



Upper Columbia Basin Network Aspen Monitoring Report 2008-2012

City of Rocks National Reserve (CIRO)

Natural Resource Technical Report NPS/UCBN/NRTR—2013/795



ON THE COVER

View over City of Rock National Reserve

NPS Photograph from City of Rocks National Reserve, courtesy of Eva Strand.

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Executive Summary

The mission of the National Park Service is “to conserve unimpaired the natural and cultural resources and values of the national park system for the enjoyment of this and future generations” (NPS 1999). To uphold this goal, the Director of the NPS approved the Natural Resource Challenge to encourage national parks to focus on the preservation of the nation’s natural heritage through science, natural resource inventories, and expanded resource monitoring (NPS 1999). Through the Challenge, 270 parks in the national park system were organized into 32 inventory and monitoring networks.

The Upper Columbia Basin Network (UCBN) has identified 14 priority vital signs, indicators of ecosystem health, which represent a broad suite of ecological phenomena operating across multiple temporal and spatial scales. Quaking aspen is one particularly high priority vital sign for two UCBN parks, City of Rocks National Reserve (CIRO) and Craters of the Moon National Monument and Preserve (CRMO). Aspen is a focal resource at CIRO and CRMO because of its biological and aesthetic significance. Although aspen comprise only a small percentage of the land cover in the parks, the community type contributes significantly to species diversity and richness. In addition, current observations of aspen decline and die-off in the western states are of concern to natural resource managers and scientists.

The sampling design for aspen is divided into three sampling panels. Panel 1 consists of aspen stands in CRMO while panel 2 and 3 consist of aspen stands in CIRO. Panel 1 was sampled in 2007 and the 21 stands with 102 plots were re-sampled in 2010. Panel 2, consisting of 77 plots in 15 stands in CIRO, was sampled in 2008 and re-sampled in 2011, while panel 3 consisting of 45 plots in 9 stands in CIRO was sampled in 2009 and re-sampled in 2012. Details regarding the sampling in CRMO 2007-2010 can be found in Strand et al. (2011) while sampling in CIRO in 2008, 2009 and 2011 is described in Strand and Bunting (2009, 2010, 2012). During the field seasons 2008-2009 and 2011-2012 in CIRO, 122 plots in 23 stands were common to both field seasons. One stand was added in 2012 (Stand #13). Only plots sampled in both sampling periods were included in the statistical analysis.

The average stem densities (stems/ha) in panel 2 and 3 for aspen for the 2008-09 and 2011-12 sampling seasons in CIRO are summarized in the following table.

Park	Species	Year	Suckers¹	Regeneration²	Mature³	Dead⁴
CIRO	Aspen	2008-09	2,800	2,249	435	310
CIRO	Aspen	2011-12	5,429	2,479	724	365
CIRO	Conifer*	2008-09	28	96	33	8
CIRO	Conifer*	2011-12	64	85	28	15

¹ Suckers include suckers or seedlings < 5 feet tall. A sucker is an aspen shoot originating from vegetative sprouting from another aspen tree.

² Regeneration includes trees greater than 2.5 cm (1 inch) in diameter breast height (dbh) and shorter than 75% of the stand height.

³ Mature trees are greater than 2.5 cm (1 inch) in dbh and taller than 75% of the stand height.

⁴ Dead stems are greater than 2.5 cm (1 inch) in dbh.

* Conifer species include limber pine, pinyon pine, lodgepole pine, Rocky mountain juniper, and Douglas-fir

The vital signs aspen monitoring protocol (Strand et al. 2009) was approved in September 2009. The methods presented in this report reflect version 1.0 of the protocol. The majority of the aspen stands sampled in CIRO in 2011-2012 are suckering, regenerating and contain a distribution of age classes. The regeneration in stand #24 is low (119 stems/ha), a few stands have a relatively low mature aspen stem density, and some stands contain conifer species of all size classes. Stand #6, #9, #37, #72, and #73 have mature aspen stem counts lower than 350 stems/ha. The suckering and regeneration in these stands is however above average, with regeneration higher than 1000 stems/ha, which has been recommended by Bartos and Campbell (1998) as a threshold for an aspen stand with adequate regeneration. A drastic change in suckering occurred in stand #33 with an increase in aspen size class I from 2,188 stems/ha in 2008 to 66,513 stems/ha in 2011. In stands #6, #37, #43, #56, and #57, conifer species are present in all live size classes. In stand #37 the mature aspen and conifer count are at the same level, 249 stems/ha.

This change detection analysis of data from 2008-2009 and 2011-2012 examines a step trend change rather than a linear trend since data from only two time periods are currently available. As more monitoring data become available, more complex models will be applied. This step trend analysis tested for change in stem counts within tree size categories for aspen and conifers.

A statistically significant increase in aspen regeneration, mature trees and dead trees from 2008-2009 to 2011-2012 was observed ($P < 0.05$), and no difference was detected for suckers. A statistically significant increase in conifer seedlings (< 0.52 cm tall) was also detected ($P < 0.05$), however no change was detected for the larger conifer size classes. While stands may be considered somewhat independent within the park, they are not independent in terms of time, thus any assessment of the long-term trend is based on only two points in time for each site, and four calendar years total for all data. Additional sampling data will help determine whether such temporal differences are indicative of long-term trends. The next sampling period is scheduled for 2015 in CRMO and 2016-2017 in CIRO.

Acknowledgements

Funding for this project was provided through the National Park Service Natural Resource Challenge and the Servicewide Inventory and Monitoring Program. We thank the Upper Columbia Basin Network program leader Lisa Garrett for encouragement, provision of resources and fruitful discussions and data manager Gordon Dicus for development and maintenance of the aspen database and invaluable assistance with data quality assurance and control. We thank the staff at City of Rocks National Monument and Craters of the Moon National Monument and Preserve for contributions and critique of the aspen monitoring protocol and annual reports, and for assistance during field reconnaissance. Thank you to the field assistants and summer interns that worked in CIRO during the summers of 2008-2012, you contributed immensely to field data collection, data recording, and fun.

Introduction

Aspen Ecology and Rationale for Monitoring

Quaking aspen (*Populus tremuloides*) is a member of the willow (*Salicaceae*) family and is the most widespread deciduous tree in North America (Little 1971). Although the geographic range is large, aspen's high evapotranspiration demands limit the species to areas where the annual precipitation exceeds 400 mm (DeByle 1985), or wet micro sites near streams or springs, and areas where snow melt contributes to water availability throughout the dry months.

The life cycle of quaking aspen in the West is unique. Although aspen is a prolific producer of viable seed, conditions required for successful germination and establishment are rare in the West (Kemperman and Barnes 1976; Romme 1982; Mitton and Grant 1996). Many botanists argue that significant sexual reproduction in aspen has not occurred in the western United States within the last 10,000 years, since the last glacial retreat (Einspahr and Winton 1976; McDonough 1985). An example of more recent successful establishment of aspen followed the severe fires in Yellowstone in 1988, which apparently provided a 'window of opportunity' of suitable substrate and climate conditions for seed germination (Romme et al. 2005). The primary means of aspen reproduction in the West is via vegetative root suckering (Bartos 2001). While limited vegetative reproduction occurs within many established stands, prolific vegetative reproduction in aspen clones is thought to require disturbance to promote suckering. Mortality of individual aspen stems caused by disturbance interrupts the balance between the two hormones auxin and cytokinin such that when mature stems are killed or stressed, the flow of auxin is suppressed, and cytokinin can begin to stimulate root suckering (Bartos 2001). According to Barnes (1975) aspen clones can exist as self-regenerating organisms for thousands of years through periodic disturbance. Although aspen clones are long-lived, individual stems normally live 100-150 years (Shepperd et al. 2001) with some occasionally exceeding 200 years (Mueggler 1989). Since sexual regeneration requires prolonged moist conditions and is thought to be rare for intermountain western aspen, an aspen clone lost from the landscape will likely not regenerate from seed (Mitton and Grant 1996). Recent research however indicates that genetic variability within aspen clones is common, suggesting that sexual reproduction in xeric aspen may occur more frequently than previously suggested (Mock et al. 2008).

Aspen stands in the western mountains commonly occur in conjunction with conifer species but have also been observed as uneven-aged aspen stands where aspen appears to persist as a stable, self-regenerating ecosystem (Rogers et al. 2010). These stable aspen systems are unsuitable for conifers or are far away from conifer seed sources (Mueggler 1989). In biophysical settings where aspen is seral to conifer species, slow-growing shade tolerant conifers begin to overtop aspen late in succession and will eventually outcompete and lead to aspen loss (Shepperd et al. 2001). Shepperd et al. (2001) show that aspen growth rates are independent of conifer presence in early to mid-succession and estimate that conifers will begin to out-compete aspen at a stand age of 100-150 years.

Browsing by wildlife and livestock has been shown to inhibit successful regeneration in aspen stands (Bartos and Campbell 1998; Kay and Bartos 2000; Kaye et al. 2005; Jones et al. 2009). Growth in aspen suckers is reduced when browsing results in removal of terminal leaders and large amounts of branch biomass (Jones et al. 2009). Browsing during mid-season over

consecutive years and repeated browsing in the same growing season should be avoided in areas where aspen regeneration is a management goal (Jones et al. 2009). Aspen regeneration is particularly affected within elk (*Cervus elaphus*) winter range in areas when elk populations are high (Hart and Hart 2001). Research by Kaye et al. (2005) confirms that high levels of elk browsing and conifer dominance negatively influence aspen establishment but do not affect the growth or mortality of individual mature aspen ramets.

Drought within the past decade has been reported to cause mortality in aspen in Colorado (Worrall et al. 2008) and in the Canadian parklands (Brandt et al. 2003; Frey et al. 2004). In Colorado, mature stands on south-facing slopes at low elevation were found to be particularly susceptible to disease and insects as a result of acute drought and high temperatures. Aspen dieback in Canada has been correlated to factors such as stand age, drought and freeze-thaw events, defoliation, wood-boring insects, and fungal pathogens (Brandt et al. 2003; Frey et al. 2004). Rising temperatures and drought have also been correlated with increased forest mortality in the southwestern U.S. (van Mantgem and Stephenson 2007; van Mantgem et al. 2009; Huang and Anderegg 2011) potentially caused by hydraulic failure of roots (Anderegg et al. 2012).

A recent phenomenon affecting western aspen is referred to as *aspen die-off* and is different from the slow decline in aspen populations that has been occurring over the past century. In cases of *aspen die-off* mature aspen stems are dying with no apparent regeneration in the form of suckering. Scientists and managers are currently researching the causes and trying to find solutions to this die-off, which is currently affecting as much as 10% of western aspen stands. In the summer of 2010, USFS forest pathologist Jim Worall reported that the spread of the *aspen die-off* appears to have stopped in Colorado; however, damage continues in affected areas.

Aspen is an important resource to City of Rocks National Reserve (CIRO) and Craters of the Moon National Monument and Preserve (CRMO) because of its biological and aesthetic significance. Although aspen comprise only a small percentage of the land cover in the parks, the community type contributes significantly to species diversity and richness (Shive and Peterson 2001; Madison et al. 2003). Aspen brings visitors to the western mountains and parks, improves local economies, inspires poets and artists, and is portrayed in modern stories as well as tribal myths (McCool 2001). Aspen is an important attraction for campers, naturalists, and recreationists in the otherwise semi-arid landscapes of CIRO and CRMO.

The Upper Columbia Basin Network (UCBN) has identified 14 priority vital signs to monitor (Garrett et al. 2007). Aspen exhibits a relatively slow rate of change compared to other vital signs and covers a greater spatial extent in the two parks where it is monitored. Information gained from monitoring aspen will contribute to the weight of ecological knowledge about natural resources at CIRO and CRMO and to regional management strategies for the conservation of aspen. In particular, aspen in CIRO and CRMO occur in areas that are near or below the precipitation threshold of 400 mm per year (Perala 1990) where upland aspen can persist long-term. A changing climate may result in a reduced snow pack, which could affect the availability of water for aspen stands in the parks. Aspen in these parks may be one of the first species to respond to locally changing climate, and the response may be a decline in regeneration or a die-off of water stressed clones. It is not currently known how aspen will react to a changing

climate, and the trends observed, as part of this monitoring protocol, will contribute timely, valuable data to future aspen management in the western United States.

Objectives

The overarching programmatic goal of the UCBN aspen vital signs monitoring program is to obtain data that will inform management decisions pertaining to the perpetuation of quaking aspen populations at CIRO and CRMO. The aspen protocol (Strand et al. 2009) was approved in September 2009 and the methods presented in this report reflect version 1.0 of the protocol. The monitoring protocol addresses the following specific measurable monitoring objectives:

- Estimate current status and long-term trend in regeneration of park aspen populations as well as individual stands.
- Estimate status and trend in aspen abundance, as measured by stem density of live and dead trees, within aspen stands. Specifically, live aspen stems will be counted in five size classes: class I - suckers or seedlings < 46 cm (1.5 ft) tall, class II - suckers or seedlings 46 - 152 cm (1.5-5 ft) tall, class III - greater than 152 cm (5 ft) and up to 2.5 cm (1 inch) in diameter at breast height (dbh), class IV - greater than 152 cm (5 ft) and > 2.5 cm (1 inch) in diameter at breast height (dbh) but < 75% of the stand height, class V - greater than 2.5 cm (1 inch) in dbh and > 75% of the stand height.
- Estimate the status and trend in dead standing aspen stems.
- Estimate the status and trend of conifer density within aspen stands.

