



Upper Columbia Basin Network Aspen Monitoring Report 2007–2017

*City of Rocks National Reserve and Craters of the Moon
National Monument and Preserve*

Natural Resource Report NPS/UCBN/NRR—2023/2538



ON THE COVER

Populus tremuloides (Michx) at City of Rocks National Reserve

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

Upper Columbia Basin Network

Aspen Monitoring Report 2007–2017

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July 2023

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Please cite this publication as:

Strand, E. K., S. C. Bunting, T. R. Johnson, J. Lonneker, and G. Dicus. 2023. Upper Columbia Basin Network aspen monitoring report 2007–2017: City of Rocks National Reserve and Craters of the Moon National Monument and Preserve. Natural Resource Report NPS/UCBN/NRR—2023/2538. National Park Service, Fort Collins, Colorado. <https://doi.org/10.36967/2298956>

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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.

Quaking aspen was selected as a priority vital sign for the Upper Columbia Basin Network (UCBN), specifically within 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. 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. In 2007, 2010, and 2015, 102 plots in 21 stands were sampled in CRMO. Panel 2, consisting of 85 plots in 15 stands in CIRO, was sampled in 2008, 2011, and 2016, and panel 3 consisting of 49 plots in 10 stands in CIRO was sampled in 2009, 2012, and 2017. This report details status estimates for aspen and conifer densities by size class in CIRO and CRMO and a statistical trend analysis for stands sampled 2007–2017. Park average stem densities (stems per hectare) for aspen and conifer species are summarized in Table ES-1.

Table ES-1. Park stem density (stems/ha) by size class for aspen and conifers during the three sampling periods 2007–2017.

Park	Panel	Year	Aspen Stem Density				Conifer Stem Density			
			Suckers ¹	Regen ²	Mature ³	Dead ⁴	Seedling ¹	Regen ²	Mature ³	Dead ⁴
CRMO	1	2007	4,839	1,545	818	1,009	48	6	14	20
CRMO	1	2010	5,723	2,001	741	1,001	68	14	8	0
CRMO	1	2015	3,955	2,668	683	724	59	43	6	0
CIRO	2&3	2008/09	2,463	2,235	416	316	27	103	31	4
CIRO	2&3	2011/12	5,204	2,441	760	342	67	112	31	21
CIRO	2&3	2016/17	3,912	2,557	840	230	141	67	59	0

The aspen protocol (Strand et al. 2009b) was approved in September 2009. The methods presented in this report reflect that version, version 1.0 of the protocol. The majority of the aspen stands sampled in CRMO and CIRO 2015–2017 are regenerating and contain a distribution of age classes. There are however stands with relatively low mature aspen stem density, low regeneration, and/or high

numbers of dead aspen stems. Regeneration lower than 1000 stems/ha was recorded in three stands in CRMO in 2015: stand #5, stand #26, and stand #27. Mature stem density lower than 100 stems/ha was recorded in four stands in CRMO in 2015: stand #5, stand #12, stand #13 (0 stems/ha), and stand #20 (0 stems/ha). Regeneration lower than 1000 stems/ha was recorded in CIRO in two stands in 2016–2017: stand #24 and stand #51. The stand with the lowest mature stem count in CIRO was stand #72 (149 stems/ha). Even though a few stands in both parks had a low to no density of mature stems, they were still suckering and recruitment of young stems was occurring.

The number of stands in CRMO with conifers in the regeneration class increased from one stand in 2007 to ten stands in 2015, ranging from 25 to 199 stems/ha in 2015. The number of stands with conifers in the seedling class in CRMO increased from seven in 2007 to eleven in 2015, ranging from 25 to 398 stems/ha in 2015. Density of mature conifers was low in CRMO and decreased from 14 to 6 stems/ha between 2007 and 2015. In CIRO, the number of stands with conifers in the regeneration class stayed constant at 13–14 stands (33–398 stems/ha) while in the seedling class we observed an increase from nine in 2008/2009 to twelve in 2016/2017 ranging from 50 to 497 stems/ha in 2016/2017. The number of stands with mature conifers increased from eight to twelve in CIRO from 2008/2009 to 2016/2017, ranging from 33 to 597 stems/ha in 2016/2017.

