Changes in Fire Season Precipitation in Idaho and Montana from 1982-2006

Ann-Marie Hadlow[1] and Carl A. Seielstad[2]

[1]USFS McCall Smokejumpers, Payette National Forest, 605 S. Mission St., McCall, ID 83638 ; [2]National Center for Landscape Fire Analysis, University of Montana College of Forestry and Conservation- CHCB439, Missoula, MT 59812

ABSTRACT

Fire season precipitation trends were investigated using daily rainfall data obtained from 76 Remote Automated Weather Stations (RAWS) across Idaho and Montana for the period 1982 to 2006. Station records were made temporally consistent/comparable by replacing missing/erroneous observations with data from the North American Regional Reanalysis (NARR) using methods easily reproducible by fire managers. Monthly precipitation was then analyzed during the core fire season (July-Sept) and biweekly precipitation was analyzed for the start of fire season (June). The end of the season was examined using October precipitation data and through identification of season slowing rain events (SSE). These analyses reveal significant changes in precipitation amount, timing and spatial autocorrelation between stations. While June precipitation has generally increased, core fire season is getting drier and longer. Season slowing events are occurring 15 days later, on average, than they did in 1982, while summer rainfall is decreasing at 97% of stations with clusters of significant change focused in the central Idaho mountains and in west-central Montana. The observed trends in precipitation paired with later season slowing events could result in more active fire seasons in the Northern Rockies and may help explain some of the changes in fire season that have been previously attributed to earlier spring snowmelt and warmer temperatures.

1. INTRODUCTION

In recent years, the idea that fire season severity is increasing has become prevalent. According to the Government Accountability Office (GAO), the average number of acres burned between 2000 and 2005 was 70 percent greater than burned during the 1990s, despite the fact that federal appropriations have tripled since the mid-1990s, to more than $3 billion dollars annually. In their 2006 analysis of large fires in the Western United states, Westerling et al. noted that from the mid-1980s until 2003, wildfire frequency was nearly four times the average of 1970-1986 (Westerling et al., 2006). National Interagency Fire Center (NIFC) records of annual fire numbers and acres burned since 1960 shows that the average number of fires has decreased while the number of acres burned has increased; a trend implying that fires are getting larger. Current research considers the possibility that recent increases in fire activity are linked to anthropogenic climate change (Miller 2006; Running 2006; Westerling et al., 2006). While much of this research investigates the effect of increased global temperature on wildfire activity, changes in precipitation are more uncertain (Trenberth et al., 2003). Precipitation has an important link to fire behavior and seasonal decreases in precipitation can increase fire activity by reducing fuel moisture and relative humidity.

To date, investigations regarding trends in precipitation have focused on broad temporal and spatial factors, such as annual trends at continent and global scales (Chang and Kwon, 2007; Huntington, 2006; Regonda et al., 2004; Trenberth et al., 2003). Surprisingly, within fire season factors at the local and regional level have not been systematically examined. Many events that occur within and around fire season alter the complex link between weather and fuels that ultimately determines the nature of a particular season. In consideration of weather aspects alone, ignitions from lightning, air temperature, rain, and atmospheric stability among others, can change the magnitude of a fire season (Agee, 1993; Werth and Ochoa, 1993). Precipitation can alter fire behavior, but will have different results depending on amount, timing, and continuity. For example, fire managers in the Northern Rockies often focus on June precipitation as a major predictor of fire season potential. Alternatively, a single rain event at the end of August can foreshorten the most spectacular fire season, while the fire-slowing effects of a heavy rain in the middle of the season can vanish in a matter of days.

This research examines the occurrence and timing of fire season precipitation in Idaho and Montana from 1982 until present with the objective of producing a systematic assessment of spatial-temporal patterns at the regional level. Specifically, monthly and bi-weekly precipitation trends are assessed with historic data from 76 Remote Automated Weather Stations (RAWS) within the two-state area. Additionally, precipitation events that signal the end of fire season are investigated for trends, and comparable event probabilities are produced. Instead of considering events as "season ending events", we look at the primary season slowing precipitation event, hereafter referred to as season slowing event (SSE). The SSE is defined as 0.5 in. of precipitation over five consecutive days or less, occurring after August 13 of each year.

Objectives of the work are threefold: 1) Produce a complete historical record of weather data from RAWS that is statistically defensible, comparable, and that is familiar and accessible to fire managers; 2) Identify temporal and spatial precipitation patterns in the Northern Rockies over the past 25 years via trend analysis and evaluation of spatial autocorrelation; 3) Produce season slowing event (SSE) probabilities, and identify trends in fire season length.

2. METHODS

2.1. DATA

Historically, the relative importance of weather events to fire season has been difficult to evaluate due to incomplete fire RAWS datasets and inconsistencies in analytical methods. For this analysis, RAWS data in .fwx format were combined with modeled weather data from the North American Regional Reanalysis (NARR) (Messinger et. al, 2006) to produce complete records for the period of interest. The weather data were manipulated using the FireFamily Plus (FFP) program (Bradshaw and Brittan, 1999), a common weather analysis tool used by fire managers. In the resultant datasets, weather events are defined consistently from station to station, creating comparable records across Idaho and Montana.

2.1.1. Remote Automated Weather (RAWS). RAWS stations were selected as the primary source for weather data because they are currently the only available stations that consistently record real-time weather observations in remote, fire prone areas. In addition, RAWS are the source of weather observations used by the fire community. Only RAWS stations with archived data from 1982 or earlier were used in the analysis. This provided complete datasets for a large sample of stations at various elevations across Montana and Idaho. Because many remote weather stations were added and automated in the early 1980's, including these stations greatly increased the sample size and provided a more complete regional weather picture. Stations selected included 32 from Idaho and 45 from Montana, representing a variety of locations and microclimate patterns (Figure 1).

It is worth noting that in the past, RAWS stations have not been standardized regarding length of record, or number of months annually during which data is recorded. While standardization is becoming more common, RAWS data tends to have incomplete records for spring and fall months. In addition, many RAWS are limited in the amount of historic data that have been recorded and archived, making it difficult to compare weather trends between stations and between seasons. Many stations are only funded to record data during the fire season which can range anywhere between April and October, leaving managers with data sets of varying length for any given station and season. The length of record for archived data varies substantially between RAWS, ranging from one year up to almost 50 years.

To overcome shortcomings in data length and quality, fire managers often use Special Interest Groups (SIGS) in the FFP program. SIGS allow the user to combine data from multiple stations into one dataset. A SIG will automatically take an average of all values for each data field or fill in missing data when only one value is available. With 3 or more stations, gaps in data from one station may be filled in with data from another. Although gaps in data often still occur, an appreciably more complete data set is produced. While this method still may not produce a complete dataset, a more notable problem occurs with trying to group stations. It is important to fill a SIG with stations from areas with similar weather, but there is much debate regarding how these weather zones can be determined. The user must decide whether the SIG is based on elevation, precipitation amounts, daily temperature, or proximity-among many other potential variables. In addition to the problem of determining weather zones, creating a SIG also makes it impossible to compare results from individual stations. In remote, mountainous terrain weather can fluctuate considerably over small distances. SIGS tend to hide these microclimatic tendencies, which can be important in determining fire weather trends and in turn fire behavior characteristics. Instead of combining RAWS data in SIGS, for this study, individual gridded data sets from the North American Regional Reanalysis were paired with each RAWS to produce complete and independent datasets for analysis.

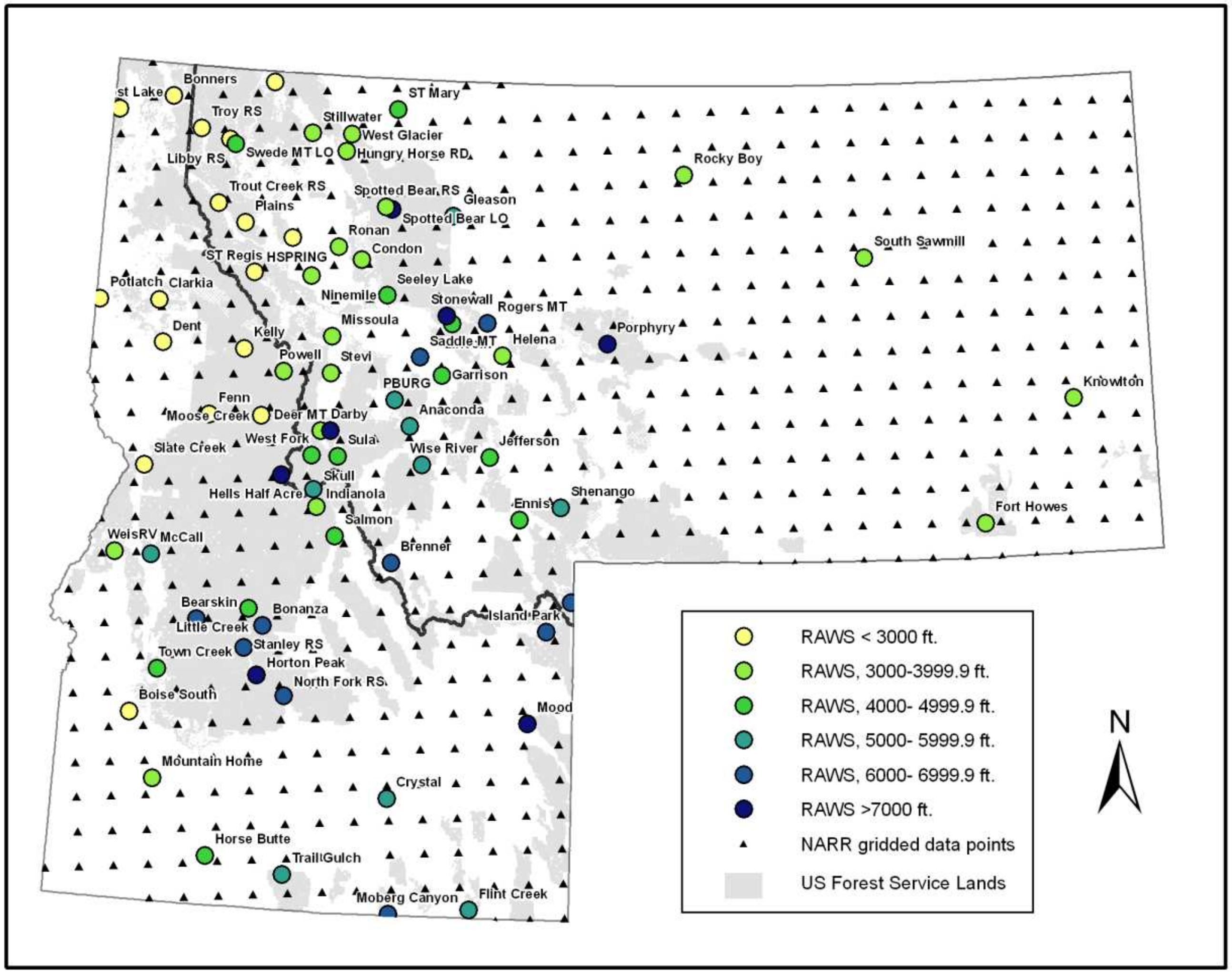

Figure 1. Location of RAWS (circles) used for precipitation analysis and all NARR gridded array points in Idaho and Montana (triangles). RAWS symbols are colored by elevation of station and labeled with station name.