The following statistical sampling objectives have been developed for this protocol:

- Estimate with 90% confidence the mean, $\hat{\mu}$, within $\pm 25\%$ of the true mean, μ , for aspen stem density (stems/ha) of suckers (class I+II), regeneration (class III+IV), mature trees (class V) and dead stems within aspen clones.
- Detect with >80% certainty (power, or $1-\beta$) a change $\geq 25\%$ between any two sequential time periods (5 years) of mean aspen live or dead stem density estimates with a 0.10 acceptable false-change (α) error rate. All upland aspen stands, larger than 0.3 ha in size, that are not located in entirely in riparian areas or composed of shrubby snow-damaged aspen will be sampled. Aspen on private inholdings in CIRO will not be sampled. The difficult access and ecologically sensitive location of aspen on Big Cinder Butte in CRMO resulted in our excluding this stand from the sampling frame.

Data are examined to assess whether there is evidence of a change in mean number of trees per plot between sampling periods, or whether there is evidence suggesting these differences varied between the 2008/2011 and 2009/2012 pairings. It should be noted that this analysis should be considered preliminary, as only two time periods for each stand have been measured to date, and long-term trends may not yet be apparent in the data. Failing to find evidence of a long-term trend does not necessarily suggest that a long-term trend is not present. Rather, it suggests that either a long-term trend is not present -or- the magnitude of the trend and the amount of data available is insufficient to detect a trend that is present.

Methods

Field data collection

Sampling methods followed those detailed by Strand et al. (2009). All aspen stands available for sampling were classified via remote sensing, delineated on aerial photos or via a Global Positioning System unit (GPS) in the field in the CIRO (Figure 1) in 2006. According to the protocol revisit design (Table 1) panel 1 in CRMO was sampled in 2007, and panel 2 and 3 were sampled in CIRO in 2008 and 2009. During the field season 2010, the stands in CRMO were revisited for the first time, three years after permanent markers were established in 2007. During the field season 2011 and 2012, stands in panel 2 and 3 in CIRO were revisited for the first time, three years after permanent markers were established in 2008 and 2009. Once baseline data have been collected over two time periods (2007-2009) and (2010-2012) for each stand in CIRO and CRMO, sampling will continue on a 5-year cycle.

Table 1. Proposed revisit design for CRMO and CIRO. The first two sampling sessions will follow a [1-2] revisit design. Subsequent sampling sessions will follow a [1-4] revisit design in which one panel is located in CRMO and two panels are located in CIRO.

Panel	Sampling Occasion (Year)										
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1 - CRMO	X			X					X		
2 - CIRO1		X			X					X	
3 - CIRO2			X			X					X

Permanent sampling transects were established within aspen stands in CIRO and CRMO in 2007-2009. The number of transects established in each stand was determined by completing a power analysis that allowed for detection of trend with statistical confidence (0.90) and power (0.80) while minimizing the sampling effort. The number of transects placed in each stand was further weighted by the area of the stand such that more transects were placed in larger stands. The starting point for each transect was randomly located within the stand boundary and transects were oriented north-south or east-west depending on the orientation of the stand. Four plots were placed along each transect with a distance of 25 m between plot centers. Based on a variogram analysis, plots located at least 25 m apart can be considered spatially independent (Strand et al. 2009). The number of transects within each aspen stand was determined via the power analysis and then weighted by the areal extent of the stand. Altogether 57 aspen stands have been identified in CIRO (Figure 1) of which 25 are sampled, divided in two sampling panels. Aspen stands on private land, in riparian areas, stands smaller than 0.3 ha, or those damaged by snow are not sampled.

The numbers of aspen and conifer stems within pre-determined size classes (Table 2) that were rooted or had at least 50% of the stem diameter at ground level rooted within the 4-m radius plot were counted. Conifer plants shorter than 10 cm above ground were not counted. Dead stems that were lying on the ground were not counted; however, dead stems that were leaning or otherwise partially standing were counted, if they were rooted or had at least 50% of the stem diameter at ground level rooted in the plot.



Aspen stands and sampling units

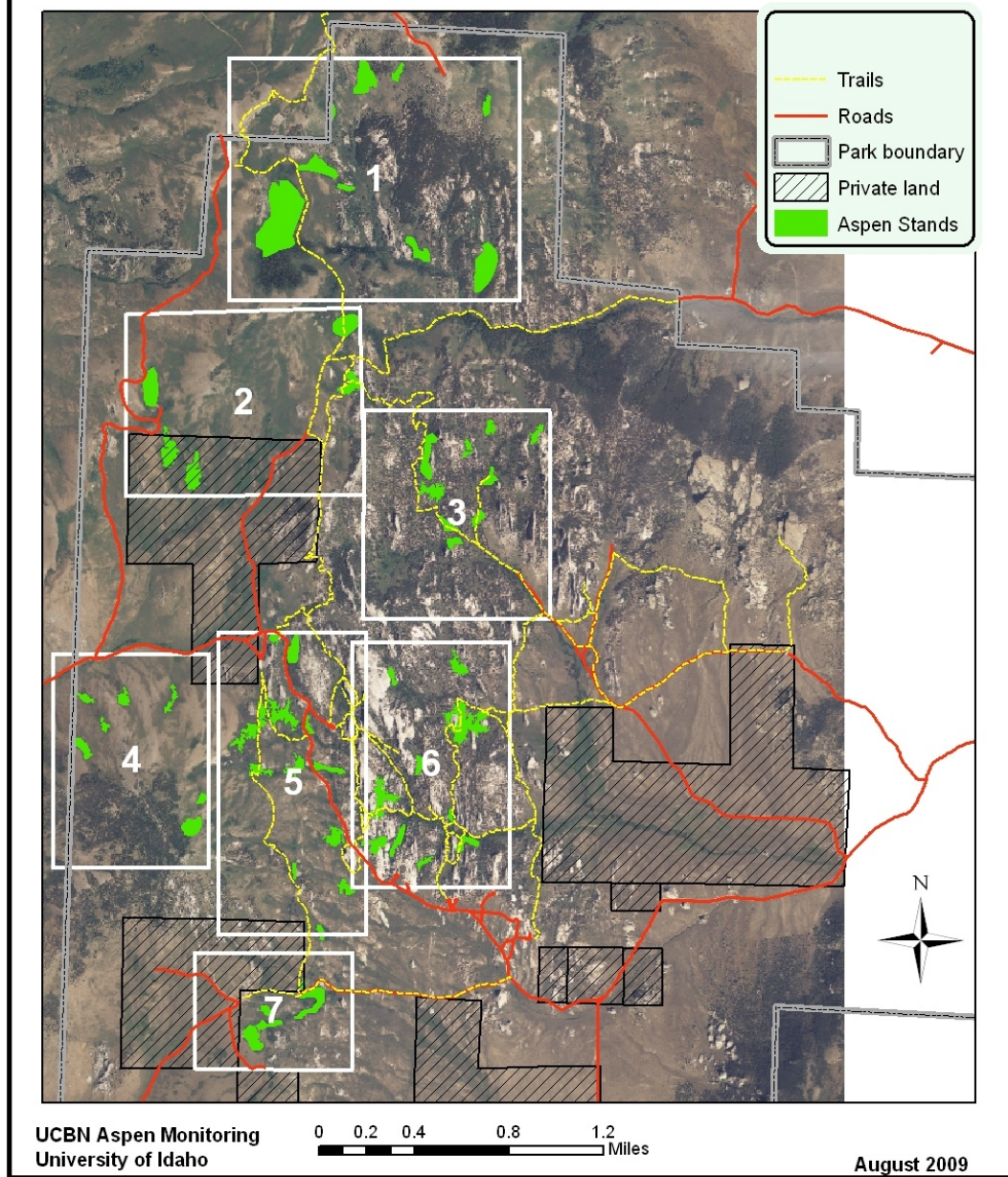


Figure 1. Map of aspen stands in CIRO. A total of 57 aspen stands have been identified of which 25 stands are selected for sampling. The stands in CIRO are divided into 2 panels and 7 sampling units. The panels are not shown.

Table 2. Size classes of aspen and conifer stems.

Class I	Suckers or seedlings < 46 cm (1.5 ft) tall. Conifer seedlings shorter than 15 cm (6 inches) are not counted due to uncertainty in survival
Class II	Suckers or seedlings < 46 - 152 cm (1.5-5 ft) tall
Class III	Greater than 152 cm (5 ft) and up to 2.5 cm (1 inch) in dbh (diameter at breast height)
Class IV	Greater than 2.5 cm (1 inch) in dbh and shorter than 75% of the stand height
Class V	Greater than 2.5 cm (1 inch) in dbh and taller than 75% of the stand height
Class VI	Dead stems > 2.5 cm (1 inch) in dbh

During the field seasons 2008-2009 and 2011-2012 in CIRO, 122 plots in 23 different stands were visited in both sampling periods (Figure 2-8). One stand was added in 2012 (Stand #13) because it was determined that this stand is located on NPS land although it was previously thought to be located on private land. Only plots sampled in both sampling periods were included in the statistical analysis.

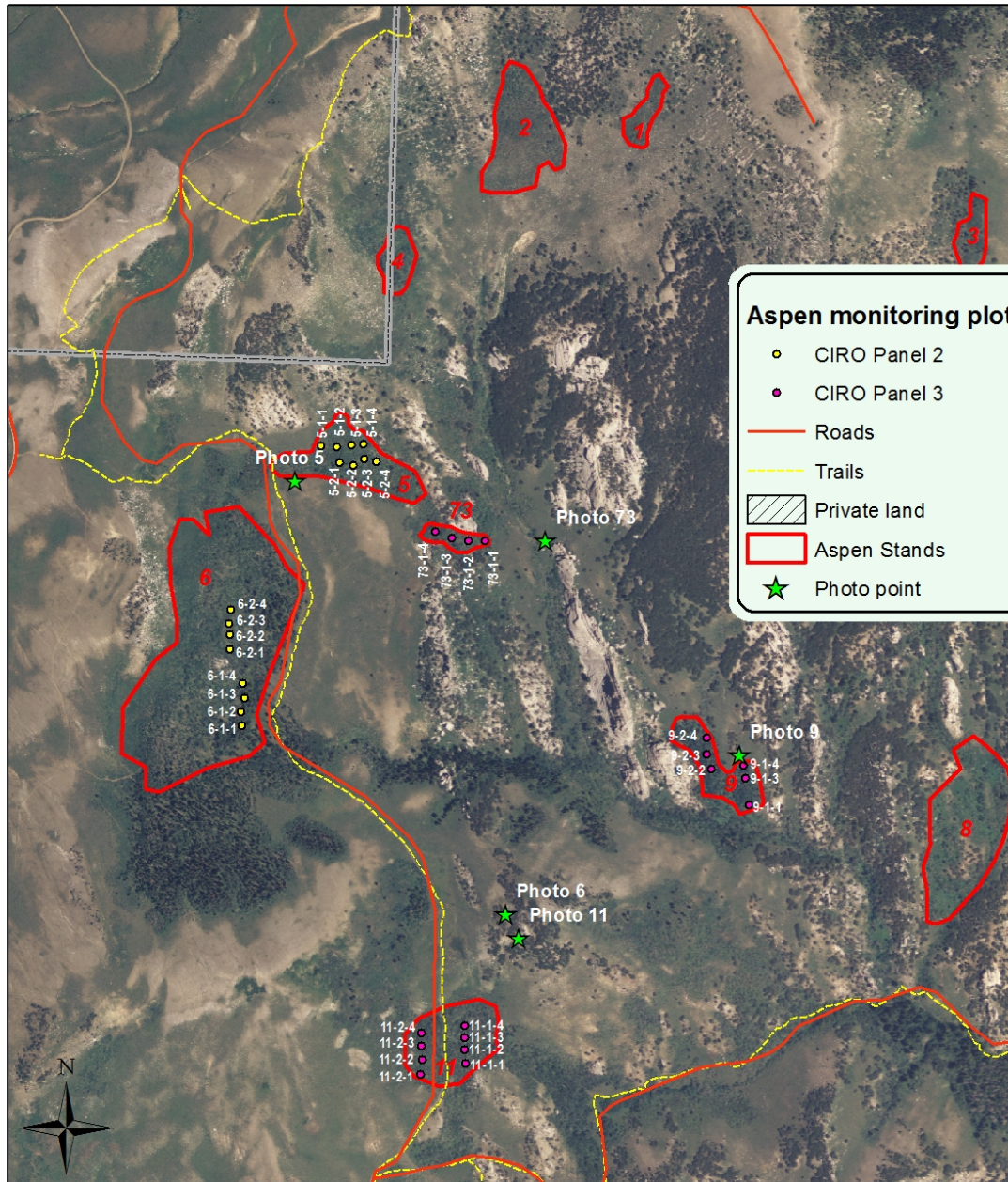
GPS locations for all stands sampled in 2011 were recorded with a GeoXT Trimble GPS unit with a horizontal locational error estimate to be < 1 m according to the Trimble specifications. These easting and northing locations collected in 2011 replaced those collected with a Garmin GPSMAP 76 (error estimate 3-5 m) in 2008 in the aspen database. The GeoXT Trimble GPS unit was used to record plot locations in both 2009 and 2012.

Aspen total stem density by size class was calculated for each transect, for each stand, and for the entire park, by adding all individual aspen stems within the sampled area and then dividing by the total sampled area (sum of sampled area within transect, stand, or park). Summary statistics are reported for four combinations of size classes as follows: Suckers (class I+II), Regeneration (class III+IV), Mature trees (class V) and Dead stems (class VI).

A distance photo of each aspen stand was taken from a location with a good vantage point that overlooked the stand. The UTM coordinates, NAD83 datum, and true north azimuth in the direction the photo was oriented are recorded. The locations for the distance photos are mapped in Figure 2-8.



Aspen stands - Unit 1



UCBN Aspen Monitoring
University of Idaho

0 0.125 0.25 0.5 Miles

October 2012

FILE: C:\nps\ciro\Ci-ro-stands-Frame1_2011.mxd

Figure 2. Aspen stands in CIRO, sampling unit 1.