Data from 2007 to 2017 were tested for a change in stem density in aspen and conifers within size groups between sampling periods using a linear mixed model analysis. Significant increases ($p < 0.05$) were detected for the aspen regeneration class in CRMO from 2007 to 2010 and from 2007 to 2015. A significant decrease in dead aspen stems was detected between 2007 and 2015 in CRMO. There were no statistically significant differences in aspen sucker density or mature stem density in CRMO although mature aspen density decreased by 16.5% from 2007 to 2015. An increase in aspen suckering was observed in panel 2 between 2008 and 2011 and in panel 3 between 2009 and 2012 in CIRO, but no change was detected in CIRO's panels between 2008 and 2016 or 2009 and 2017. Increases in the aspen regeneration class was observed in CIRO in panel 2, 2008 to 2011 and 2008 to 2016, while a decrease in aspen regeneration was observed in panel 3 2009 to 2017. Significant increases in stem density of the mature class was observed in CIRO in both panels across all time periods. An increase in dead aspen stems occurred between 2008 and 2011 but there was no difference between 2008 and 2016 or in panel 3. General observations suggest that stands on warmer aspects (south and west), lower elevation, and higher on the hillslope have lower aspen regeneration density.

An increase in the conifer regeneration class was detected in CRMO while a decrease was detected in panel 2 in CIRO 2008 to 2016. An increase in conifer seedlings was detected in panel 3 in CIRO 2009–2017.

Acknowledgments

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 and Gordon Dicus for encouragement, provision of resources and fruitful discussions. Support from program data managers Leona Svancara, Gordon Dicus, Kirk Sherrill, and Jeff Lonneker for development and maintenance of the aspen database and assistance with data quality assurance and control has been invaluable. We thank the staff at 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 CRMO during the summers of 2007, 2010 and 2017, you contributed immensely to field data collection, data recording, and fun. Many thanks to Wallace Keck and NPS staff at CIRO, including help from the Youth Conservation Corps leaders and field crews, and high school students. Statistical expertise has over the years been provided by Dr. Kirk Steinhorst, Dr. Leigh Ann Starcevich, and Matthew Nahorniak.

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), 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 of aspen are thought to be rare in the West (Kemperman and Barnes 1976; Romme 1982; Mitton and Grant 1996). Recent research has however shown that sexual reproduction via seedling establishment in aspen of the West is more common than previously thought (Mock et al. 2008), particularly after severe disturbances. An example of recent successful establishments of aspen seedlings followed the severe fires in Yellowstone in 1988, which apparently provided a 'window of opportunity' of suitable substrate and climate conditions (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 aspen trees 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, most commonly fire. However, recent research by Shinneman et al. (2013) suggests that in pure aspen, or even in mixed stands with an absence of a strong conifer component, aspen may subsist without fire through steady rates of tree recruitment, or through episodic gap succession as overstory trees succumb to old age or pathogens. Although aspen clones are long-lived, individual aspen stems are short-lived, normally living 100–150 years (Shepperd et al. 2001) with some occasionally exceeding 200 years (Mueggler 1989).

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; Shinneman et al. 2013). 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 and where elk are not hunted (Hart and Hart 2001). Recent research (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 stems.

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 insect damage 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), potentially caused by hydraulic failure of roots (Anderegg et al. 2012). Climate modeling by Rehfeldt et al. (2009) forecasts that in 50 years approximately 40% of existing aspen stands may no longer have a suitable climate regime to support their presence in the western U.S. due to moisture stress and the annual balance between temperature and precipitation.

A phenomenon affecting western aspen in the recent decade is referred to as *sudden aspen decline* (SAD) and is different from the slow decline in aspen populations that has been occurring over the past century (Worrall et al. 2010) due to fire suppression and successional development towards conifer dominance (Bartos 2001). In cases of SAD mature aspen stems are dying with no apparent regeneration in the form of suckering. Scientists and managers are currently researching the causes, trying to find solutions to SAD, currently affecting as much as 17% of aspen stands in Colorado in 2008 (Worrall et al. 2010). Aerial surveys in 2008 indicated that aspen stands affected by SAD had a greater moisture deficit compared to healthy aspen stands, therefore, warm and dry growing seasons in the future may lead to reoccurrence of SAD.

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.

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 warming 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, may contribute valuable data to future aspen management in the western United States.

