to extensive farmland abandonment (Piemeisel, 1932). In 1931, two 16-ha study sites in the Magic Valley (one near Burley and one near Castleford, Idaho), were established on sagebrush steppe rangelands that had been altered by two different types of disturbance: 1) long periods of unrestricted livestock grazing resulting in degraded rangelands, and 2) native vegetation removal through repeated tillage for crop production that was eventually abandoned. The Burley and Castleford study sites) were fenced in 1931 with 1-m tall, woven wire to prevent livestock grazing by Robert L. Piemeisel (Piemeisel, 1938; Hironaka, 1986; Hironaka & Tisdale, 1963). Piemeisel was a scientist for the Division of Sugar Plant Investigations in the USDA-Bureau of Plant Industry (which later became the USDA-Agricultural Research Service).

The Burley study site is located in Cassia County (42.50633°N, 113.89365°E) and is divided into two treatment plots, approximately 9-ha of abandoned farmland and 7-ha of degraded rangeland. Prior to 1931, the farmland plot lay fallow after abandonment in 1916, and the degraded rangeland plot had unrestricted grazing until 1931 (Piemeisel, 1945). Today, the Burley study site is surrounded by irrigated farmland.

The Castleford study site is located in Twin Falls County (42.41171°N, -114.70412°E) and contains approximately 6-ha of abandoned farmland where farming ceased in 1920, and 10-ha of degraded rangeland. Similar to the Burley study site, the Castleford study site was grazed until the site was fenced in 1931 (Piemeisel, 1945; Hironaka & Tisdale, 1963). Much of the surrounding land was also cleared of native vegetation with the intent of changing the land use to irrigated farmland. However, the partial-failure of the Salmon Falls irrigation project resulted in a water shortage and the cleared farmland was quickly abandoned due to the inability to irrigate. Today, the land surrounding the Castleford study site is sagebrush steppe rangeland, primarily used for livestock grazing and wildlife habitat.

RESEARCH OF ROBERT L. PIEMEISEL

The original objective of Piemeisel's research at the Burley and Castleford study sites was to study annual vegetation affecting beet leafhopper (*Circulifer tenellus* Baker) populations and movement (Figure 1.1; Piemeisel, 1932). The beet leafhopper is a vector for sugar beet curly top virus *(Geminiviridae curtovirus*) which has detrimental effects on the sugar beet (*Beta vulgaris L.)* agriculture commodity that is extensively grown in southern Idaho (Hironaka, 1986). A few years into the study, however, Piemeisel's original objective evolved into evaluating plant community change (or succession) in the absence of disturbance, particularly herbivory (Piemeisel, 1945).

Piemeisel’s study of plant succession was based on the assumption that unregulated livestock grazing produced “less than favorable vegetation conditions,” and labeled grazing as the major factor delaying secondary succession on rangelands (Piemeisel, 1932; Piemeisel, 1945). He predicted it would take 70-80 years before mature sagebrush (*Artemisia L.)* and native perennial bunchgrasses would re-establish to pre-disturbance levels (Piemeisel, 1932; Piemeisel & Lawson, 1937). Piemeisel (1938) suggested that southern Idaho rangelands lacked establishment of perennial vegetation primarily because unmanaged livestock grazing, hence, these study sites provided a way to evaluate secondary succession in the absence of livestock grazing (Piemeisel, 1940). Piemeisel’s 1945 study also identified lagomorph herbivory, specifically Nuttall’s cottontail (*Sylvilagus nuttallii*) and black-tailed jackrabbit (*Lepus californicus),* as a potential influence on secondary succession and site recovery. Piemeisel (1945) proposed that inducing, halting, or reversing successional stages may be possible by altering the onset or removal of major forms of herbivory.

Piemeisel (1938) hypothesized early secondary succession on rangelands in the Snake River Plain progressed linearly in three annual vegetation “replacement stages.” The first plant community stage is dominated by prickly Russian thistle (*Salsola tragus* L.); the second stage is dominated by annual mustards (*Brassicaceae* family), including native western tansymustard (*Descurainia pinnata* [Walter] Britton) and introduced tall tumblemustard (*Sisymbrium altissimum* L.); and the third stage is dominated by cheatgrass (*Bromus tectorum* L.), an introduced annual grass. Piemeisel (1945) suggested if disturbance occurred during one of the early replacement stages, it would cause reversion back to stage one, instead of advancing past stage three into a perennial vegetation community (Piemeisel, 1945). Similar to Piemeisel’s “replacement stages”, researchers in western Nebraska and western Montana predicted that post-disturbance stages start with an annual weed stage that ranges from 1 to 3 years, then a mixed annual-perennial stage from 2 to 4 years, followed by a mixed perennial grass-forb stage 3 to 8 years post-disturbance (Judd & Jackson, 1939; Judd, 1940).

Piemeisel began to notice the effects of lagomorph herbivory in 1936 when examining a smaller, 30 x 30-m seeded exclosure within the abandoned farmland portion of both the Burley and Castleford study sites (Figure 1.2; Piemeisel, 1945). The seeded exclosures were originally fenced in 1932 using a 61-cm high wire poultry fence around the external borders, with a barbed wire strand hung above. Half (15 x 30-m) of the seeded exclosures were sown with native perennial grasses (species were not identified) and the remaining 50% with cheatgrass (Piemeisel, 1945). The seeded exclosures were originally established to monitor changes in perennial and annual plant populations, however, the study evolved once Piemeisel began to observe differences in plant communities between the interior and exterior of the seeded exclosures. In 1936, Piemeisel (1945) hypothesized that the lack of lagomorph herbivory was influencing the three “replacement stages” of plant succession by enabling annual and perennial seed sources to multiply and establish more rapidly. In 1937 at both study sites, Piemeisel reported that cheatgrass cover was 100% within the seeded exclosures where lagomorph herbivory was removed (Piemeisel, 1945). At the Castleford study site, the area outside the seeded exclosure had 20% cheatgrass cover in 1936 and 15% in 1937; outside the seeded exclosure at the Burley study site, cheatgrass cover was under 5% from 1936-1937 (Piemeisel, 1945). The increases in cheatgrass cover found within the seeded exclosures support Piemeisel’s hypothesis for annual species and suggest that a lack of lagomorph herbivory influenced the rate of cheatgrass expansion. Perennial species, however, did not increase inside the seeded exclosure (Piemeisel, 1945).

In 1936, Piemeisel established an additional 61 x 122-m lagomorph-proof exclosure within the abandoned farmland portion of each study site using the same fencing materials as the seeded exclosures (Figure 1.2). The lagomorph-proof exclosures allowed Piemeisel to evaluate the effect of herbivory on secondary succession in areas not seeded after abandonment. Before establishing the lagomorph-proof exclosures, Piemeisel observed very few perennial bunchgrasses at the Burley study site, and the few observed had excessive lagomorph herbivory (Piemeisel, 1945). Piemeisel observed increases in perennial grasses within the lagomorph-proof exclosures between

1936-1937, prompting the entire Burley study site to be fenced against lagomorphs in 1938 (Piemeisel, 1945). The additional fencing at the Burley study site allowed for secondary plant succession to be observed on a larger scale without the disturbance of livestock and lagomorph grazing. In 1938-1939 at the Burley study site, replacement stage one (prickly Russian thistle) dominated the plant community within the abandoned farmland portion, giving way to replacement stage two (mustards) in 1940-1941, and finally exhibiting replacement stage three (cheatgrass) in 1942-1944. In 1944, co-dominance between cheatgrass and perennial bunchgrasses was observed. Piemeisel (1945) theorized the increase in perennial bunchgrasses was likely due to a lack of disturbance from lagomorph herbivory. Piemeisel (1945) found that 80% of the quadrats measured at the Burley study site between 1938-1944 exhibited overall increases in perennial bunchgrass cover; perennial bunchgrass species included: squirreltail (*Elymus elymoides* [Raf.] Swezey), Sandberg bluegrass (*Poa secunda* J. Presl), thickspike wheatgrass (*Elymus lanceolatus* [Scribn. & J.G. Sm.] Gould) and Thurber's needlegrass (*Achnatherum thurberianum* [Piper] Barkworth). Based on observations from 1944, Piemeisel (1945) predicted that by 1953 at the Burley study site, perennial bunchgrass densities would increase and cheatgrass densities would decrease in the abandoned farmland portion. In 1954, perennial bunchgrass densities were greater than those measured previously in 1947 (85.0 plants/m^2 compared to 15.0 plants/m^2), however, cheatgrass was also greater in densities than 1947 (100.0 plants/m^2 compared to 48.0 plants/m^2). Following 1954, perennial bunchgrass densities continually declined (1961: 65.0 plants/m^2; 1992: 50.0 plants/m^2; 2015:

12.0 plants/m^2) while cheatgrass densities remained high (1961 and 1992: 100.0 plants/m^2; 2015: 69.0 plants/m^2).

Within the lagomorph-proof exclosure at the Castleford study site, cheatgrass cover steadily increased from 4% in 1937 to 100% in 1942. Outside of the lagomorph-proof exclosure, cheatgrass cover remained less than 5% until 1945 when it increased to 45% in the abandoned farmland portion (Piemeisel, 1945). In 1944, the entire Castleford study site was also exteriorly protected with lagomorph-proof fencing; nevertheless, increases in perennial bunchgrass densities did not occur (Piemeisel, 1945). Although the lagomorph-proof exclosure was not seeded with cheatgrass, cheatgrass cover inside the exclosure reached 100% within a few years after it was established. Similar to the seeded exclosure, multiple variables may have affected cheatgrass cover within the lagomorph-proof exclosure, therefore the removal of lagomorphs grazing cannot be identified as the specific cause. However, an increase in cheatgrass cover did occur within the lagomorph-proof exclosure at a faster rate than the surrounding abandoned farmland (Piemeisel, 1945). The abandoned farmland portion was not grazed by livestock, but did have for lagomorph herbivory prior to 1944, which may explain the differences in cheatgrass cover between the lagomorph-proof exclosure and abandoned farmland at the Castleford study site.

More recent studies evaluating livestock grazing and annual grasses support Piemeisel's results. They suggest that livestock may minimize spread of cheatgrass if grazing is applied at a time that reduces future seed production and competitive ability (Pyke, 1986; 1987; Diamond et al., 2010; Strand et al., 2014; Davies et al., 2016a; Davies et al., 2016b). On the other hand, improper grazing (e.g., overgrazing) has been linked to cheatgrass invasions (Klemmedson & Smith, 1964; DeFlon, 1986; Young & Allen, 1997), hence, land management decisions to utilize grazing to manage cheatgrass, is complex and should be site specific.

EROSION OBSERVED

Between 1933-1945 at the Castleford study site, many quadrats were recorded as bare soil due to wind erosion of the tilled silt-loam soil (Piemeisel, 1945). Piemeisel et al. (1951) described the wind erosion caused by tillage as a wind-blown seed source for annual species. Through photography, Piemeisel documented drifting soil into piles measuring nearly a meter high which created an impassable road to the Castleford study site (University of Idaho Library Archives; Piemeisel Exclosures Collection, 2016). In 2015, effects of past wind erosion and earlier tillage (e.g., hard-plated and compacted soil) were observed in the abandoned farmland portion of the Castleford study site. The Burley study site experienced minimal erosion, likely due to the progressive establishment of irrigation canals that provided water to surrounding land parcels where crop production occurs.

ADDITIONAL SAMPLING QUADRATS AT THE BURLEY AND CASTLEFORD STUDY SITES

During 1933-1947, plant densities were recorded using 0.25-m^2 sampling quadrats in the exterior of both the Burley and Castleford study sites. At the Burley study site, 47 sampling quadrats were located 30-m outside the exterior fence line on the northwest and southwest sides. Piemeisel (1945) observed similar overall cheatgrass densities outside and inside the Burley study site (outside in 1944, 71.0 plants/m^2; inside in 1944, 64.0 plants/m^2). However, annual introduced forbs (e.g., mustards and prickly Russian thistle) densities were higher outside versus inside the study site in 1944 (86.0 plants/m^2 and 15.0 plants/m^2, respectively).

At the Castleford study site, 43 sampling quadrats located 30-m outside the fence line on the northwest and southwest sides were established where disturbance (primarily livestock grazing) has been ongoing since 1931. Piemeisel (1945) observed results similar to the Burley study site at the Castleford study site. Cheatgrass densities outside the Castleford study site were comparable to inside the study site in 1944 (93.0 plants/m^2 and 82.0 plants/m^2, respectively). Annual introduced forb (e.g. mustards and prickly Russian thistle) densities were also higher outside versus inside the study site in 1944 (80.0 plants/m^2 and 3.0 plants/m^2, respectively). Piemeisel (1945) concluded that the disturbance of livestock and lagomorph grazing negatively impacted secondary succession, resulting in the inability of the plant community to progress past the three replacement stages defined by Piemeisel.

Due to crop production surrounding the Burley study site, the outside sampling areas no longer exists, however, that is not the case at the Castleford study site. In 2016, plant densities were collected outside the Castleford study site, however, no data were collected inside the study site. The prominent plant species during the 2016 data collection included: crested wheatgrass (*Agropyron cristatum* (L.) Gaertn; 12.0 plants/m^2), sagebrush (4.0 plants/m^2), Sandberg bluegrass (40.0 plants/m^2), tall tumblemustard (19.0 plants/m^2), and cheatgrass (100+ plants/m^2). Data collected in 2016 were not used as a part of this study, however, raw data is archived at the University of Idaho Library (University of Idaho Library Archives; Piemeisel Exclosures Collection, 2016).

Piemeisel also established sampling points using a 0.25-m^2 quadrat frame along the interior of the fence line for the abandoned farmland portions of both study sites (26 quadrats in Burley and 21 quadrats in Castleford). Plant densities from these quadrats were measured from 1933-1947 only and not used in this study. Raw data is archived at the University of Idaho Library (University of Idaho Library Archives; Piemeisel Exclosures Collection, 2016).

The degraded rangeland portions of the Burley and Castleford study sites have a different grid system for data collection than its abandoned farmland counterpart. The degraded rangeland sampling grid (Figure 1.3) consists of two intersecting transects, one running north to south and the other west to east. Permanent steel posts were placed every 30-m, with the first post placed 30-m from the fence line along both transects for a total of 15 posts at the Burley study site and 17 posts at the Castleford study site. Sampling quadrats (0.25-m^2) were placed every 15-m along both transect lines, starting 15-m from the fence line. Plant densities in the degraded rangeland portions were collected in 1943-1953 at the Burley study site, and 1945-1949 at the Castleford study site (it is unclear why data were not collected at the Castleford study site in 1943, 1944, 1950-1953). In 1992, a systematic grid mimicking that of the abandoned farmland portion was established on the degraded rangeland portion at each study site (a full description of the systematic grid used to measure the abandoned farmland can be found in Chapter 2). Data were collected using this design in 1992 and 2015; raw data is archived in the University of Idaho Library (University of Idaho Library Archives; Piemeisel Exclosures Collection, 2016).

Within the degraded rangeland portions of both the Burley and Castleford study sites, Piemeisel established a 23 x 23-m sagebrush exclosure in 1937 (Figure 1.4). The sagebrush exclosure was fenced identical to the seeded and lagomorph-proof exclosures located in the abandoned farmland portion of the study sites. A 4.5 x 4.5-m grid system was placed within the sagebrush exclosure to monitor sagebrush activity (most-likely seedling establishment) without the effects of lagomorph and livestock grazing. Four transect lines were established running west to east with sampling quadrats (0.25-m^2) placed every 4.5-m (16 total), starting 4.5-m from the fence line (Figure 1.4). Additional sampling quadrats were established as control variables every 4.5-m surrounding the outside of the sagebrush exclosure for comparison. The results of the sagebrush exclosure study and raw data were unable to be located and not included in this study; maps are archived in the University of Idaho Library (University of Idaho Library Archives; Piemeisel Exclosures Collection, 2016).

ADDITIONAL INFORMATION

Originally, three study sites (Burley, Castleford, and Wendell) were established for Piemeisel's research of the beet leafhopper on annual vegetation. The 16-ha Wendell study site located in Gooding County (42.465263°N, -114.485110°W) was destroyed in the late 1930s when the Hagerman highway (2950 South Road, located in Hagerman, Idaho) was built (Hironaka, 1986). Located within each study site, Piemeisel erected 15-m observation towers at the center of the study site to gain an elevated perspective and to take annual photographs documenting plant succession. The Burley study site tower was deemed a public health hazard and removed in the 1970s (Hironaka, 1986). The tower at the Castleford study site is still standing. Upon Piemeisel's retirement in 1954, all raw data, research documents, and over 1,000 photographs pertaining to Piemeisel's research were donated to the University of Idaho and are currently archived at the University of Idaho Library in Moscow, Idaho; Piemeisel Exclosures Collection, 2016 (Hironaka & Tisdale, 1963; Hironaka, 1986; University of Idaho Library Archives; Piemeisel Exclosures Collection, 2016).

1954 DATA COLLECTION

Plant densities collected at both the Burley and Castleford study sites in 1954 were used by Peters and Bunting (1992), however, raw data was unable to be located for this study although an extensive search was performed. Plant densities were extracted from the Peters and Bunting (1992) manuscript for this study.

1961 DATA COLLECTION

In 1961, plant densities were collected at both the Burley and Castleford study sites by Hironaka and Tisdale (1963), however, their study analyzed only the Burley study site. The raw data from 1961 was also used by Peters and Bunting (1992), however, the raw data could not be located. Plant densities were also extracted from the Peters and Bunting (1992) manuscript for this study.

1992 DATA COLLECTION

In 1992, plant densities were collected on both the Burley and Castleford study sites (Peters & Bunting, 1992). The data from 1948-1954, 1961 and 1992 were converted to frequency (percentage of quadrats with selected species) for Peters and Bunting (1992) data analysis, and vegetation were grouped into the following functional groups: mustards, borage species, perennial bunchgrasses, cheatgrass, and prickly Russian thistle.

2015 DATA COLLECTION

In 2015, plant densities were collected on both the Burley and Castleford study sites by Gearhart and Cunningham from the University of Idaho. Data collected in 1933-1947, 1954, 1961, 1992 and 2015 will be discussed in Chapter 2 (Figure 1.5).

CONCLUSION

It is unclear if Piemeisel had foreseen the implications the Burley and Castleford study sites would provide to the future understanding of secondary plant succession. Long-term data sets from livestock-excluded study sites located in the sagebrush steppe are uncommon, particularly such large fenced sites. Piemeisel may not have known the extent of the future implications his research would provide, but it is clear that there was a thoughtful process behind the establishment and data collection method. It is recommended that the Burley and Castleford study sites be examined regularly, as the limitless value provided may not only influence current and future land management decisions. The raw data, detailed maps, notes, and photographs are available for the Burley and Castleford study sites from 1931-2016 at the University of Idaho Library (University of Idaho Library Archives; Piemeisel Exclosures Collection, 2016).

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CHAPTER 2: Effects of Precipitation Variation on Secondary Plant Succession in the Sagebrush Steppe Ecosystem of Southern Idaho over 80 Years.

INTRODUCTION

The sagebrush (*Artemisia L.*) biome is one of the largest ecosystems in the United States (Miller & Eddleman, 2000; Homer et al., 2015), historically covering more than 40 million hectares in western North America (Connelly et al., 2004; Wisdom et al., 2005). Over the last decade, the sagebrush steppe ecosystem, a type of perennial grassland co-dominated by sagebrush (Young et al., 2007), has rapidly declined in health and size primarily due to: 1) large wildfires prompted by and subsequently promoting the expansion of invasive annual grasses, and 2) the expansion of conifer trees (Hanna & Fulgham, 2015). Wisdom et al. (2002) estimated that more than 40% of the sagebrush biome has been lost since European settlement. West (2000) suggested that merely 1% of the sagebrush steppe ecosystem existed in a mature plant community stage in 2000, West described this mature community as dominated by sagebrush with a healthy herbaceous perennial understory. Effects of this progressive decline in sagebrush habitat have resulted in over 350 plant and animal species at risk of extirpation (Dobkin & Sauder, 2004), including greater sage-grouse (*Centrocercus urophasianus).*

Effects of fluctuating precipitation also contribute to rising concern about the future vitality of the sagebrush steppe ecosystem (Nowak et al., 1994; Suttle, Thomsen & Power, 2007; Bradley, 2010; Svejcar et al., 2016). Significant decreases in key seasonal precipitation could have catastrophic effects on the health and viability of the entire sagebrush steppe ecosystem (Bradley 2010), and fluctuating precipitation patterns have the ability to increase or decrease plant productivity, composition, and diversity in sagebrush steppe communities (Bates et al., 2006; Bradley, 2010). Increases in fall precipitation, especially in years of abundant seed sources, allows for increased germination of exotic winter annual species such as cheatgrass (*Bromus tectorum* L.; Young et al., 1987; Horn et al., 2017). Exotic annual plants effectively out-compete perennial species for water and nutrient resources (Young & Allen, 1997), and recover more rapidly than native species after disturbance, further promoting the grass-fire cycle (D'Antonio and Vitousek, 1992). Homer et al., (2015) recommends precipitation fluctuation patterns be closely monitored and proactively managed to preserve the remaining healthy sagebrush steppe plant communities.

Temperature fluctuation is another potential risk to the sagebrush steppe ecosystem (Anderson & Inouye, 2001). Fluctuating temperatures have been shown to disrupt ecosystem function, particularly plant species distribution and composition (Araujo & Luoto, 2007). Mote et al. (2013) suggest temperature increases of 2-6℃ for the U.S. Pacific Northwest are possible for the future. Christensen et al. (2007) predict an increase in temperature for the Great Basin in excess of 6℃ over the next 100 years, while Wagner (2003) predicts the increase could actually be as high as 5-10℃. These higher temperatures will likely decrease soil moisture and premature snowpack melt which may shift plant species distribution and composition. For example, sagebrush is a species that depends on soil moisture during the dry summer months for survival (Fisser, 1968), so a decrease in soil moisture will likely have a detrimental effect on its establishment and distribution.

Thuiller (2007) suggests that for every increase or decrease of 1℃ in temperature variation, ecological zones could shift nearly 160-km. Effects to the sagebrush steppe are likely to involve elevation transitions of plant communities, which raises concerns for species dependent on the ecosystem for food and habitat (Backlund et al., 2009). Rising temperatures may also increase migration of invasive exotic annual species into higher elevations than previously observed (Taush, 2008; Sutherst, 2000). Knapp (1996) suggests more than 20% of the sagebrush steppe is dominated by invasive annual grass species such as cheatgrass, therefore, the possibility of more variability in climatic conditions could increase invasion threats (Compagnoni & Adler, 2014).