Aspen stands - Unit 2

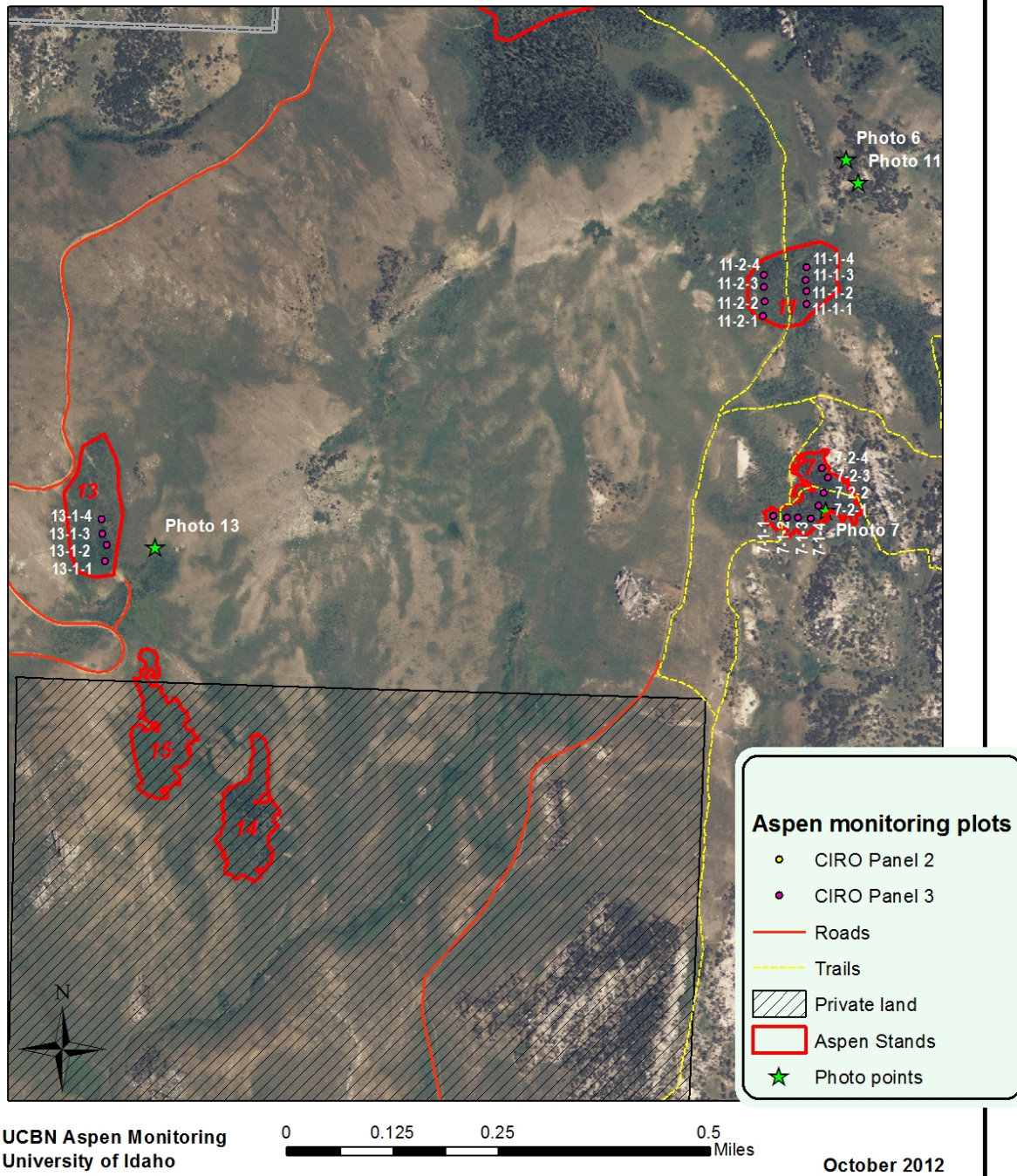
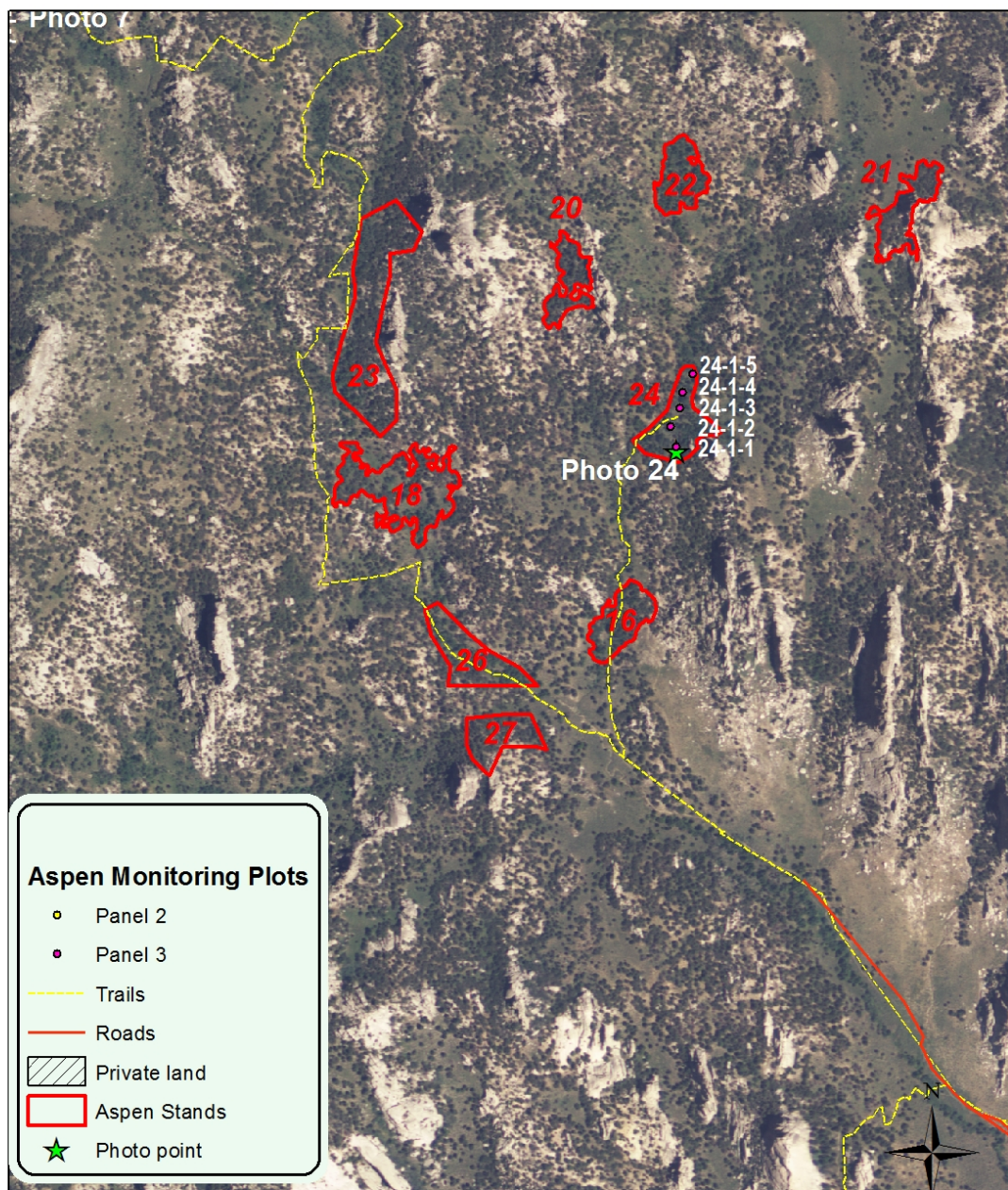


Figure 3. Aspen stands in CIRO, sampling unit 2.



Aspen stands - Unit 3



UCBN Aspen Monitoring
University of Idaho

0 0.1 0.2 0.4
Miles

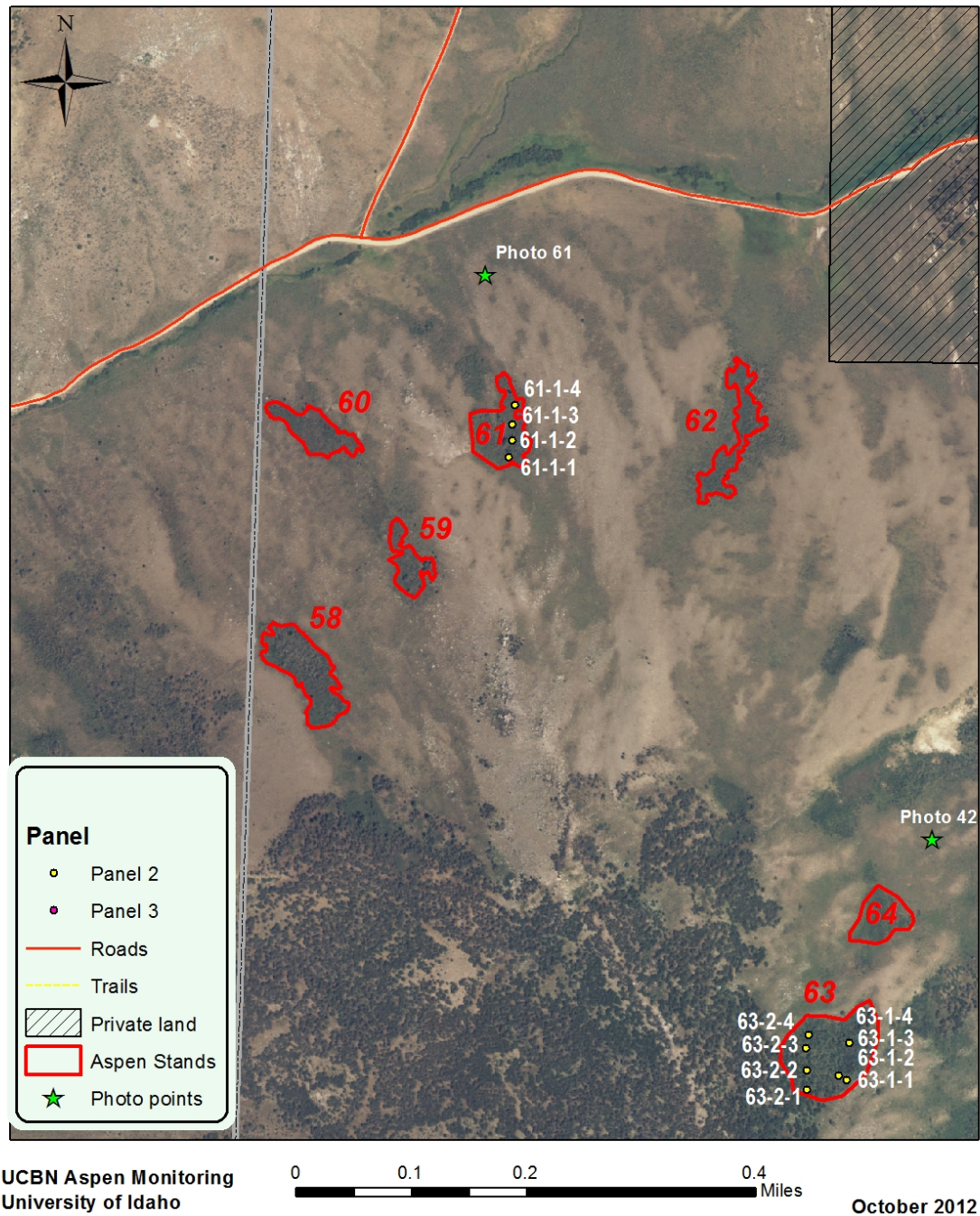
October 2012

FILE: C:\nps\ciro\Ciro-stands-Frame2_2009.mxd

Figure 4. Aspen stands in CIRO, sampling unit 3.



Aspen stands - Unit 4



FILE: C:/nps/ciro/Ciro-stands-Frame4_2009.mxd

Figure 5. Aspen stands in CIRO, sampling unit 4.



Aspen stands - Unit 5

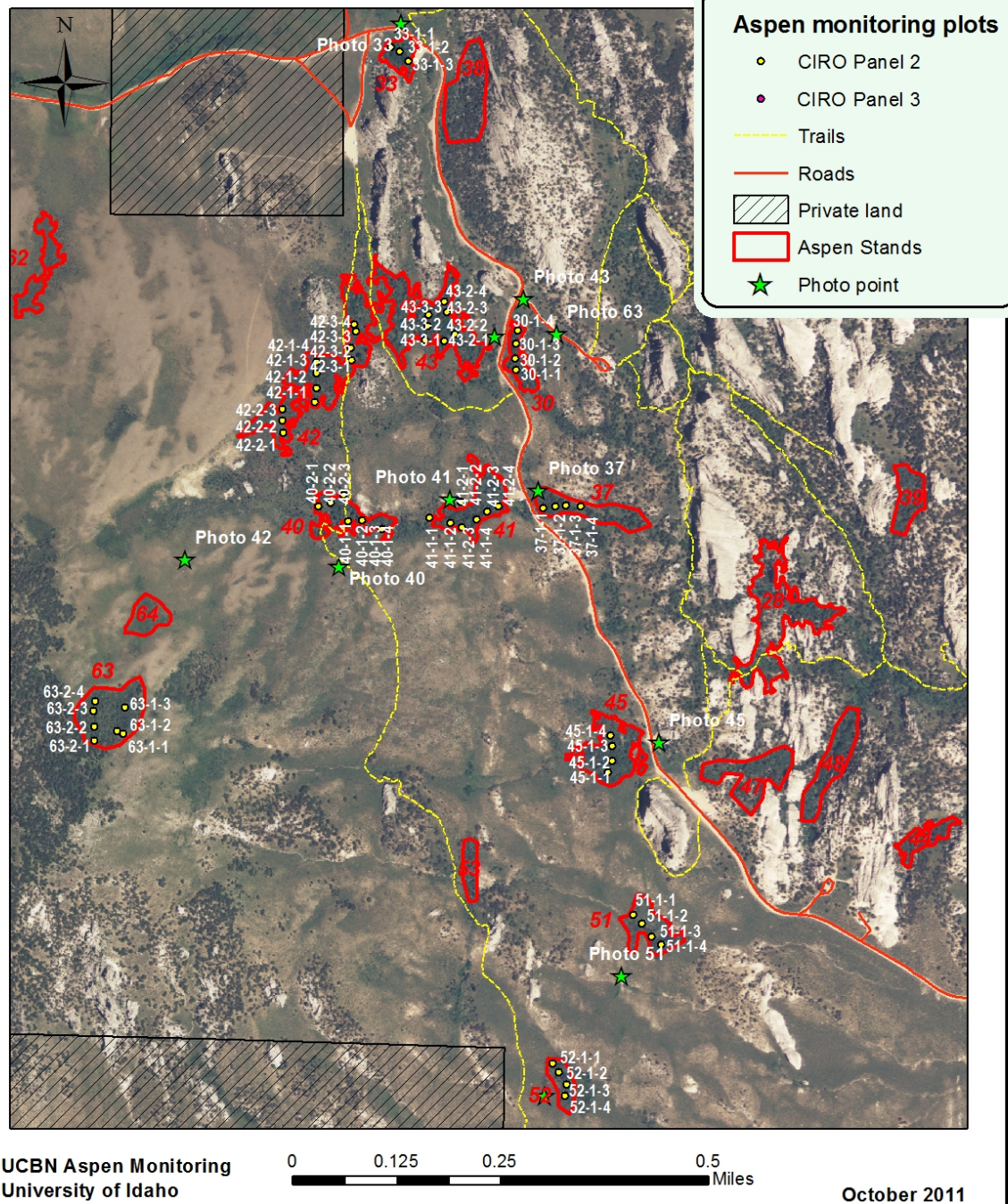


Figure 6. Aspen stands in CIRO, sampling unit 5.