2.1.2. The North American Regional Reanalysis (NARR). NARR is an atmospheric and land surface hydrology dataset at a 32-km spatial and 3-hour temporal resolution. It is based upon data from real-time observations including rawinsondes, aircraft, and surface weather stations combined with gridded data sets (Messinger et. al, 2006). The NARR dataset includes the Parameter-elevation relationships on Independent Slopes Model (PRISM) which calculates a climate-elevation regression for gridded sites. PRISM increases the accuracy of the model in mountainous terrain, making the NARR dataset a logical model to pair with RAWS data. (Daly et. al, 1994) In addition, the Fire Program Analysis (FPA) has recently made the NARR dataset available format compatible to RAWS, and they can be managed using similar processes.

2.1.3. Snowpack Telemetry Stations (Snotel). Snotel stations are operated and maintained by the Natural Resources Conservation Service (NRCS) with the intent of collecting snowpack and climatic data in the western United States. Because these stations are often located in remote areas, occasionally near RAWS, data from several snotel stations were used to corroborate results obtained from RAWS data. Snotel collect precipitation data in the form of rain and snow, whereas RAWS generally only collect liquid precipitation. For this investigation, five Snotel were paired with RAWS at similar location and elevation to investigate potential discrepancies in RAWS data caused by changes in the form of precipitation over time (snow becoming rain with warming temperatures) (Table 2). While Snotel are useful in association with RAWS, they tend to cluster at high-elevation with the purpose of representing basin-wide snowpack. They are not commonly used for fire applications.

2.2. DATA ANALYSIS

2.2.1. Data Correlation in the Study Area. Pearson's correlation analysis was conducted for the 76 RAWS-NARR weather pairs used in this study. Each RAWS record was joined with a proximate gridded NARR weather point of similar elevation. Rules for pairing were: < ±1000 ft elevation offset and no further than 30 miles apart. This differs slightly from the approach of Hall and Brown (2007), who used nearest neighbor proximity alone to pair stations across the conterminous United States. The average distance between paired stations was 18 miles, and average difference in elevation was ± 310 feet. Daily RAWS data from 1982-2006 were compared with corresponding data from each adjacent grid point to determine correlation between the two datasets for daily precipitation, temperature, and relative humidity. Only dates which contained a value for both RAWS and NARR data were considered in the analysis, and because most RAWS stations are seasonally operational a majority of the records compared were between May 1 and October 31. Pearson's correlations generated from the analysis were similar to those found by Hall and Brown (1970) (Table 1, B) in their evaluation of 591 RAWS from 1990-2004. Discrepancies between the two assessments may be due to the differences in sample size and sample area. In addition, RAWS in Idaho and Montana are located in mountainous terrain, and large changes in elevation over short distances are known to decrease the accuracy of gridded data.

	Percent Confidence (A)	Percent Confidence (B) (Brown & Hall)
Precipitation	60	64
Relative Humidity	75	67
Temperature	94	90

Table 1. Percent confidence in model derived values from Pearson's correlation for precipitation, relative humidity, and temperature from (A) the FPA correlation (Hall and Brown 2007) and (B) the study area.

2.2.2. Data Processing. Weather data were accessed from RAWS using the Kansas City Fire Access Software (KCFast) provided by the U.S. Forest Service. NARR gridded datasets were obtained from Fire Program Analysis (FPA) historical weather data delivery system. All raw datasets were interfaced and initial queries were performed using the FFP program. Data were exported for cleaning, and completed records were stored in database format. All RAWS and NARR weather files were entered into the FFP program. NARR data do not have a metadata file that physically describes the location for which the weather data is modeled. Metadata from each paired RAWS was used for individual NARR datasets with the exception of NARR site elevation, which was manually entered using elevations derived from the DEM. SIGS were created in FFP using data from each of the 76 individual RAWS stations throughout Idaho and Montana combined with its paired NARR data set. By weighting the RAWS data to 99% and the NARR data to 1% within each SIG, missing RAWS observations were filled with corresponding gridded NARR data and the near-original values of the RAWS observations were maintained. This approach was adopted because it represents an achievable way for fire managers to incorporate NARR data in their analyses without knowledge of database programming. Fields containing both RAWS and NARR data were automatically recorded as an average of the two values, weighing the RAWS value to 99% of this average. If a field contained only a NARR value and no RAWS, the NARR value was retained in the dataset. Additionally, individual RAWS values that were above or below the record historical range in Idaho and Montana during the past 100 years, as recorded by the Western Regional Climate Center (WRCC), were changed to a "no data". Removed data accounted for 0.03% of the precipitation data, 0.1% of the relative humidity data, and less than .01% of the temperature data. Following cleaning, data were queried to create tables containing monthly precipitation totals for May to October from each station for the entire period of record. Bi-weekly precipitation totals were extracted for the month of June.

2.2.3. Season Ending Event Definition (SSE) The definition of a Season Ending Event is highly variable. In general, fire management officers use precipitation totals over a number of days and/or combine precipitation with Energy Release Component thresholds. In this analysis, precipitation alone is used to define the Season Ending Event, and instead of considering this event a season ender, we define it as the primary season slowing precipitation event (SSE). SSE values were extracted by querying the first precipitation event of 0.5 inches or greater over a 5 day period that occurred after August 11 each year. The date of August 11 was chosen because a single-day negative maximum temperature singularity exists for the 13 of August (Soule', 2007), and major precipitation events near and after this date have the potential to impact the end of fire season. A single date was identified for each station, for each year of the 25 year period.

2.2.4. Trend Analysis and Spatial Autocorrelation. Precipitation data were analyzed for temporal trends using least squares linear regression for monthly and biweekly totals and for SSE date. Regression statistics were used to evaluate trends in monthly precipitation, bi-weekly precipitation, and the SSE over time (Kenney and Keeping, 1962; Ott and Longnecker, 2001). The statistical significance of trends was assessed using the Kendall-Tau test (Mann, 1945; Kendall, 1975). Although this test is not entirely unaffected by highly skewed distributions, it is sufficient for trend detection in hydrologic time series (Yue et. al, 2002). The Weibull probability distribution was used to generate probability curves for the occurrence of SSE at each station. Because the SSE can vary greatly in time from season to season, probability curves are used to calculate the chance of a SSE occurring on any particular date, after the chosen starting date (Latham and Rothermel, 1993). Moran's I was used to test for spatial autocorrelation of trends between RAWS (Moran 1950). Spatial autocorrelation has been used to indicate microclimate patterns and regional variability in weather trends related to precipitation (Chang and Kwon 2007).

3. RESULTS

3.1. SUMMER PRECIPITATION NORMALS

June to October average, precipitation in Idaho and Montana varies considerably from station to station ranging from 2.57 inches at Mountain Home, ID to 11.98 inches at West Glacier, MT (Figure 3). In general, precipitation increases with elevation and latitude, with northwestern Montana receiving the highest precipitation amounts, and southern Idaho receiving the lowest. Southern Idaho displays fairly uniform precipitation, while west-central Montana, and central and northern Idaho are highly variable due to steep elevation gradients.

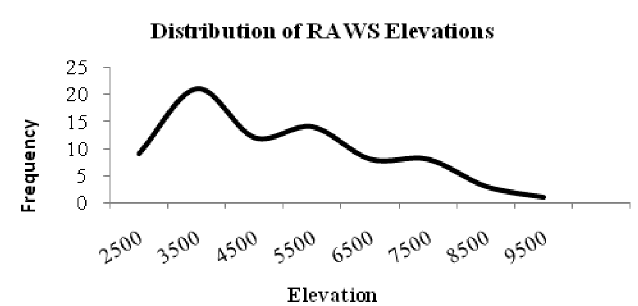

Figure 2. Distribution of elevations of 76 RAWS in the study

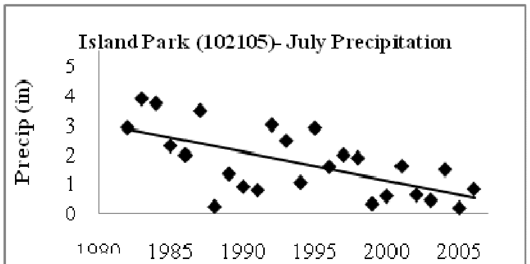

Figure 4

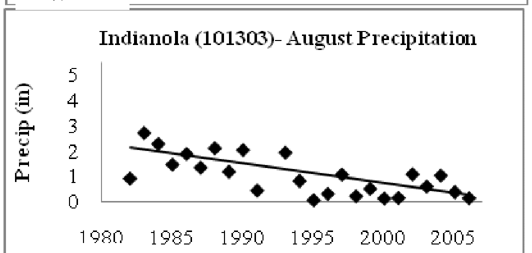

Figure 5

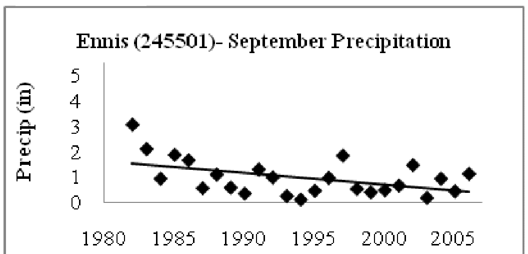

Figure 6

Figures 4,5,6. Least squares regression line fitted to total monthly precipitation from RAWS for (7) July at Island Park, (8) August at Indianola, and (9) September at Ennis displaying trends of -2.33 in., -1.89 in., and -1.09 in. respectively.