Climate fluctuations threaten existing plant communities within the sagebrush steppe, and may also influence secondary succession following disturbance. Secondary succession is the act of plant communities passing through stages, or thresholds, of species dominance eventually reaching a climax community or the final stage of biotic succession (Horn, 1974). Plant communities can remain in a stable state or “suspended stage of succession” for long periods of time (Laycock, 1991; Anderson & Inouye, 2001), or may transition through a threshold due to natural and/or human-influenced disturbances (e.g., excessive increases and decreases in climate variation, unregulated grazing, agriculture or urban development, recreation, and/or shifts in historical fire regimes). Hironaka and Tisdale (1963) suggested that secondary succession in sagebrush steppe ecosystems can become static when annual grasses become dominant in a plant community, and can over time affect ecosystem biodiversity.

How historical climate variation affects plant community vitality is crucial for understanding and protecting the sagebrush steppe (Dalgleish et al., 2011). Hence, our objectives were to: 1) identify shifts in plant functional groups (PFG), particularly cheatgrass and native perennial species, based on precipitation fluctuations over time, and 2) increase our understanding of secondary successional patterns in sagebrush steppe plant communities. To do this, we examine a long-term vegetation datum with reference to seasonal precipitation over the last 80 years. We hypothesize that exotic annual grass densities will increase with above average fall precipitation and at or below average winter and spring precipitation. This will ultimately favor annuals grasses over perennial species and suspend secondary succession. We also hypothesize that native perennial grass densities will increase with above average winter and spring precipitation, and at or below average fall precipitation. This will favor perennial species ability to compete with annual species and encourage secondary succession. Results may inform land management decisions for long-term planning, and assist in predicting the impacts of precipitation fluctuations on sagebrush steppe rangelands.

MATERIALS AND METHODS

STUDY SITES

This study was conducted within two, fenced study sites that were established in 1931 on the Snake River Plain of south-central Idaho. The Burley study site is 9-ha located in Cassia County, Idaho (42.50633°N, -113.89365°E); the Castleford study site is 6-ha located in Twin Falls County, Idaho (42.41171°N, -114.70412°E). The historic climax plant community for sagebrush steppe communities in the Snake River Plain was dominated by perennial species including: Wyoming big sagebrush (*Artemisia tridentata* Nutt. subsp. *wyomingensis* Beetle & Young), spiny hopsage (*Grayia spinosa* (Hook.) Moq.), and Thurber's needlegrass (*Achnatherum thuberianum* [Piper] Barkworth (Major Land Resource Area 011-Snake River Plains; NRCS Ecological Description, 2017).

Historically, each study site was a sagebrush steppe plant community. However, in the early 1900s all vegetation was cleared from the study sites to create farmland for crop production. After multiple years of tillage, these lands were ultimately abandoned due to the lack of available irrigation water in the region (Burley and Castleford study sites were abandoned in 1916 and 1920, respectively). The climate in this area is a semi-arid desert with summer temperatures averaging 21°C (70°F) and cold winter temperatures averaging -2°C (28°F; PRISM Climate Group, 2016). Annual mean precipitation levels at the Burley and Castleford study site are 265-mm (10.4") and 245-mm (9.6"), with elevations of 1310-m (4297-ft) and 1372-m (4501-ft), respectively (PRISM Climate Group, 2016). Both study sites have a silt loam texture and a < 5% slope (NRCS Web Soil Survey, 2016).

DATA COLLECTION

During the summers of 1933-1947, 1954, 1961, 1992, and 2015, plant densities were collected to evaluate plant community change. Permanent steel posts were systematically placed across each study site and 2 sampling quadrats were associated with each post (Figure 2.1). The Burley study site had 84 posts for a total of 168 sampling quadrats. The Castleford study site had 60 posts for a total of 120 sampling quadrats. Sampling quadrats were placed 10-m north and 10-m east (NE quadrat) and 10-m south and 10-m west (SW quadrat) of each post (Figure 2.1).

Sampling quadrats from 1933-1947 were 0.25-m^2 frames. From 1954 through 2015, 1-m^2 quadrat frames were used to capture a more-complete representation of the plant community. Data collected before 1954 were multiplied by 4 for data analysis to account for the change in quadrat frame size (e.g., a density of 10.0 plants/0.25-m^2 x 4 = 40.0 plants/m^2). Frames containing plant species with plant densities over 25.0 were categorized as 25+ in raw data pre-1954. Raw plant densities in 1954, 1961, 1992 and 2015 were recorded as actual densities; if the densities were greater than 100 plants/m^2, it was classified as 100 for uniformity with prior collection years. Plant densities for all sampling years were placed into plant functional groups (PFG; Table 2.1). Although Sandberg bluegrass is a native perennial grass, a separate functional group was established because of the species earlier phonological development compared to other native perennial grasses (Davies, 2008). Sandberg bluegrass is one of the first native perennial grasses to come out of dormancy during the spring, and usually has cured and returned to dormancy by early summer (USDA Plant Guide, 2017). Raw data of plant densities were available for 1933-1947 and 2015. Raw data for 1954, 1961, and 1991 could not be located, hence, averaged plant densities for those years were extracted from Peters and Bunting's (1992) paper. Climate data (precipitation and temperature) from 1931 to 2015 were gained from the web-based PRISM database (Figure 2.3; PRISM Climate Group, 2016). Precipitation data were categorized into seasons (Figure 2.4; i.e., winter = December, January, and February; spring = March, April, May, and June; summer = July and August; fall = September, October, and November).

DATA ANALYSIS

Using JMP® 13 statistical software, an analysis of variance by site was used to evaluate plant community change over time by year and PFG.

Tukey-Kramer Honestly Significant Difference (HSD) multiple comparison procedure were used to evaluate pair-wise comparisons across data collection years. The analysis was conducted on 1933-1947 and 2015 years using raw density data only. Annual and seasonal precipitation was analyzed using an analysis of variance by site to identify significant climatic changes. A student's t-test was used to evaluate pair-wise comparisons across years. Please note that figures 2.4-2.14 include average plant densities for 1954, 1961, and 1992 were extracted from Peters & Bunting (1992). Raw data for these years could not be located and were not included in the analysis.

RESULTS

PRECIPITATION

From 1931-2015, the Burley study site had fluctuations in annual precipitation across years (Figure 2.2a; Table 2.2). The 30-year (1981-2010) normal annual precipitation was 265.5-mm (10.5-inches). Yearly annual precipitation was not significantly different from the 30-year normal with the exception of 2013, where precipitation was only 112-mm (4.4-inches). Seasonal precipitation also fluctuated across years (Figure 2.3a). Summer precipitation at the Burley study site was significantly different ($p < 0.05$) than the 30-year normal 2014 (17-mm compared to 67-mm of precipitation, respectively). Although no other measurements were signification different from the normal, precipitation did range across the study site.

Winter precipitation ranged from 16-mm in 1946 to 128-mm in 1936 (30-year normal winter precipitation is 76-mm). Spring precipitation ranged from 43-mm in 1939 to 171-mm in

1944 (30-year normal spring precipitation is 110-mm). Fluctuations were also common in the summer and ranged from 1-mm in 1935 to 67-mm in 2014 (30-year normal summer precipitation is 17-mm). Fall precipitation ranged from 11-mm in 1940 to 16-mm in 1936 (30-year normal fall precipitation is 62-mm).

From 1931-2015, the Castleford study site also had fluctuations in precipitation across years (Figure 2.2b; Table 2.2). The 30-year (1981-2010) normal annual precipitation is 245.5-mm (9.7-inches). Although there was a range of annual precipitation across years, no years were significantly different from the 30-year average ($p > 0.05$). Similar to the Burley study site, seasonal quanities of precipitation also across years (Figure 2.3b). Summer precipitation in 2014 (112-mm) was significantly different from the 30-year average (17.2-mm). Winter precipitation ranged from 14-mm in 1992 to 118-mm in 1936 (30-year normal winter precipitation 60-mm), spring precipitation ranged from 43-mm in 1939 to 176-mm in 1944 (30-year normal spring precipitation 115-mm), summer precipitation ranged from 1-mm in 1940 to 112-mm in 2014 (30-year normal summer precipitation 17-mm), fall precipitation ranged from 11-mm in 1936 to 100-mm in 1946 (30-year normal fall precipitation 52-mm). From 1931-2015, the Burley and Castleford study sites had yearly temperature averages with minimal temperature fluctuations of (± 2℃), in which no statistical differences were found between years (Figure 2.2). Seasonal temperature fluctuations were not analyzed in this study.

FORB DENSITIES

Introduced Annual Forbs

Introduced annual forb (IAF) densities at the Burley and Castleford study sites varied significantly between 1933-2015 (Figure 2.4; Table A.1). The Burley study site had greater overall IAF densities than the Castleford study site (76.0 plants/m^2 and 66.0 plants/m^2, respectively). In 1939, the greatest IAF densities were recorded at the Burley study site (76.0 plants/m^2; Figure 2.4a; Table A.1). The fall precipitation season before data collection was 25-mm above the average 30-year normalcy, while winter and spring were 36-mm and 67-mm below the average, respectively. The two most common IAF species during 1939 were prickly Russian thistle (*Salsola tragus* L.; 52% plant composition) and tall tumblemustard (*Sisymbrium altissimum* L.; 47% plant composition). The years of low IAF densities ($\leq$ 14.6 plants/m^2) at the Burley study site were measured in 1934, 1936, 1942-1944, 1946, 1947, 1954, 1961, 1992 and 2015 (Figure 2.4a; Table A.1). For these years, 8 of the 11 years had below average fall, winter, and spring precipitation; on average the precipitation seasons were 18.2-mm, 32.6-mm and 27-mm below the 30-year normalcy. The primary IAF species measured during these years were tall tumblemustard and prickly Russian thistle (30% and 70% plant composition, respectively).

At the Castleford study site, the years of high IAF densities were 1938, 1939, 1954 and 2015 ($\geq$ 47.0 plants/m^2; Figure 2.4b; Table A.1). During these years, 3 of the 4 fall precipitation seasons were above average, averaging 14.7-mm above the 30-year normalcy. Winter and spring precipitation seasons were both below average for 3 of the 4 years averaging 19-mm and 38.7-mm below the 30-year normalcy, respectively. Similar to the Burley study site, the two most common species during the years of high densities at the Castleford study site were prickly Russian thistle and tall tumblemustard (71% and 29% plant composition, respectively). The Castleford study site recorded low densities of IAF ($\leq$ 11.8 plants/m^2) during the years 1933-1935, 1937, 1941-1947, 1961 and 1992 (Figure 2.4b; Table A.1). During these years, 8 of the 13 years had spring precipitation that averaged 30.6-mm below the 30-year normalcy. Unlike the Burley study site, fall and winter precipitation prior to data collection was above average for 8 of the 13 years averaging 19.5-mm and 9.9-mm above the 30-year normalcy, respectively. Prickly Russian thistle was the only IAF species measured during the years of low IAF plant densities. As a comparison, the remaining 5 years not included in the low IAF densities recorded below average fall and winter precipitation averaging 25-mm and 9.4-mm below the 30-year normalcy, respectively, and above average spring precipitation averaging 29.8–mm above the 30-year normalcy.

Native Annual Forbs

Native annual forb (NAF) densities at the Burley and Castleford study sites varied significantly between 1933-2015 (Figure 2.5; Table A.1). At the Burley study site, NAF densities were greater than all other years in 1940 (36.5 plants/m^2; Figure 2.5a; Table A.1). Native annual forbs consisted primarily of moth combseed (*Pectocarya setosa* A. Gray; 93% plant composition), and flatspine stickseed (*Lappula occidentalis* [S. Watson] Greene; 7% plant composition). In 1941, NAF densities at the Burley study site declined sharply to 1.6 plants/m^2 and shifted to a plant composition of 100% flatspine stickseed, which was the most predominate NAF species for the remaining years measured. The precipitation patterns between 1940 and 1941 also varied widely. Fall and spring precipitation prior to data collection in 1940 were 24-mm and 37-mm below the 30-year normalcy, respectively, while the winter season was 21-mm above the 30-year normalcy. Fall and spring precipitation prior to data collection in 1941 were 49-mm and 10-mm above the 30-year normalcy, respectively, while winter precipitation was only 1-mm below the 30-year normalcy. Low NAF densities (0.0-6.4 plants/m^2) for the Burley study site were recorded during the years 1933, 1934, 1936, 1939, 1941, 1942, 1944-1947, 1954, 1961 and 2015 (Figure 2.5a; Table A.1). During these years, 9 of the 13 fall precipitation seasons were below average, averaging 19-mm below the

30-year normalcy. Winter precipitation for 11 of the 13 years and spring precipitation for 8 of the 13 years were also below average (averaging 22.9-mm and 34.6-mm below the 30-year normalcy, respectively).

The Castleford study site recorded the greatest densities of NAF in 1941 (90.0 plants/m^2; Figure 2.5b; Table A.1), which was dominated by western tanseymustard (*Descurainia pinnata* [Walter] Britton; 97% plant composition). Precipitation in 1941 at the Castleford study site was above average during all 3 effective precipitation seasons (fall 42-mm,
winter 17-mm, and spring 19-mm above the 30-year normalcy); this year was the only year during the entire study period that recorded above average precipitation during fall, winter, and spring. Low densities of NAF (≤ 8.4 plants/m^2) at the Castleford study site were recorded during 1933, 1934, 1936-1940, 1943, 1945-1947, 1954, 1961, 1992 and 2015 (Figure 2.5b; Table A.1). During these years, fall precipitation was neutral, favoring neither above or below average precipitation, while winter precipitation for 9 of the 16 years was above average and spring precipitation for 11 of the 16 years was below average. Winter precipitation averaged 12.8-mm above the 30-year normalcy during the NAF low densities years, and spring precipitation averaged 33.2-mm below the 30-year normalcy. The two most common species at the Castleford study site were western tanseymustard (95% plant composition) and Menzies' fiddleneck (*Amsinckia menziesii* [Lehm.] A. Nelson & J.F. Macbr.; 5% plant composition).

Introduced Perennial Forbs

Introduced perennial forb (IPF) densities at the Burley study site were very low (< 0.1 plant/m^2) and showed no significant yearly variation between 1933-2015 ($p = 0.330$; Figure 2.6; Table A.2). The two species of IPF recorded at the Burley study site were meadow knapweed (*Centaurea debeauxii* Gren. & Godr) and field bindweed (Convolvulus arvensis L.). The Castleford site had 0.0 plants/m^2 of IPF recorded during the study period (Table A.2).

Native Perennial Forbs

Native perennial forb (NPF) densities at the Burley and Castleford study sites varied significantly between 1933-2015 (Figure 2.7; Table A.2). In 1936, the Burley study site had the highest recorded densities of NPF(15.0 plants/m^2; Figure 2.7a; Table A.2). The fall and spring precipitation seasons prior to data collection in 1936 were both below average (27-mm and 18-mm below the 30-year normalcy, respectively), while the winter season was above average (58-mm above the 30-year normalcy). The primary NPF species during 1936 were sulphur penstemon (*Penstemon attenuatus* Douglas ex Lindel; 70% plant composition) and Brenda's yellow cryptantha (*Cryptantha flava* [A. Nelson] Payson; 30% plant composition). The years of 1934, 1937-1947, 1954, 1961, 1992, and 2015 measured low NPF densities (≤ 1.5 plants/m^2) at the Burley study site (Figure 2.7a; Table A.2). During these years, precipitation during the fall, winter and spring were all neutral. Brenda's yellow cryptantha was the only recorded species.

The Castleford study site had NPF densities < 1.0 plant/m^2 for all measured years, with the exception of 1941 (15.1 plants/m^2; Figure 2.7b; Table A.2). Fall, winter, and spring precipitation prior to data collection in 1941 were above average (42-mm, 17-mm, and 19-mm above the 30-year normalcy, respectively). In 1941, NPF plant composition was only composed of western houndstongue (*Cynoglossum occidentale* A. Gray).

GRASS DENSITIES

Introduced Annual Grass

Introduced annual grass (IAG) densities at the Burley and Castleford study sites varied significantly between 1933-2015 (Figure 2.8; Table A.3). The only IAG species recorded, or observed, at either site during the study was cheatgrass. Cheatgrass densities at the Burley study site were higher than all other years during 1943-1946 and 2015 (≥ 59.0 plants/m^2; Figure 2.8a; Table A.3). Years 1954, 1961, and 1992 also had high densities of cheatgrass (100 plants/m^2) supporting the trend of increased invasion measured over time. During these years, fall, winter and spring precipitation were all below average. Fall precipitation for 6 of the 8 years, winter precipitation for 7 of the 8 years, and spring precipitation for 5 of the 8 years averaged 11.5-mm, 32.6-mm, and 25.4-mm below the 30-year normalcy, respectively. The years with low cheatgrass densities (≤ 4.6 plants/m^2) during the study period were 1933-1940 (Figure 2.8a; Table A.3). Between the fall of 1932 and spring of 1940, fall and winter precipitation for 5 of the 8 years, and spring precipitation for 6 of the 8 years were below average (averaging 37-mm, 15-mm, and 45-mm below the 30-year normalcy, respectively).

At the Castleford study site, 2015 cheatgrass density was statistically higher than all of the other measured examined (100 plants/m^2). Years 1954 and 1992 also had high cheatgrass density (both 100 plants/m^2) but were not included in the analysis. The years of 1942-1947 and 1961 were also relatively high in cheatgrass densities (≥ 40.0 plants/m^2; Figure 2.8b; Table A.3). During these years, fall precipitation prior to data collection for 6 of the 10 years were below average and spring precipitation for 6 of the 10 years were above average (averaging 20.8-mm below and 18.2-mm above the 30-year normalcy, respectively). The years of 1933-1941 measured low cheatgrass densities at the Castleford study site (≤ 22.0 plants/m^2; Figure 2.8b; Table A.3) Between the fall of 1932 and the spring of 1941, fall precipitation for 5 of the 9 years averaged 30-mm below the 30-year normalcy, however, winter and spring precipitation for 5 of the 9 years were above average (averaging 17-mm and 31-mm above the 30-year normalcy, respectively).

Native Annual Grass

Native annual grass (NAG) densities at the Burley study site varied significantly between 1933-2015 (Figure 2.9; Table A.4). The highest NAG densities at the Burley study site were measured in 1942 (73.0 plants/m^2; Figure 2.9; Table A.4). During 1942, fall and spring precipitation prior to data collection were 6-mm and 4-

mm below the 30-year normalcy, while winter precipitation was 26-mm above the 30-year normalcy. The only NAG species recorded at the Burley study site was sixweeks fescue (*Vulpia octoflora* [Walter] Rydb.).The Burley study site measured low NAG densities during 1939 and 2015 (≤ 5.0 plants/m^2; Figure 2.9; Table A.4). During these years, fall and winter precipitation prior to data collection were below average, averaging 6.5-mm and 10.5-mm below the 30-year normalcy, respectively. At the Castleford study site, 0.0 plants/m^2 of NAG were recorded during the study (Figure 2.9; Table A.4).

Introduced Perennial Grass

Densities of Introduced perennial grass (IPG) were very low at the Burley and Castleford study sites and varied significantly between 1933-2015 (Figure 2.10; Table A.4). At the Burley study site, 2015 was significantly higher than all years analyzed (0.4 plants/m^2). As a note, the highest densities were recorded in 1992 (2.0 plants/m^2), however, this data point was not included in the analysis. Throughout the remainder of the study period 0.0 plant/m^2 of IPG was recorded (Figure 2.10a; Table A.4). Fall, winter, and spring precipitation prior to the data collection of 1992 and 2015 were all below average, averaging 10.5-mm, 33.5-mm and 29.6-mm below the 30-year normalcy. During the study period, crested wheatgrass (*Agropyron cristatum* [L.] Gaertn) was the only IPG species recorded at either site.

The Castleford study site had 0.0 plants/m^2 IPG densities documented until the 2015 data collection year (4.8 plants/m^2; Figure 2.10b; Table A.4). During 2015, fall and winter precipitation before data collection were slightly above average (3-mm and 1-mm above the 30-year normalcy), while spring precipitation was BA (38-mm below the 30-year normalcy).

Native Perennial Grass

Native perennial grass (NPG) densities within the Burley and Castleford study sites were significantly different between 1933-2015 (Figure 2.11; Table A.3). The greatest NPG densities measured at the Burley study site were recorded during 1945-1947, 1954, 1961, 1992, and 2015 (≥ 11.0 plants/m^2; Figure 2.11a; Table A.3). During these years, fall precipitation for 5 of the 7 years and winter precipitation 7 of the 7 years averaged 10.8-mm and 34.9-mm below the 30-year normalcy, respectively. Spring precipitation for 4 of the 7 years averaged 9.3-mm above the 30-year normalcy. The primary species of NPG during the years of high densities at the Burley study site were squirreltail (70% plant composition) and thickspike wheatgrass (30% plant composition). The low years of NPG densities at the Burley study site were measured in 1933-1940 and 1943 (≤ 6.2 plants/m^2; Figure 2.11a; Table A.3). During these years, fall and winter precipitation for 5 of the 9 years and spring precipitation for 7 of the 9 years were below average, averaging 37-mm, 15.2-mm, and 39.8-mm below the 30-year normalcy, respectively.

Unlike the Burley study site that exhibited increases and decreases in NPG densities over the study period, the Castleford study site recorded 0.0 plants/m^2 during the study period until 1961, and remained static during 1992 and 2015 (2.0 plants/m^2; Figure 2.11b; Table A.3). During these years, fall precipitation for 3 of the 3 years averaged 9.3-mm above the 30-year normalcy. Winter and spring precipitation were both below average; winter precipitation for 2 of the 3 years and spring precipitation for 3 of the 3 years averaged 28-mm and 35.7-mm below the 30-year normalcy, respectively. Thickspike wheatgrass was the only NPG species recorded at the Castleford study site during the study. Observed seed sources of NPG surrounded the Castleford study site in 2015 included: thickspike wheatgrass, squirreltail, Thurber's needlegrass, and needle and thread (*Hesperostipa comata* [Trin. & Rupr.] Barkworth).