Aspen stands - Unit 6

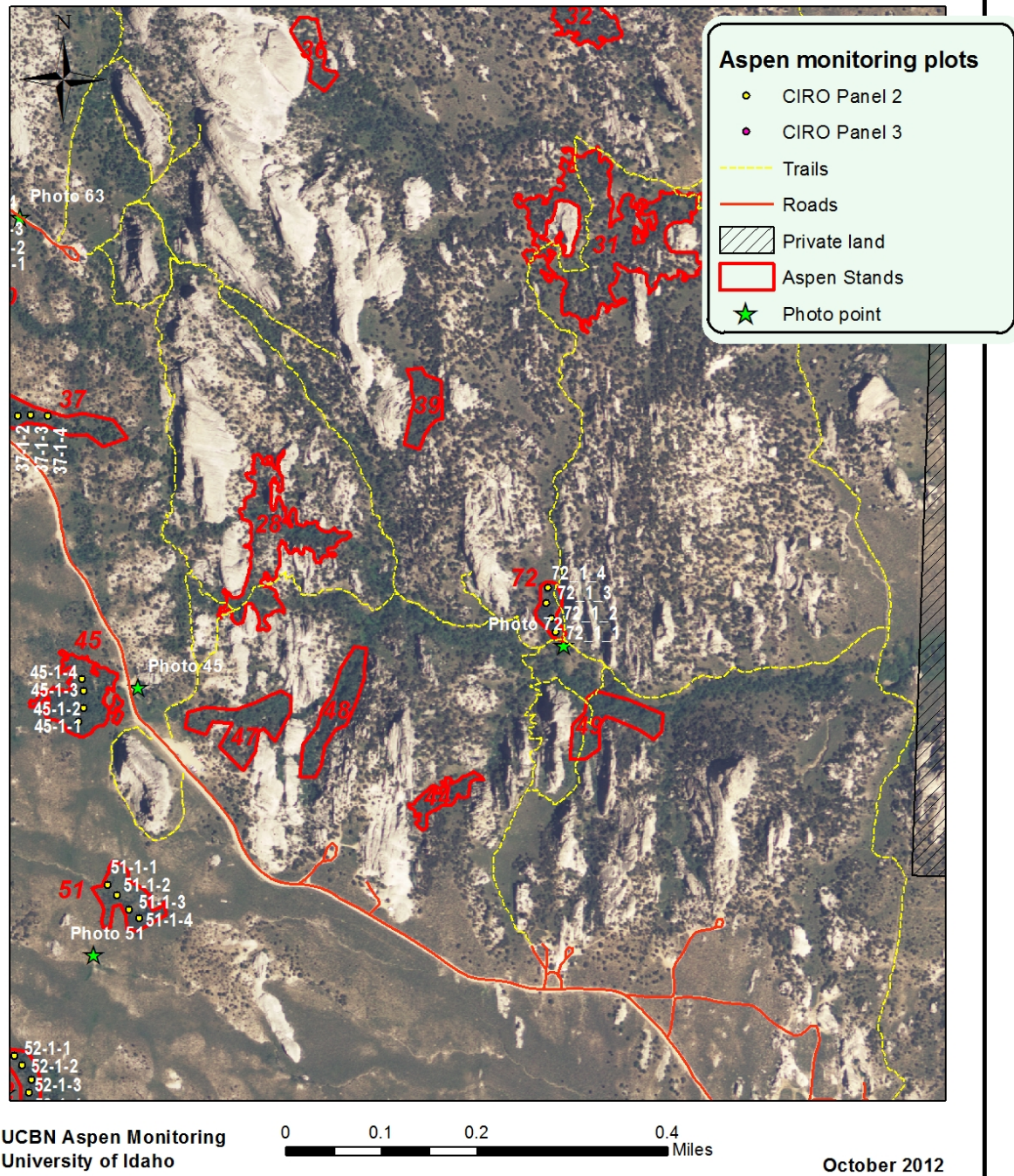
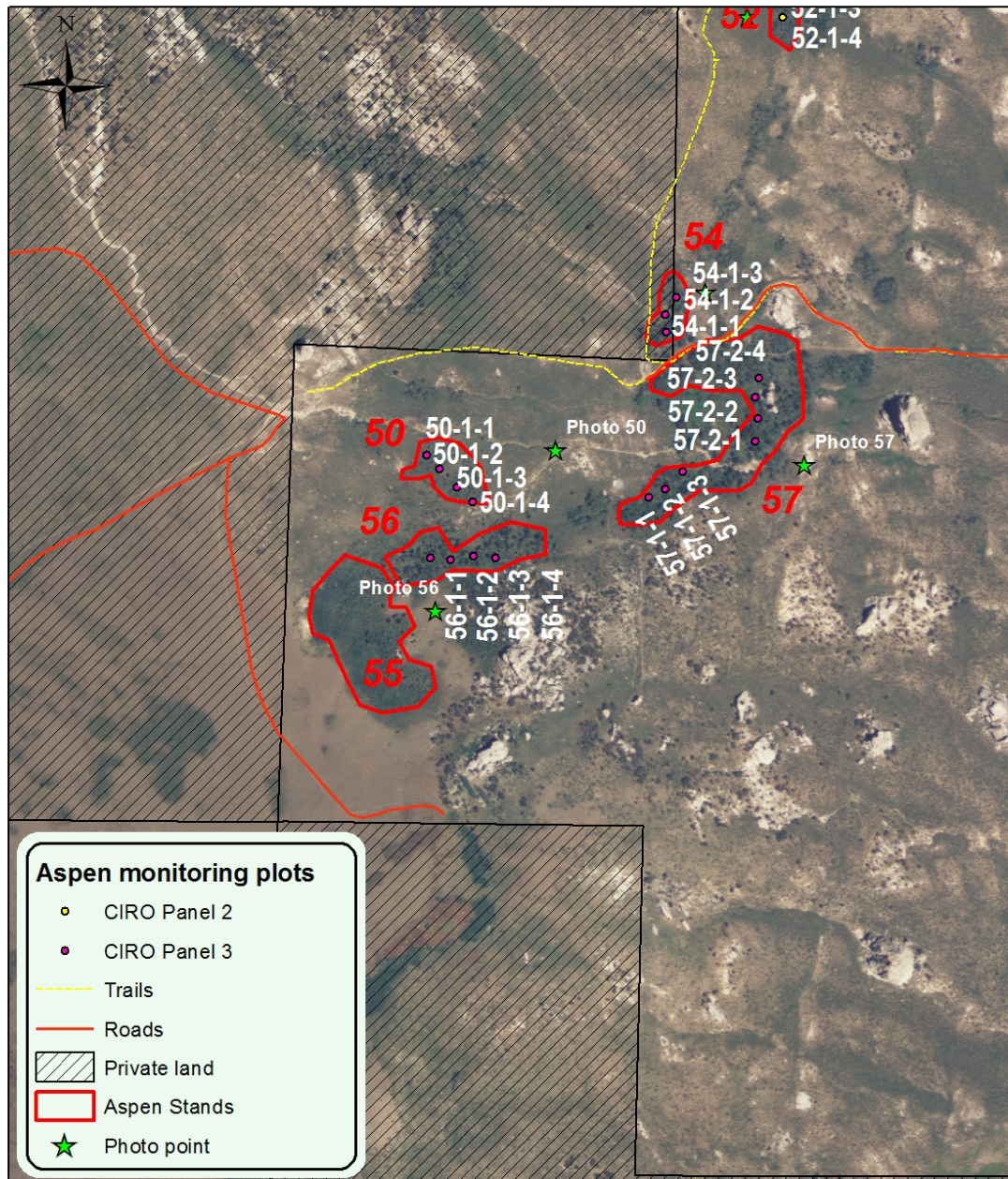


Figure 7. Aspen stands in CIRO, sampling unit 6.



Aspen stands - Unit 7



UCBN Aspen Monitoring
University of Idaho

0 0.05 0.1 0.2
Miles

October 2012

FILE: C:\nps\ciro\Ciro-stands-Frame7_2009.mxd

Figure 8. Aspen stands in CIRO, sampling unit 7.

Statistical analysis

Stands sampled during the time period 2008-2009 and 2011-2012 were included in the statistical analysis, which included a total of 23 stands. Fifteen of these stands were measured in 2008 and 2011, while 8 stands were measured in 2009 and 2012. Within each stand, multiple transects, and multiple plots per transect, were measured, with the number of aspen and conifers trees, by age classification, counted in each plot. Altogether, 122 plots were sampled in 2008-2009 and also in 2011-2012. The age classifications used in the statistical analysis are: sucker (class I+II), regeneration (class III+IV), mature trees (class V), and dead trees (class VI). In most cases, the same transects and plots were used for the first and second visits to each stand. However, in 10 instances, it was noted that the plot locations may not be identical because the original permanent plot marker could not be located and by necessity had to be replaced. Using plots that are not placed in the identical location may decrease the precision of estimates and reduce the overall power to detect changes, but, assuming changes in plots sampled occurred at random (i.e. are not in any way related to the response itself), inference from the data should not be biased.

While this analysis was done for the response at the stand level with average trees per plot being the response variable for each stand, future analyses may wish to consider trends and changes within individual transects or plots within each stand. However, with the current limited data set (containing only two measurements for each time series at each location), and given the often little or no change in tree counts observed to date within each plot, inference at the transect or plot levels is not particularly informative at this time.

Because the sample involves repeated visits to the same stands, stand must be considered a fixed effect. With only two visits per stand conducted so far, data were paired, and analysis was done on the paired differences in stand level mean trees per plot, with the difference between the first (year 0) and second (year 3) assessments of each stand being the pair difference. Paired differences provide a powerful sampling technique to assess changes in the midst of potentially high stand-to-stand variability. For future analyses, more than two points in time per stand will be available for analysis allowing for trend assessments using more complex models.

For each set of paired differences, testing was done to determine whether there is evidence of a non-zero mean difference in stand level mean trees per plot. In addition, testing was done to determine whether evidence suggested that mean differences in stand level average tree counts changed between the 2008/2011 and 2009/2012 time periods. Note that these groups are not (and cannot be) paired, thus there is low power to detect these trends if present. Nevertheless a check for them is included and may yield some preliminary indication of long-term trends common across all stands.

Statistical methods used to make inference differed for aspen and conifer trees, due to the different nature of the responses. For aspen tree counts, there were sufficient differences in tree counts between the two sampling times, and a sufficient number of stands sampled, that large sample normal assumptions could be made, and standard linear regression models, assuming normality in residual errors, were applicable.

For conifer tree counts, there were a high number of tree counts equal to zero, and in a high percentage of cases this resulted in zeros for stand level average tree/plot differences between

time periods. Thus, techniques relying on normality assumptions may be problematic or misleading. Zero-inflated models were considered, as used by Strand et al. (2011) on the CRMO data. However, commonly used zero inflated models are not directly applicable in analysis of paired differences. Instead of relying on normal approximations or zero-inflated models, the non-normal distribution problem was addressed using non-parametric analysis methods.

In the future, as multiple years' of data become available and small trends are more readily detected, standard regression models may be applicable for conifer counts as they are for aspen counts. This should be assessed upon each revision of the data set prior to analysis.

Results

Park and stand level stem counts

During the field seasons 2008-2009 and 2011-2012 in CIRO, 122 plots in 23 stands were visited in both sampling periods (Figure 2-8). One stand was added in 2012 (Stand #13), but not included in this analysis that evaluated only plots sampled in both sampling periods. See Appendix A for a summary of all mapped aspen stands in CIRO, including the rationale for stands that were not sampled.

Aspen total stem density by size class was calculated for each stand by adding all individual aspen stems within the sampled area and then dividing by the total sampled area (sum of sampled area within stand). Summary statistics are reported for aspen and conifers in stems/ha for four combinations of size classes as follows: Suckers (class I+II), Regeneration (class III+IV), Mature trees (class V) and Dead stems (class VI) for CIRO during the sampling seasons 2008-2009 and 2011-2012 (Table 3) and by stand (Table 4 and 5). The difference in aspen stem density between 2008-2009 and 2011-2012 and stand characteristics are listed in Table 6.