3.2. CORE FIRE SEASON PRECIPITATION TRENDS (JULY – SEPTEMBER)

Core fire season showed trends of decreasing precipitation at 95% of stations, indicating that these months are becoming dryer (Figures 7, 8, 9). Overall, July precipitation displayed the largest, significant decreases in precipitation with an extreme of -2.33 inches at Island Park near West Yellowstone in Eastern Idaho, and an average precipitation decrease of -0.87 inches across all stations. Although not all trends were statistically significant, July trends displayed the largest number of significant trends. Magnitudes of trends and significance were reduced for August and September, respectively. The largest, significant trend decrease for August was at Indianola, on the Salmon River, showing a decrease in precipitation of -1.86 inches (Figure 4), with an average decrease for all stations of -0.56 inches.

For September, a significant decrease of -1.09 inches was found at Ennis in southwestern Montana (Figure 5), with an average precipitation decrease of -0.77 inches.

<u>3.2.1. July Precipitation.</u> July precipitation decreased for all 76 stations, with magnitudes ranging from -0.04 in. to -2.33 in. (Figure 7). Declines in precipitation are significant at the 95% confidence level for 22 stations (28%) based on Kendall's τ. Weak spatial autocorrelation for significant precipitation trends was found for stations in central Idaho near the town of McCall (Moran's I = 0.04 to 0.20). Autocorrelation for trend magnitude was found at 5 stations on the border of Montana-Idaho, west of Anaconda (Moran's I = 0.10 to .28).

<u>3.2.2. August Precipitation</u>. August precipitation data showed a decreasing trend for 72 stations (95%) with magnitudes ranging from -0.08 in. to -1.89 in., and results of the Kendall's τ showed significance at the 95% confidence level for 10 of these stations Figure 4. Four stations displayed increasing precipitation trends with magnitudes ranging from 0.02 in. to 0.45 in. (Figure 8), with no statistical significance. Weak spatial autocorrelation for significant precipitation trends was found for three stations on the border of Idaho and Montana near Salmon, ID (Moran's I= 0.07 to 0.16), adjacent to the significant cluster noted in July. Weak autocorrelation was found for decreasing trend magnitude for 10 stations in west central Montana (Moran's I = 0.08 to 0.29).

3.3.3. September Precipitation. September precipitation decreased for 74 stations (97%) with magnitudes ranging from -0.07 in. to -2.29 in., with 3 of these stations showing significance at the 95% level for Kendall's τ. Two stations displayed weak, increasing trends with magnitudes of 0.02 and 0.17, with no statistical significance (Figure 9). September stations showed no spatial autocorrelation for significant trends, or trend magnitudes.

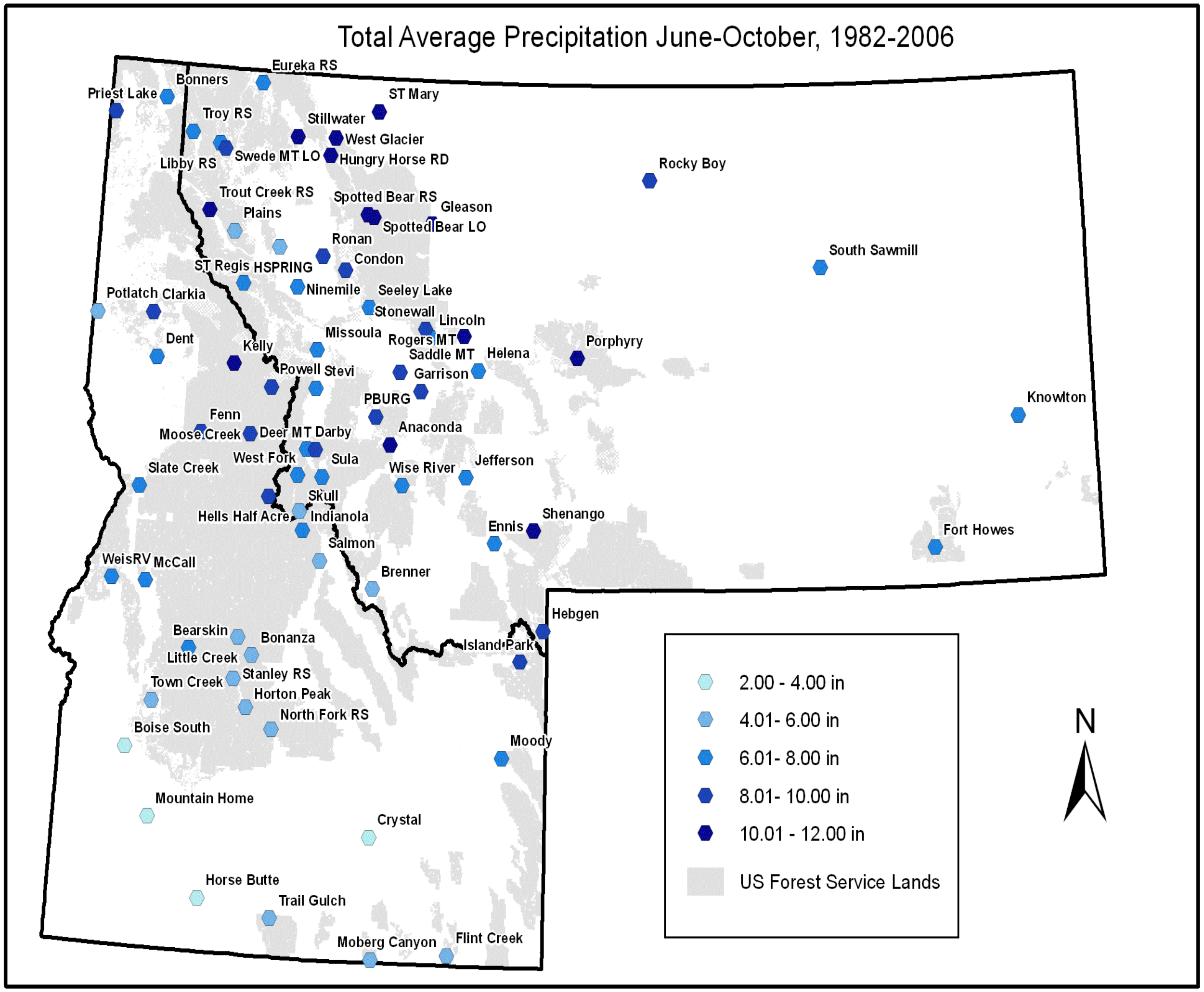

Figure 2. Total average, daily precipitation from RAWS in study area from June to October, 1982-2006. Labeled with RAWS name.