Objectives

The overarching goal of the UCBN aspen 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 monitoring protocol (Strand et al. 2009b) was approved in September 2009 and the methods presented in this report reflect that version, 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 entirely in riparian areas or composed of shrubby snow-damaged aspen will be sampled. The difficult access and ecologically sensitive location on Big Cinder Butte in CRMO prevents us from including this stand in the sampling frame.

Methods

Sampling methods followed those detailed by Strand et al. (2009b). 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 CRMO (Figure 1) in 2006 and in CIRO in 2008 and 2009.

According to the protocol revisit design (Table 1) panel 1 in CRMO was sampled in 2007, 2010, and 2015, and panel 2 and 3 were sampled in CIRO in 2008/2009, 2011/2012, and 2016/2017. Sampling is scheduled to continue on a 5-year cycle with the next sampling event occurring in CRMO in 2020 and CIRO in 2021/2022.

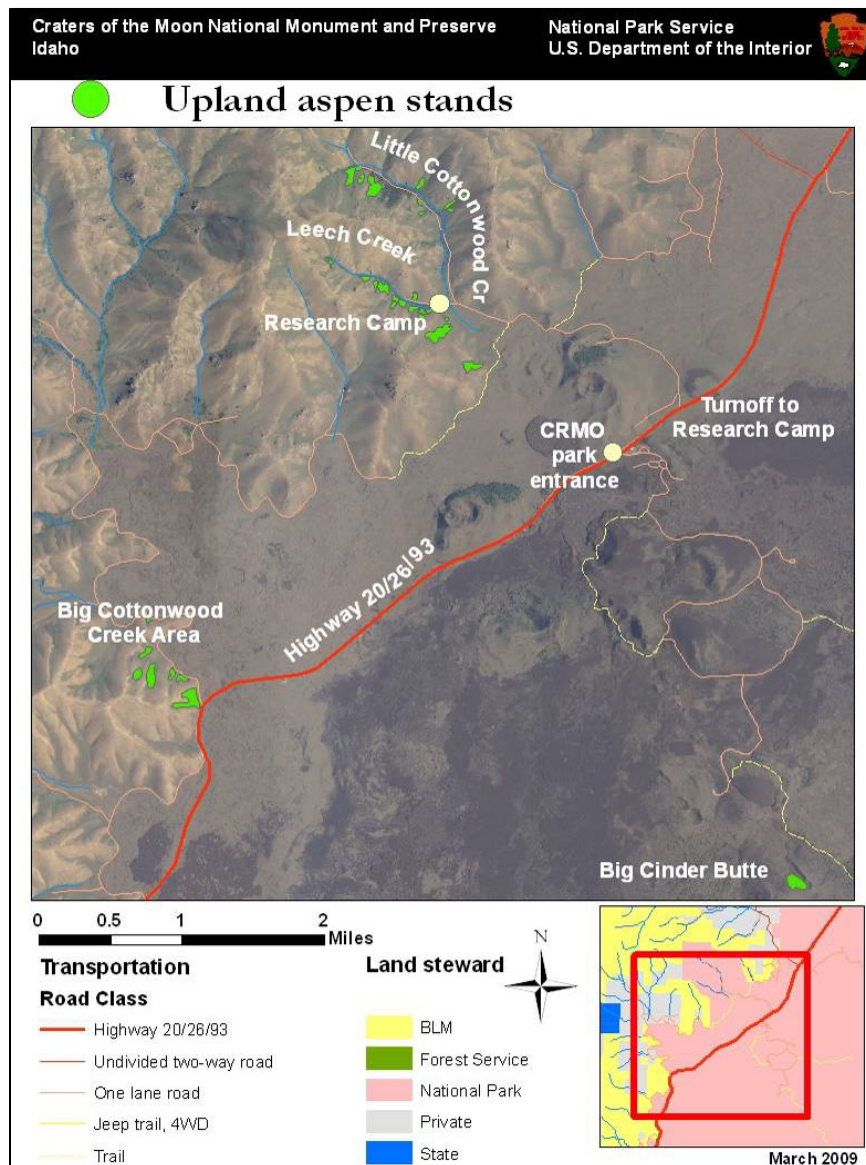


Figure 1. Map of aspen stands in CRMO. Stands are located in the Leech Creek, Little Cottonwood Creek, and Big Cottonwood Creek drainages. The aspen stand on Big Cinder Butte was removed from the CRMO sampling panel in 2010.