Table 3. Park stem count averages in stems/ha for the 2008-2009 and 2011-2012 sampling effort for size classes of aspen and conifers.

Park	Species	Year	Suckers¹	Regeneration²	Mature³	Dead⁴
CIRO	Aspen	2008/09	2,800	2,249	435	310
CIRO	Aspen	2011/12	5,429	2,479	724	365
CIRO	Conifer	2008/09	28	96	33	8
CIRO	Conifer	2011/12	64	85	28	15

¹ Suckers include suckers or seedlings < 5 feet tall. A sucker is an aspen shoot originating from vegetative sprouting from another aspen tree.

² Regeneration includes trees greater than 2.5 cm (1 inch) in diameter breast height (dbh) and shorter than 75% of the stand height.

³ Mature trees are greater than 2.5 cm (1 inch) in dbh and taller than 75% of the stand height.

⁴ Dead stems are greater than 2.5 cm (1 inch) in dbh.

The majority of the aspen stands sampled in CIRO in 2011-2012 are suckering, regenerating and contain a distribution of age classes (Table 4). The regeneration in stand #24 is low (119 stems/ha), a few stands with relatively low mature aspen stem density, and some stands contain conifer species in all size classes. Stand #6, #9, #37, #72, and #73 have mature aspen stem counts lower than 350 stems/ha. The suckering and regeneration in these stands is however above average, with regeneration higher than 1,000 stems/ha, which has been recommended by Bartos and Campbell (1998) as a threshold for an aspen stand with adequate regeneration. A drastic change in suckering occurred in stand #33 with an increase in aspen size class I from 2,188 stems/ha in 2008 to 66,513 stems/ha in 2011 (Figure 9).



Figure 9. A drastic change in suckering occurred in Stand #33 with an increase in aspen size class I from 2,188 stems/ha in 2008 to 66,513 stems/ha in 2011.

Conifers are present at low levels in 16 of the 25 stands sampled in 2011-2012 (Table 5). Mature conifer trees are present in stands #6, #30, #37, #42, #43, #56, #57 and #73. In stand #37 the mature aspen and conifer count are at the same level, 249 stems/ha. Rocky mountain juniper (*Juniperus scopulorum*) was present in 12 stands (#9, #24, #30, #37, #40, #41, #42, #43, #45, #54, #56, and #57), limber pine (*Pinus flexilis*) was present in four stands (#6, #42, #43 and #73), Douglas-fir (*Pseudotsuga menziesii*) was present in two stands (#6 and #42), pinyon pine (*Pinus monticola*) was present in one stand (#24), and lodgepole pine (*Pinus contorta*) was present in one stand (#6).

Paired photographs of the aspen stands sampled in 2009 and 2012 are compiled in Appendix B. Paired photographs of the aspen stands sampled in 2008 and 2011 are available in Strand and Bunting (2012).

Table 4. Aspen stem density in stems/ha in CIRO stands sampled in 2008-2009 and 2011-2012. Stands #13 and #50 are listed in this table but were only sampled in 2011-2012 and were therefor not included in statistical analysis.

Stand #	Suckers 2008/09	Regeneration 2008/09	Mature 2008/09	Dead 2008/09	Suckers 2011/12	Regeneration 2011/12	Mature 2011/12	Dead 2011/12	Sampling periods
5	2,700	1,449	654	114	1,790	1,819	1,108	256	2008 & 2011
6	2,462	3,506	373	124	1,840	4,277	224	274	2008 & 2011
7	1,616	3,855	174	771	1,194	3,357	696	771	2009 & 2012
9	3,017	2,918	464	398	8,223	3,050	232	265	2009 & 2012
11	1,393	2,537	448	547	2,188	2,387	572	448	2009 & 2012
13	NA	NA	NA	NA	6,864	2,039	1,840	149	2009 & 2012
24	597	279	239	80	2,905	119	438	40	2009 & 2012
30	3,233	2,586	597	99	9,102	4,029	448	746	2008 & 2011
33	2,188	1,923	265	66	66,513	3,581	2,056	265	2008 & 2011
37	5,123	2,934	298	149	9,500	3,979	249	249	2008 & 2011
40	1,592	1,790	149	99	2,735	1,691	696	149	2008 & 2011
41	1,421	1,222	540	171	1,790	1,478	1,052	256	2008 & 2011
42	2,984	2,122	619	486	2,829	3,316	951	265	2008 & 2011
43	4,741	1,194	564	431	8,256	1,260	729	332	2008 & 2011
45	4,526	2,537	448	50	4,377	2,387	1,243	149	2008 & 2011
50	NA	NA	NA	NA	1,293	1,641	846	149	2009 & 2012
51	2,537	995	995	249	1,492	895	945	547	2008 & 2011
52	2,934	2,487	696	249	4,228	3,283	1,044	597	2008 & 2011
54	2,852	2,586	66	133	4,111	729	1,592	0	2009 & 2012
56	2,437	2,586	199	298	13,279	1,741	1,243	348	2009 & 2012
57	6,650	3,240	313	284	5,713	3,894	455	369	2009 & 2012
61	5,836	1,790	663	796	1,459	1,592	464	729	2008 & 2011
63	1,293	1,326	332	199	1,592	1,094	597	265	2008 & 2011
72	1,741	1,194	348	0	1,243	1,243	199	0	2008 & 2011
73	2,288	3,332	448	895	1,741	3,581	348	1,044	2009 & 2012

Table 5. Conifer stem density in stems/ha in CIRO stands sampled in 2008-2009 and 2011-2012. Stands #13 and #50 are listed in this table but were only sampled in 2011-2012 and were therefor not included in statistical analysis.

Stand #	Suckers 2008/09	Regeneration 2008/09	Mature 2008/09	Dead 2008/09	Suckers 2011/12	Regeneration 2011/12	Mature 2011/12	Dead 2011/12	Sampling periods
5	0	0	0	85	0	0	0	0	2008 & 2011
6	25	497	75	0	25	99	50	25	2008 & 2011
7	0	0	0	0	0	0	0	0	2009 & 2012
9	0	99	0	0	33	33	0	0	2009 & 2012
11	0	0	0	0	0	0	0	0	2009 & 2012
13	NA	NA	NA	NA	0	0	0	0	2009 & 2012
24	80	80	0	0	40	80	0	40	2009 & 2012
30	0	50	50	0	0	99	50	0	2008 & 2011
33	0	0	0	0	0	0	0	0	2008 & 2011
37	50	199	298	50	298	249	249	0	2008 & 2011
40	0	149	149	0	50	99	0	0	2008 & 2011
41	28	114	57	0	85	0	0	0	2008 & 2011
42	0	0	0	0	0	111	22	0	2008 & 2011
43	99	33	33	33	99	166	133	0	2008 & 2011
45	99	99	0	0	348	50	0	0	2008 & 2011
50	NA	NA	NA	NA	0	0	0	0	2009 & 2012
51	0	0	0	0	0	0	0	0	2008 & 2011
52	0	0	0	0	0	0	0	0	2008 & 2011
54	0	199	0	0	199	398	0	0	2009 & 2012
56	99	50	50	0	249	149	50	0	2009 & 2012
57	85	369	0	0	227	341	57	0	2009 & 2012
61	0	0	0	0	0	0	0	464	2008 & 2011
63	0	0	0	0	0	0	0	0	2008 & 2011
72	99	50	0	0	0	99	0	0	2008 & 2011
73	0	50	149	0	0	99	50	0	2009 & 2012

Table 6. Difference in stem density (stems/ha) in CIRO between 2008/09 and 2011/12 and stand characteristics (elevation, slope, aspect, height) Positive numbers in stem counts mean an increase in stem density from 2008/09 to 2011/12. Missing information is labeled NA.

Stand #	Suckers 2011/12-2008/09	Regeneration 2011/12-2008/09	Mature 2011/12-2008/09	Dead 2011/12-2008/09	Elevation m	Slope %	Aspect	Height m
5	-910	370	454	142	2339	22	170	
6	-622	771	-149	150	2302	10	10	16
7	-422	-498	522	0	2197	26	60	13.5
9	5,206	132	-232	-133	2185	18	160	10.5
11	795	-150	124	-99	2244	25	43	9
13	NA	NA	NA	NA	NA	NA	NA	NA
24	2,308	-160	199	-40	1952	11	240	NA
30	5,869	1,443	-149	647	2041	12	96	10
33	64,325	1,658	1,791	199	2059	7	120	6
37	4,377	1,045	-49	100	2006	18	105	8.25
40	1,143	-99	547	50	2080	20	50	10.5
41	369	256	512	85	2006	19	50	6.75
42	-155	1,194	332	-221	2096	15	50	6.5
43	3,515	66	165	-99	2058	24	20	7.5
45	-149	-150	795	99	1990	15	50	10.5
50	NA	NA	NA	NA	NA	NA	NA	NA
51	-1,045	-100	-50	298	1990	8	120	12
52	1,294	796	348	348	2005	12	70	8
54	1,259	-1,857	1,526	-133	2003	11	90	10.5
56	10,842	-845	1,044	50	2026	18	0	9.5
57	-937	654	142	85	1965	11	110	16
61	-4,377	-198	-199	-67	2131	35	20	7.5
63	299	-232	265	66	2252	20	30	6.75
72	-498	49	-149	0	1859	11	200	12
73	-547	249	-100	149	2259	35	90	12

Statistical analysis: aspen

The stand level mean trees per plot for CIRO aspen, by age group has remained relatively stable between sampling periods (Figure 10). Each line on the plot connects the stand level average tree count in for the first and second time periods. The solid lines represent stands measured in 2008 and 2011, while the dashed lines represent stands measured in 2009 and 2012. For sucker and regeneration age groups, there is little graphical indication of changes between time periods (i.e. a non-zero slope). For mature trees, there may be some indication of increasing stand level averages between time periods. In all age groups and in mature trees in particular, there is some suggestion that the differences observed (the slope of the lines) varies between the 2008/2011 and 2009/2012 groups.

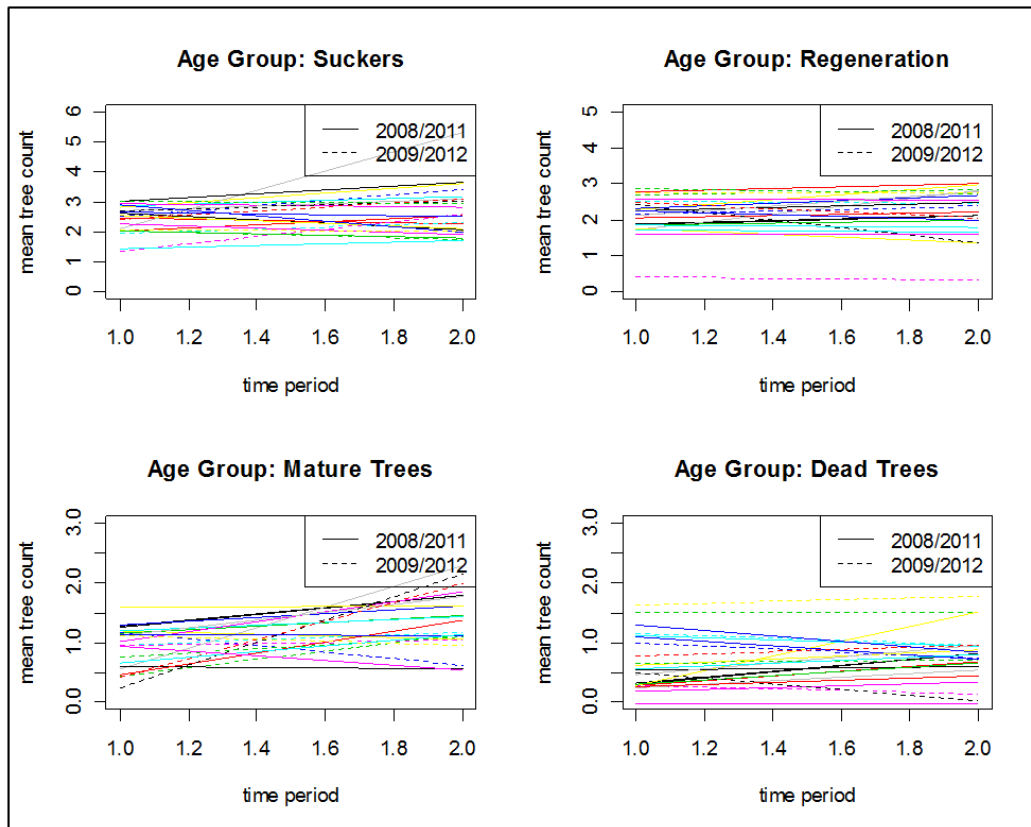


Figure 10. CIRO aspen trees: Stand level mean trees/plot, by age group.

Histograms of the paired differences of mean stand level tree counts, indicate higher mean tree counts in the 2nd time period measured (positive values) (Figure 11). Note the outlier value in the suckers age group, based on a single plot count of > 700 trees (stand #33). Analysis was done with and without this outlier, with no important changes in conclusions. Ignoring the outlier, the changes in mean tree counts over the three year interval, (i.e. the three year trend estimate) appear to be centered near zero for suckers and regeneration age groups, while possibly slightly positive for mature and dead tree age groups.