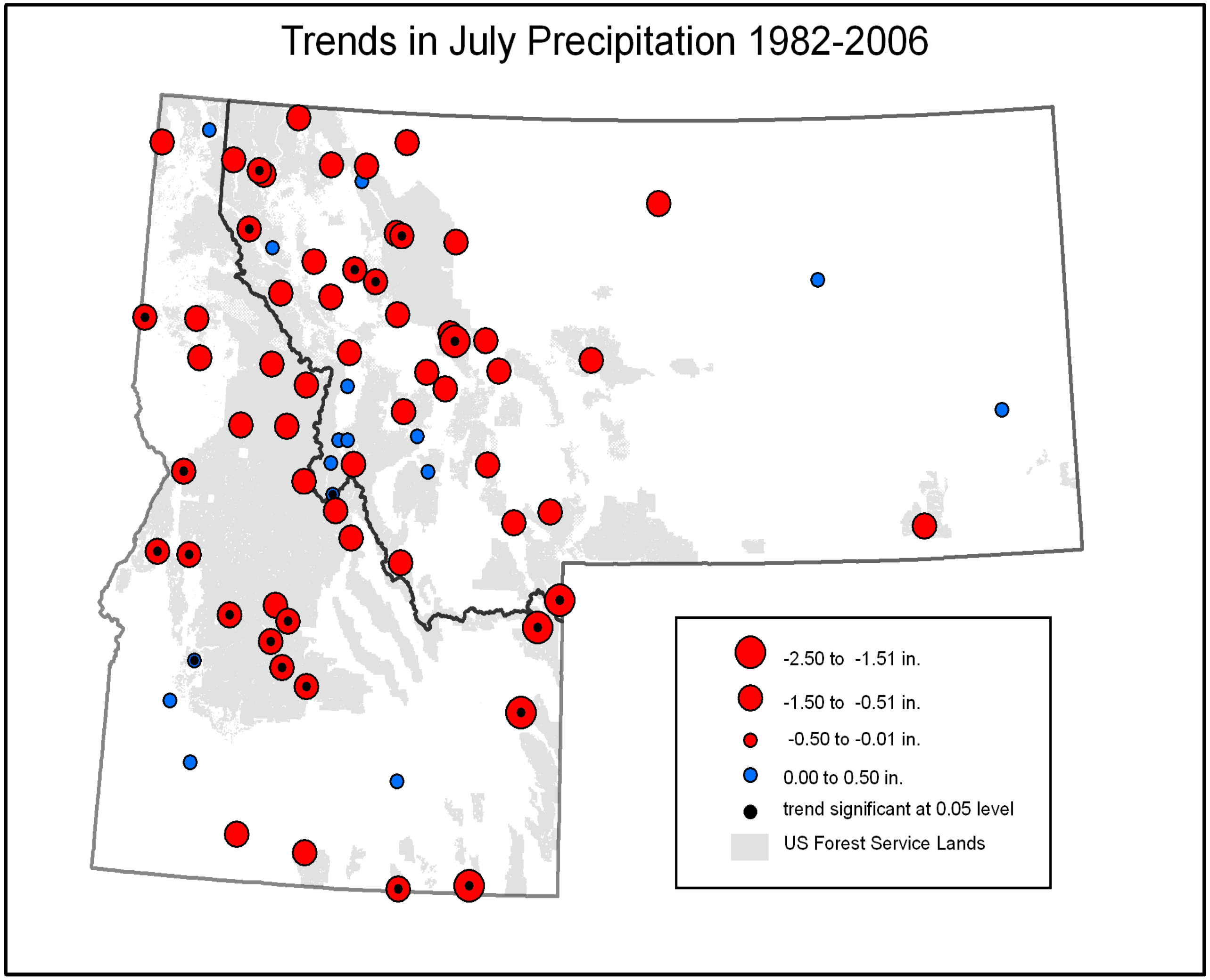

Figure 7. Trend in total, daily July precipitation for RAWS in the study area, 1982-2006. Black center indicates significance at the 95% confidence level for Kendall's Tau.

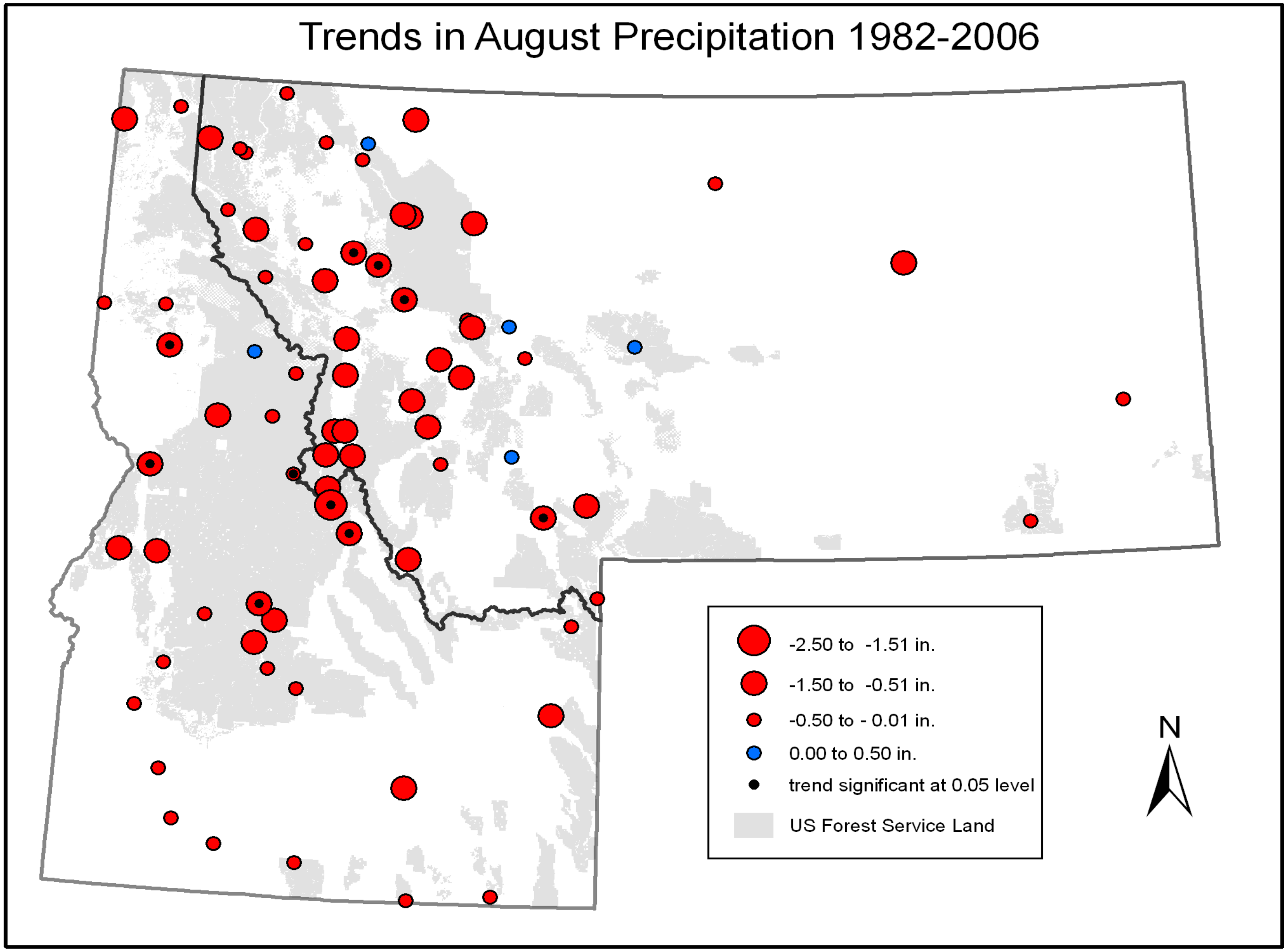

Figure 8. Trend in total, daily August precipitation for RAWS in the study area, 1982-2006. Black center indicates significance at the 95% confidence level for Kendall’s Tau.

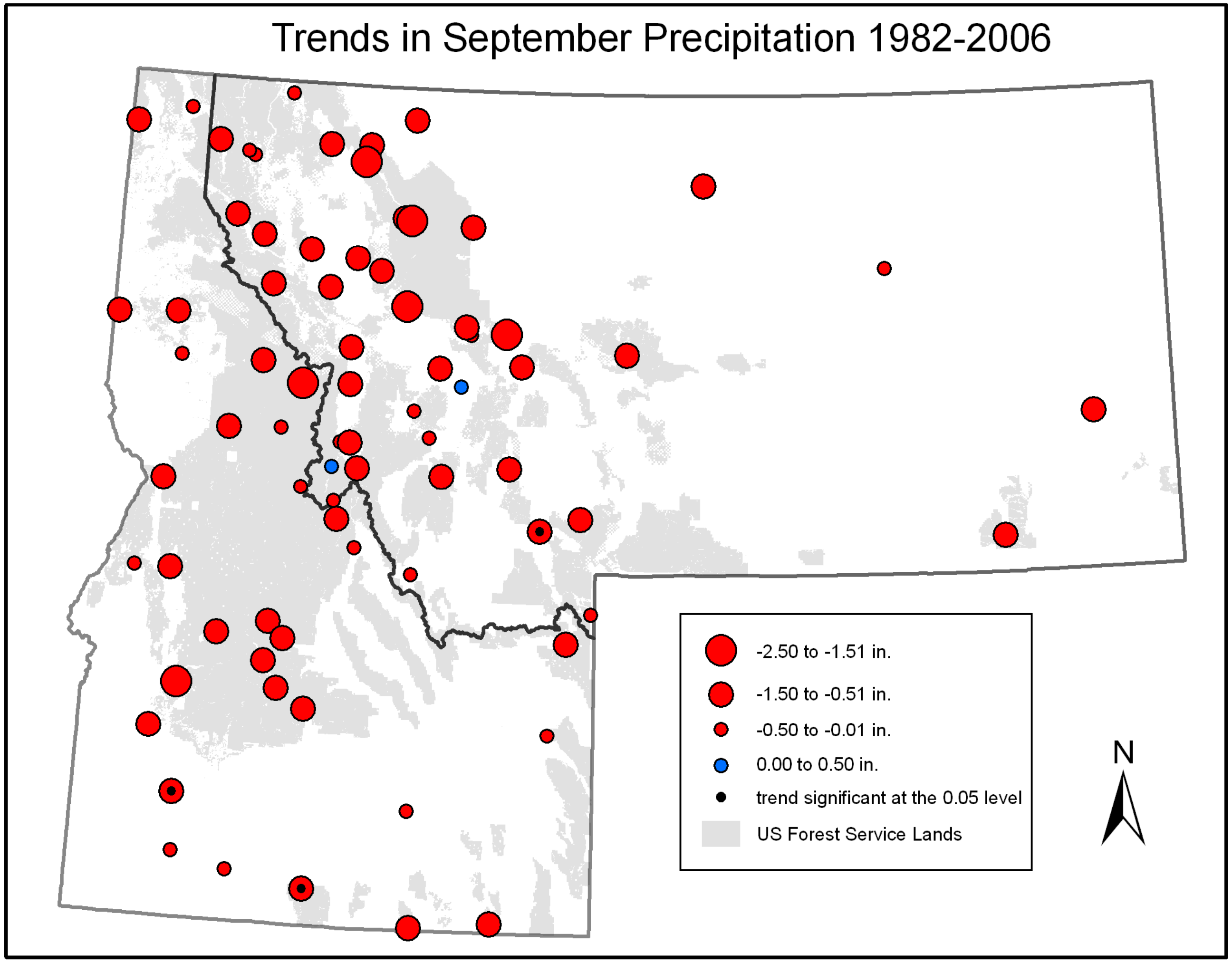

Figure 9. Trend in total, daily September precipitation for RAWS in the study area, 1982-2006. Black center indicates significance at the 95% confidence level for Kendall's Tau.