Sandberg Bluegrass

Sandberg bluegrass *(Poa secunda* J. Presl) densities at Burley and Castleford study sites varied significantly between 1933-2015 (Figure 2.12; Table A.5). At the Burley study site, Sandberg bluegrass densities greater than 1.0 plant/m^2 were measured in 1945-1947, 1961, 1992 and 2015 (Figure 2.12a; Table A.5). During these years, fall precipitation for 4 of the 6 years and winter precipitation for 6 of the 6 years averaged 6-mm and 35-mm below the 30-year normalcy, respectively.

The Castleford study site was comparable to the Burley study site, only measuring Sandberg bluegrass densities greater than 1.0 plant/m^2 in 1961, 1992, and 2015 (Figure 2.12b; Table A.5). During these years, fall precipitation for 3 of the 3 years averaged 9.3-mm above the 30-year normalcy. Winter and spring precipitation for 3 of the 3 years averaged 22-mm and 35.7-mm below the 30-year normalcy, respectively.

WOODY PLANT DENSITIES

Sagebrush

Sagebrush densities at the Burley study site varied significantly between years 1933-2015 (Figure 2.13a; Table A.6). At the Burley study site higher sagebrush densities were measured in 1937, 1939, 1940, 1942-1947 ($\leq$ 6 plants/m^2; Figure 2.13a; Table A.6). The years of 1954 and 1961 also had relatively high sagebrush densities (3.0 plants/m^2) but were not included in the analysis. During these years, fall precipitation for 7 of the 11 years averaged 17.7-mm below the 30-year normalcy. Winter precipitation for 9 of the 11 years and spring precipitation for 8 of the 12 years were also below average (averaging 30.2-mm and 30-mm below the 30-year normalcy, respectively). Sagebrush densities remained relatively low at the Castleford study site (<1.0 plant/m^2) throughout the entire study period and no significant differences were found over time (Figure 2.13b; Table A.6).

Other Woody Plants

Other woody plant (OWP) densities at the Burley and Castleford study site varied significantly between 1933-2015 (Figure 2.14; Table A.6). Other woody plant densities at the Burley and Castleford study sites were 0.0 plants/m^2 until 1992 and 2015 when densities measured 0.1 plants/m^2 and 0.3 plants/m^2, respectively. The only OWP species recorded at the Burley and Castleford study sites was yellow rabbitbrush (*Chrysothamnus viscidiflorus* [Hook.] Nutt).

DISCUSSION

This study evaluated shifts in plant functional groups based on annual and seasonal precipitation patterns. General shifts in plant community composition were observed at both study sites. At the Burley study site following the initial disturbance (i.e., farmland abandonment in 1916; Piemeisel, 1945), the plant community consisted mainly of annual forbs between 1933-1936, and then from 1937-1939 sagebrush and perennial forbs became established. From 1940-1947 introduced and native grasses were measured in addition to sagebrush and forbs; Sandberg bluegrass did not appear until 1945. During 1954 and 1961, forbs and perennial grasses declined, while cheatgrass increased. In 1992, neither forbs nor sagebrush were recorded, perennial grasses declined from previous measurements and cheatgrass increased. In 2015, perennial grasses and cheatgrass declined, however, forbs again became present along with the new, although minimal, appearance of other woody plants. At the Castleford study site following the initial disturbance (i.e., farmland abandonment in 1920; Piemeisel, 1945), the plant community was very similar to what was observed at the Burley study site. Annual forbs were the primary species recorded between 1933-1944, however, cheatgrass was also present. In 1941, perennial forbs were measured but were not found in 1942. Between 1945-1947, sagebrush and introduced annual grass were first observed. In 1954, sagebrush was not present and was not measured again for the remainder of the study period.

During 1961 and 1992, perennial native grasses were measured, adding to the cheatgrass and annual forb plant community. In 2015, introduced perennial grass became established, and a minimal amount of other woody plants was measured.

The timing of precipitation (or seasonal precipitation), appears to have influenced plant community shifts more than annual precipitation. Other studies have suggested that the timing of precipitation events in sagebrush steppe ecosystems is critical. For example, Svejcar et al. (2003) suggest that rainfall received between October and March is crucial for plant species survival in the sagebrush steppe. Rainfall occurring when it is most influential to plant growth is also referred to as effective precipitation, and has been identified as a key influential variable in seed expression and plant densities fluctuation of sagebrush steppe plant communities (Chambers et al., 2007; Roundy et al., 2007). Our hypotheses test the influence of the seasonal effective precipitation amount on plant community composition, particularly plant functional groups, and are described below.

For years with above average winter and spring precipitation, and normal or below average fall precipitation, native perennial grass densities were hypothesized to increase. In our study, we found the highest densities of native perennial grasses when winter precipitation was below average and spring precipitation was above average, which occurred in 1945-1947, 1954, 1961, 1992, and 2015 at the Burley study site. The Castleford study site lacked native perennial grass densities until 2015, which proved difficult to compare with precipitation patterns. Sandberg bluegrass, however, was present during the years 1945-1947, 1961, 1992, and 2015 at the Burley study site and 1961,1992, and 2015 at the Castleford study site. Sandberg bluegrass also increased with below average winter precipitation at both study sites, however, at the Castleford study site spring precipitation was recorded as below average, suggesting Sandberg bluegrass did not favor spring precipitation, like native perennial grasses. These results were not surprising as abundant literature affirms similar outcomes of perennial grass densities fluctuating based on winter and spring seasonal precipitation (Bates et al., 2006; Davies, 2008; Boyd & Lemos, 2015).

Potential explanations for greater perennial grass densities at the Burley study site compared to the Castleford study site may include differences in humidity levels. During the 2015 data collection, higher humidity from surrounding cropland was observed at the Burley study site compared to the Castleford study site. Higher humidity has been linked to increased soil moisture and decreased air temperatures (Dai et al., 1999). At the Burley study site, native perennial grass may have experienced less stress due to increased humidity. Decreased environmental stress would have allowed plants to allocate resources for growth rather than survival, most likely positively influencing seed production and reducing seedling mortality rates. Many of the native perennial grass physiological processes are restricted during drought-stress; increased soil moisture made possible by increased humidity can combat these restrictions (Smith, 2000). A study by Kueppers et al. (2007) found humidity from adjacent croplands can also decrease summer temperatures by up 2.7℃, suggesting humidity could have influenced native perennial grass densities at the Burley study site by reducing drought-stress and increasing soil moisture.

Our second hypothesis was that cheatgrass densities would increase with above average fall precipitation and neutral winter and spring precipitation. We speculated this would give cheatgrass a competitive advantage over seedlings of native species. Cheatgrass is a winter annual that often germinates in the fall which allows its roots to continually grow throughout the winter, giving it a competitive advantage over winter dormant perennials for soil moisture and resources during the spring (Sheley & Larson, 1994; Knapp, 1996; Beckstead et al., 2010; Mealor, 2013). Although cheatgrass has a short life-cycle compared to perennial native species, cheatgrass is still considered by many as one of the most invasive exotic species in the sagebrush steppe due to its ability to spread and multiply quickly (Stewart &

Hull, 1949). Cheatgrass is also known to germinate with very little surface water, therefore, even a single fall rainfall can initiate germination, making it extremely drought tolerant (Young et al., 1987).

In our study, we found the greatest densities of cheatgrass when precipitation was below average in general. The Burley study site had higher cheatgrass densities during 1943-1946, 1954, 1961, 1992, and 2015, which were all years of below average fall, winter, and spring precipitation, however, during years of low cheatgrass densities, all years also had consistent below average seasonal precipitation. At the Castleford study site, greater densities of cheatgrass were expressed during 1942-1947, 1954, 1961, 1992, and 2015. Unlike the Burley study site, the Castleford study site primarily had below average fall and winter precipitation and above average spring precipitation.

Cheatgrass densities likely influenced other plant functional groups more than fluctuating seasonal precipitation. For example, data from 1943-1947, 1954, 1961, 1992, and 2015 identified cheatgrass as the dominant species at the Castleford study site. Introduced perennial grass and other woody plants densities were not recorded prior to 2015 although seed sources outside of the study site were available. It is likely that seed sources were brought into the study site by lagomorphs (Howard & Wolfe, 1976; Johnson, 1979; Ganskopp et al., 1993), however, the inability of these species to establish prior to 2014 was likely influenced by cheatgrass competition. Summer precipitation in 2014 (described below) was greater than the normal and may have also influenced the establishment of introduced perennial grass and other woody plants at the Castleford study site due to increased resource availability.

Summer precipitation in 2014 at the Castleford study site was above average and highly abnormal. The National Weather Service (2016) referred to the 2014 summer precipitation as “the 100-year storm”, since the bulk of the precipitation fell in a single early August storm. Considering the combination of warm summer temperatures (30-year normal 22°C) and spring-like precipitation, it is probable that the sudden appearance of two dormant species in the 2015 data collection year was related to the 2014 summer season at the Castleford study site. At the Burley study site, 2014 summer precipitation was not spring-like, but more comparable to a typical fall or winter precipitation season (fall/winter 30-year normal: 62-76-mm; summer 2014: 67-mm). However, the increased 2014 summer precipitation season did not have any apparent effects plant functional groups at the Burley study site during the 2015 data collection year.

The second objective of this study was to increase our understanding of secondary successional patterns in sagebrush steppe plant communities. The plant community change at the Burley study site offers long-term insight of secondary plant succession in the sagebrush steppe. The Burley study site plant community transitions from native and introduced forbs to sagebrush, and then to native grasses followed by introduced grasses. This is unlike many other long-term studies that have started with forbs, evolved to grasses, and then reached the potential natural community with sagebrush (Biondini et al., 1985; McLendon & Redente, 1990; Allen-Diaz & Bartolome, 1998). Historic literature suggests Sandberg bluegrass to be an earlier successional species than other native perennial grass (Anderson, 1962; Robertson; 1971; Bates et al., 2000; Davies & Svejcar; 2008). The plant community at the Burley study site had native perennial grasses five years prior to the presence of Sandberg bluegrass. These results were not expected, and are unlike traditional secondary succession patterns described in other long-term studies. The establishment of introduced forbs in 2015 is also of interest because forbs are considered a earlier successional species than shrubs. It is likely that the abnormal increase in summer precipitation of 2014 extended late season moisture influencing the increase in forb densities expressed in 2015.

It is possible that classic secondary succession patterns were not followed at the Burley and Castleford study sites because of plant competition between functional groups, particularly competition with cheatgrass. This study found that both introduced annual grass (i.e., cheatgrass) and native perennial grasses favor spring precipitation and compete for the same soil nutrient resources. Although seasonal temperature was not analyzed in this study, several studies suggest it influences plant dynamics between introduced annual and native perennial grasses. Aguirre & Johnson (1991) suggests that below average spring temperatures could delay perennial bunchgrass seedling emergent, and where introduced annual grass is present, invasive annuals may take full-advantage of available soil resources before perennial bunchgrasses even begin their lifecycle.

For a plant community to be resilient to exotic annual grass invasions, native perennial grasses need to be present. Davis et al. (2000) describe plant communities that are most susceptible to annual invasion as those with available unused soil resources, which are abundantly available on disturbed sites. A comparison of annual invasion resistance between the Burley and Castleford study sites suggests, the Castleford study site has far less ability to resist exotic annuals such as cheatgrass due to the general absence of native perennial grasses. The high densities of introduced annual grass at the Castleford study site, most likely prevented conventional secondary succession from taking place through intense competition. The first time native perennial grass was recorded post-abandonment of the Castleford study site was in 1961. Hence, the secondary plant successional timeline of the Castleford study site is quite different than what was observed at the Burley study site.

During the 2015 data collection at both sites, dense stands of annuals, specifically cheatgrass and mustards, were abundant, as were layers of litter with very little bare ground throughout most of the study sites. Herbaceous litter on rangelands is often minimized through livestock grazing which consumes forage (Whisenant &

Uresk, 1990; West, 2000; Bates et al., 2009; Davies et al., 2010). Because both study sites have not been exposed to grazing for more than 80 years, litter accumulation was plentiful. Litter has been shown to enhance the competitive ability of annual species over time. Annual plant litter decomposes slowly in semi-arid conditions and years of litter accumulation can make it extremely difficult for native seeds to reach the soil (Norton, 2004; Sheley et al., 2009). Additionally, in areas of high annual plant densities, precipitation is often unable to effectively infiltrate into the soil, and is instead trapped within the litter preventing water movement downward (Debano & Krammes, 1966; Nagler et al., 2000). It is highly probable that native perennial grass seed germination was restricted due to limited access to soil. The amount of cheatgrass and mustard litter observed in 2015 could also be considered an increased fire risk, especially at the Castleford study site which is surrounded by sagebrush steppe rangeland. Excessively high fuel load levels in a concentrated area, increase ignition potential and fire spread (Hilken & Miller, 1980).

CONCLUSION

Rangeland conservationist and managers are important assets that aid in preserving the sagebrush steppe, one of nature’s most complex and indispensable resources. Stewards of the land must employ adaptive management in an uncertain future, making proactive attempts to reduce habitat loss and promote plant community resilience to invasive annual species. Major disturbances (e.g., agriculture or urban development, exotic annual grass invasion, wildfires) affect the sagebrush steppe, threatening not only health and viability, but also the existence for future generations (McLendon & Redente, 1990; Anderson & Inouye, 2001). Furthermore, effects of climate variation, specifically precipitation, are altering plant community responses after a major disturbance (West, 2000). This long-term study has increased our understanding of how climate patterns influence secondary plant succession after one major disturbance, farmland abandonment.

Understanding precipitation influences on different plant functional groups is critical in evaluating risks to the sagebrush steppe, including exotic annual invasion, fuel loads, and wildlife habitat health (i.e., sage grouse nesting grounds). Monitoring current effective precipitation patterns (i.e. fall, winter, and spring precipitation) and comparing those with results from long-term studies, such as this one, can be an essential asset for land managers. A below average winter followed by above average spring precipitation season can lead to increases in native perennial grasses, specifically below average winters were shown to increase Sandberg bluegrass. Increased forb densities are likely to occur during years of above average fall precipitation. Introduced annual grasses are extremely drought tolerant, increasing even when general effective precipitation patterns are below average and other plant functional groups suffer drought-stress effects.

The usefulness of long-term precipitation patterns relative to increases and decreases of plant functional groups can assist land managers in grazing management, prediction of fuel loads, available food and habitat for wildlife, and the effectiveness of treatment and/or prevention programs to combat the spread of invasive annual species. Invasive annual species, such as cheatgrass, have well-recognized negative impacts to rangelands, especially in the sagebrush steppe ecosystem (Davies et al., 2014). Cheatgrass invasion was shown to be an immediate threat at both the Burley and Castleford study site, acting as an inhibitor through inter-specific competition and litter accumulation which prevented soil-seed contact needed for germination in perennial species. This study found that the Burley study site was able to more effectively resist cheatgrass invasion likely due to higher densities of native perennial grasses than the Castleford study site. It can be presumed that the lack of established native perennial grass at the Castleford study site undoubtedly contributed to the cheatgrass dominance observed in 2015.

At the Castleford study site, a once pristine native sagebrush steppe landscape is currently an exotic annual grassland. A shift in community composition happened through disturbance and annual grass invasion. If restoration efforts were implemented within the Castleford study site, such as livestock grazing to reduce litter, native perennial grass may have a better chance of establishing in the rangeland and increasing the sites resilience to future annual grass invasion. Livestock grazing has been shown to effectively remove plant litter (West et al., 1984; Davies et al., 2010). Fall livestock grazing on sites that are dominated by cheatgrass may also be an effective way to minimize the spread of cheatgrass enhancing opportunities for native perennial bunchgrass establishment (Davies et al., 2009; Davies et al., 2010). Hence, livestock grazing is expected to provide an enrichment benefit at the Castleford study site by minimizing cheatgrass dominance and reducing soil restrictions (i.e., increasing soil seed contact). The Castleford study site is surrounded by desirable native seeds that could quickly utilize available resources released through the removal of cheatgrass. Other long-term studies with restricted grazing sites have reported minimal plant community differences between the interior and exterior of their sites (Sneva et al., 1984; Rose et al., 1993; 1994). However, Young & Evans (1982) suggest that any advancement, no matter how small, that allows native perennial grasses to gain a competitive edge is important.

Site-specific management planning can be improved by accounting for responses to effective precipitation fluctuation within a plant community. These historic seasonal climate patterns and the observed effects on plant functional groups provide information that can be used in management discussions and objectives for similar sites within the sagebrush steppe.

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FIGURES & TABLES

(a) (b)

Figure 1.1. Photographs of Robert L. Piemeisel conducting research at the Castleford study site. (a) Piemeisel next to a prickly Russian thistle (*Salsola tragus* L.) plant in 1940. (b) Piemeisel collecting beet leafhopper (*Circulifer tenellus* Baker) on prickly Russian thistle plants in 1932. Photo Credit: R.L. Piemeisel; Courtesy of the University of Idaho Library Archives; Piemeisel Exclosures Collection, 2016

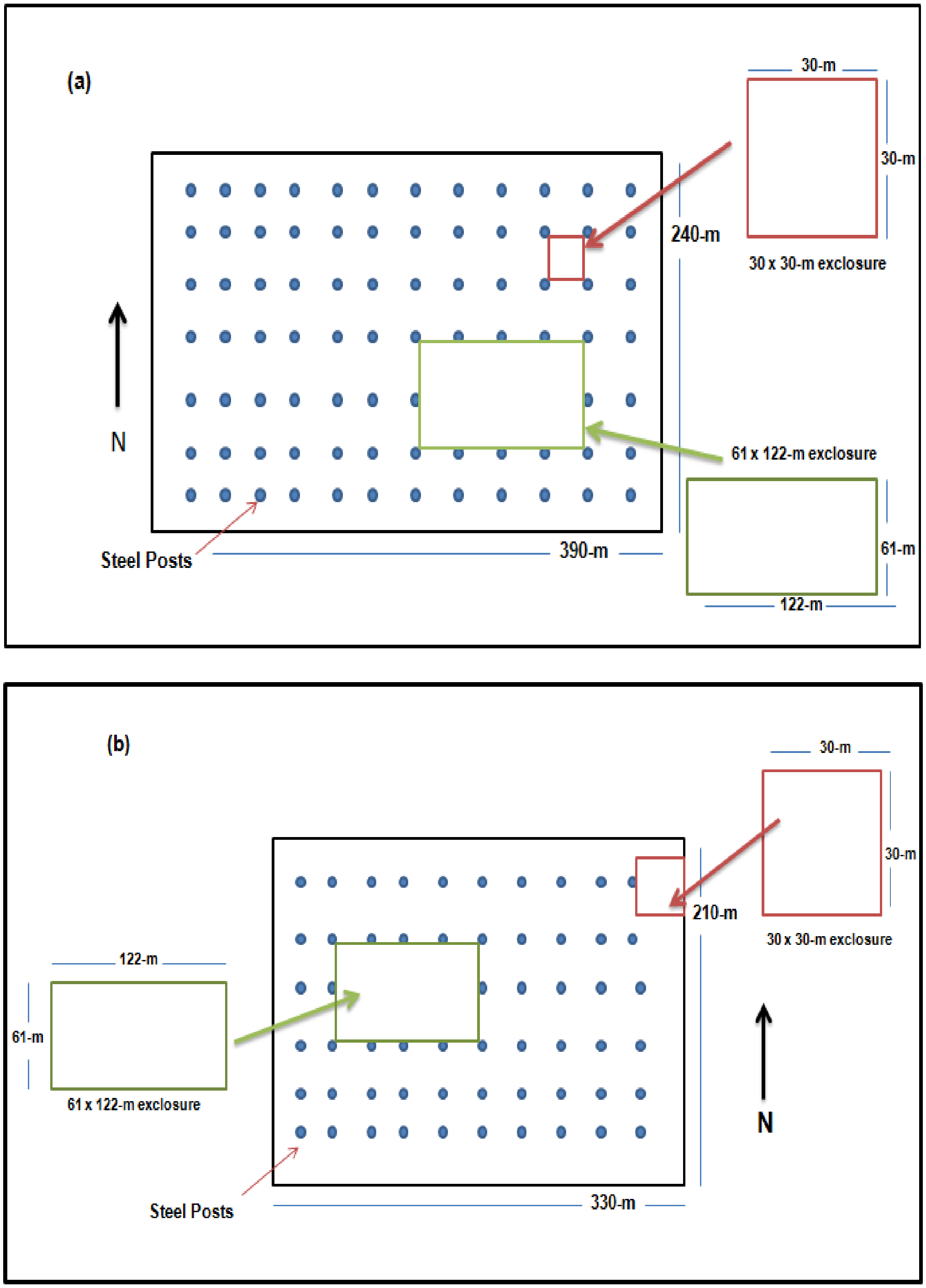

Figure 1.2. Diagram of the abandoned farmland portion of the Burley (a) and Castleford (b) study sites with the seeded (30 x 30-m) and lagomorph-proof (61 x 122-m) exclosures.