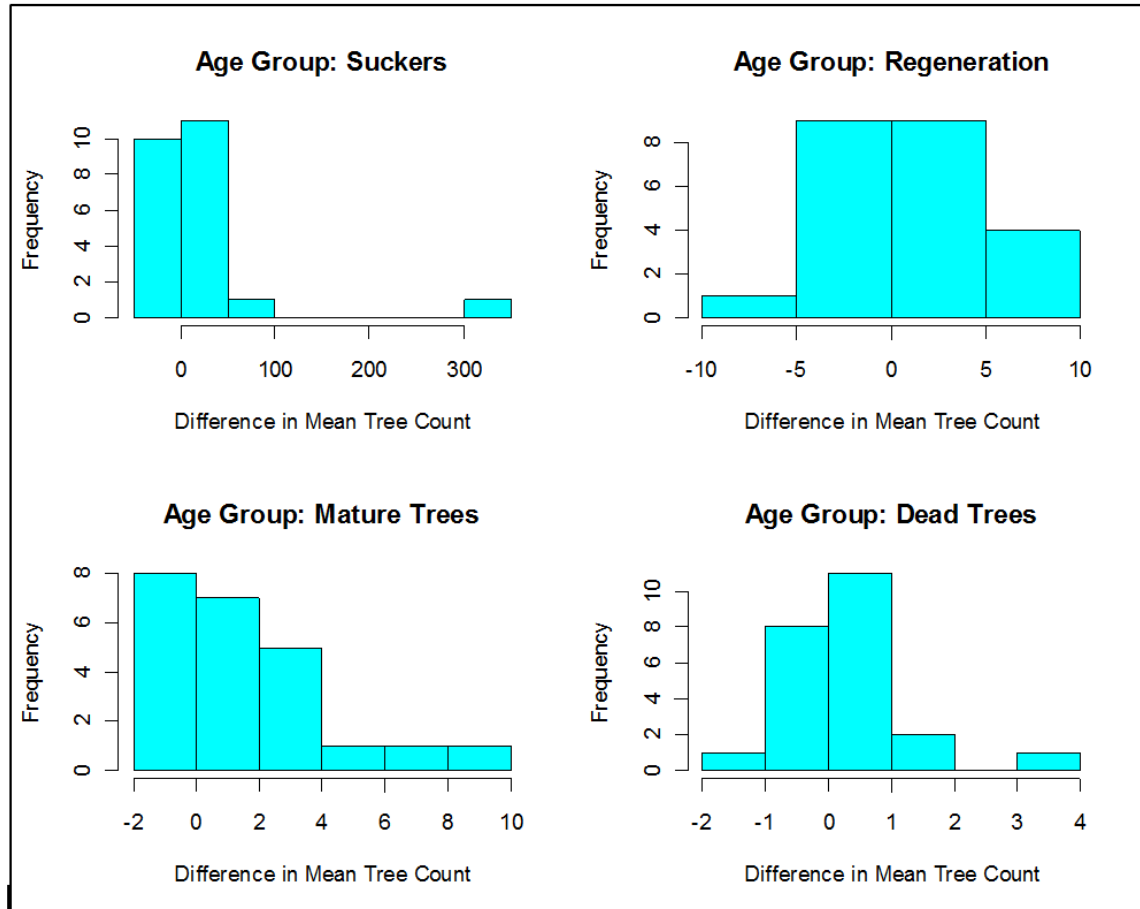


Figure 11. CIRO aspen trees: Difference in stand level mean trees/plot across time periods. (Positive difference indicates an increase in mean tree counts.)

In addition to treating stand as a fixed effect (i.e. analyzing the data as paired differences), the three year trend was estimated, as was the effect of the initial sampling year (2008 or 2009) (Table 7). Differences deemed significant at the 0.05 α level are highlighted in green.

There is evidence, at the 0.05 rejection level, that the stand level mean trees per plot increased between the two sampling periods for regeneration, mature, and dead tree age groups, but not the sucker age groups (Table 7). For the regeneration age group, the positive trend is offset somewhat by the fact that the mean tree counts differences were less, and even negative, for the stands measured in 2009/2012. This should temper any conclusion that the positive difference observed for regeneration trees (or any other group, for that matter) is yet providing evidence of long-term trend, rather than merely evidence of a difference for the specific time periods measured to date.

There is no evidence, at the 0.05 α level, of changes in the stand average number of trees per plot, for the suckers age group.

Table 7. Observed trends in aspen stand mean tree counts, and corresponding p-values. Differences significant at the 0.05 level are marked in green.

Age Group	Difference Between Time Periods (3 Year Trend)		Difference in Mean Trees per Plot by First Year Sampled 2008 or 2009	
	Difference in Mean Trees per Plot	P-Value for Diff <>0	Differences in Mean Trees per Plot	P-Value for Diff <>0
Suckers	24.61	0.183	-13.01	0.672
Suckers (no outlier)	9.42	0.156	2.181	0.843
Regeneration	2.29	0.019	-3.77	0.022
Mature Trees	1.51	0.046	0.44	0.716
Dead Trees	0.62	0.014	-0.70	0.092
All Trees Combined	7.26	0.136	-4.26	0.597

Statistical analysis: conifer

Stand level mean trees per plot for conifers, by age group has increased for the younger cohorts (Figure 12). As in Figure 10, each line on the plot connects the stand level average tree count in for the first and second time periods. The solid lines represent stands measured in 2008 and 2011, while the dashed lines represent stands measured in 2009 and 2012. In the conifer tree counts, at the plot level and at the entire stand level, there are a large number of plots with zero conifer trees counted for some age groups. For graphical purposes, a small amount of jitter has been added to the data to allow viewing of the multiple lines at zero.

For sucker and regeneration age groups, there is some graphical indication of increases in stand level average trees per plot between time periods (i.e. a non-zero slope). For mature trees, there is no clear signal, while for dead trees there is some indication of decreases in mean tree counts for some stands, with one outlier stand showing a strong increase in mean dead trees per plot.

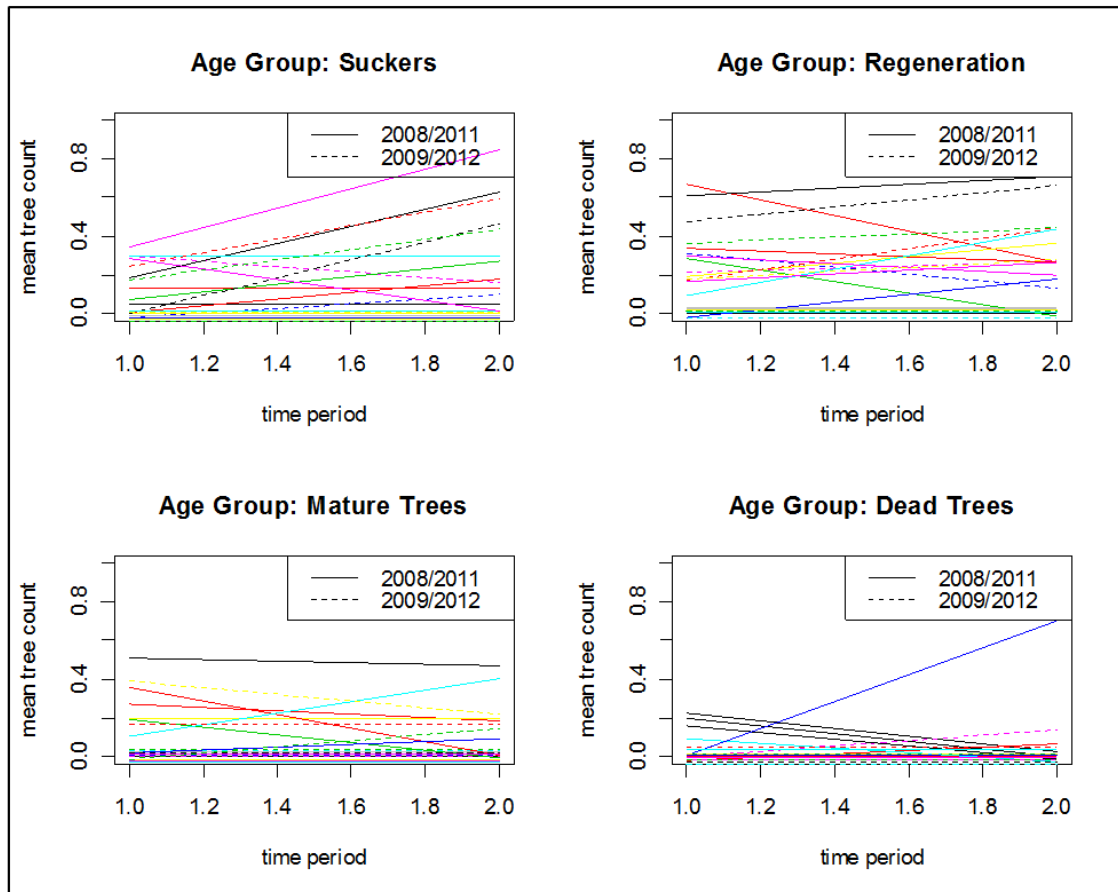


Figure 12. CIRO conifer trees: Stand level mean trees/plot, by age group. (Jitter added to distinguish multiple zeros.)

Histograms of the paired differences of stand level mean trees per plot indicate higher mean tree counts in the 2nd time period measured (positive values) (Figure 13). Note that for all groups, there are a high number of stands with zero change in stand average trees per plot. For all age groups, the mode of the sample = 0. Because of the high number of zeros, and a fairly modest sample size (23 stands), large sample normal approximations may not be appropriate for analysis of this data. Instead, non-parametric analysis methods are used to test for evidence that the population of stands has a mean time period-time period difference in stand level average tree/plot unequal to zero; and to test for evidence that the differences between time periods are different between the 2008/2011 and 2009/2012 pairings.

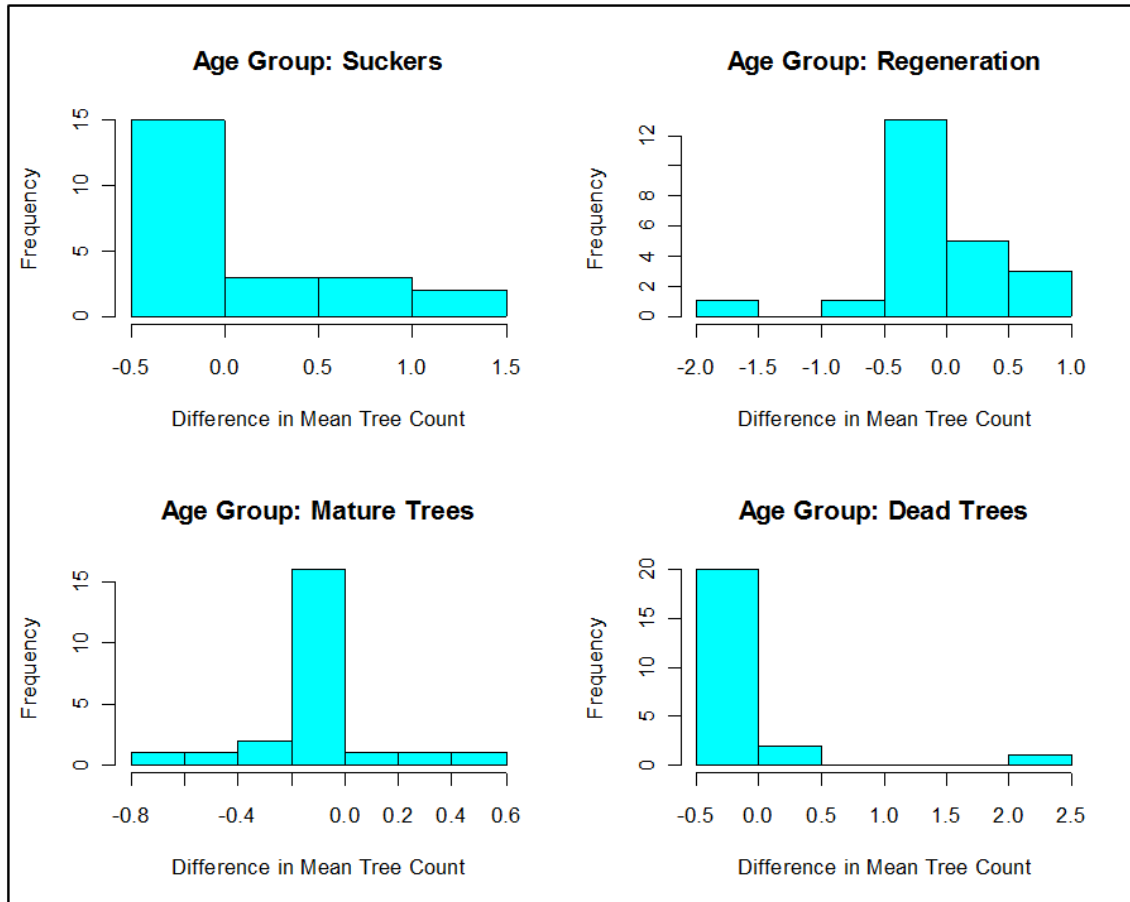


Figure 13. CIRO conifer trees: Difference in stand level mean trees/plot across time periods. (Positive difference indicates an increase in mean tree counts. Mode=0 for all groups.)

To test for evidence that the average change in stand level trees/plot is non-zero, a non-parametric permutation test was conducted. The permutations were conducted under the null hypothesis that the mean difference in stand level trees per plot is zero, and any non-zero stand level data points are simply randomly sampled about the true mean of zero. To test this null hypothesis, a series of simulations was conducted where a sign (positive or negative) was randomly assigned for each paired difference, and under each simulation, the simulated mean difference in trees per plot was calculated. The p-value was calculated as the proportion of simulated samples for which the simulated mean difference in stand level trees per plot that was greater in magnitude than the actual mean difference observed.

Note that in this permutation test, randomly assigning a positive or negative to a difference of zero has no impact on simulated results, and thus no impact on the p-value. The zero difference stands, thus, provide no information regarding the strength of the evidence. The zero values do, of course, contribute to the overall estimated mean difference in stand level trees/plot.

Similarly, to test whether the stand level differences in mean trees/plot varied between the 2008/2011 and 2009/2012 pairings, a permutation test was conducted, where simulated data were constructed by randomly re-assigning the observed data to one of the two groups, and the p-value

was calculated as the proportion of simulated data where the observed differences in were greater in magnitude than the actual observed difference (Table 8).