3.3. SEASON START: JUNE PRECIPITATION

In the Northern Rockies, June is a transition month, often marking the end of spring rains and the beginning of the summer drying period. In consideration of this transition, June precipitation was investigated on both a monthly and biweekly timestep. In June, more than half of the stations displayed increasing precipitation trends, with the majority of this increase occurring in the first two weeks (Figures 10, 11). Compared to stations with decreasing precipitation, the increasing trends were substantially stronger and many were also statistically significant. The greatest increases in precipitation occurred at stations along the Front Range of Montana, in eastern Montana, and in west central Montana near Anaconda.

3.3.1. Total June Precipitation. Trends in June precipitation were spatially variable. Decreasing precipitation was observed at 34 stations (45%) with magnitudes ranging from -0.005 in. to - 0.94 in., and no statistical significance. Forty-two stations (55%) displayed increasing precipitation ranging from 0.02 in. to 2.55 in. (Figure 10), and 7 of these stations exhibited significance for Kendall's τ at the 95% confidence level. These 7 stations, centered around Anaconda, MT also displayed weak, significance for spatial autocorrelation. Thirty-three of the 42 stations with increasing precipitation are located in Montana. Seventeen of these stations, located on the Front Range and around Anaconda, show weak to moderate spatial autocorrelation for trend magnitude (Moran's I = 0.03 to 0.34). Conversely, 23 of the 34 stations with decreasing precipitation trends are located throughout Idaho, and 12 of these, centered primarily around McCall, show weak autocorrelation for trend magnitude (Moran's I = 0.05 to 0.15). Data from these same stations also displayed autocorrelation for significant decreasing trends in the July precipitation results.

3.3.2. June Precipitation: Biweekly. In the first half of June, precipitation at a majority of stations is increasing, in contrast to the second half of June. Fifty-two stations (68%) displayed increasing precipitation during this period ranging from 0.01 in. to 2.6 in. (Figure 11). Twenty-two of the increasing trends are significant for Kendall's τ, with 19 of these significant stations showing weak to moderate autocorrelation (Moran's I = 0.20 to 0.48). Similar to the results found in total June precipitation datasets, forty-one of the 52 stations that displayed increasing precipitation were again located in Montana, and 17 stations showed weak to moderate autocorrelation for increasing trend magnitude (Moran's I = 0.02 to 0.40). Datasets attained from stations for the initial two-week period in June displayed a decreasing trend for 24 stations (32%) with magnitudes ranging from -0.02 in. to -0.82 in., and only one station presenting significance for Kendall's τ. Twenty-one of the 24 stations displaying decreasing precipitation trends were again located in Idaho, with a more concentrated location to the south and east, and 13 of these, around Stanley, Idaho showing weak autocorrelation for decreasing trend magnitude (Moran's I = 0.04 to 0.26). In contrast, there is no apparent trend in the second half of June, with many of the stations that had previously displayed strong increasing precipitation during the first two weeks of June showing slightly decreasing precipitation during the second two week period (Figure 12). The 48 stations (63%) with decreasing trends in the second half of June ranged from -0.01 in. to -0.96 in., with no significance for Kendall's τ or autocorrelation. The 28 stations (37%) with increasing precipitation trends in late June ranged from 0.01 in. to 0.61 in., and also showed no significance for trend magnitude or spatial autocorrelation.

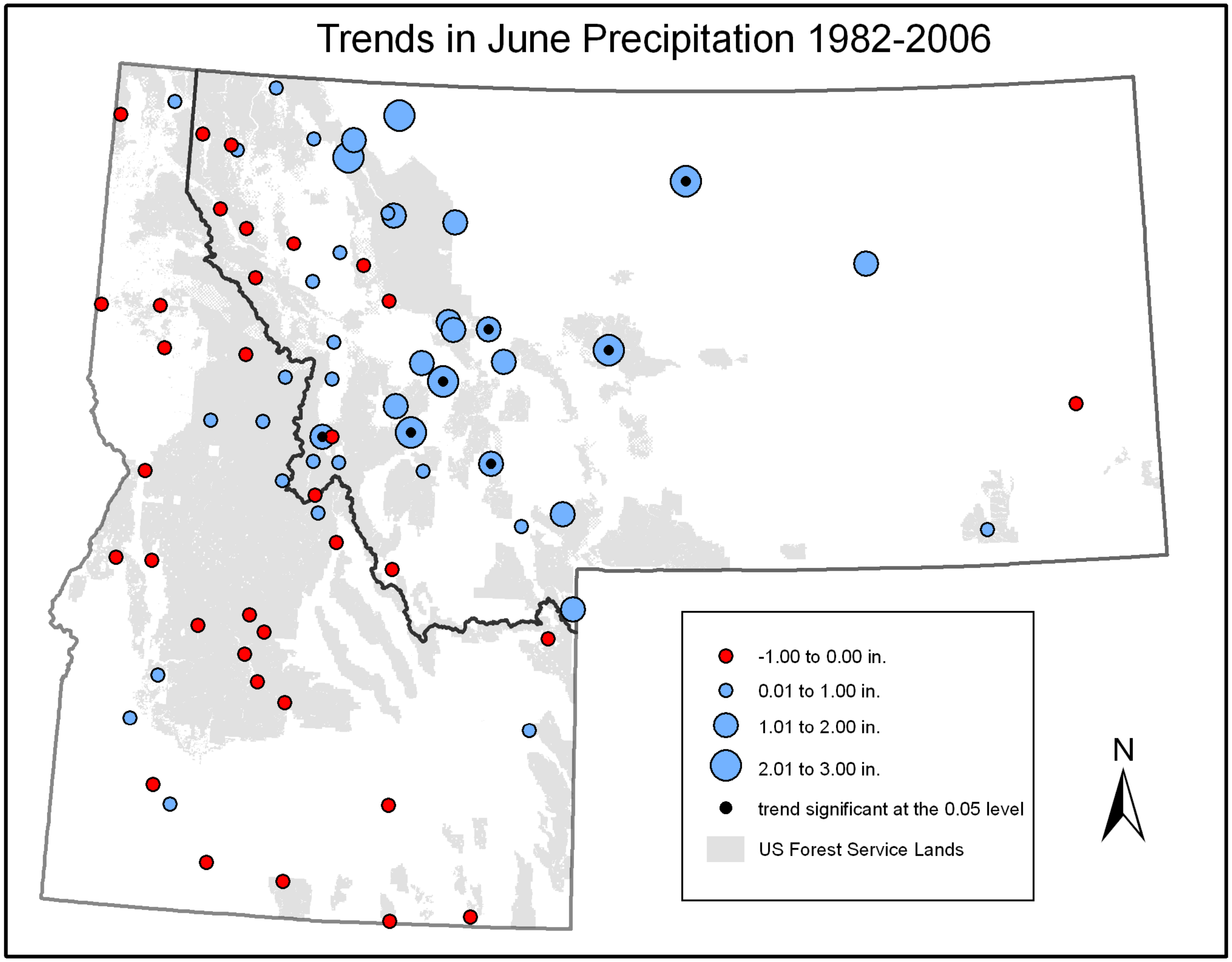

Figure 10. Trend in total, daily June precipitation for RAWS in the study area, 1982-2006. Black center indicates significance at the 95% confidence level for Kendall's Tau.

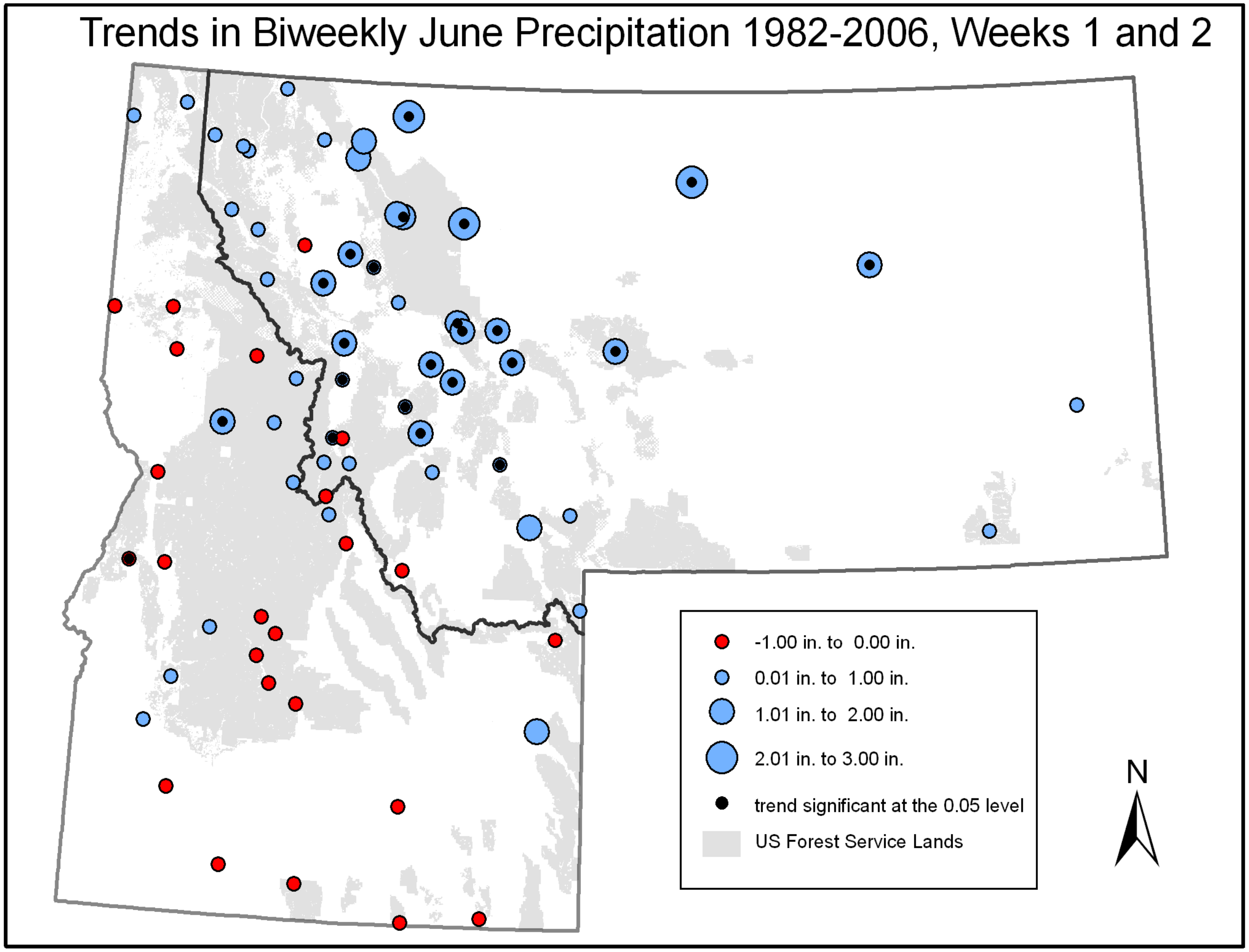

Figure 11. Trend in daily, biweekly June precipitation for the first half of June . Data obtained from RAWS in the study area, 1982-2006. Black center indicates significance at the 95% confidence level for