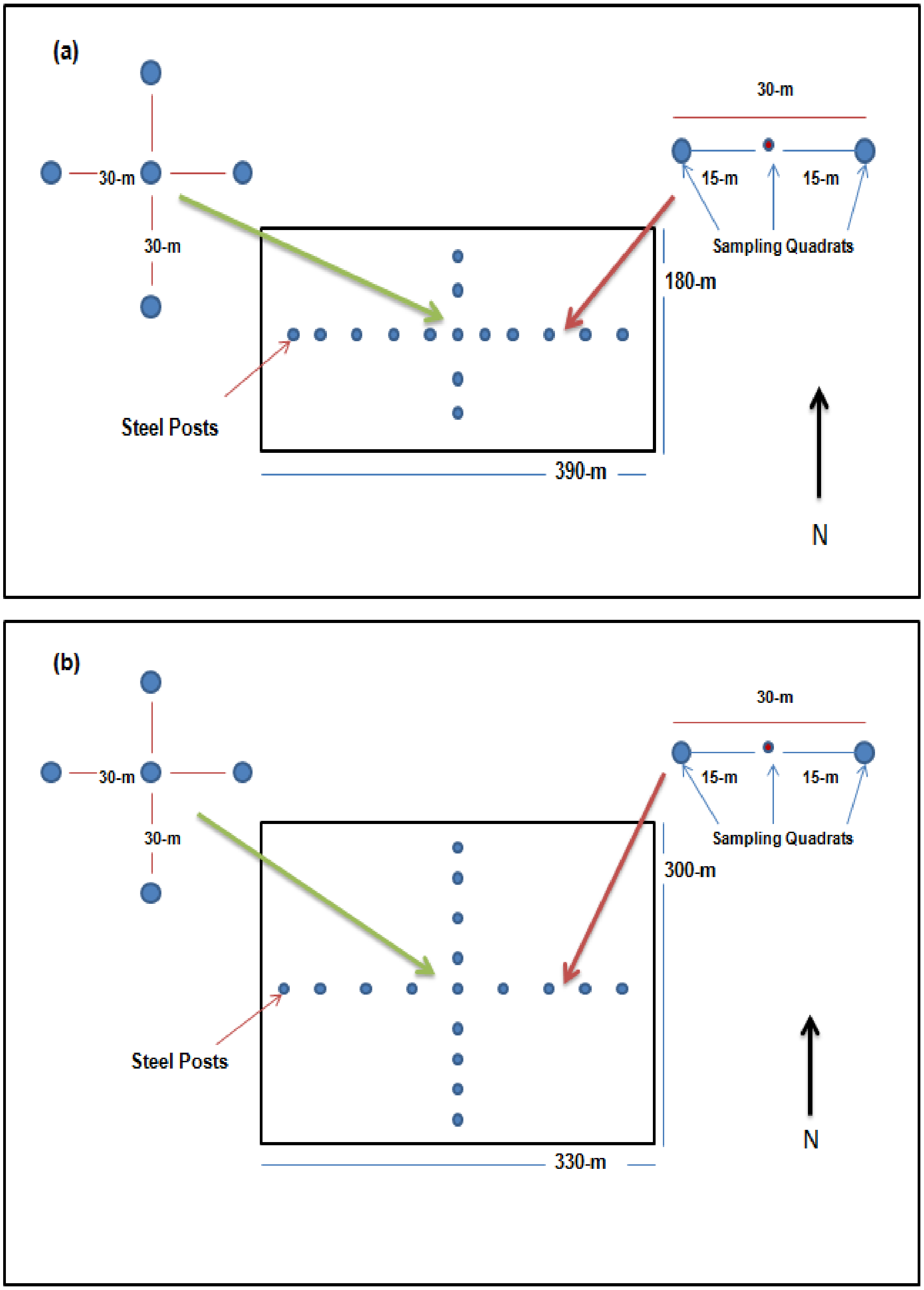

Figure 1.3. Diagram of the degraded rangeland portion of the Burley (a) and Castleford (b) study sites.

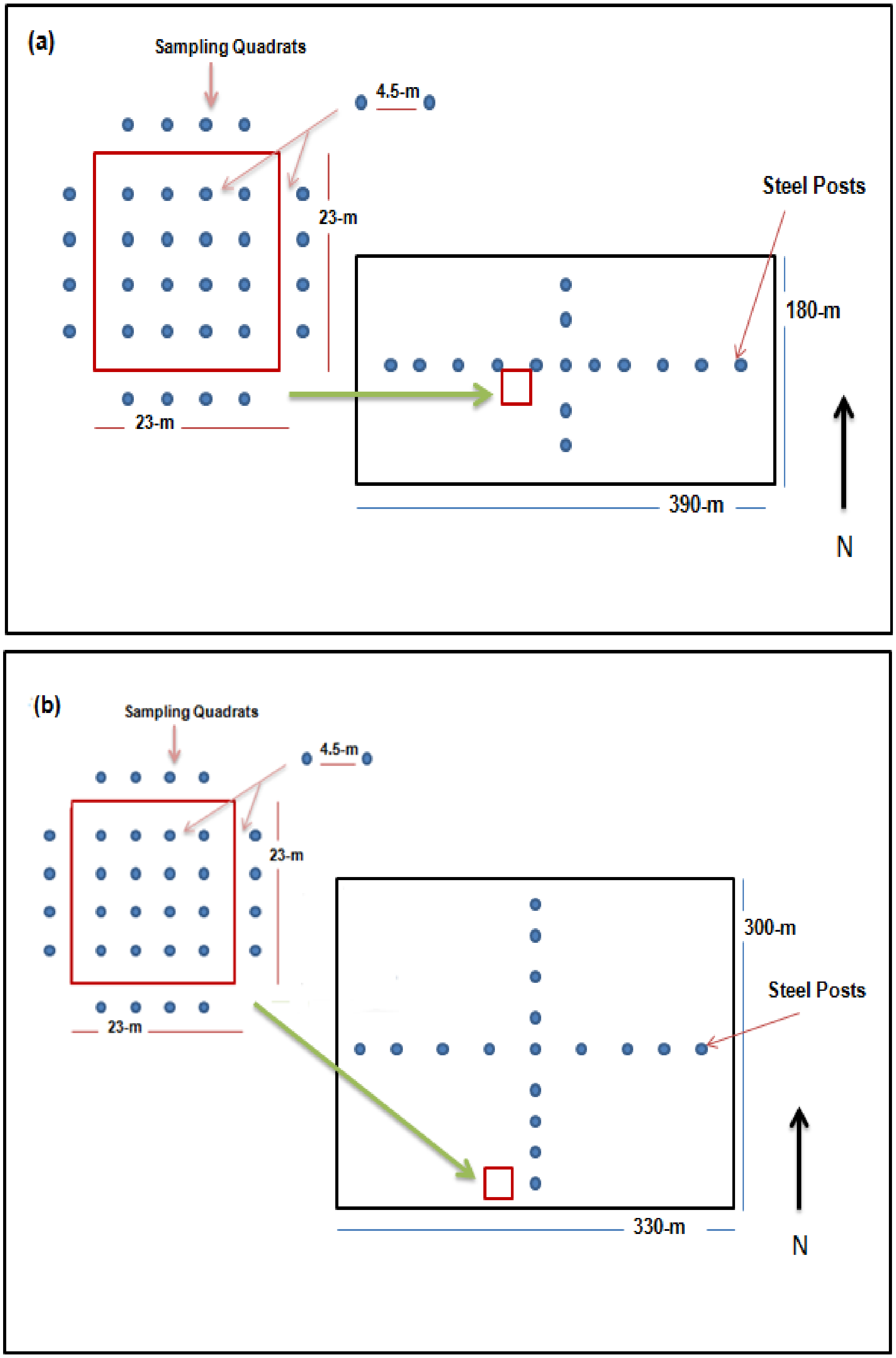

Figure 1.4. Diagram of the degraded rangeland portion of the Burley (a) and Castleford (b) study sites with the sagebrush (23 x 23-m) exclosure.

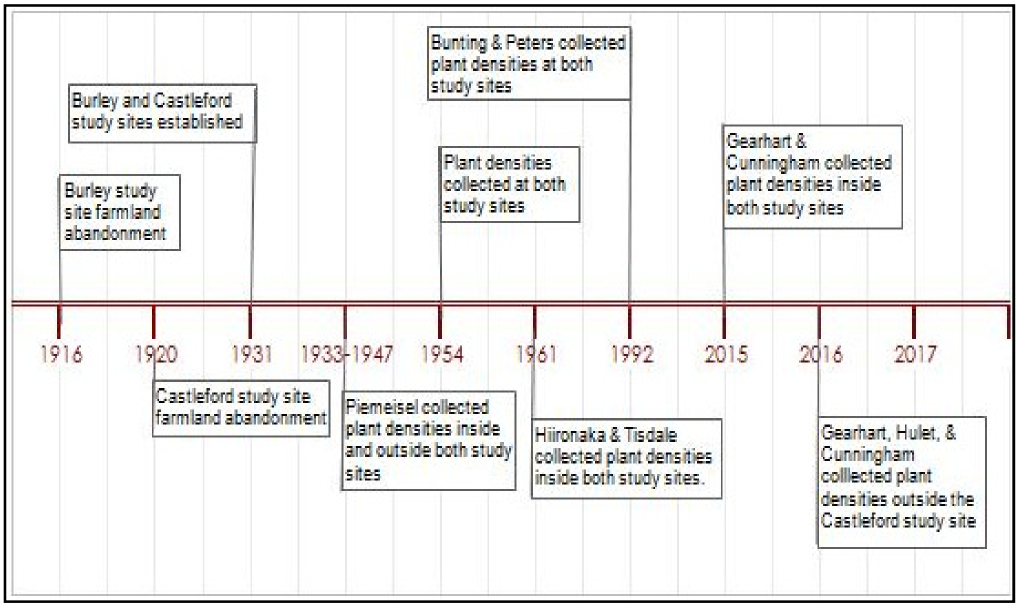

Figure 1.5. Data collection timeline for the Burley and Castleford study sites, data can be accessed at the University of Idaho Library (University of Idaho Library Archives; Piemeisel Exclosures Collection, 2016).

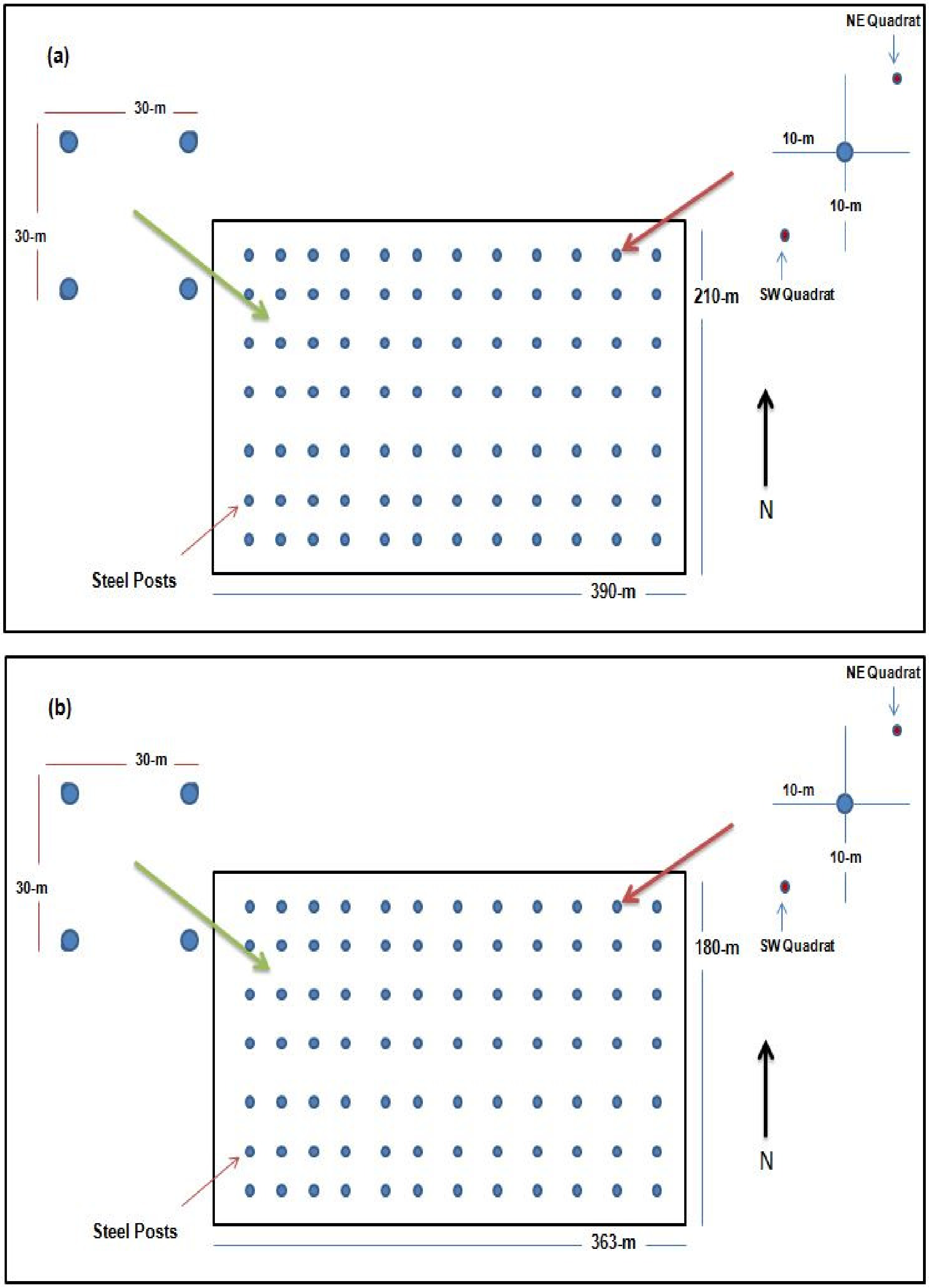

Figure 2.1. Diagram of the Burley (a) and Castleford (b) study sites sampling grid. Steel posts were established every 30-m apart. Two sampling quadrats (NE & SW quadrat) correspond with each post.

Table 2.1. Species composition for plant functional groups.

Plant Functional Groups	**Species**
Introduced Annual Forbs	*Alyssum desertorum* Stapf,; *Arabidopsis thaliana* (L.) Heynh; *Chenopodium album* L. var. album; *Descurainia sophia* (L.) Webb ex Prantl; *Helianthus annuus* L.; *Lactuca serriola* L.; *Melilotus indicus* (L.) All.; *Salsola tragus* L.; *Sisymbrium altissimum* L.; *Tragopogon dubius* Scop.
Native Annual Forbs	*Amaranthus albus* L.; *Amsinckia menziesii* (Lehm.) A. Nelson & J.F. Macbr.; *Chenopodium atrovirens* Rydb.; *Descurainia pinnata* (Walter) Britton; *Lappula occidentalis* (S. Watson) Greene; *Lesquerella densiflora* (A. Gray) S. Watson; *Oenothera primiveris* A. Gray; *Pectocarya setosa* A. Gray; *Polemonium micranthum* Benth.; *Solanum triflorum* Nutt.
Introduced Perennial Forbs	*Centaurea debeauxii* Gren. & Godr.; *Convolvulus arvensis* L.
Native Perennial Forbs	*Agoseris* Raf.; *Astragalus atratus* S. Watson; *Astragalus crassicarpus* Nutt.; *Cryptantha flava* (A. Nelson) Payson; *Cynoglossum occidentale* A. Gray; *Erigeron asperugineus* (D.C. Eaton) A. Gray; *Iva axillaris* Pursh; *Mentzelia laevicaulis* (Hook.) Torr. & A. Gray; *Penstemon attenuatus* Douglas ex Lindl.; *Phlox hoodii* Richardson; *Phlox longifolia* Nutt.; *Sphaeralcea coccinea* (Nutt.) Rydb; *Zigadenus paniculatus* (Nutt.) S. Watson
Introduced Annual Grasses	*Bromus tectorum* L.
Native Annual Grasses	*Vulpia octoflora* (Walter) Rydb.
Introduced Perennial Grass	*Agropyron cristatum* (L.) Gaertn
Native Perennial Grass	*Achnatherum thurberianum* (Piper) Barkworth; *Elymus elymoides* (Raf.) Swezey; *Elymus lanceolatus* (Scribn. & J.G. Sm.) Gould; *Elymus trachycaulus* (Link) Gould ex Shinners; *Hesperostipa comata* (Trin. & Rupr.) Barkworth
Sandberg Bluegrass	*Poa secunda* J. Presl
Sagebrush	*Artemisia tridentata* Nutt. subsp. *wyomingensis* Beetle & Young
Other Woody Plants	*Chrysothamnus viscidiflorus* (Hook.) Nutt.

Table 2.2. Summary statistics for total yearly precipitation by study site (Burley and Castleford).

Precipitation (mm)				
	Burley		**Castleford**	
Year	**Annual Total (mm)**	**Tukey-Kramer HSD**	**Annual Total (mm)**	**Tukey-Kramer HSD**
1931	164	CDE	146	CDE
1932	273	ABCD	266	ABCDE
1933	166	BCDE	132	E
1934	182	BCDE	188	BCDE
1935	193	ABCDE	188	BCDE
1936	286	ABC	265	ABCDE
1937	258	ABCD	259	ABCDE
1938	309	AB	291	ABC
1939	137	DE	130	E
1940	304	ABC	289	ABC
1941	299	ABC	304	AB
1942	301	ABC	286	ABCD
1943	219	ABCDE	207	ABCDE
1944	298	ABC	291	ABC
1945	285	ABC	298	AB
1946	297	ABC	278	ABCDE
1947	231	ABCDE	238	ABCDE
1952	203	ABCDE	195	ABCDE
1953	231	ABCDE	221	ABCDE
1954	175	BCDE	160	BCDE
1959	208	ABCDE	239	ABCDE
1960	214	ABCDE	220	ABCDE
1961	239	ABCDE	243	ABCDE
1990	187	BCDE	241	ABCDE
1991	203	ABCDE	228	ABCDE
1992	162	DE	196	BCDE
2013	112	E*	138	DE
2014	337	A	346	A
2015	265	ABCDE	269	ABCDE
AVG	**265**	**ABCD**	**245**	**ABCDE**

AVG = 30 year normalcy (1981-2010). Annual precipitation with different letters within each site are significantly different using student’s t test. Letters with an asterisk (*) are significantly different from the 30-year normalcy.

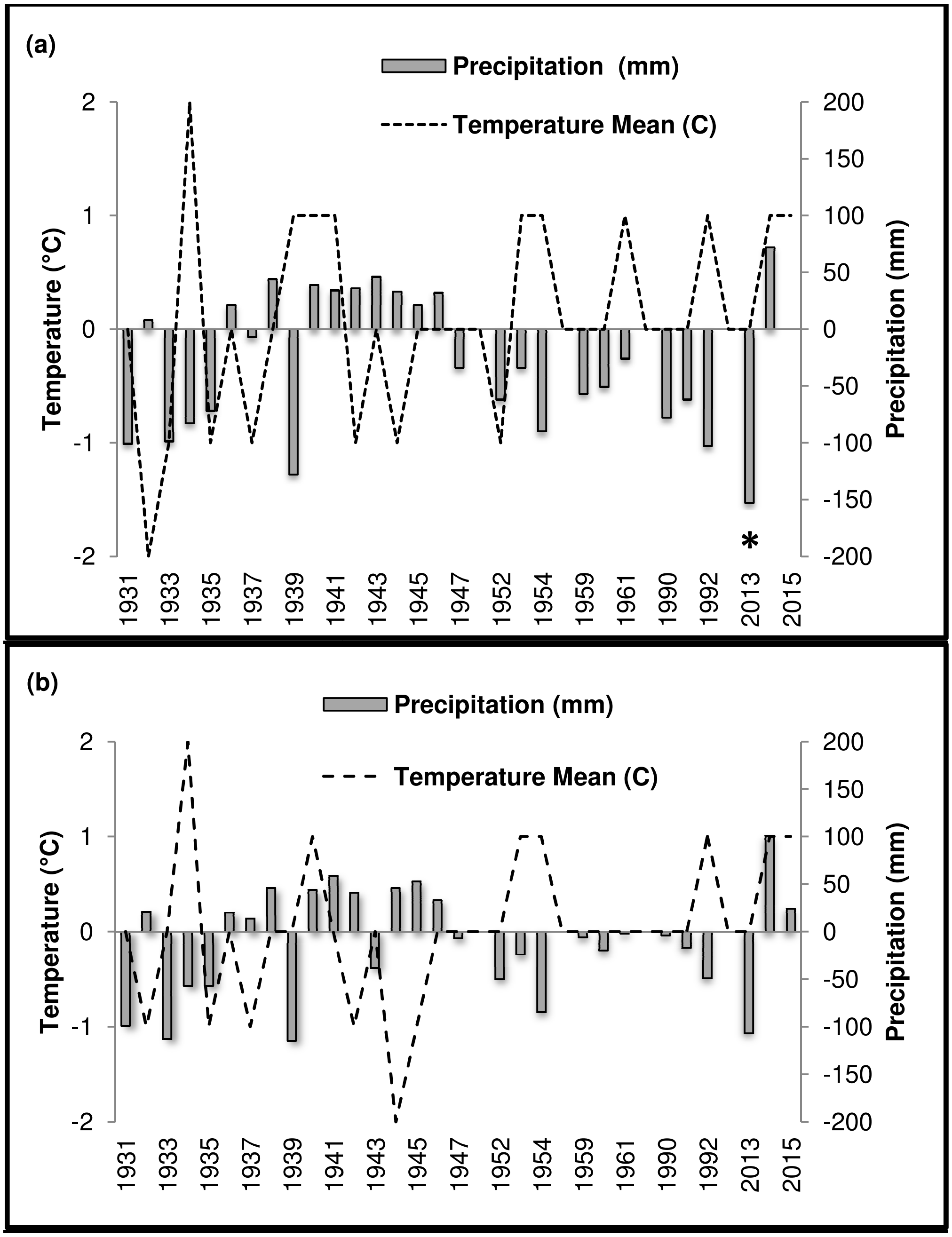

Figure 2.2. Burley (a) and Castleford (b) study sites precipitation and temperature differences by year (1931-2015) from the 30-year normalcy (zero line; Prism Climate Group 2016). The Burley study site 30-year normalcy (1981-2010) annual precipitation and temperature is 265-mm and 9°C, respectively. The Castleford study site 30-year normalcy (1981-2010) annual precipitation and temperature is 245-mm and 9°C, respectively. Bars with an asterisk (*) are significantly different from the 30-year normalcy.