For the four age groups considered, only suckers showed evidence of a change in stand level mean trees / plot. However, with so many stands showing zero change in regeneration, mature, and dead age groups, any actual change in stand level mean trees/plot is likely small, making it unlikely to find statistical evidence, at these sample sizes, with only two time periods measured.

Table 8. Observed trends in Conifer stand mean tree counts, and corresponding p-values.

Age Group	Difference Between Time Periods (3 Year Trend)		Difference in Mean Trees per Plot by First Year Sampled 2008/2011 and 2009/2012	
	Difference in Mean Trees per Plot	P-Value for Diff <>0	Differences in Mean Trees per Plot	P-Value for Diff <>0
Suckers	0.22	0.034	-0.12	0.537
Regeneration	0.01	0.968	-0.12	0.394
Mature Trees	>-0.01	0.414	-0.03	0.810
Dead Trees	0.08	0.805	0.08	0.972
All Trees Combined	0.06	0.201	-0.08	0.486

Discussion

Statistical analysis and future plans

Overall, the average aspen stem densities of regeneration, mature, and dead trees have increased from 2008-2009 to 2011-2012, with no statistically significant change in suckers. The densities of conifer seedlings (< 46 cm in height) have increased while no difference was detected between time periods for larger conifer trees.

Caution should be used in describing these changes as indicative of a long-term trend. While stands may be considered somewhat independent within a park, they are not independent in terms of time, thus any assessment of the long-term trend is really based on only two points in time for each site, and four calendar years total for all data. Additional sampling data will help determine whether such temporal differences are indicative of long-term trends. As more monitoring data become available, more complex models can be applied and better understanding of trends will emerge.

In the future, we plan to incorporate local climate data as a covariate for trend analysis. Annual climate data is available via the online NOAA Climate Reference Network site (<http://www.ncdc.noaa.gov/crn/station.htm?stationId=1021>), which provides daily temperature and precipitation information. The stand level environmental variables, elevation, slope, and aspect will also be used as covariates. Plot-level covariates such as dominant understory species may be useful for modeling the mean structure of aspen and conifer stem counts.

Stands of potential concern in CIRO

Although thresholds indicating when management action may be desirable for long-term maintenance of aspen stands at CIRO and CRMO have not been established, the following is a short summary describing stands with the lowest aspen stem density by size class for stands sampled in CIRO in 2008-2009 and 2011-2012. Photos of the stands can be found in Appendix B in this report for year 2009/2012 while photos for 2008/2011 can be found in Strand and Bunting (2012).

A few stands exhibit relatively low mature aspen stem density, and some stands contain conifer species in all size classes. Stand #6, #9, #37, #72, and #73 have a mature aspen stem count lower than 350 stems/ha. The suckering and regeneration in these stands is however above average, with regeneration higher than 1,000 stems/ha, which has been recommended by Bartos and Campbell (1998) as a threshold for an aspen stand with adequate regeneration. A drastic change in suckering occurred in stand #33 with an increase in aspen size class I from 2,188 stems/ha in 2008 to 66,513 stems/ha in 2011. In stands #6, #37, #43, #56, and #57, conifer species are present in all live size classes. In stand #37 the mature aspen and conifer count are at the same level, 249 stems/ha.

Stand #6: This stand has a low stem count of mature aspen, 224 stems/ha in 2011 and 373 stems/ha in 2008. However the suckering is 1,840 stems/ha and the regeneration is 4,277 stems/ha in 2011. We hypothesize that the mature stems are reaching an age where they face mortality and that mature stems are being replaced by new aspen stems, i.e. a natural

regeneration of the stand. It would be interesting to collect increment core samples from a couple of the older stems to get a better understanding for the age distribution within the stands.

Stand #9: This stand has a low and decreasing mature stem count, 232 stems/ha in 2012 and 464 stems/ha in 2009. The regeneration is however high, 4,277 stems/ha in 2012, and the suckering was 1,840 stems/ha in 2012. The stand structure is similar to the one in stand #6.

Stand #24: The regeneration and mature stem counts are low, 119 stems/ha for regeneration and 438 stems/ha for mature stems. The suckering increased from 597 stems/ha in 2009 to 2,905 stems/ha in 2012. Protection of a few regenerating stems could be beneficial in this stand to ensure continued recruitment into the mature size class.

Stand #33: A drastic change in suckering occurred with an increase from 2,188 stems/ha in 2008 to 66,513 stems/ha in 2011. Although this is not of particular concern, it will be interesting to observe the development of the stand in the future.

Stand #37: This stand has a low stem count of mature aspen, 249 stems/ha and the stem count of mature Rocky Mountain juniper is as high (249 stems/ha). The suckering is very high, 9,500 stems/ha and the regeneration is 3,979 stems/ha. We hypothesize that the mature aspen stems are reaching an age where they face mortality and that the mature stems are being replaced by new aspen stems, i.e. a natural regeneration of the stand. Potentially the aspen will eventually be replaced by Rocky Mountain juniper.

Stand #43: This stand contains conifer stems of all size classes but at low stem counts. Given time these conifers may grow, regenerate and potentially begin to compete with the aspen population. No changes has been observed in the aspen population over this 3 year sampling period and the suckering, regeneration, and mature stem counts are about average for the park.

Stand #56 and #57: These stands contain conifer stems of all size classes but at low stem counts. Given time these conifers may grow, regenerate and potentially begin to compete with the aspen population. The sucker and regeneration stem counts are high in both stands.

Stand #72: A low stem count of mature aspen stems is observed in this stand (199 stems/ha) and the regeneration is only 1,243 stems/ha, which is close to the threshold of 1,000 stems/ha as recommended by Bartos and Campbell (1998). This area near Circle Creek has been closed to grazing for several years, but these characteristics may be related to impacts from previous grazing and browsing. Protection of a few regenerating stems could be beneficial in this stand to ensure continued recruitment into the mature stem population.

Stand #73: The mature stem count is low (348 stems/ha) and the dead stem count is high (1,044 stems/ha). However the suckering is 1,741 stems/ha and the regeneration is high at 3,581 stems/ha. The young cohort of regenerating stems will likely replace the dying mature stems given time.

Long-term monitoring of aspen – what have we learned?

Aspen stands are dynamic with high variability in suckering from year to year, growth leading to change in size class, and mortality occurring in all size classes. Aspen stands are also spatially variable and suckering and regeneration can be high in one portion of the stand while non-existent in other portions. Conifer populations are encroaching on aspen in parts of stands while conifers are completely absent in other parts of the stands. Given this variability in both time and space, our monitoring protocol (Strand et al. 2009) established a large number of small sampling plots distributed across each stand rather than a single large plot within each stand, and ensured adequate distribution of sampled stands across the study area. Power analyses of potential sampling designs was critical, and led us to establish permanent plots rather than temporary, unmarked plots.

In a sampling design with permanent plots, it is naturally extremely important to have the ability to quickly and accurately relocate plots. We used 50-cm long rebar with a yellow plastic cap to mark the plot centers. The rebar was inserted into the ground with only the 3-cm tall cap above ground. The marker locations were recorded using a high accuracy Trimble GeoXT GPS unit with < 1 m spatial accuracy after differential correction. The importance of using a high accuracy GPS unit cannot be emphasized enough. We had the opportunity to compare plots marked with the high accuracy Trimble unit and a unit of lower accuracy (3-5 m). Permanent plot markers originally set with a lower accuracy GPS unit were extremely difficult to relocate the following sampling period, 3 years later in this case. Plots located with the lower accuracy unit took much longer to find because of the larger search radius, and they were sometimes not found at all. Re-establishing plot monuments introduced error, particularly in this case where the plots are relatively small (4 m radius) and in the same size range as the GPS error. We also determined that the lower accuracy GPS units are sufficient for locating permanent markers as long as the marker was originally recorded using a high accuracy unit, hereby avoiding the compounding spatial error of both setting and searching for the plot using a low accuracy GPS. Locating plots with GPS rather than stretching tapes between plot centers is much more time efficient. We tested both methods while designing the monitoring strategy. Overall, we achieved an 85% plot center relocation rate, which would have been higher if we had initially used the high accuracy GPS unit to monument plot centers. In general, we relocated plots within only a few minutes while occasionally we searched as long as 15 minutes. Searching longer than 15 minutes rarely resulted in finding the plot. In cases where the plot marker was not found we suspect that the marker had been removed by humans, animals or other disturbance to the soil. It is also possible that we simply did not find the plot marker.

In all monitoring, training of personnel is extremely important, aspen monitoring is no exception. It may appear straight forward to determine the size class of an aspen stem, determine if the stem is in or out of the plot, deciding if a stem is dead or alive or if a dead stem is standing or not, but we found that many of these questions were raised during training in the field. According to the standard operating procedures of this monitoring protocol (Strand et al. 2009) we found that the recommended half day of training is generally sufficient. During this half day of training, the trainers sample one plot while explaining each sampling step to the trainees. The trainees then sample several plots through the half day with the trainers available for guidance as needed. During training, it is important to emphasize the size breaks between aspen size classes and also

emphasize careful counting and recording of stems. Clear communication between the plot reader and the recorder is extremely important.

Diligent field data handling and database management is of great importance. We recommend that field data is entered into the project master database each day if possible. Ideally the project leader and the data manager review the data as soon as possible after it has been entered into the database. Many potential mistakes can be avoided by communication between the field crew members, project manager and data manager. As time goes by, it is difficult for all parties to remember the plot, the data, issues during sampling etc., which may shed light on apparent inconsistencies, outliers, and errors. The aspen database has evolved over time and several new queries have been added over these six years by the data manager. The data manager has developed specific queries for output of data in a format ready for summary table and statistical analysis. These specific queries are extremely helpful in reducing the risk of making errors during data handling, summarization, analysis, and reporting.

Overall, the protocol developed for vital signs monitoring of aspen in CIRO and CRMO has provided effective guidance over the past six years. The next sampling period will occur in five year intervals from this point forward, with the next sampling in CRMO scheduled in 2015 and in CIRO during the 2016 and 2017 field seasons. As more data are collected, trend analyses and correlations with climate will be conducted.

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Appendix A. Aspen stands in CIRO, updated 2012

(Including explanations of why some stands were not sampled)

Stand #	Area (Ha)	Transects	Plots	Sample	Data Frame	Why not sampled	Panel
1	0.5	0	0	No	1	Shrubby aspen	0
2	2.3	0	0	No	1	Shrubby aspen	0
3	0.6	0	0	No	1	Shrubby aspen	0
4	0.6	0	0	No	1	Shrubby aspen	0
5	2.0	2	8	Yes	1		2
6	10.4	2	8	Yes	1		2
7	1.4	2	8	Yes	2		3
8	3.6	0	0	No	1	Rocky very scattered stand	0
9	1.2	2	6	Yes	1		3
11	2.1	2	8	Yes	2		3
13	2.2	1	4	Yes	2		3
14	1.8	0	0	No	2	Private	0
15	1.8	0	0	No	2	Private	0
16	0.6	0	0	No	3	Riparian	0
18	1.2	0	0	No	3	Riparian	0
20	0.4	0	0	No	3	Rocky ravine	0
21	0.6	0	0	No	3	Not much aspen	0
22	0.5	0	0	No	3	Ravine	0
23	1.8	0	0	No	3	Riparian	0
24	0.7	1	5	Yes	3		3
26	0.8	0	0	No	3	Riparian	0
27	0.5	0	0	No	3	Riparian	0
28	1.9	0	0	No	6	Rocky transect not possible	0
30	0.4	1	4	Yes	5		2
31	4.0	0	0	No	6	Rocky transect not possible	0
32	1.0	0	0	No	6	Rocky transect not possible	0
33	0.3	1	3	Yes	5		2
36	0.4	0	0	No	6	Rocky transect not possible	0
37	0.8	1	4	Yes	5		2
38	1.2	0	0	No	5	Not aspen habitat	0
39	0.6	0	0	No	6	Rocky transect not possible	0

Stand #	Area (Ha)	Transects	Plots	Sample	Data Frame	Why not sampled	Panel
40	0.7	2	6	Yes	5		2
41	0.9	2	7	Yes	5		2
42	2.1	3	11	Yes	5		2
43	1.9	3	7	Yes	5		2
44	0.4	0	0	No	6	Rocky transect not possible	0
45	1.1	1	4	Yes	5		2
47	1.0	0	0	No	6	Rocky transect not possible	0
48	0.9	0	0	No	6	Rocky transect not possible	0
49	0.8	0	0	No	6	Riparian	0
50	0.4	1	4	Yes	7		3
51	0.7	1	4	Yes	5		2
52	0.4	1	4	Yes	5		2
53	0.3	0	0	No	5	Riparian	0
54	0.3	1	3	Yes	7		3
55	1.5	0	0	No	7	Shrubby	0
56	0.7	1	4	Yes	7		3
57	1.9	2	7	Yes	7		3
58	0.8	0	0	No	4	Shrubby	0
59	0.3	0	0	No	4	Shrubby	0
60	0.5	0	0	No	4	Shrubby	0
61	0.6	1	4	Yes	4		2
62	0.6	0	0	No	4	Shrubby	0
63	1.3	2	7	Yes	4		2
64	0.4	0	0	No	4	Shrubby	0
72	0.3	1	4	Yes	6		2
73	0.4	1	4	Yes	1		3

Appendix B. Distance Photos in CIRO

Comparison between 2009 and 2012 (stands sampled 2008 and 2011, see Strand and Bunting 2011)