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. Sampling through 2017 has been completed according to this design.

Panel	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1 - CRMO	X	–	–	X	–	–	–	–	X	–	–	–	–	X	–	–	–	–	X	–	–
2 - CIRO1	–	X	–	–	X	–	–	–	–	X	–	–	–	–	X	–	–	–	–	X	–
3 - CIRO2	–	–	X	–	–	X	–	–	–	–	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. 2009b). 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 108 plots were placed within 22 stands in CRMO in 2007 (Figure 1) and in 2010, 102 of those plots were re-visited (Figures 2–4). Stand #34 located on Big Cinder Butte was not re-sampled in 2010 and will not be sampled in the future due to difficult access and unstable substrate composed of cinder.

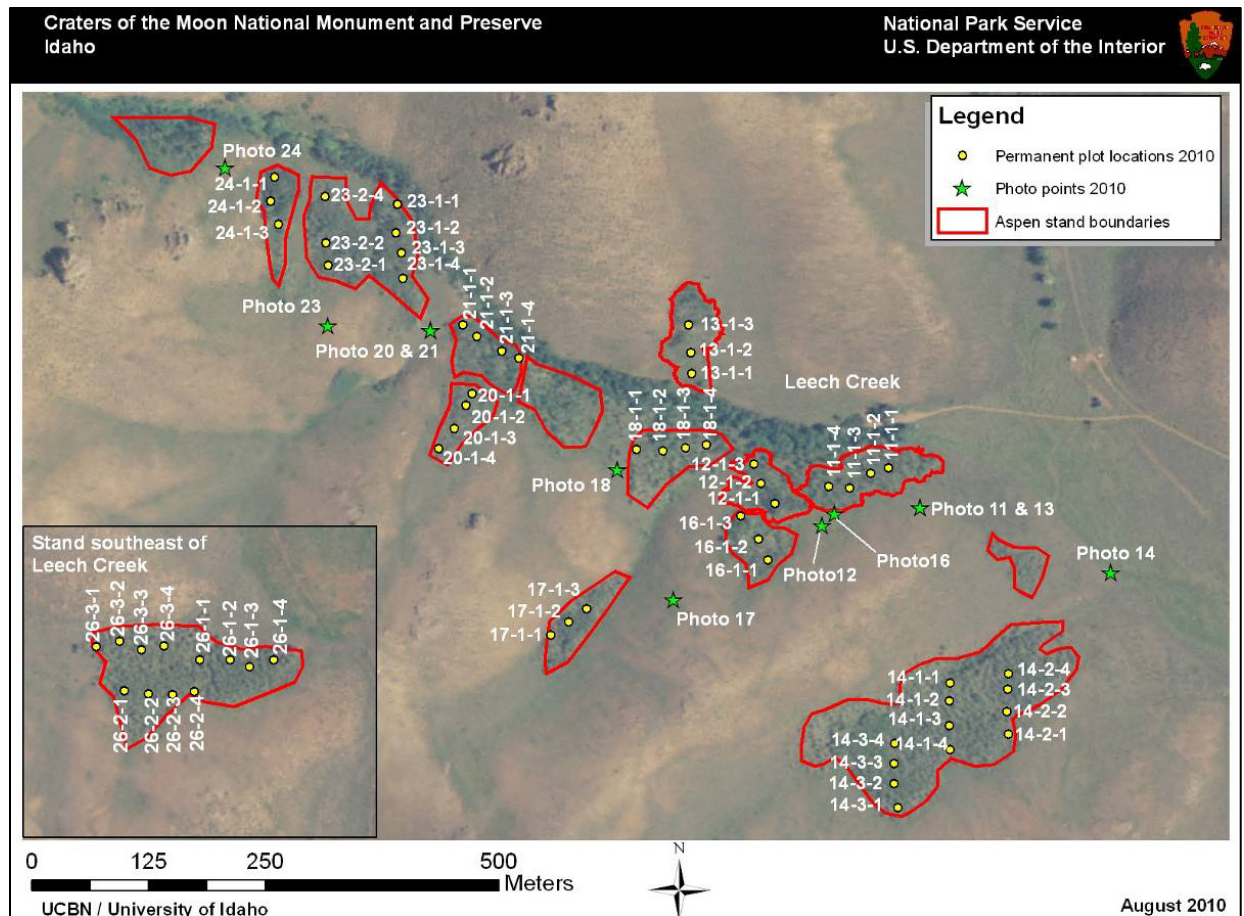


Figure 2. Aspen stands and plots in the Leech Creek drainage. Stands with no plots are excluded from sampling based on criteria described in the objectives.