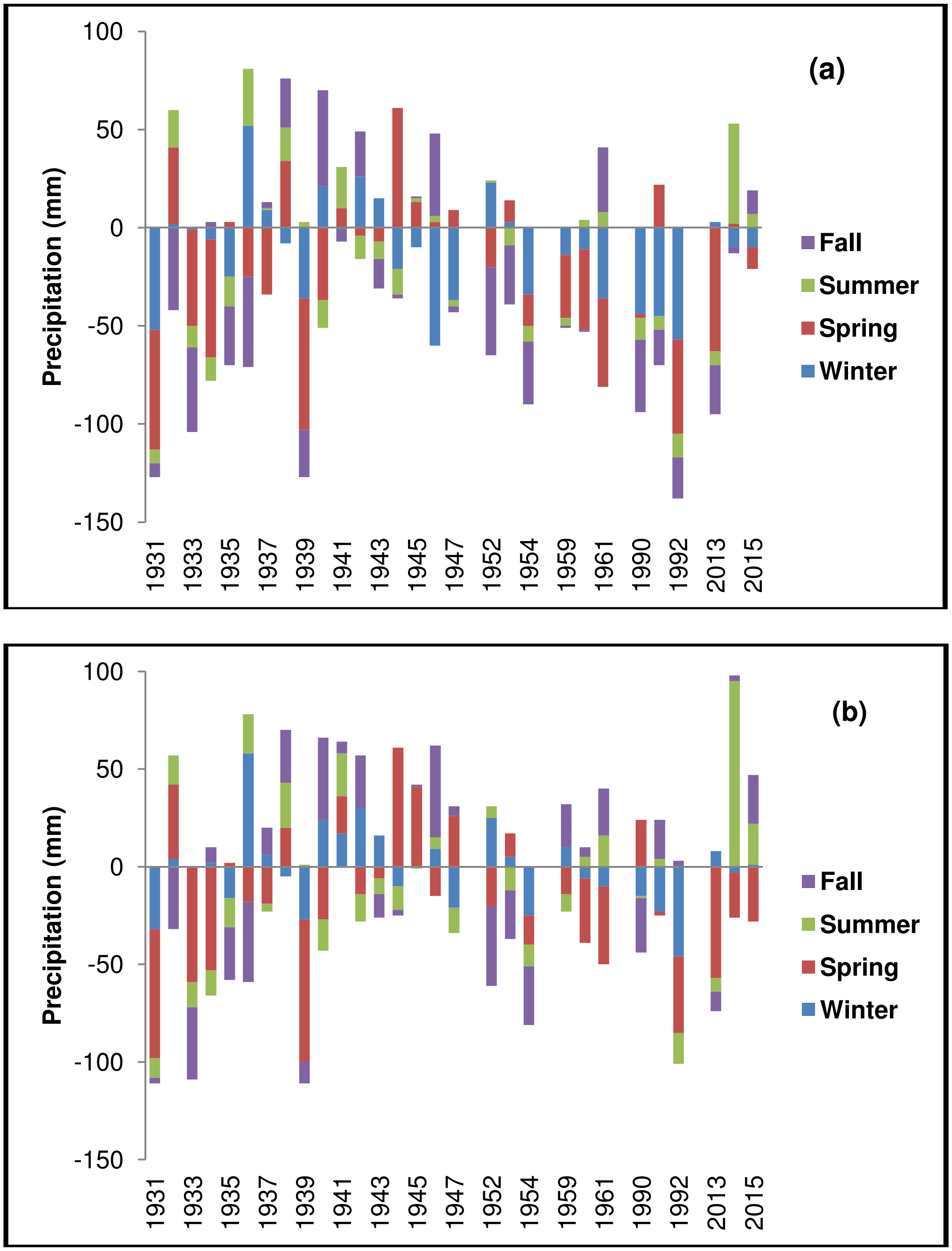

Figure 2.3. Burley (a) and Castleford (b) study sites seasonal precipitation differences by year (Dec 1930-Nov 2015) from the 30-year normalcy (zero line; Prism Climate Group 2016). Seasons are categorized as follows: winter (December [previous year]-February), spring (March-June), summer (July-August), fall (September-November).

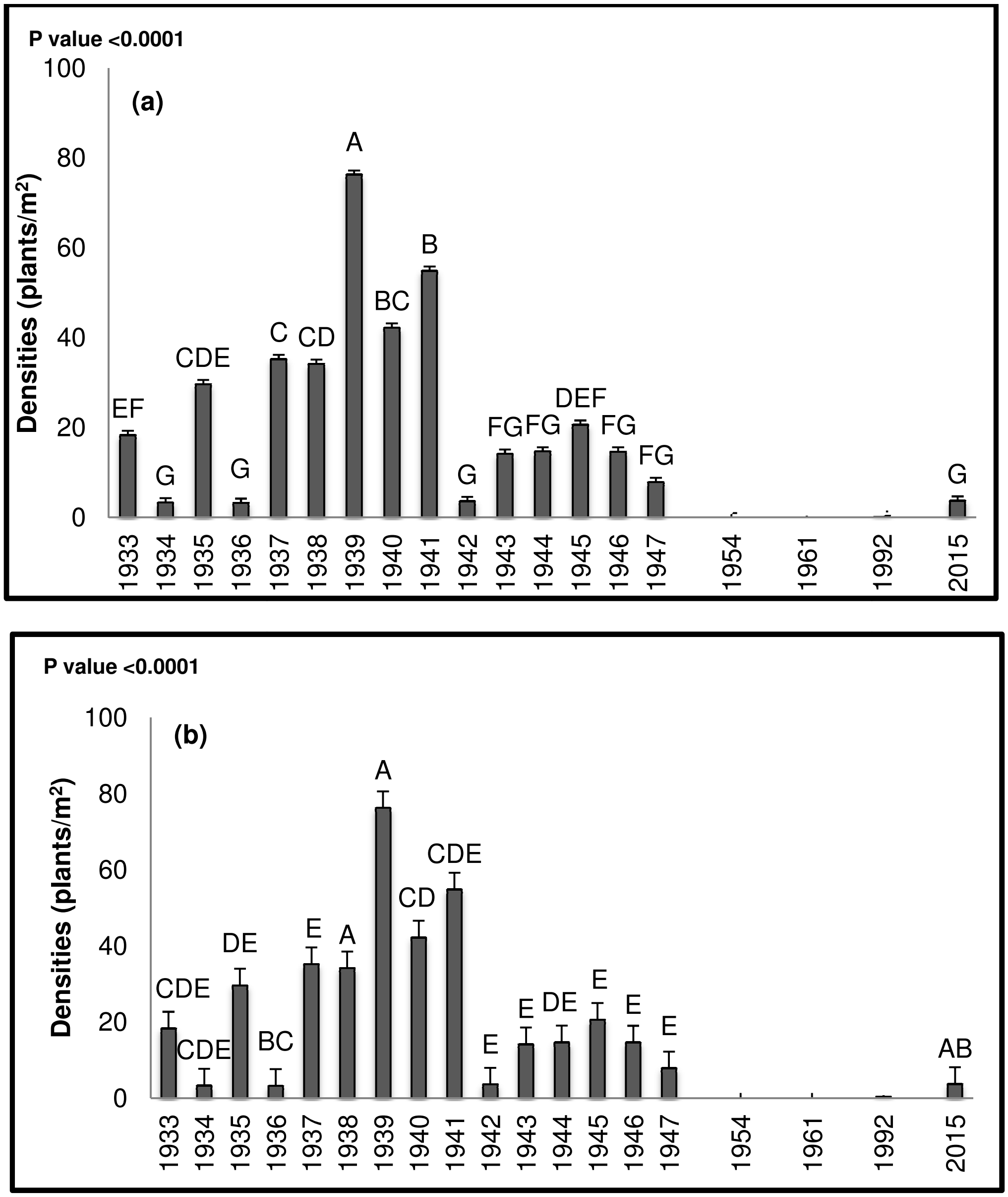

Figure 2.4. Introduced annual forb mean densities (plants/m^2) ± SE from 1933-2015 at the Burley (a) and Castleford (b) study sites. Means with different letters within each site are statistical difference using the Tukey-Kramer honestly significant difference multiple comparison procedure ($p < 0.05$).

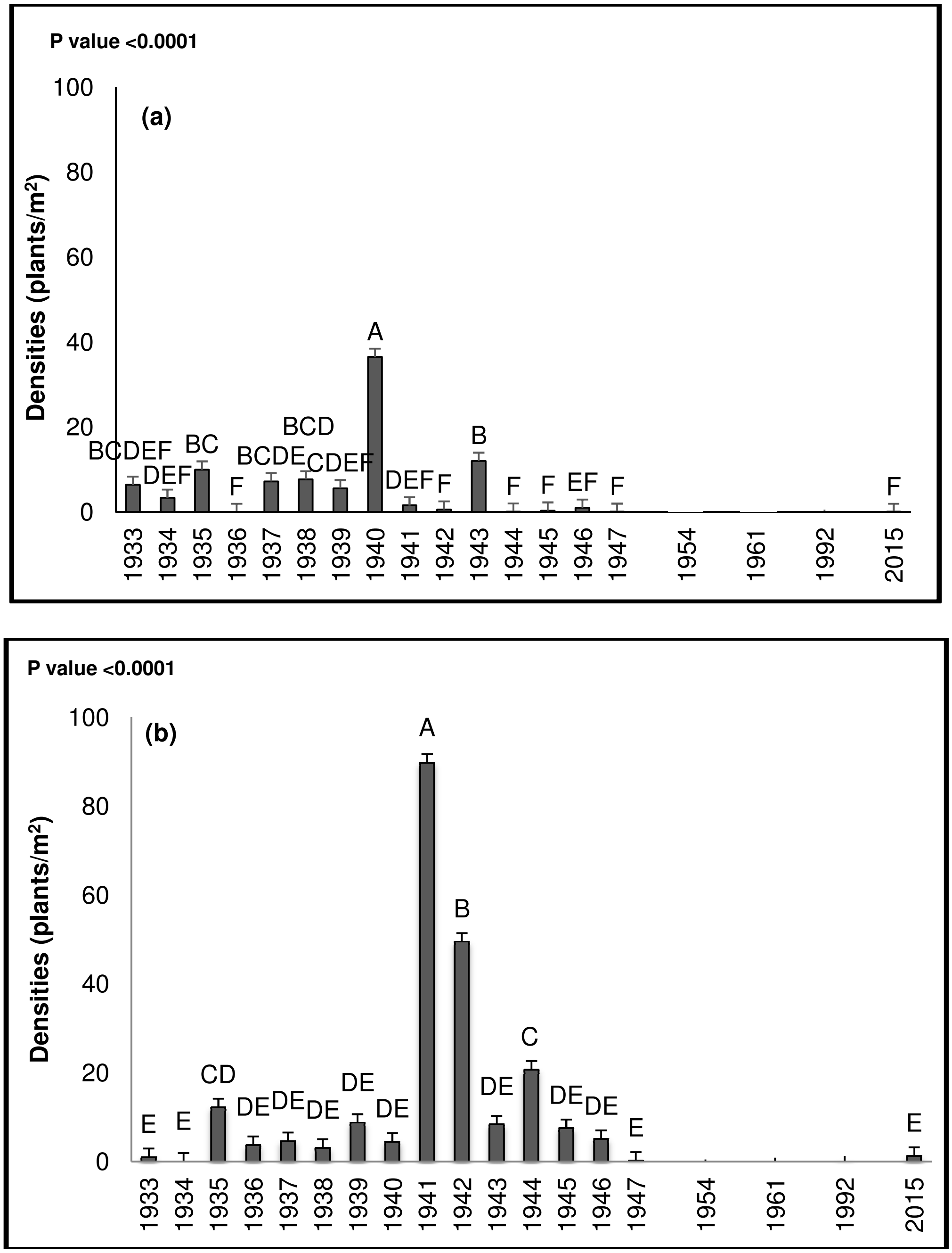

Figure 2.5. Native annual forb mean densities (plants/m^2) ± SE from 1933-2015 at the Burley (a) and Castleford (b) study sites. Means with different letters within each site are statistical difference using the Tukey-Kramer honestly significant difference multiple comparison procedure ($p < 0.05$).

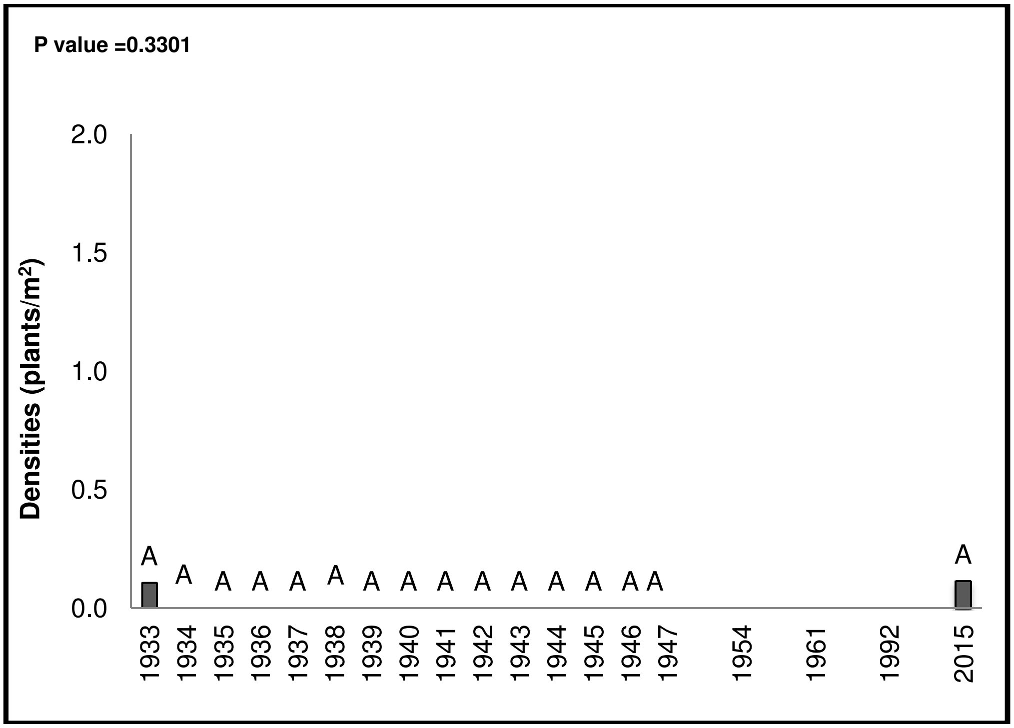

Figure 2.6. Introduced Perennial forbs mean densities (plants/m^2) ± SE from 1933-2015 at the Burley study site. Means with different letters within each site are statistical difference using the Tukey-Kramer honestly significant difference multiple comparison procedure ($p < 0.05$).

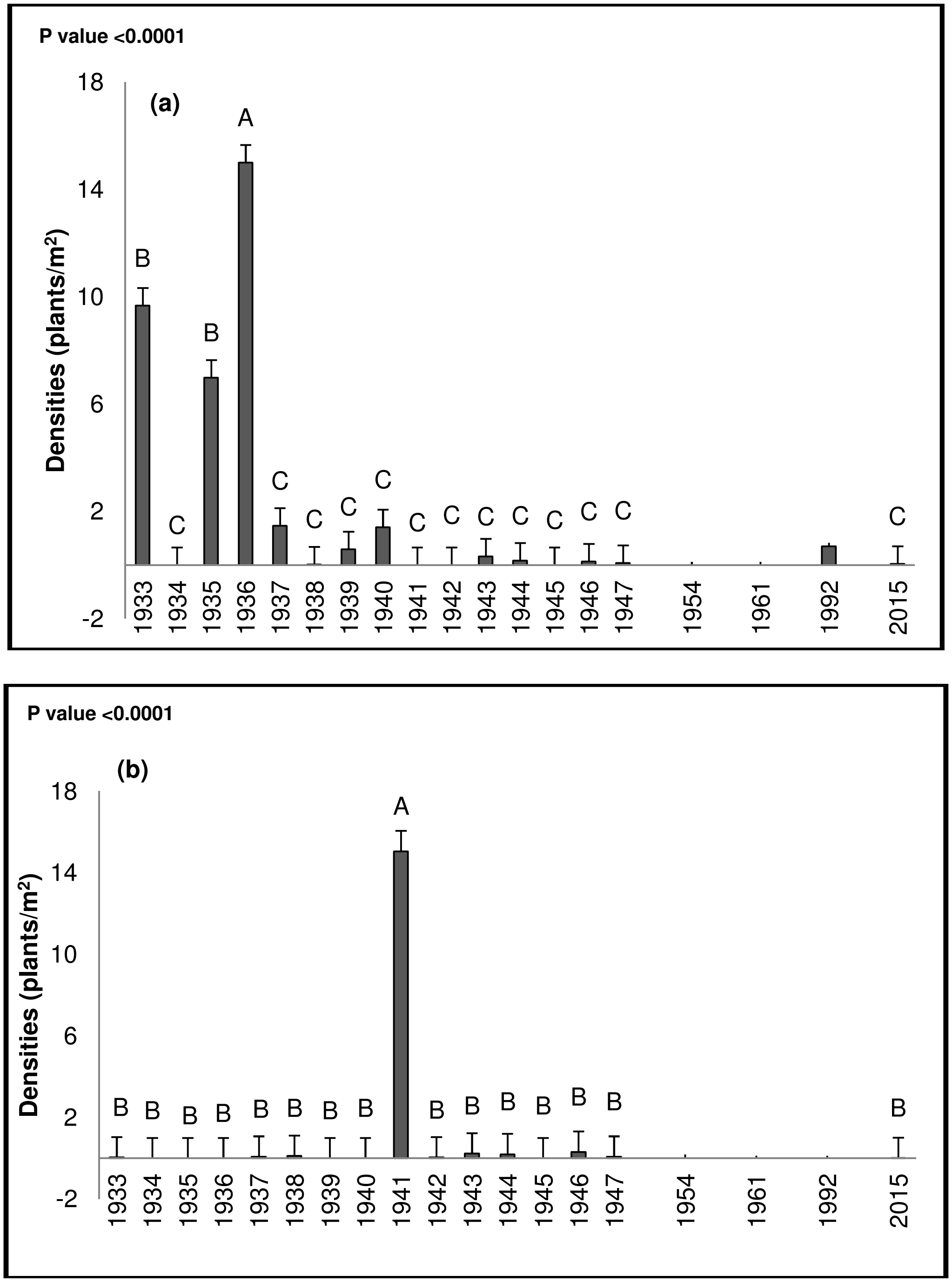

Figure 2.7. Native perennial forb mean densities (plants/m^2) ± SE from 1933-2015 at the Burley (a) and Castleford (b) study sites. Means with different letters within each site are statistical difference using the Tukey-Kramer honestly significant difference multiple comparison procedure ($p < 0.05$).

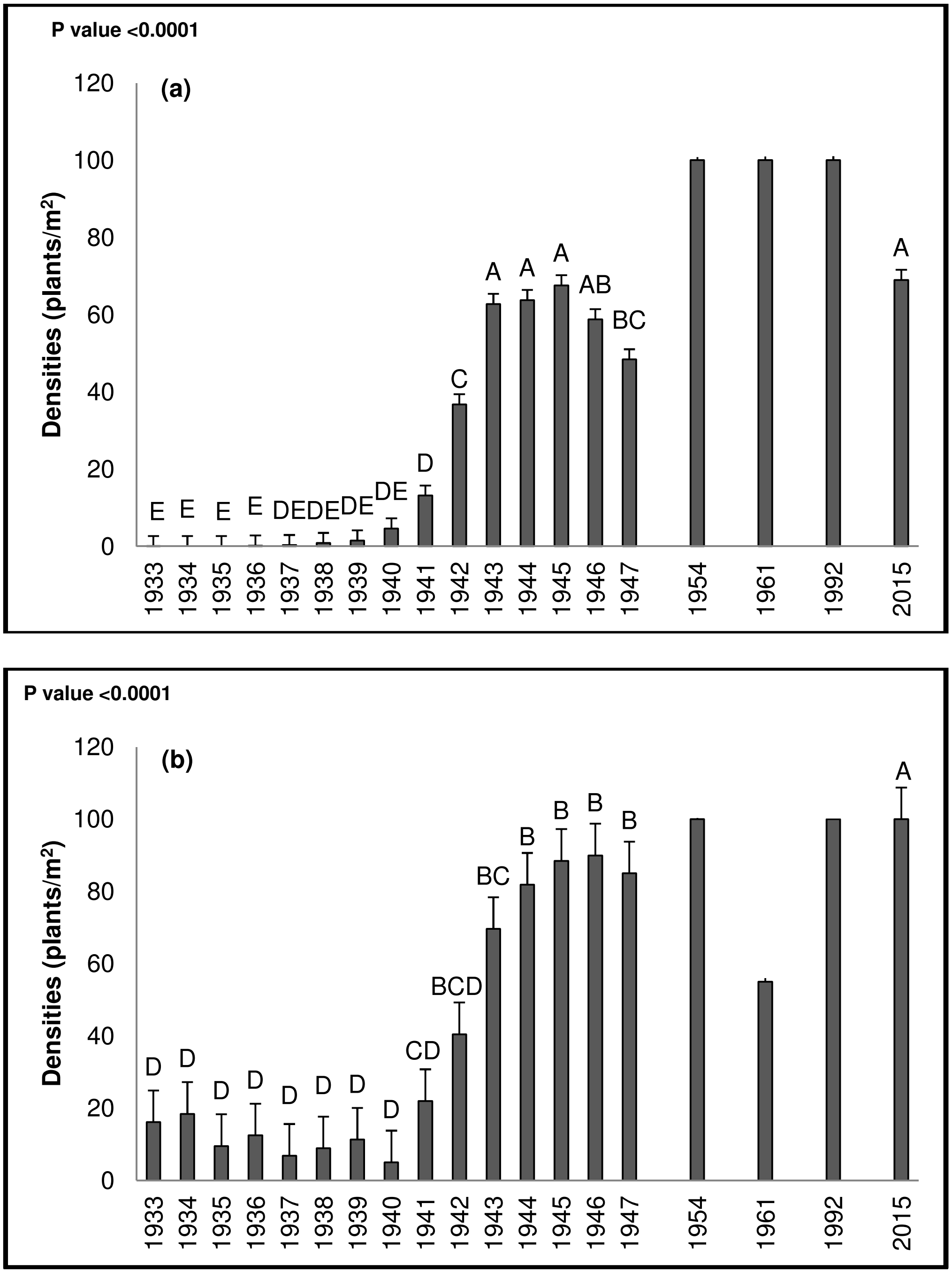

Figure 2.8. Introduced annual grass mean densities (plants/m^2) ± SE from 1933-2015 at the Burley (a) and Castleford (b) study sites. Means with different letters within each site are statistical difference using the Tukey-Kramer honestly significant difference multiple comparison procedure ($p < 0.05$).