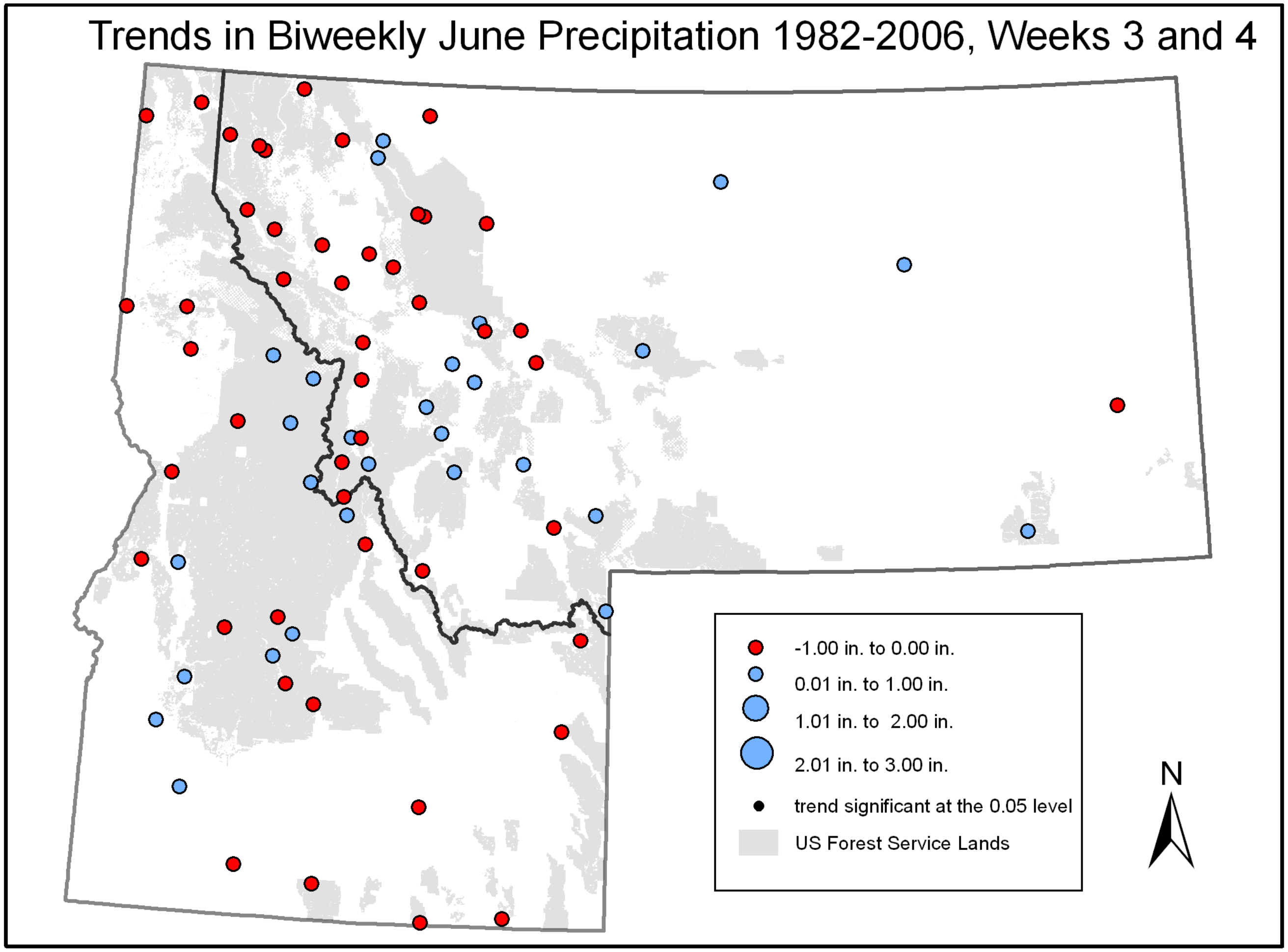

Figure 12. Trend in daily, biweekly June precipitation for the second half of June. Data obtained from RAWS in the study area1982-2006. Black center indicates significance at the 95% confidence level for Kendall's tau.

3.4. SEASON END: OCTOBER PRECIPITATION AND SLOWING EVENTS.

October loosely signals an end to the summer fire season in the Northern Rockies, excepting the grasslands of eastern Montana and southern Idaho. As in June, October tends to be a transition month, and precipitation trends during this month can affect the length of fire season. In general, October precipitation displayed increasing precipitation at many stations, with smaller trends and less significance than in June (Figure 13). Again, a pattern of autocorrelation for increasing precipitation was displayed in stations near Anaconda, MT., and decreasing precipitation for stations located in central Idaho. Because season slowing events (SSE) are also helpful for defining the end of fire season, SSE data was investigated for a trend increase or decrease (in days) that could signal a change in the length of fire season (Figure 14). In addition, a cumulative probability curve representing occurrence of the SSE was generated for each station using the annual SSE date for the period of record. The 90th percentile date for each station was extracted, and dates ranged from the beginning of September to the end of November, with the majority centered at the beginning of October (Figure 15) 90th percentile dates were compared to identify areas displaying similar precipitation patterns at the end of the season.

3.4.1. October Precipitation. In October, precipitation decreased at 24 (32%) stations, with magnitudes ranging from -0.03 in. to -1.32 in. None of the decreasing trends showed statistical significance for Kendall's τ; however, stations in central Idaho, near McCall, displayed weak to moderate significance in autocorrelation for decreasing trend magnitude (Moran's I = 0.09 to 0.38). Interestingly, this pattern of autocorrelation for decreasing precipitation was similar to that displayed in central Idaho stations in June and July monthly precipitation. Fifty-two stations (68%) displayed increasing precipitation with magnitudes ranging from 0.01 in. to 1.80 in. (Figure 13). Trends at 5 of these stations were significant for Kendall's τ, although they showed no significant autocorrelation. Similar to June precipitation trends, 35 of the 52 stations displaying increasing precipitation were located in Montana; however there was no autocorrelation between trend magnitudes.

3.4.2. Primary Season Slowing Precipitation Events. The SSE at 70 stations (92%) is occurring later over the 25 year period, representing an increase in the overall length of fire season. The magnitude of change at these stations ranged from 1 day to 54 days, with 19 stations showing significance by Kendall's τ. Fourteen of the 19 significant stations were grouped in western Montana with seven stations around Missoula, MT showing weak, spatial autocorrelation (Moran's I = 0.15 to 0.22). Six stations, spread throughout Idaho and Montana,

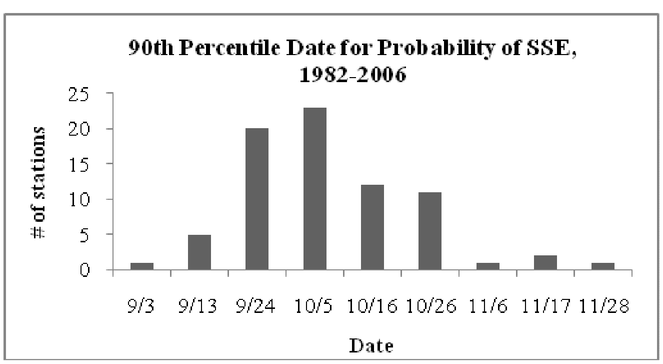

Figure 15. Distribution of 90th percentile dates obtained from probability curves generated for season slowing events (SSE) for 76 RAWS in the study area.

displayed a decrease in days ranging from -1.7 days to -8 days, representing a decrease in overall length of fire season (Figure 14), and trends from these stations were not significant for magnitude or autocorrelation. The 90th percentile date for occurrence of a SSE was extracted for each station, and ranged from September 3 to November 28, with an average date of October 2. Stations with significant autocorrelation for similar SSE dates were located in Montana near Anaconda, and along the Front Range (Moran's I = 0.05 to 0.23); and in central Idaho (Moran's I = 0.03 to 0.30) similar to those stations that were spatially significant for decreasing precipitation trends in June, July, and October.