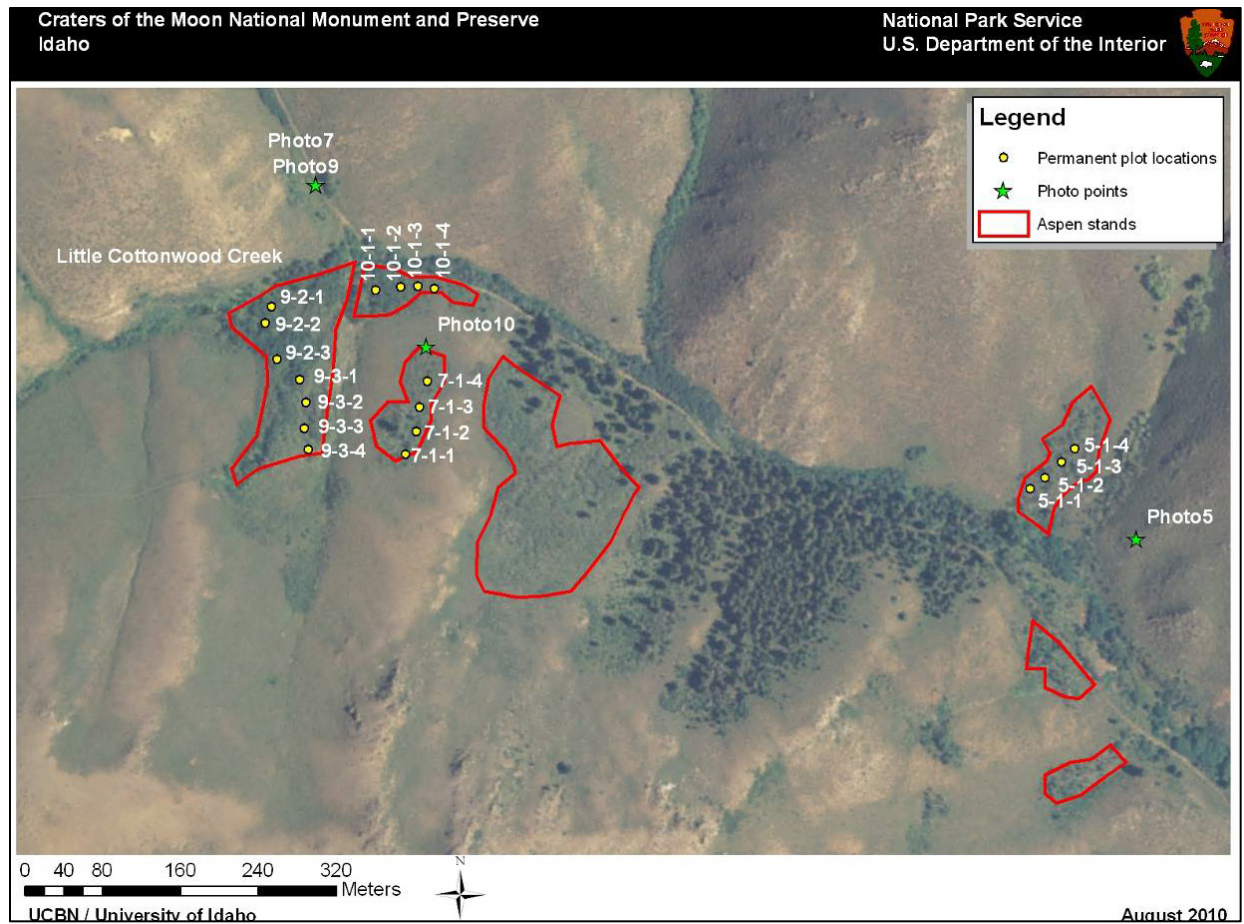


Figure 3. Aspen stands and plots in the Little Cottonwood drainage. Stands with no plots are excluded from sampling based on criteria described in the objectives.