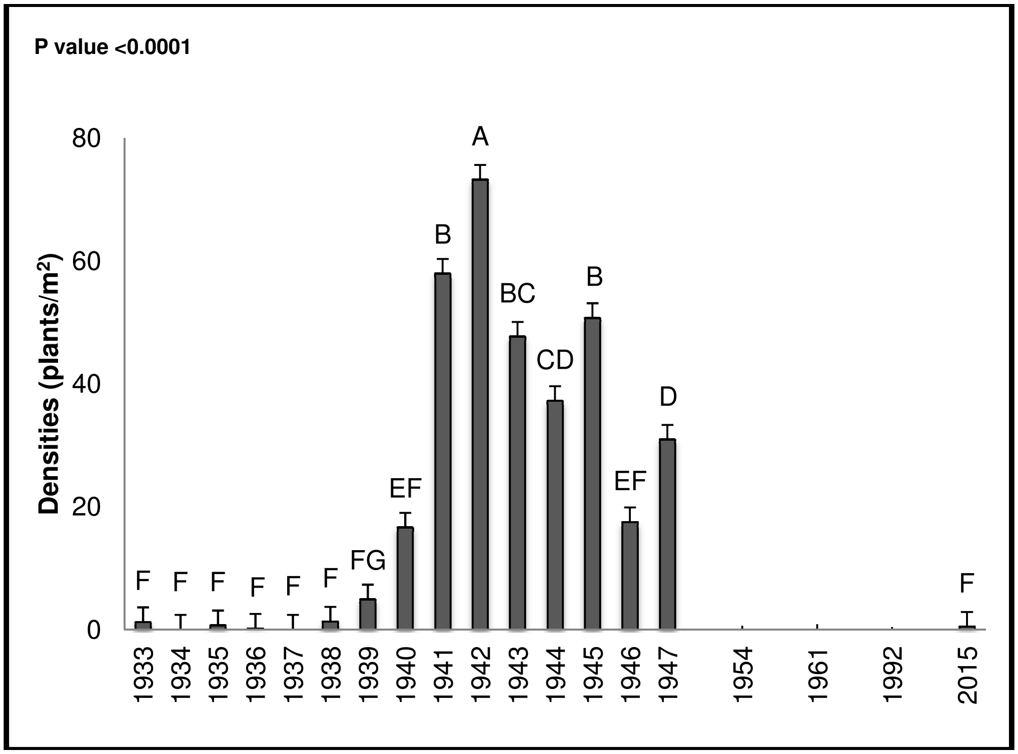

Figure 2.9. Native annual grass mean densities (plants/m^2) ± SE from 1933-2015 at the Burley study site. Means with different letters within each site are statistical difference using the Tukey-Kramer honestly significant difference multiple comparison procedure ($p < 0.05$).

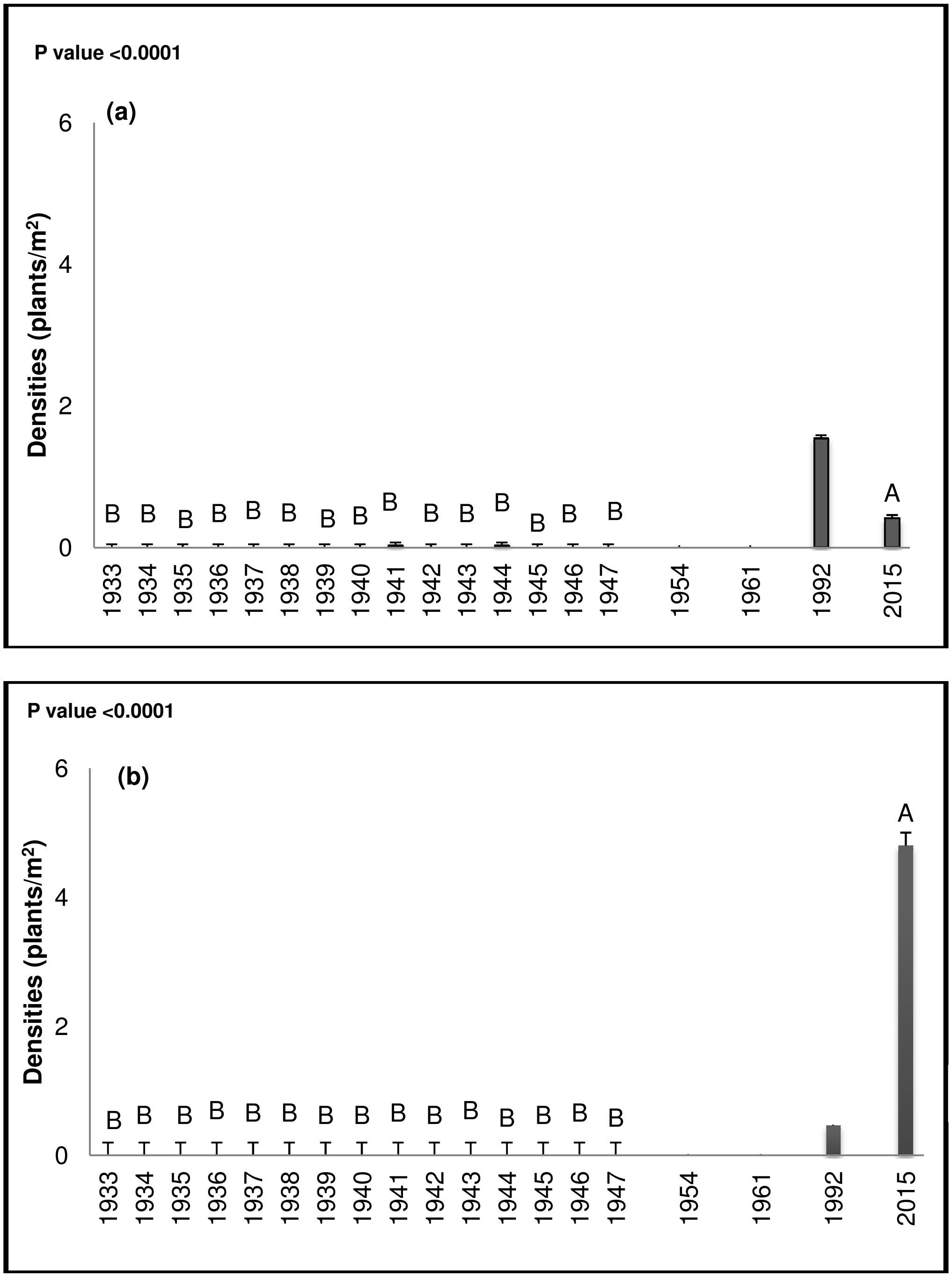

Figure 2.10. Introduced perennial grass mean densities (plants/m^2) ± SE from 1933-2015 at the Burley (a) and Castleford (b) study sites. Means with different letters within each site are statistical difference using the Tukey-Kramer honestly significant difference multiple comparison procedure ($p < 0.05$).

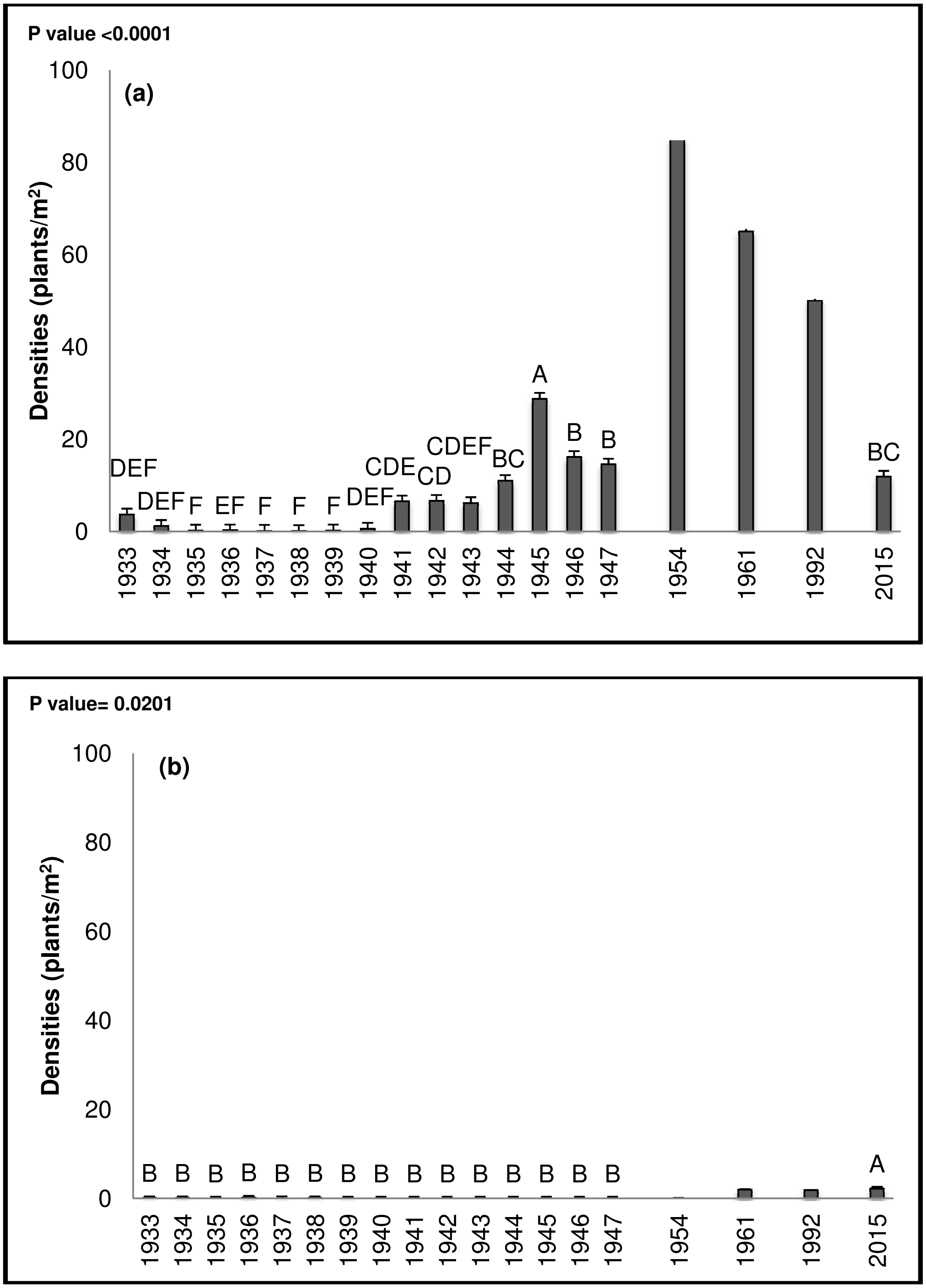

Figure 2.11. Native perennial grass mean densities (plants/m^2) ± SE from 1933-2015 at the Burley (a) and Castleford (b) study sites. Means with different letters within each site are statistical difference using the Tukey-Kramer honestly significant difference multiple comparison procedure ($p < 0.05$).

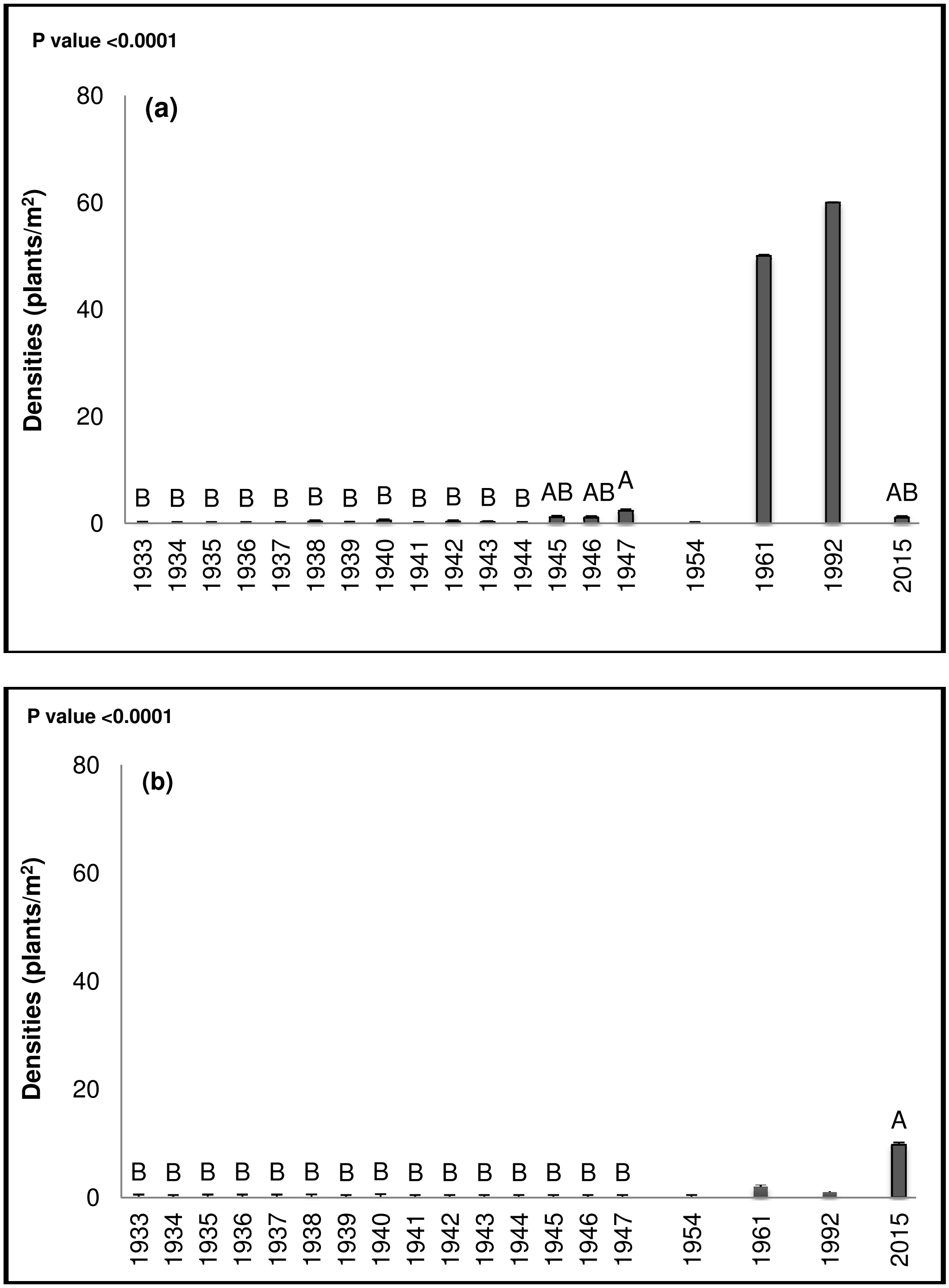

Figure 2.12. Sandberg bluegrass (*Poa secunda* J. Presl) mean densities (plants/m^2) ± SE from 1933-2015 at the Burley (a) and Castleford (b) study sites. Means with different letters within each site are statistical difference using the Tukey-Kramer honestly significant difference multiple comparison procedure ($p < 0.05$).

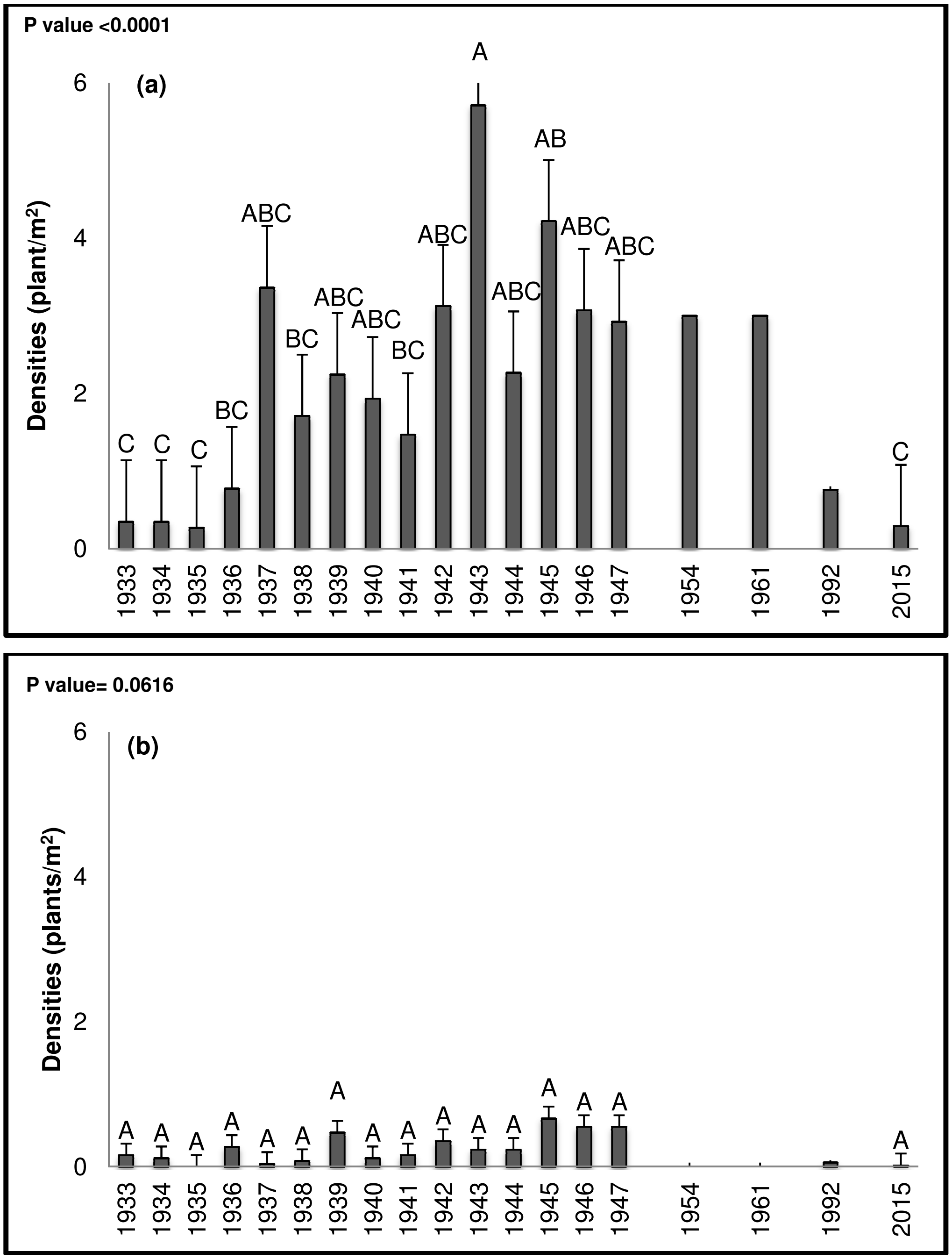

Figure 2.13. Sagebrush (*Artemisia tridentata* Nutt. subsp. *wyomingensis* Beetle & Young) mean densities (plants/m^2) ± SE from 1933-2015 at the Burley (a) and Castleford (b) study sites. Means with different letters within each site are statistical difference using the Tukey-Kramer honestly significant difference multiple comparison procedure ($p < 0.05$).

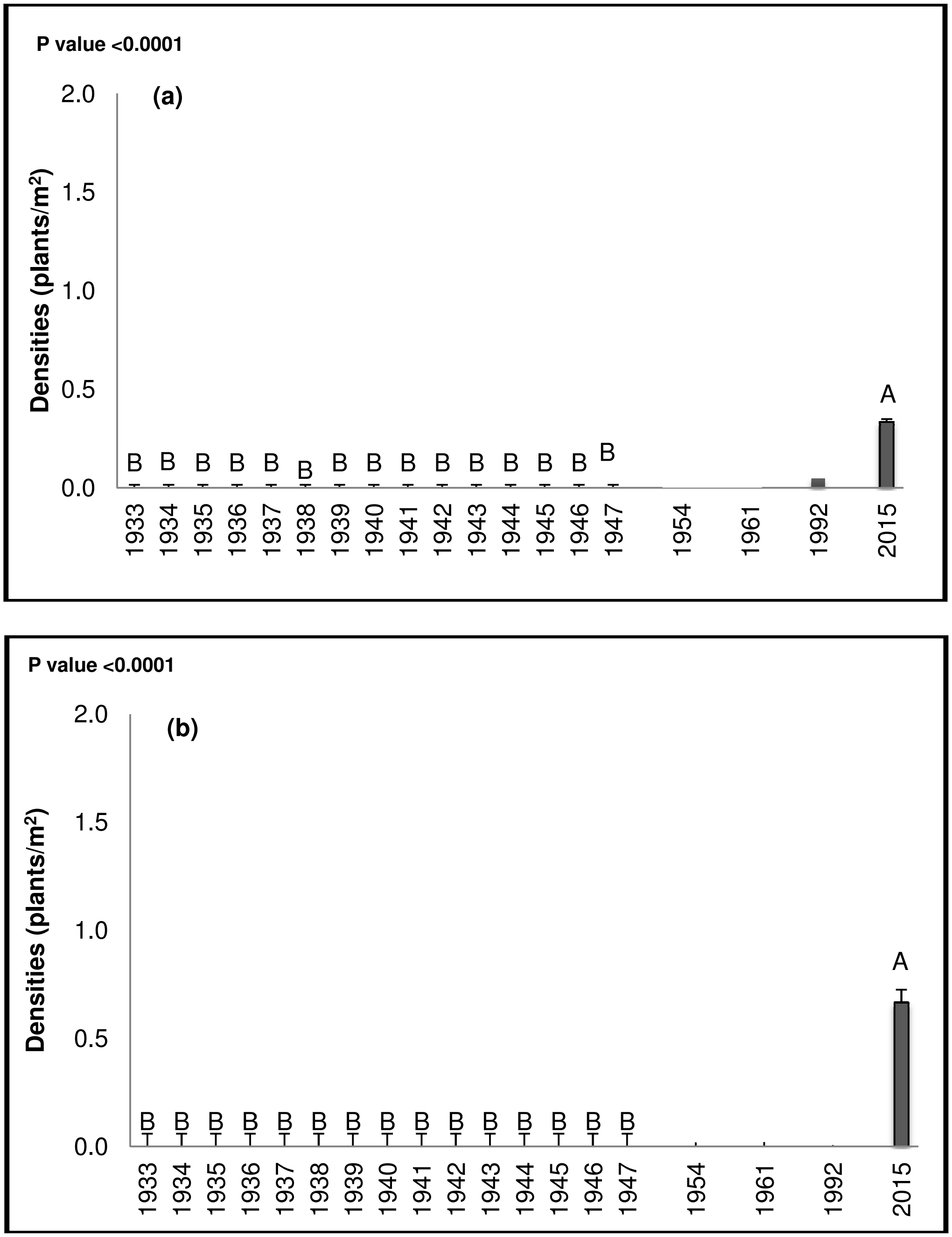

Figure 2.14. Other woody plants mean densities (plants/m^2) ± SE from 1933-2015 at the Burley (a) and Castleford (b) study sites. Means with different letters within each site are statistical difference using the Tukey-Kramer honestly significant difference multiple comparison procedure ($p < 0.05$).