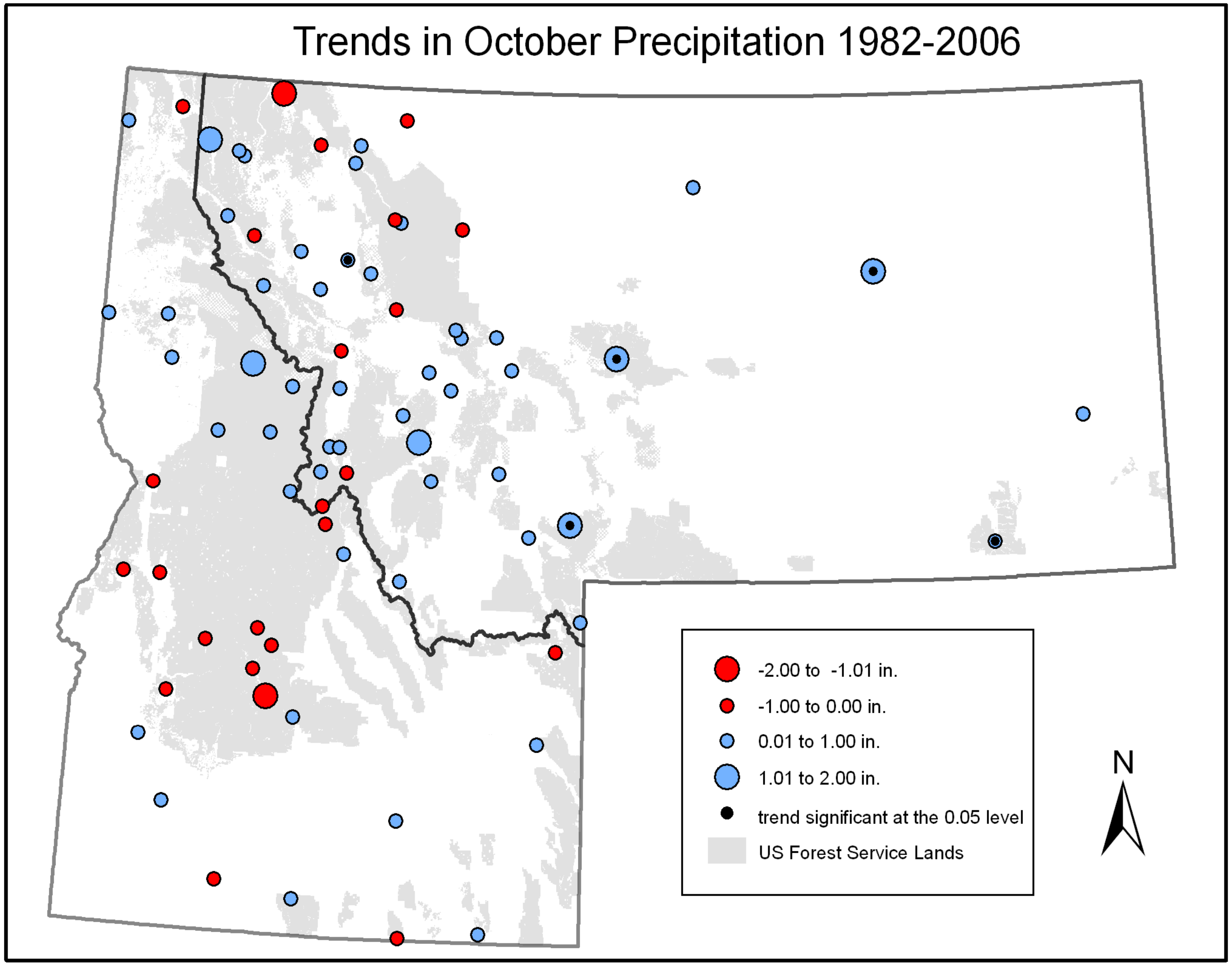

Figure 13. Trend in total, daily October precipitation for RAWS in the study area, 1982-2006. Black center indicates significance at the 95% confidence level for Kendall's Tau.

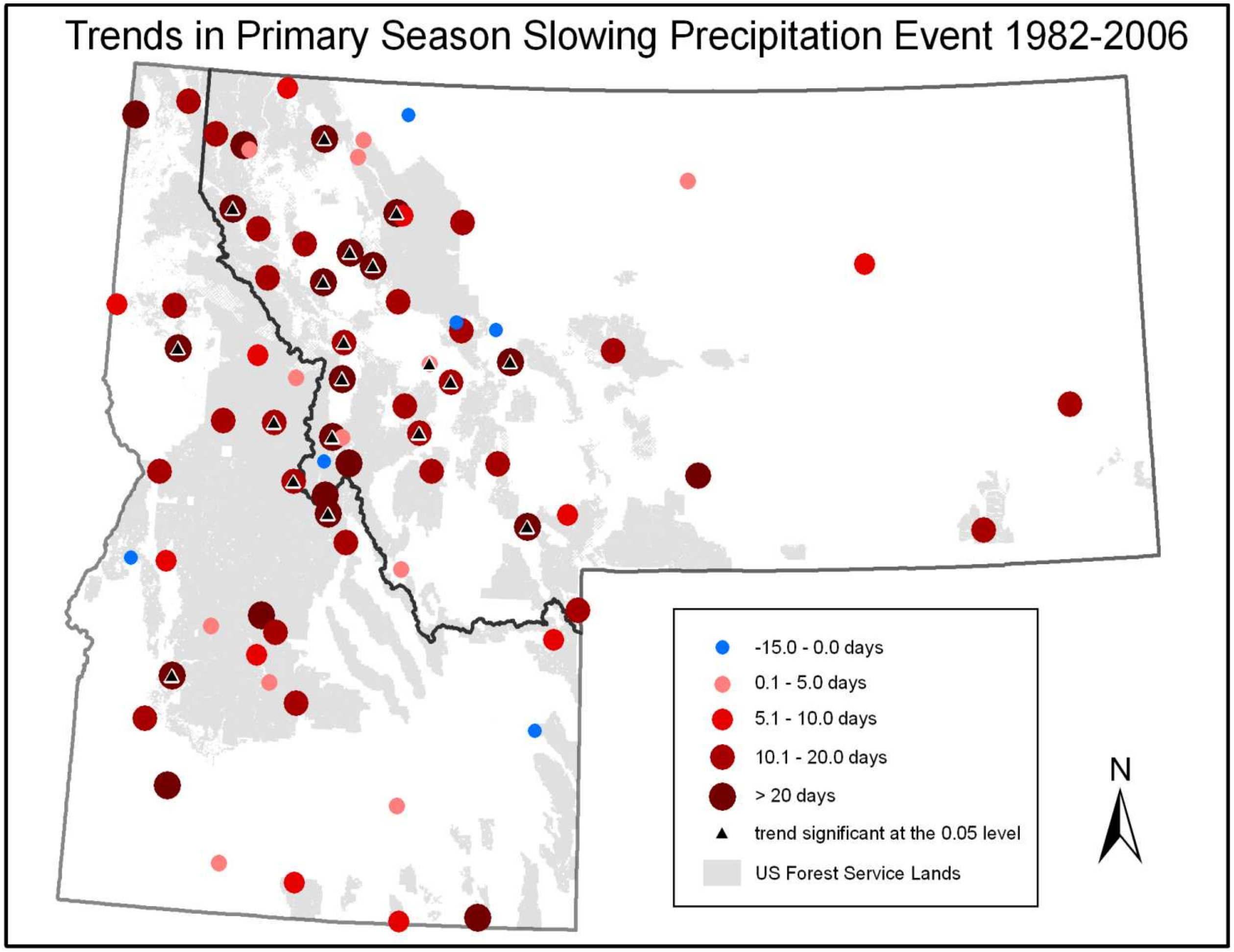

Figure 14. Trend change in days of the annual occurrence of the primary season slowing precipitation event at RAWS in the study area, 1982-2006. Black center indicates trend significance at the 95% confidence

4. DISCUSSION

4.1. CORE FIRE SEASON PRECIPITATION.

The results of precipitation analysis show significant drying over the past 25 years in July, August, and September. While not all trends are statistically significant, almost all stations displayed downward trends with an average, monthly precipitation decrease of -0.87 in. (67% decrease), -0.56 in. (47% decrease), and -0.77 in. (57% decrease) during July, August, and September respectively. While the amount and frequency of precipitation has an effect on the frequency, size, and intensity of fires, the relationship between wildland fire, climate, and fuels is complex (Dale and Joyce 2001, Shoennagel et. al 2004). Decreased fire season precipitation may increase fire activity in the Northern Rockies, although increases in fire activity will differ depending on fuel type, elevation, moisture, and fire regime. It is difficult to extrapolate long-term trends from a 25 year analysis, but the decrease in precipitation during this period of record alone is considerable given the aridness of the Interior West. It is possible that the trends signal long term change in the climate, but it is important to consider the effects of global variation in the atmosphere and short-term and decadal oscillations that may produce changes in local weather.

4.2. JUNE AND OCTOBER PRECIPITATION

Perhaps the most striking aspect of the beginning and end of season data, is the large increase in precipitation observed at many stations. Trends in June and October were similar, although June displayed statistically significant trends, and with larger magnitude. June precipitation has increased by an average of 1.05 in. (47% increase), with most of this occurring in the first two weeks of June where stations displayed an average precipitation increase of 0.95 in. (75% increase). In October, average precipitation increased by 0.54 in. (34% increase), with similar spatial patterns to those in June. These trends are most likely the result of a change in local weather patterns (Bauck, 2009), and it is difficult to speculate regarding the longevity or permanence of these changes. While increased spring precipitation may reduce fire severity at higher elevations in Idaho and Montana, it could actually increase severity in low elevation fuel types comprised of grass or grass understory (Young, et al. 1987).

4.3. SEASON END

Fire season in Idaho and Montana, as defined by RAWS-based SSE probabilities, is getting longer. Precipitation events at the end of the fire season that often bring a close to the fire season have increased by an average of 15.5 days in the past 25 years. In their analysis of a comprehensive database of large fires in the west, Westerling et. al found that the date of the last reported wildfire ignition increased by an average of 15 days between 1980 and 2003 (Westerling et al., 2006). This change in fire activity would be expected to accompany an increase in the length of fire season. A later end to the season expands the time that fuels will continue to actively burn and the availability of fuels to support new fire starts.

4.4. PRECIPITATION AS SNOW

One concern regarding increased precipitation in June and October is that observed trends are due to increases in snow falling as rain, rather than actual increases in total precipitation. Recent increases in global temperature have resulted in more precipitation falling as rain instead of snow in some areas (Knowles et. al, 2006). An increase in rain at the expense of snow would be particularly noticeable at low elevations in the Pacific Northwest where winter temperatures hover close to the freezing point, and where small interannual variations in temperature could subsequently have a dramatic effect on precipitation form (Regonda et al., 2004).