2012

2009

CIRO-7



CIRO-9



CIRO-11



CIRO-13



No photo in 2009

CIRO-24



CIRO-50



No photo in 2009

CIRO-54

No photo in 2012

No photo in 2009

CIRO-56



CIRO-57



CIRO-73



Appendix C: R-Code Used for Aspen Analysis

```
POPTRE= read.csv("POPTRE.csv")
levels(factor(POPTRE$Stand))
levels(factor(POPTRE$Stand[POPTRE$Year==2008]))
levels(factor(POPTRE$Stand[POPTRE$Year==2009]))
names(POPTRE)
POPTRE$Plot<-as.factor(POPTRE$Plot)
names(POPTRE)
## Remove Outlier
#nrow(POPTRE)
#POPTRE= POPTRE[POPTRE$TreeCount != max(POPTRE$TreeCount),]

#Site_Data = read.csv("POPTRE_Stand-Measures_Summary_for
Statistical Analysis.csv")
POPTRE$Time=POPTRE$Year-2007

# First Check lognormal models. In the end I didn't use these,
because the data
# are far from lognormally distributed. Too many zero and
skewness. But these
# make a good "rough check" against final results.
if (1==2) {
Allages.fit1 = lm(log(TreeCount+1) ~ TimePeriod + Time +
factor(Stand), data=POPTRE)
summary(Allages.fit1)
names(Allages.fit1)
Sucker.fit1 = lm(log(TreeCount+1) ~ TimePeriod + Time +
factor(Stand)+
, data=POPTRE[POPTRE$AgeGroup=="Sucker",])
summary(Sucker.fit1)

Sucker.fit2 = lm(log(TreeCount+1) ~ TimePeriod + factor(Stand),
data=POPTRE[POPTRE$AgeGroup=="Sucker",])
summary(Sucker.fit2)

Regen.fit1 = lm(log(TreeCount+1) ~ TimePeriod + Time +
factor(Stand), data=POPTRE[POPTRE$AgeGroup=="Regen",])
```

```

summary(Regen.fit1)

Mature.fit1 = lm(log(TreeCount+1) ~ TimePeriod + Time +
factor(Stand), data=POPTRE[POPTRE$AgeGroup=="Mature",])
summary(Mature.fit1)

Dead.fit1 = lm(log(TreeCount+1) ~ TimePeriod + Time +
factor(Stand), data=POPTRE[POPTRE$AgeGroup=="Dead",])
summary(Dead.fit1)

}

Stands=levels(factor(POPTRE$Stand))

#####
Make Plots of before/after
#####

par(mfrow=c(2,2))
for (k in 1:4) {
# Brute Force Programming:
if (k==1) { data=POPTRE[POPTRE$AgeGroup=="Sucker",];
Age="Suckers"; attach(data); ymax=6;}
if (k==2) {data=POPTRE[POPTRE$AgeGroup=="Regen",];
Age="Regeneration"; attach(data); ymax=5;}
if (k==3) {data=POPTRE[POPTRE$AgeGroup=="Mature",]; Age="Mature
Trees"; attach(data); ymax=3}
if (k==4) {data=POPTRE[POPTRE$AgeGroup=="Dead",]; Age="Dead
Trees"; attach(data);ymax=3}
if (k==5) {data=POPTRE; Age="All Age Groups";
attach(data);ymax=5}

plot(x=c(1,2),
y=c(mean(log(TreeCount[Stand==Stands[1]][TimePeriod[Stand==Stand
s[1]]==1]+1)),

mean(log(TreeCount[Stand==Stands[1]][TimePeriod[Stand==Stands[1]
]==2]+1))),
type="l", col=1,ylab= "mean tree count",xlab = "time period",
main = paste("Age Group:", Age),ylim=c(0,ymax))

for (i in 1:length(Stands)){
jitter=rnorm(1,0, .02)
jitter
lines(x=c(1,2),

```

```

y=c(jitter+mean(log(TreeCount[Stand==Stands[i]][TimePeriod[Stand
==Stands[i]]==1]+1)),

jitter+mean(log(TreeCount[Stand==Stands[i]][TimePeriod[Stand==St
ands[i]]==2]+1))),

col=i,lt=(Time[Stand==Stands[i]][TimePeriod[Stand==Stands[i]]==1
][1]))
}
legend("topright", c("2008/2011", "2009/2012"), lt=c(1,2))
detach(data)
}

#####
# Run Permutation Test (non-parametric test) to test for non-
zero differences time period
# 1 vs Time Period 2 (3 year trend), and between start time
=2008 and start time = 2009
#####

for (k in 1:5) {
# Brute Force Programming:
if (k==1) { data=POPTRE[POPTRE$AgeGroup=="Sucker",];
Age="Suckers"; attach(data); ymax=5;}
if (k==2) {data=POPTRE[POPTRE$AgeGroup=="Regen",];
Age="Regeneration"; attach(data); ymax=4;}
if (k==3) {data=POPTRE[POPTRE$AgeGroup=="Mature",]; Age="Mature
Trees"; attach(data); ymax=3}
if (k==4) {data=POPTRE[POPTRE$AgeGroup=="Dead",]; Age="Dead
Trees"; attach(data);ymax=2}
if (k==5) {data=POPTRE; Age="All Age Groups";
attach(data);ymax=5}

data.y1 = data[data$TimePeriod==1,]
data.y2 = data[data$TimePeriod==2,]
diffs=
tapply(data.y2$TreeCount, data.y2$Stand, mean)-
tapply(data.y1$TreeCount, data.y1$Stand, mean)

y1.stand=factor(tapply(data.y2$Stand, data.y2$Stand, mean))
y1.year = factor(tapply(data.y2$Year, data.y2$Stand, mean))

y1.stand

```

```

names(data.y1)
cbind(diffs, y1.stand, y1.year)

fit = lm(diffs ~ y1.year)
print(Age)
print(summary(fit))

Year.Diffs= mean(diffs[Year1==2008])-mean(diffs[Year1==2009])

Year1
if (k !=5) {
hist(diffs, main = paste("Age Group:", Age),xlab = "Difference
in Mean Tree Count",
col="cyan")}

#main=paste("Stand Level Differences in Tree Count:",Age))

## Permutation Test
# non-parametric test. Assume, under Ho, that differences can
be
# positive or negative at random, so mult each response by -1, 1
at
# random (.5 probability of each), and see how often the
magnitude
# of the mean response is as extreme as that observed here

n.p=1000
ptest.diffs=rep( 0, n.p)
ptest.year=ptest.diffs

for (i in 1:n.p){
  diff.sign=-1+2*(runif(n.diffs)>.5)
  p.diffs = diffs*diff.sign
  ptest.diffs[i]=1*(abs(mean(p.diffs))<abs(mean(diffs)))
length(diffs)
year.index= sample(c(1:length(diffs)),length(diffs), replace=F)

# test for year0 effect (i.e. is 2008 different from 2009 start
years)
ptest.year[i] =
  1*(ptest.year[i]=1*abs(Year.Diffs) >

```

```
abs(mean(diffs[year.index[16:length(diffs)]]) -
mean(diffs[year.index[1:15]])))
}
```

```
p.perm = 1 - mean(p.test.diffs)
p.per.year = 1 - mean(p.test.year)
```

```
p.perm
p.per.year
```

```
print(paste("Age=", Age))
print(paste("Mean Difference=", mean(diffs), "more trees per
stand"))
print(paste("Permutation Test for paired differences <> 0, p-
value=", p.perm))
print(paste("T-Test for paired differences <> 0, p-value=",
t.test(diffs)$p.value))
print(paste("Mean Differences between 2008 and 2009 start year",
Year.Diffs))
print(paste("Permutation Test for diff between 2008 and 2009
start year, p-value=", p.per.year))
detach(data)
}
```


Appendix D: R-Code Used for Conifer Analysis

```
Conifer= read.csv("CONIFER.csv")
names(Conifer)
Conifer$Plot<-as.factor(Conifer$Plot)

#Site_Data = read.csv("Conifer_Stand-Measures_Summary_for
Statistical Analysis.csv")
Conifer$Time=Conifer$Year-2007

# First Check lognormal models. In the end I didn't use these,
because the data
# are far from lognormally distributed. Too many zero and
skewness. But these
# make a good "rough check" against final results.

Allages.fit1 = lm(log(TreeCount+1) ~ TimePeriod + Time +
factor(Stand), data=Conifer)
summary(Allages.fit1)

Sucker.fit1 = lm(log(TreeCount+1) ~ TimePeriod + Time +
factor(Stand), data=Conifer[Conifer$AgeGroup=="Sucker",])
summary(Sucker.fit1)

Regen.fit1 = lm(log(TreeCount+1) ~ TimePeriod + Time +
factor(Stand), data=Conifer[Conifer$AgeGroup=="Regen",])
summary(Regen.fit1)

Mature.fit1 = lm(log(TreeCount+1) ~ TimePeriod + Time +
factor(Stand), data=Conifer[Conifer$AgeGroup=="Mature",])
summary(Mature.fit1)

Dead.fit1 = lm(log(TreeCount+1) ~ TimePeriod + Time +
factor(Stand), data=Conifer[Conifer$AgeGroup=="Dead",])
summary(Dead.fit1)

Stands=levels(factor(Conifer$Stand))

#####
Make Plots of before/after
#####

par(mfrow=c(2,2))
for (k in 1:4) {
```

```

# Brute Force Programming:
if (k==1) { data=Conifer[Conifer$AgeGroup=="Sucker",];
Age="Suckers"; attach(data); ymax=1;}
if (k==2) {data=Conifer[Conifer$AgeGroup=="Regen",];
Age="Regeneration"; attach(data); ymax=1;}
if (k==3) {data=Conifer[Conifer$AgeGroup=="Mature",];
Age="Mature Trees"; attach(data); ymax=1}
if (k==4) {data=Conifer[Conifer$AgeGroup=="Dead",]; Age="Dead
Trees"; attach(data);ymax=1}
if (k==5) {data=Conifer; Age="All Age Groups";
attach(data);ymax=1}

plot(x=c(1,2),
y=c(mean(log(TreeCount[Stand==Stands[1]][TimePeriod[Stand==Stand
s[1]]==1]+1)),

mean(log(TreeCount[Stand==Stands[1]][TimePeriod[Stand==Stands[1]
]==2]+1))),
type="l", col=1,ylab= "mean tree count",xlab = "time period",
main = paste("Age Group:", Age),ylim=c(0,ymax))

for (i in 1:length(Stands)){
jitter=rnorm(1,0, .02)
jitter
lines(x=c(1,2),
y=c(jitter+mean(log(TreeCount[Stand==Stands[i]][TimePeriod[Stand
==Stands[i]]==1]+1)),

jitter+mean(log(TreeCount[Stand==Stands[i]][TimePeriod[Stand==St
ands[i]]==2]+1))),

col=i,lt=(Time[Stand==Stands[i]][TimePeriod[Stand==Stands[i]]==1
][1]))
}
legend("topright", c("2008/2011", "2009/2012"), lt=c(1,2))
detach(data)
}

#####
# Run Permutation Test (non-parametric test) to test for non-
zero differences time period
# 1 vs Time Period 2 (3 year trend), and between start time
=2008 and start time = 2009
#####

for (k in 1:5) {

```

```

# Brute Force Programming:
if (k==1) { data=Conifer[Conifer$AgeGroup=="Sucker",];
Age="Suckers"; attach(data); ymax=1;}
if (k==2) {data=Conifer[Conifer$AgeGroup=="Regen",];
Age="Regeneration"; attach(data); ymax=1;}
if (k==3) {data=Conifer[Conifer$AgeGroup=="Mature",];
Age="Mature Trees"; attach(data); ymax=1}
if (k==4) {data=Conifer[Conifer$AgeGroup=="Dead",]; Age="Dead
Trees"; attach(data);ymax=1}
if (k==5) {data=Conifer; Age="All Age Groups";
attach(data);ymax=1}


data.y1 = data[data$TimePeriod==1,]
data.y2 = data[data$TimePeriod==2,]
diffs=
tapply(data.y2$TreeCount, data.y2$Stand, mean)-
tapply(data.y1$TreeCount, data.y1$Stand, mean)

cbind(diffs, Year1)
Year1 = tapply(data.y1$Year, data.y1$Stand, mean)

Year.Diffs= mean(diffs[Year1==2008])-mean(diffs[Year1==2009])

Year1
if (k !=5) {
hist(diffs, main = paste("Age Group:", Age),xlab = "Difference
in Mean Tree Count",
col="cyan")}}

#main=paste("Stand Level Differences in Tree Count:",Age))

## Permutation Test
# non-parametric test. Assume, under Ho, that differences can
be
# positive or negative at random, so mult each response by -1, 1
at
# random (.5 probability of each), and see how often the
magnitude
# of the mean response is as extreme as that observed here


n.p=1000
ptest.diffs=rep( 0, n.p)

```

```

ptest.year=ptest.diffs

for (i in 1:n.p){
  diff.sign=-1+2*(runif(n.diffs)>.5)
  p.diffs = diffs*diff.sign
  ptest.diffs[i]=1*(abs(mean(p.diffs))<abs(mean(diffs)))
length(diffs)
year.index= sample(c(1:length(diffs)),length(diffs), replace=F)

# test for year0 effect (i.e. is 2008 different from 2009 start
years)
ptest.year[i] =
  1*(ptest.year[i]=1*abs(Year.Diffs) >
abs(mean(diffs[year.index[16:length(diffs)])]-
mean(diffs[year.index[1:15]])))
}

p.perm = 1-mean(ptest.diffs)
p.per.year = 1-mean(ptest.year)

p.perm
p.per.year

print(paste("Age=", Age))
print(paste("Mean Difference=", mean(diffs),"more trees per
stand"))
print(paste("Permutation Test for paired differences <> 0, p-
value=", p.perm))
print(paste("T-Test for paired differences <> 0, p-value=",
t.test(diffs)$p.value))
print(paste("Mean Differences between 2008 and 2009 start year",
Year.Diffs))
print(paste("Permutation Test for diff between 2008 and 2009
start year, p-value=", p.per.year))
detach(data)
}

```

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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National Park Service
U.S. Department of the Interior



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