APPENDIX

2015 STUDY SITE OBSERVATIONS

The south and east side of the Burley study site is bordered by two roads, 200 South 500 West in Burley, Idaho. North of the study site is a two-track road used to access a center-pivot that is northwest of the study site. Crop production in close proximity to the Burley study site includes sugar beets, barley, and pinto beans. Humidity from irrigated crops likely created higher humidity levels at the Burley study site than Castleford study site. Sagebrush located along the fence line to the west of the Burley study site is taller than those located within the site suggesting that neighboring irrigated fields may have influenced the growth of the sagebrush. The Burley study site is open to the public for non-motorized use and includes a sign-in book that was visited 5 times by recreational walkers during the data collection year of 2015. In 2015, it was observed that the rabbit fencing is no longer effective due to the lack of upkeep and many lagomorphs within the study site were observed. Remnants of the dismantled observation tower are also scattered across the study site. Sampling quadrat markers and permanent steel transect posts were replaced during the 2015 data collection if missing; all were placed according to the systematic grid throughout the entire study site (Figure 1.2; 2.1).

The Castleford study site is bordered by sagebrush steppe rangeland. Livestock grazing was evident when data was collected in 2015 and 2016. A two-track road borders the south side of the study site and is utilized primarily by local ranchers. Access to the Castleford study site requires a high clearance vehicle, where 4x4 would be recommended during the winter and spring seasons. An abandoned canal dating back to the original Salmon Irrigation Tract water rights distribution runs through the middle of the site along the disturbance separation line. Prior to 2014, the exterior fencing protecting the Castleford study site was in need of repair and incidental trespass by both cattle and motorized vehicles may have occurred. After this issue was brought to the attention of the BLM, it was promptly repaired and currently excludes livestock grazing access. An observation tower is located in the center of the Castleford study site and is in need of repair due to aged dilapidation. During 2015 data collection, partially buried tubes were observed throughout the Castleford study site. An extensive search of all records was conducted to investigate why the tubes were buried but no information was discovered.

PIEMEISEL EXCLOSURE COLLECTION

Archived at the University of Idaho Library is a collection of documents known as the Piemeisel Exclosure Collection. Within this collection are over 1,000 printed photographs and film negatives related to southern Idaho rangelands and the research conducted by Dr. Robert L. Piemeisel. Piemeisel participated in other studies within close proximity to the Burley and Castleford study site which furthered his understanding of secondary plant succession. Another exclosure, the Berger site, was used by Piemeisel to evaluate different crested wheatgrass varieties. The Berger site, which is in close proximity to the Castleford study site, also has an observation tower located in the center.

Original handwritten, raw data sheets and maps created by Dr. Piemeisel (1933-1952), Dr. Stephen Bunting (1992), and Dr. Amanda Gearhart (2015-2016), as well as published manuscripts relating to the study sites are available in the collection. Also available is the raw data that was entered into a digital format (Microsoft Excel) in 2016.

PEARSON'S CORRELATION

Using Microsoft Excel® software, Pearson's correlations (r) by site were used to evaluate the relationship between plant functional groups (PFG) and climate variables (winter and spring precipitation and temperature). This data is included in the appendix because no strong correlations were detected, however, information can be used to increase our understanding of plant communities change over time based on climate variables.

The relationship between introduced annual forbs (IAF) densities with winter and spring precipitation had weak correlations at the Burley study site (r = -0.0742 and r = -0.1020 respectively; Figure A.1) and the Castleford study site (r = -0.2328 and r = -0.1145 respectively; Figure A.2). Winter and spring average temperatures were also weakly correlated with IAF densities at both sites (Burley study site r = -0.2373 and r = -0.0173 respectively, Figure A.1; Castleford study site r = 0.3735 and r = 0.0899 respectively, Figure A.2).

The relationship between native annual forbs (NAF) densities with winter and spring precipitation were variable. Winter precipitation and native annual forbs were moderately correlated at the Burley and Castleford study site (r = 0.4352, Figure A.1 and r = 0.4501, Figure A.2, respectively). Spring precipitation on the other hand, was weakly correlated at Burley (r = -0.2161; Figure A.1) and Castleford study site (r = 0.2948, Figure A.2). Winter and spring average temperatures were weakly correlated with NAF densities at both sites (Burley study site r = 0.0200 and r = 0.2040, respectively, Figure A.1; Castleford r = -0.3066 and r = -0.0520 respectively, Figure A.2).

The relationship between introduced perennial forb (IPF) densities with winter and spring precipitation had weak correlations at the Burley study site (r = 0.0843 and r = -0.1758 respectively; Figure A.1). Winter and spring average temperatures were also weakly correlated with IPF densities at Burley study site (r = -0.1367 and r = 0.0986 respectively; Figure A.1). The Castleford site had 0 plants/m^2 of IPF recorded between 1933-2015, hence no correlation test was conducted.

The relationship between native perennial forb (NPF densities and winter and spring precipitation had weak correlations at the Burley study site (r = -0.1217 and r = -0.0400 respectively; Figure A.1) and Castleford study site (r = 0.2705 and r = 0.2177 respectively; Figure A.2). Winter and spring average temperatures were also weakly correlated with NPF at both sites (Burley study site r = -0.4187 and r = 0.0686 respectively, Figure A.1; Castleford r = -0.1217 and r = 0.0361 respectively, Figure A.2).

The relationship between introduced annual grass (IAG) densities with winter and spring precipitation had weak correlations at the Burley study site (r = -0.2722 and r = 0.0980 respectively; Figure A.3) and Castleford study site (r = -0.2441 and r = 0.2729 respectively; Figure A.4). Winter average temperature was moderately correlated to IAG densities at both sites (Burley study site r = 0.2936, Figure A.3; and Castleford study site r = 0.3398, Figure A.4). Spring average temperatures were weakly correlated with IAG at both sites (Burley study site r = -0.1473, Figure A.3; Castleford study site r = -0.2435, Figure A.4).

The relationship between native annual grass (NAG) densities with winter and spring precipitation had moderate correlations at the Burley study site (r = 0.4184 and r = 0.4524 respectively; Figure A.3). Winter and spring average temperatures were also weakly correlated with NAG at Burley study site (r = -0.2322 and r = -0.3370 respectively; Figure A,3). The Castleford site had 0 plants/m^2 of NAG recorded between 1933-2015.

The relationship between introduced perennial grass (IPG) densities with winter and spring precipitation had weak correlations at the Burley study site (r = -0.5196 and r = -0.2343 respectively; Figure A.3) and Castleford study site (r = -0.0045 and r = -0.1338 respectively; Figure A.4). Winter and spring average temperatures were weak to moderately correlated with IPG at both sites (Burley study site r = 0.2307 and r = 0.2827 respectively, Figure A.3; Castleford r = 0.2651 and r= 0.2280 respectively, Figure A.4).

The relationship between native perennial grass (NPG) densities with winter and spring precipitation had moderately negative correlations at the Burley and

Castleford study site (r = -0.5476, Figure A.3 and r = -0.4429, Figure A.4, respectively). Spring precipitation with NPG densities was weakly correlated at both sites (Burley study site r = -0.1543, Figure A.3; Castleford study site r = -0.1977, Figure A.4). At the Burley study site, winter average temperature was weak to moderately correlated with NPG (r = 0.2095, Figure A.3), and spring average temperature was weakly correlated with NPG (r = - 0.0721, Figure A.3). At the Castleford study site, winter and spring temperature were moderately correlated with NPG densities (r = 0.3730 and r = 0.3114 respectively; Figure A.4).

At the Burley study site, the relationship between Sandberg bluegrass densities with winter precipitation was moderately negatively correlated (r = -0.6143, Figure A.3). Spring precipitation had weak to moderate correlations at the Burley study site (r = -0.3466, Figure A.3). At the Castleford study site, winter and spring precipitation were weakly correlated (r = -0.0500 and r = -0.1411 respectively; Figure A.2). Winter and spring average temperatures were weak to moderately correlated with Sandberg bluegrass at both sites (Burley study site r = 0.2227 and r = 0.2522 respectively, Figure A.3; Castleford r = 0.3033 and r = 0.2377 respectively, Figure A.2).

The relationship between sagebrush density with winter precipitation was moderately correlated at the Burley study site (r = 0.3399, Figure A.5) and weakly correlated at the Castleford study site (r = 0.1775, Figure A.5). Spring precipitation with sagebrush densities at both sites was weakly correlated (Burley study site r = 0.1921 and Castleford study site r = -0.0063; Figure A.5). Winter average temperature was weakly correlated with sagebrush at the Burley study site (r = -0.1575, Figure A.5), and moderately correlated at the Castleford study site (r = -0.3079, Figure A.5). Spring temperature was moderately correlated with sagebrush densities at both sites (Burley study site r = -0.4652 and Castleford study site r = -0.6365; Figure A.5).

The relationship between other woody plant (OWP) densities with winter and spring precipitation had weak correlations at the Burley study site (r = -0.0748 and r = -0.0265 respectively; Figure A.5). At the Castleford study site, winter precipitation with OWP densities was moderately correlations (r = 0.5657, Figure A.5), and spring precipitation with OWP was weakly correlated (r = -0.1196, Figure A.5). Winter and spring average temperatures were also weakly correlated with OWP at both sites (Burley study site r = 0.2735 and r = 0.1957 respectively; Castleford study site r = 0.2480 and r = 0.2052 respectively; Figure A.5).

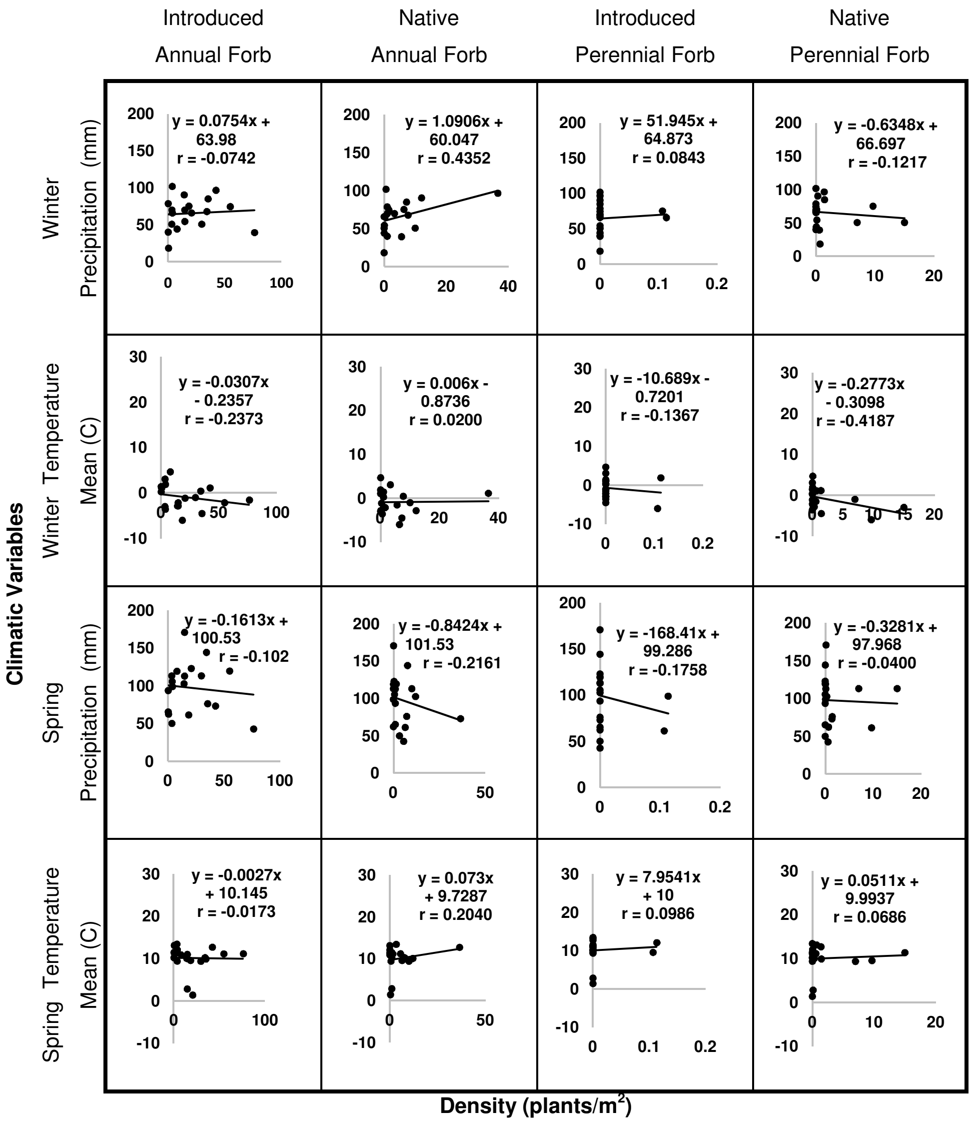

Figure A.1. Regressions of mean plant densities per m^2 (x-axis) on climatic variables (y-axis) for all sampled years at the Burley study site (n= 16 years). Each column represents a plant functional group (introduced annual forb, native annual forb, introduced perennial forb and native perennial forb). Rows represent climatic variables (winter temperature [℃] and precipitation [mm] and spring temperature [℃] and precipitation [mm]).

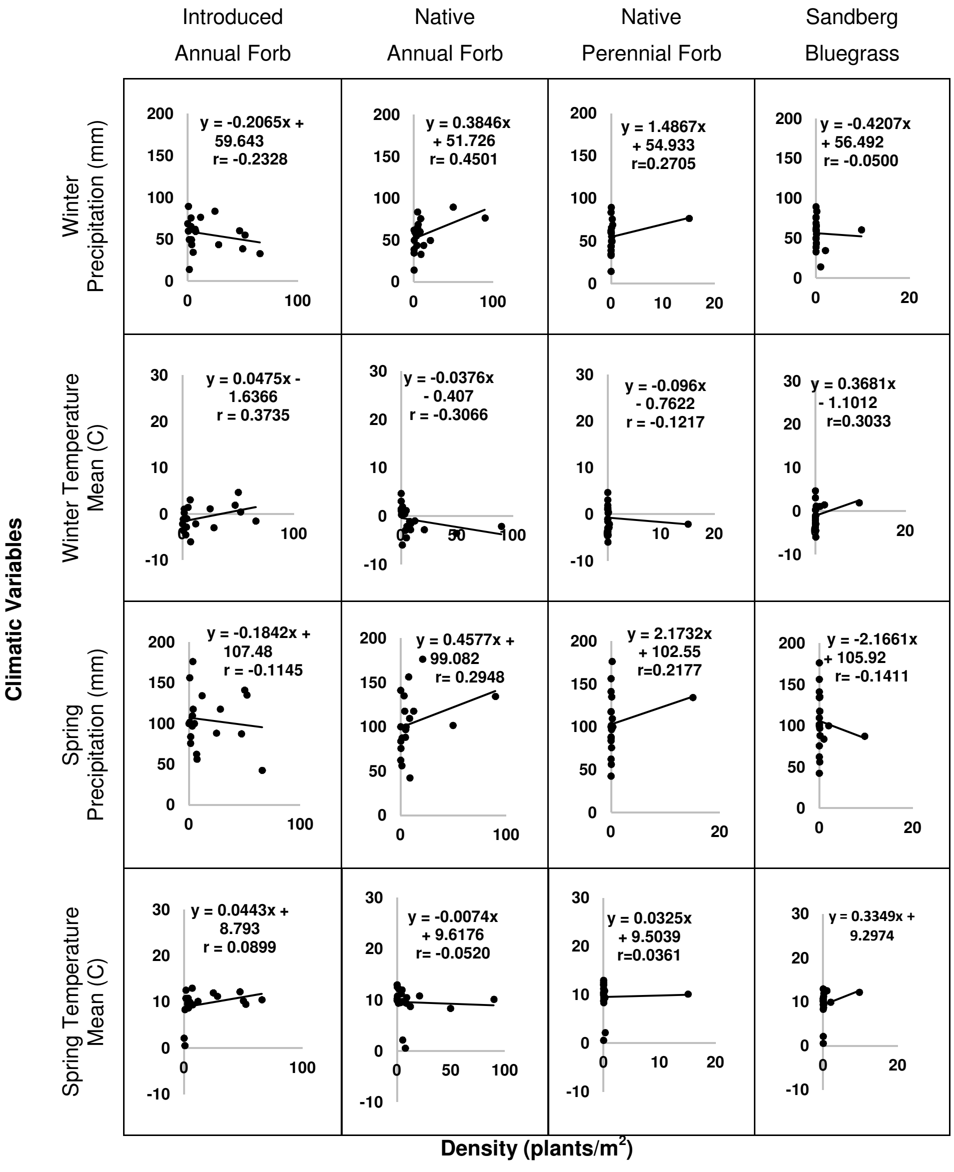

Figure A.2. Regressions of mean plant densities per m^2 (x-axis) on climatic variables (y-axis) for all sampled years at the Castleford study site (n= 16 years). Each column represents a plant functional group (introduced annual forb, native annual forb, native perennial forb, and Sandberg bluegrass). Rows represent climatic variables (winter temperature [℃] and precipitation [mm] and spring temperature [℃] and precipitation [mm]).

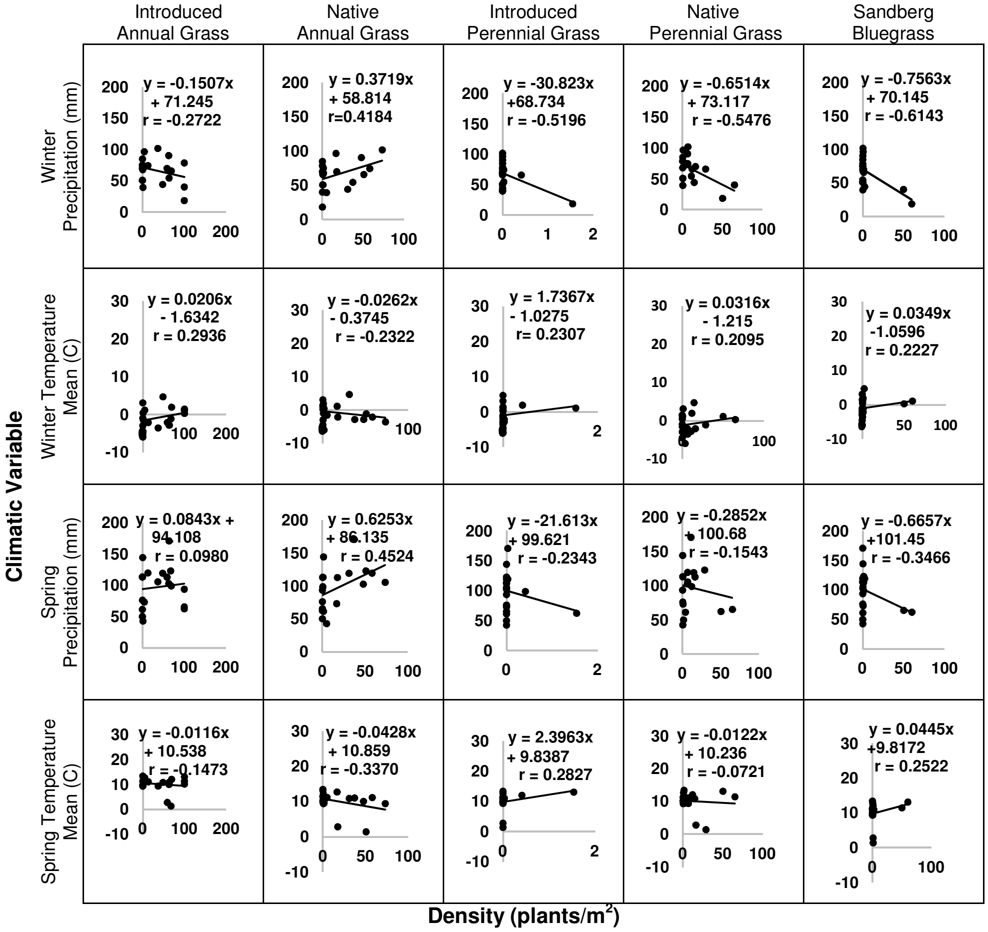

Figure A.3. Regressions of mean plant densities per m^2 (x-axis) on climatic variables (y-axis) for all sampled years at the Burley study site (n= 16 years). Each column represents a plant functional group (introduced annual grass, native annual grass, introduced perennial grass, native perennial grass and Sandberg bluegrass). Rows represent climatic variables (winter temperature [℃] and precipitation [mm] and spring temperature [℃] and precipitation [mm]).