Most RAWS do not have the capacity to accurately collect precipitation in the form of snow. Although suppliers provide heated tipping buckets for this purpose, RAWS are often too remote to provide the needed power inputs to run heaters. In addition, data from RAWS are mainly utilized during the summer fire season when snow is not an issue. Therefore, it it possible that RAWS could show large trend increases in precipitation over the past 25 years that actually represent a shift in the amount of precipitation falling as rain. After further investigation, this appears not to be the case, and the observed trends appear to represent real changes in total precipitation. Two pieces of evidence support this claim. First, one would expect to see elevational trends in the data with cold, high elevation sites showing smaller increases in precipitation than lower elevation sites with temperatures close to the freezing point. June and October data displayed a spatial trend, but no trend in elevation was observed. Second, five of the RAWS displaying large precipitation increases in June were compared with June precipition data from Snowpack Telemetry Stations (Snotel) with similar location and elevation (Figure 16). Snotel stations collect all-season precipitation via a pressure-sensing snow pillow and storage precipitation gauge. If the precipitation increases observed by RAWS were caused by an increase of snow falling as rain, a descrepency between the results of the two stations would be expected that would increase over the period of record as RAWS began to register apparent increases in precipitation data relative to snotel precipitation. This was not observed in any of the five comparisons, suggesting that the trends observed at RAWS stations with increasing precipitation in June and October are due to an actual increases in total precipitation over the 25 year period.

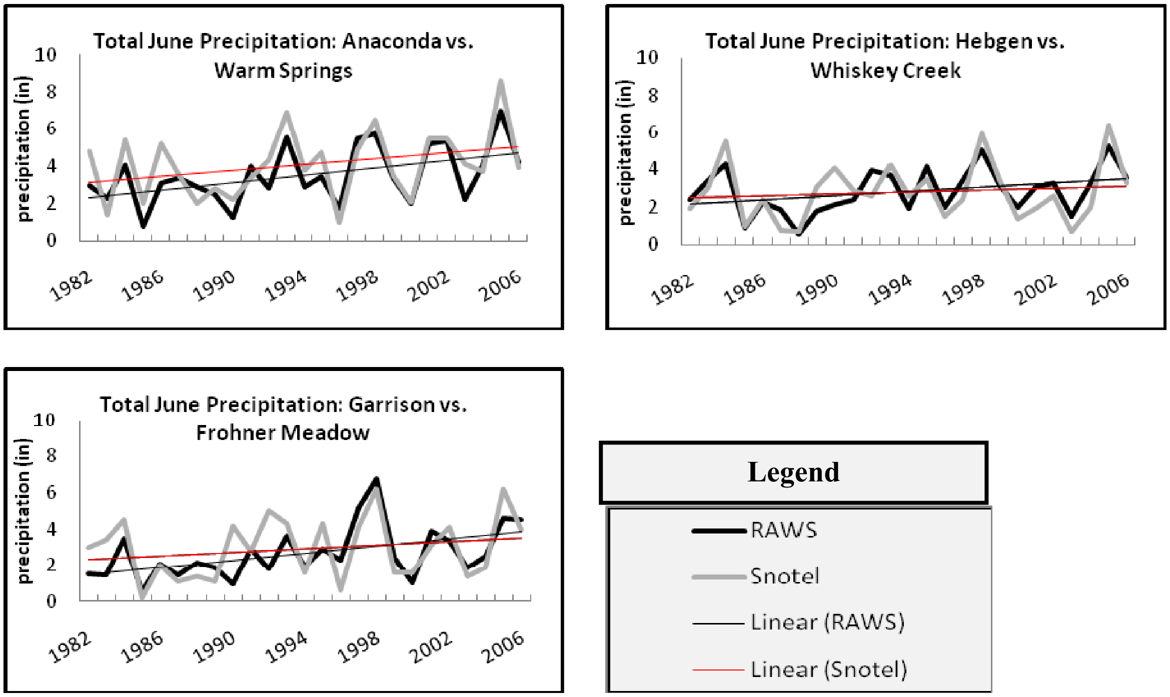

Figure16. Comparison of June monthly precipitation totals (1982-2006) from paired RAWS and Snotel stations. All stations were located in western Montana, each pair of stations matched by location (latitude and longitude) and elevation.

4.5. LOCAL AND SYNOPTIC WEATHER PATTERNS

RAWS on the Front Range of Montana, and in west central Montana show statistically significant trends of increasing precipitation in June, while stations in Idaho generally depict weak trends for decreasing precipitation. This appears to be the result of increased moisture from a common low pressure system that sets up over eastern Montana and is responsible for a majority of precipitation in Western Montana during the Spring and Fall (Bauck, 2009). Counter-clockwise movement of air around the low pressure center sends upslope moisture into the Front Range, and central mountains of Montana resulting in large amounts of precipitation. As air continues around the low, it is forced downslope into southern and eastern Idaho where precipitation tends to dissipate with adiabatic drying. It is also important to note that the northern Front Range of Montana experienced three significant rain events in the beginning of June during the latter half of the evaluated period. In 48 hours rain accumulations reached 11 inches, 7 inches, and 5 inches at locations along the Rocky Mountain Front in 1995, 2005, and 2006 respectively (National Weather Service, 2009). These three large events occuring late in the period of analysis may be responsible for much of the observed increases in monthly precipitation.

In contrast to the June and October precipitation patterns, changes in core fire season may be the result of larger, synoptic scale weather patterns. In general, the moisture that creates summer thunderstorms in Idaho and Montana originates in the Gulf of Mexico, or most commonly, in the subtropics of the Pacific Ocean (Bauck, 2009). As Pacific moisture moves through California, it is redirected by a high pressure area, commonly known as the “four corners high”. Air moving clockwise around this high pressure area redirects moisture into Idaho and across Montana (Whiteman, 2000). Changes in global atmospheric and oceanic circulation patterns can temporarily alter sites where moisture originates, effectively increasing or decreasing precipitation over land. While the possiblity remains that observed trends are the result of regional redistribution of precipitation associated with anthropogenic climate change, these trends may also be the result of these large scale variations in atmosphere and sea surface temperature, specifically the El Nino Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) (Cayan, 1998; Hamlet et al., 2005).

4.6. LIGHTNING ACTIVITY

Logic dictates that decreases in summer precipitation may be accompanied by decreased lightning activity, because much of summer preciptiaton is convective in nature. Cloud-to-ground lightning strike events are the primary cause of fire in the forested regions of the Pacific Northwest (Rorig and Ferguson, 1999). Less precipitation may make forest fuels more receptive to fire, but may also reduce the number of fire starts. The fire management officer at the Moose Creek Ranger District in north-central Idaho, has noticed a large decrease in fire starts in the area since 1994, which he attributes to a decrease in lightning (Hoyt, personal communication, 2009). The validity of this observation was not corroborated but the lightning issue merits further consideration.

5. CONCLUSIONS

In their 2006 temporal analysis of large wildfires (>988 ac), Westerling et. al found substantial evidence that the incidence of large fires in the Northern Rockies increased in the mid-1980's. In their analysis of forested areas in the western U.S., the Northern Rockies accounted for 60% of the total increase in the frequency of large fires (Westerling et al., 2006). This increase in wildfire activity was attributed to earlier spring snowmelt, and increased summer temperatures. Both of these conditions have the potential to increase fire activity, but another cause may simply be that core fire season is getting dryer.

The results of this analysis can be summarized in the following 5 points.

1. Summer precipitation in Idaho and Montana has decreased over the past 25 years during the months of July, August, and September.
2. June precipitation has increased in western Montana over the past 25 years especially during the first half of June, but has slightly decreased in Idaho.
3. Season slowing precipitation events that occur at the end of fire season are occurring later over the 25 year period, effectively increasing the length of fire season in Idaho and Montana.
4. Stations on the Front Range of Montana, and in west central Montana (centered on Anaconda) consistently displayed spatial autocorrelation with similar trends. At

these stations, in June and October precipitation is increasing, in July and August precipitation is decreasing , and the season slowing event (SSE) is getting later.

5. Stations in south central Idaho, centered around McCall and Stanley, Idaho consistently displayed spatial autocorrelation with similar trends for decreasing precipitation in June, July, and October. In addition, the SSE is getting later at these stations.

The NARR gridded dataset has proven fairly robust in its correlation with RAWS data for temperature, preciptation, and relative humidity. For a fire manager at a specific location in complex terrain, a proximal, gridded dataset with similar elevation, may produce more reliable trends for long term, historic weather evaluation than real-time data from the nearest RAWS. For comparable analysis of historic weather trends over regions, as in this study, gridded datasets with sufficient correlation could be independently useful due to length of record, coverage, and homogeneity. At this time, using the NARR gridded datasets provided in fwx. format for the FPA, seems to be a successful method to fill in missing observations from RAWS datasets for long-term analysis of weather trends. However, caution should be used when employing NARR datasets for calculation of fire danger indices such as ERC, as NARR appears to produce values lower than those calculated using RAWS data. Independent, standardized data with continuous coverage could elucidate areas with similar trends in various weather aspects such as temperature and precipitation, as well as standardized season ending event probabilities. A continuous grid of these probabilities could be used as a reference tool for fire managers, and could regulate season ending events which are currently subjective, and uncomparable across regions.

The weather products created through this project are as follows.

1. Transferrable database containing year-round observations for daily maximum and minimum temperature, maximum and minimum relative humidity, and total precipitation. Weather observations consist of cleaned RAWS data completed with NARR gridded data to produce a comprehensive, comparable record for each of 76 RAWS from 1980-2007.
2. Standardized probability curves and 90th percentile dates for the primary season slowing precipitation event (SSE) for each of 76 RAWS stations.

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