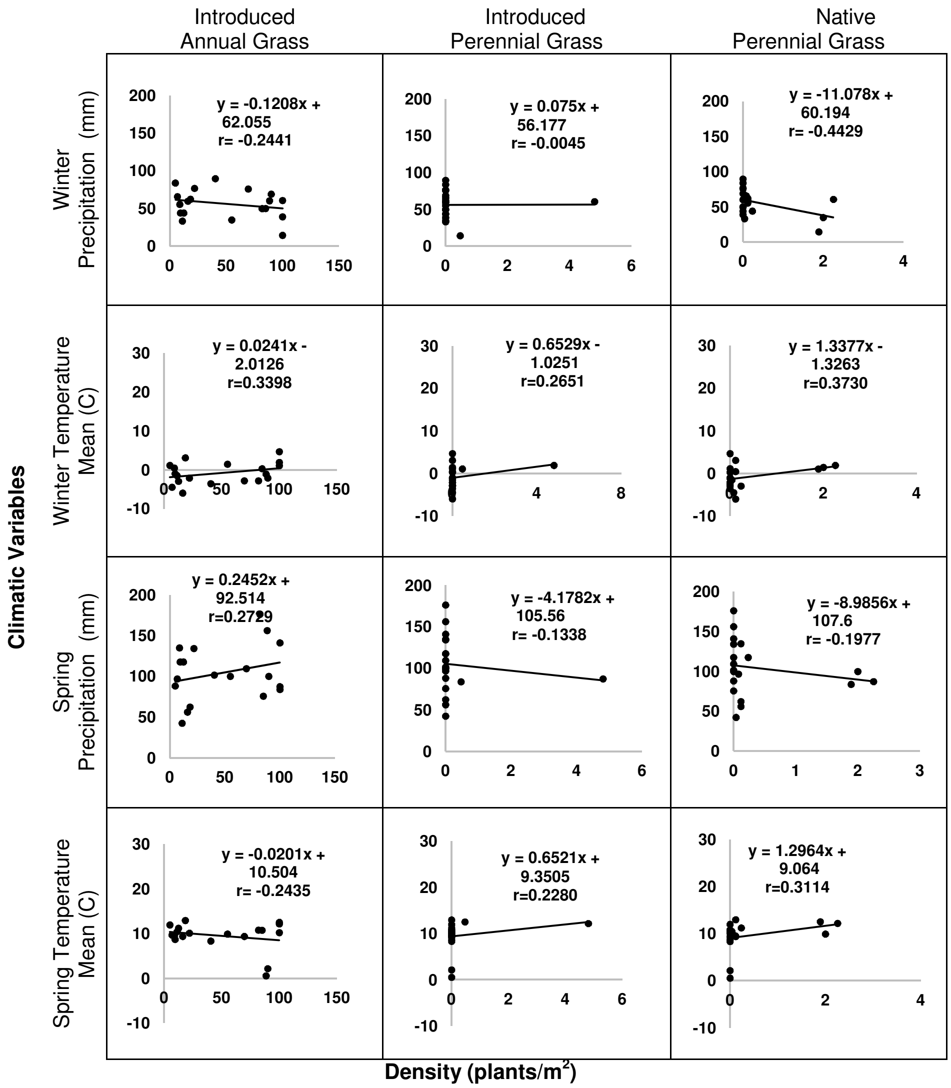

Figure A.4. Regressions of mean plant densities per m^2 (x-axis) on climatic variables (y-axis) for all sampled years at the Castleford study site (n= 16 years). Each column represents a plant functional group (introduced annual grass, introduced perennial grass and native perennial grass). Rows represent climatic variables (winter temperature [°C] and precipitation [mm] and spring temperature [°C] and precipitation [mm]).

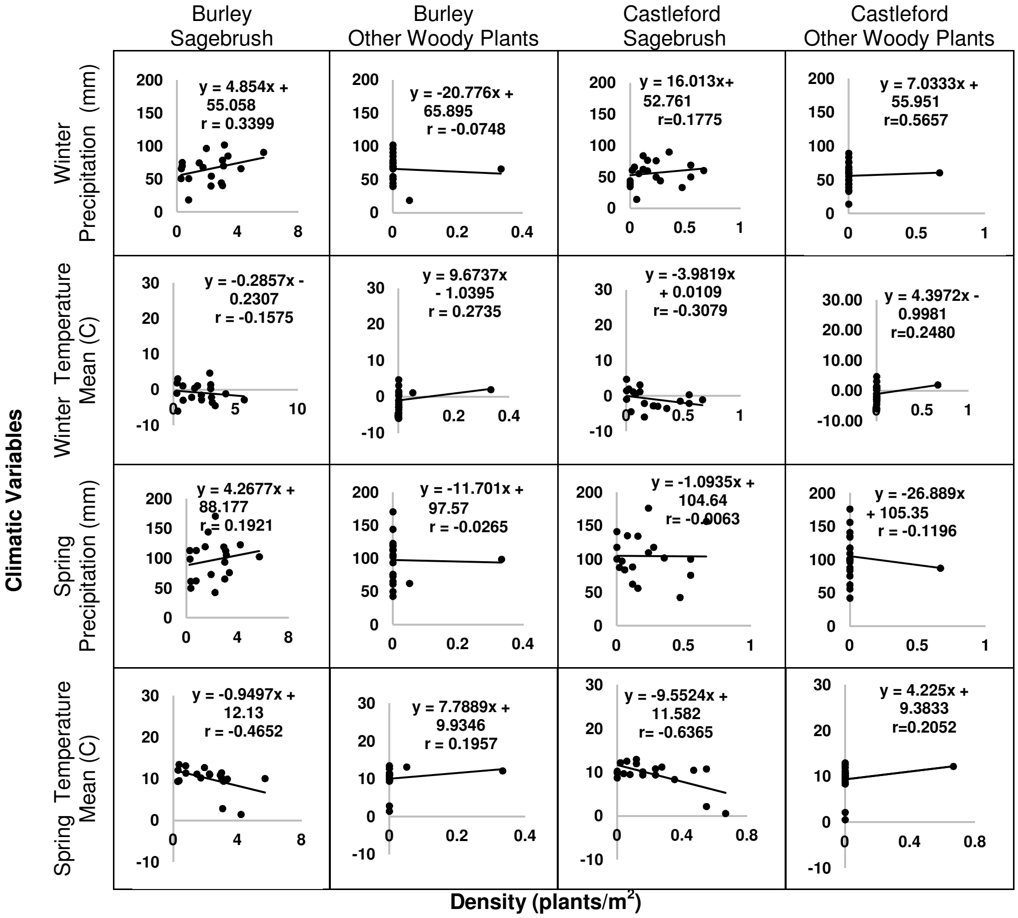

Figure A.5. Regressions of mean plant densities per m^2 (x-axis) on climatic variables (y-axis) for all sampled years at the Burley and Castleford study site (n= 16 years). Each column represents a plant functional group (Burley sagebrush, Burley other woody plants, Castleford Sagebrush and Castleford other woody plants). Rows represent climatic variables (winter temperature [℃] and precipitation [mm] and spring temperature [℃] and precipitation [mm]).

Table A.1. Summary statistics (mean densities [plants/m^2], standard error [SE], Tukey-Kramer honestly significant difference and range of plant densities) for Introduced Annual Forbs and Native Annual Forbs by study site (Burley study site, n=145-150; Castleford study site, n=102).

	Introduced Annual Forbs							
	Burley				**Castleford**			
Year	**Densities**	**SE**	**Tukey-Kramer**	**Range**	**Densities**	**SE**	**Tukey-Kramer**	**Range**
1933	18.28	2.889	EF	4-100	7.29	4.443	CDE	4-100
1934	3.31	2.889	G	4-52	6.86	4.443	CDE	4-100
1935	29.59	2.889	CDE	4-100	3.76	4.443	DE	4-44
1936	3.20	2.889	G	4-96	28.16	4.443	BC	4-100
1937	35.21	2.889	C	4-100	3.02	4.443	E	4-32
1938	34.13	2.889	CD	4-100	52.08	4.443	A	4-100
1939	76.21	2.889	A	8-100	65.69	4.443	A	4-100
1940	42.19	2.889	BC	4-100	24.74	4.443	CD	4-100
1941	54.82	2.889	B	4-100	11.80	4.443	CDE	4-100
1942	3.57	2.889	G	4-28	0.78	4.443	E	4-24
1943	14.13	2.889	FG	4-100	3.14	4.443	E	4-60
1944	14.65	2.938	FG	4-100	3.49	4.443	DE	4-100
1945	20.59	2.889	DEF	4-100	0.74	4.443	E	4-36
1946	14.61	2.889	FG	4-100	0.04	4.443	E	0-4
1947	7.84	2.889	FG	4-100	1.57	4.443	E	4-16
2015	3.69	2.889	G	1-45	47.17	4.443	AB	1-100
AVG	25.06				17.35			
	Native Annual Forbs							
1933	6.40	1.320	BCDEF	4-28	1.06	1.957	E	4-8
1934	3.33	1.320	DEF	0-0	0.00	1.957	E	4-28
1935	10.00	1.320	BC	4-100	12.23	1.957	CD	4-72
1936	0.00	1.320	F	4-60	3.76	1.957	DE	0-0
1937	7.23	1.320	BCDE	4-100	4.66	1.957	DE	4-100
1938	7.71	1.320	BCD	4-60	3.14	1.957	DE	4-100
1939	5.60	1.320	CDEF	4-100	8.75	1.957	DE	4-96
1940	36.51	1.320	A	4-100	4.51	1.957	DE	4-100
1941	1.57	1.320	DEF	16-100	89.76	1.957	A	4-56
1942	0.61	1.320	F	4-100	49.53	1.957	B	4-56
1943	12.05	1.320	B	4-100	8.39	1.957	DE	4-100
1944	0.08	1.343	F	4-100	20.74	1.957	C	0-12
1945	0.35	1.320	F	4-100	7.57	1.957	DE	4-28
1946	1.04	1.320	EF	4-100	5.14	1.957	DE	4-20
1947	0.05	1.320	F	4-12	0.23	1.957	E	0-4
2015	0.02	1.320	F	1-53	1.30	1.957	E	1-2
AVG	6.17				14.72			

Means with different letters within each site are significantly different using Tukey-Kramer honestly significant difference multiple comparison procedure ($p < 0.05$).

Table A.2. Summary statistics (mean densities [plants/m^2], standard error [SE], Tukey-Kramer honestly significant difference and range of plant densities) for introduced perennial forb and native perennial forb by study site (Burley study site, n=145-150; Castleford study site, n=102).

	Introduced Perennial Forb							
	Burley				**Castleford**			
Year	**Densities**	**SE**	**Tukey-Kramer**	**Range**	**Densities**	**SE**	**Tukey-Kramer**	**Range**
1933	0.11	0.035	A	4-60	-	-	-	-
1934	0.00	0.035	A	0-0	-	-	-	-
1935	0.00	0.035	A	0-0	-	-	-	-
1936	0.00	0.035	A	0-0	-	-	-	-
1937	0.00	0.035	A	0-0	-	-	-	-
1938	0.00	0.035	A	0-0	-	-	-	-
1939	0.00	0.035	A	0-0	-	-	-	-
1940	0.00	0.035	A	0-0	-	-	-	-
1941	0.00	0.035	A	0-0	-	-	-	-
1942	0.00	0.035	A	0-0	-	-	-	-
1943	0.00	0.035	A	0-0	-	-	-	-
1944	0.00	0.036	A	0-0	-	-	-	-
1945	0.00	0.035	A	0-0	-	-	-	-
1946	0.00	0.035	A	0-0	-	-	-	-
1947	0.00	0.035	A	0-0	-	-	-	-
2015	0.11	0.035	A	0-1	-	-	-	-
AVG	0.01				-			
	Native Perennial Forb							
1933	9.67	0.658	B	4-100	0.04	0.619	B	0-4
1934	0.00	0.658	C	0-0	0.00	0.619	B	0-0
1935	6.99	0.658	B	4-84	0.00	0.619	B	0-0
1936	15.00	0.658	A	4-100	0.00	0.619	B	0-0
1937	1.47	0.658	C	4-68	0.08	0.619	B	0-4
1938	0.03	0.658	C	0-4	0.12	0.619	B	4-8
1939	0.59	0.658	C	4-24	0.00	0.619	B	0-0
1940	1.41	0.658	C	4-68	0.00	0.619	B	0-0
1941	0.00	0.658	C	0-0	15.06	0.619	A	4-100
1942	0.00	0.658	C	0-0	0.04	0.619	B	0-4
1943	0.32	0.658	C	16-32	0.23	0.619	B	4-12
1944	0.16	0.669	C	4-8	0.20	0.619	B	4-12
1945	0.00	0.658	C	0.00	0.00	0.619	B	0-0
1946	0.13	0.658	C	4-8	0.31	0.619	B	4-24
1947	0.03	0.658	C	0-4	0.08	0.619	B	0-4
2015	0.05	0.658	C	1-5	0.01	0.619	B	0-1
AVG	2.39				1.08			

Means with different letters within each site are significantly different using Tukey-Kramer honestly significant difference multiple comparison procedure ($p < 0.05$).

Table A.3. Summary statistics (mean densities [plants/m^2], standard error [SE], Tukey-Kramer honestly significant difference and range of plant densities) for introduced annual grass and native perennial grass by study site (Burley study site, n=145-150; Castleford study site, n=102).

	Introduced Annual Grass							
	Burley				**Castleford**			
Year	**Densities**	**SE**	**Tukey-Kramer**	**Range**	**Densities**	**SE**	**Tukey-Kramer**	**Range**
1933	0.03	2.662	E	0-4	16.16	10.222	D	4-100
1934	0.00	2.662	E	0-0	18.43	10.222	D	4-100
1935	0.00	2.662	E	0-0	9.53	10.222	D	4-100
1936	0.16	2.662	E	0-24	12.48	10.222	D	4-100
1937	0.29	2.662	DE	4-20	6.86	10.222	D	4-100
1938	0.83	2.662	DE	4-100	8.90	10.222	D	4-100
1939	1.47	2.662	DE	4-100	11.29	10.222	D	4-100
1940	4.62	2.662	DE	4-100	5.02	10.222	D	4-100
1941	13.12	2.662	D	4-100	22.00	10.222	CD	4-100
1942	36.77	2.662	C	4-100	40.47	10.222	BCD	4-100
1943	62.77	2.662	A	4-100	69.61	10.222	BC	4-100
1944	63.78	2.708	A	4-100	81.88	10.222	B	4-100
1945	67.60	2.662	A	4-100	88.47	10.222	B	4-100
1946	58.81	2.662	AB	4-100	89.96	10.222	B	4-100
1947	48.04	2.662	BC	4-100	85.45	10.222	B	4-100
2015	69.01	2.662	A	1-100	100.00	10.222	A	1-100
AVG	24.49				4.43			
	Native Perennial Grass							
1933	3.68	1.294	DEF	4-100	0.12	0.404	B	4-8
1934	1.20	1.294	DEF	4-68	0.12	0.404	B	0-12
1935	0. 19	1.294	F	4-12	0.00	0.404	B	0-0
1936	0.24	1.294	EF	4-8	0.23	0.404	B	4-20
1937	0.16	1.294	F	4-8	0.08	0.404	B	0-8
1938	0.11	1.294	F	4-8	0.18	0.404	B	0-4
1939	0.21	1.294	F	4-8	0.04	0.404	B	0-4
1940	0.59	1.294	DEF	4-48	0.00	0.404	B	0-0
1941	6.51	1.294	CDE	4-100	0.00	0.404	B	0-0
1942	6.64	1.294	CD	4-100	0.00	0.404	B	0-0
1943	6.16	1.294	CDEF	4-100	0.00	0.404	B	0-0
1944	10.95	1.316	BC	4-100	0.00	0.404	B	0-0
1945	28.75	1.294	A	4-100	0.00	0.404	B	0-0
1946	16.13	1.294	B	4-100	0.00	0.404	B	0-0
1947	14.51	1.294	B	4-100	0.00	0.404	B	0-0
2015	11.87	1.294	BC	4-100	2.25	0.404	A	5-69
AVG	7.18				0.20			

Means with different letters within each site are significantly different using Tukey-Kramer honestly significant difference multiple comparison procedure ($p < 0.05$).

Table A.4. Summary statistics (mean densities [plants/m^2], standard error [SE], Tukey-Kramer honestly significant difference and range of plant densities) for introduced perennial grass and native annual grass by study site (Burley study site, n=145-150; Castleford study site, n=102).

Introduced Perennial Grass								
Burley					**Castleford**			
Year	**Densities**	**SE**	**Tukey-Kramer**	**Range**	**Density**	**SE**	**Tukey-Kramer**	**Range**
1933	0.00	0.048	B	0-0	0.00	0.204	B	0-0
1934	0.00	0.048	B	0-0	0.00	0.204	B	0-0
1935	0.00	0.048	B	0-0	0.00	0.204	B	0-0
1936	0.00	0.048	B	0-0	0.00	0.204	B	0-0
1937	0.00	0.048	B	0-0	0.00	0.204	B	0-0
1938	0.00	0.048	B	0-0	0.00	0.204	B	0-0
1939	0.00	0.048	B	0-0	0.00	0.204	B	0-0
1940	0.00	0.048	B	0-0	0.00	0.204	B	0-0
1941	0.03	0.048	B	0-4	0.00	0.204	B	0-0
1942	0.00	0.048	B	0-0	0.00	0.204	B	0-0
1943	0.00	0.048	B	0-0	0.00	0.204	B	0-0
1944	0.03	0.049	B	0-4	0.00	0.204	B	0-0
1945	0.00	0.048	B	0-0	0.00	0.204	B	0-0
1946	0.00	0.048	B	0-0	0.00	0.204	B	0-0
1947	0.00	0.048	B	0-0	0.00	0.204	B	0-0
2015	0.41	0.048	A	1-22	4.80	0.204	A	1-39
AVG	0.03				0.32			
Native Annual Grass								
1933	1.21	2.432	F	4-24	-	-	-	-
1934	0.00	2.432	F	4-24	-	-	-	-
1935	0.69	2.432	F	4-24	-	-	-	-
1936	0.13	2.432	F	0-16	-	-	-	-
1937	0.00	2.432	F	0-0	-	-	-	-
1938	1.28	2.432	F	4-52	-	-	-	-
1939	4.01	2.432	FG	4-100	-	-	-	-
1940	16.59	2.432	EF	4-100	-	-	-	-
1941	57.92	2.432	B	4-100	-	-	-	-
1942	73.20	2.432	A	4-100	-	-	-	-
1943	47.65	2.432	BC	4-100	-	-	-	-
1944	37.19	2.474	CD	4-100	-	-	-	-
1945	50.69	2.432	B	4-100	-	-	-	-
1946	17.47	2.432	EF	4-100	-	-	-	-
1947	30.91	2.432	D	4-100	-	-	-	-
2015	0.47	2.432	G	1-15	-	-	-	-
AVG	22.63				-			

Means with different letters within each site are significantly different using Tukey-Kramer honestly significant difference multiple comparison procedure ($p < 0.05$).

Table A.5. Summary statistics (mean densities [plants/m^2], standard error [SE], Tukey-Kramer honestly significant difference and range of plant densities) for Sandberg bluegrass by study site (Burley study site, n=145-150; Castleford study site, n=102).

Sandberg bluegrass

	Burley				**Castleford**			
Year	**Densities**	**SE**	**Tukey-Kramer**	**Range**	**Densities**	**SE**	**Tukey-Kramer**	**Range**
1933	0.08	0.274	B	0-12	0.08	0.477	B	0-8
1934	0.00	0.274	B	0-0	0.00	0.477	B	0-0
1935	0.03	0.274	B	0-4	0.08	0.477	B	0-8
1936	0.00	0.274	B	0-0	0.08	0.477	B	0-8
1937	0.00	0.274	B	0-0	0.08	0.477	B	0-4
1938	0.32	0.274	B	0-48	0.12	0.477	B	0-4
1939	0.05	0.274	B	0-4	0.00	0.477	B	0-0
1940	0.05	0.274	B	16-24	0.16	0.477	B	4-8
1941	0.03	0.274	B	0-4	0.00	0.477	B	0-0
1942	0.32	0.274	B	0-24	0.00	0.477	B	0-0
1943	0.19	0.274	B	4-16	0.00	0.477	B	0-0
1944	0.66	0.279	B	4-32	0.00	0.477	B	0-0
1945	1.17	0.274	AB	4-52	0.00	0.477	B	0-0
1946	1.12	0.274	AB	4-36	0.00	0.477	B	0-0
1947	2.37	0.274	A	4-72	0.00	0.477	B	0-0
2015	1.11	0.274	AB	1-39	9.70	0.477	A	1-86
AVG	0.50				0.69			

Means with different letters within each site are significantly different using Tukey-Kramer honestly significant difference multiple comparison procedure ($p < 0.05$).

Table A.6. Summary (mean densities [plants/m^2], standard error [SE], Tukey-Kramer honestly significant difference and range of plant densities) for sagebrush and other woody plants by study site (Burley study site, n=145-150; Castleford study site, n=102)

	Sagebrush							
	Burley				**Castleford**			
Year	**Densities**	**SE**	**Tukey-Kramer**	**Range**	**Densities**	**SE**	**Tukey-Kramer**	**Range**
1933	0.35	0.794	C	4-12	0.16	0.164	A	4-8
1934	0.35	0.794	C	4-12	0.12	0.164	A	4-8
1935	0.27	0.794	C	4-8	0.00	0.164	A	0.00
1936	0.77	0.794	BC	4-12	0.27	0.164	A	4-12
1937	3.36	0.794	ABC	4-100	0.39	0.164	A	0-4
1938	1.71	0.794	BC	4-100	0.78	0.164	A	0-4
1939	2.24	0.794	ABC	4-100	0.47	0.164	A	4-28
1940	1.93	0.794	ABC	4-72	0.12	0.164	A	0-4
1941	1.47	0.794	BC	4-28	0.16	0.164	A	4-8
1942	3.12	0.794	ABC	4-100	0.35	0.164	A	4-24
1943	5.71	0.794	A	4-100	0.23	0.164	A	4-12
1944	2.26	0.808	ABC	4-100	0.23	0.164	A	4-12
1945	4.21	0.794	AB	4-100	0.67	0.164	A	4-24
1946	3.07	0.794	ABC	4-100	0.55	0.164	A	4-20
1947	2.92	0.794	ABC	4-100	0.55	0.164	A	4-12
2015	0.29	0.794	C	1-4	0.02	0.164	A	0-1
AVG	2.27				0.34			
	Other Woody plants							
1933	0.00	0.016	B	0-0	0.00	0.060	B	0-0
1934	0.00	0.016	B	0-0	0.00	0.060	B	0-0
1935	0.00	0.016	B	0-0	0.00	0.060	B	0-0
1936	0.00	0.016	B	0-0	0.00	0.060	B	0-0
1937	0.00	0.016	B	0-0	0.00	0.060	B	0-0
1938	0.00	0.016	B	0-0	0.00	0.060	B	0-0
1939	0.00	0.016	B	0-0	0.00	0.060	B	0-0
1940	0.00	0.016	B	0-0	0.00	0.060	B	0-0
1941	0.00	0.016	B	0-0	0.00	0.060	B	0-0
1942	0.00	0.016	B	0-0	0.00	0.060	B	0-0
1943	0.00	0.016	B	0-0	0.00	0.060	B	0-0
1944	0.00	0.016	B	0-0	0.00	0.060	B	0-0
1945	0.00	0.016	B	0-0	0.00	0.060	B	0-0
1946	0.00	0.016	B	0-0	0.00	0.060	B	0-0
1947	0.00	0.016	B	0-0	0.00	0.060	B	0-0
2015	0.33	0.016	B	1-4	0.67	0.060	A	1-19
AVG	0.02				0.04			

Means with different letters within each site are significantly different using Tukey-Kramer honestly significant difference multiple comparison procedure ($p < 0.05$).