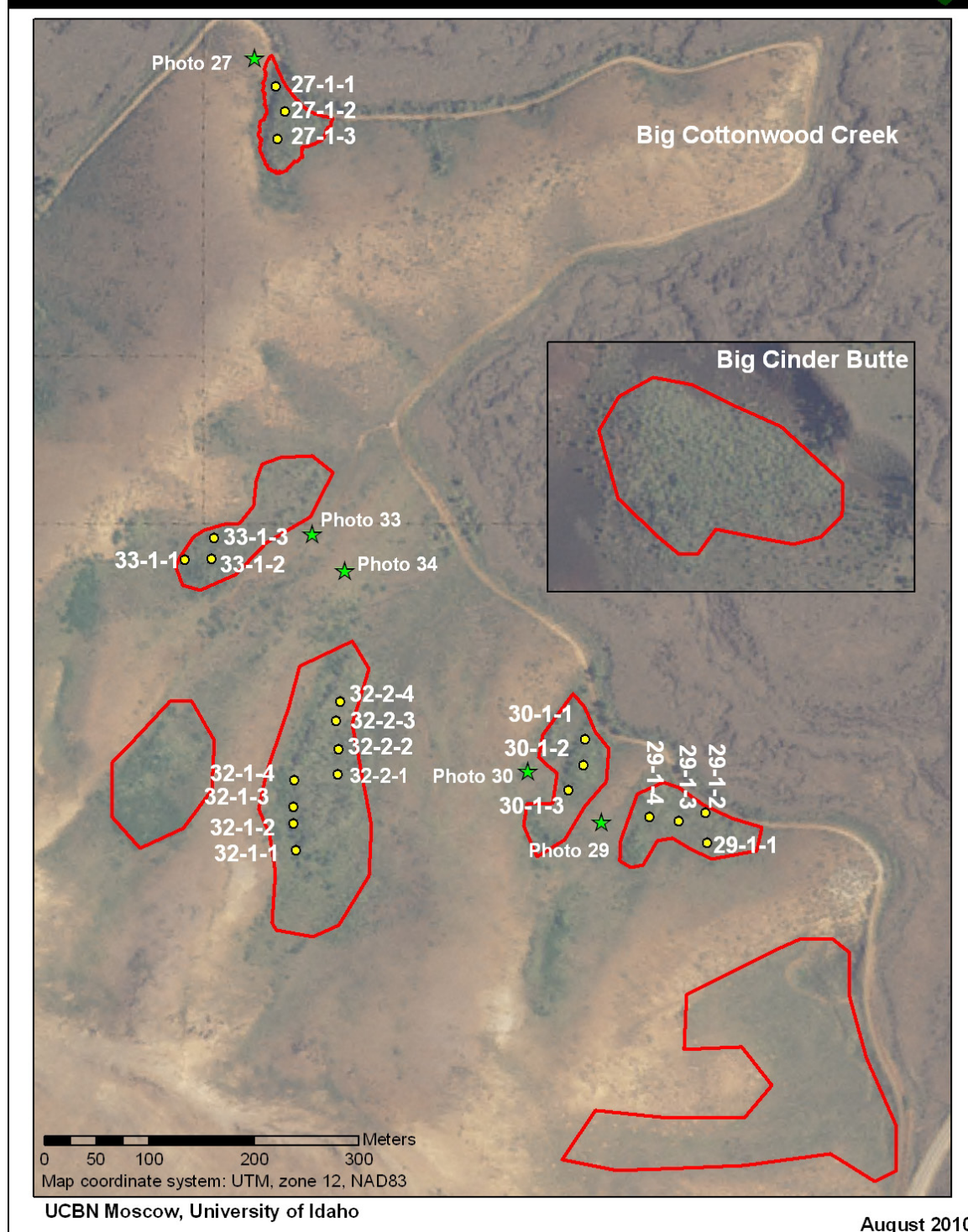


Figure 4. Aspen stands and plots in the Big Cottonwood drainage. Stands with no plots are excluded from sampling based on criteria described in the objectives.

It should be noted that in 2007 in CRMO, permanent markers were only established for the first plot in each transect. Due to difficulties in relocating plots, all plots were monumented in 2008. Consequently, measurements in plots numbered 2, 3, or 4 in each transect, may not have been taken exactly at the same location in 2010 as in 2007.

Panel 2, consisting of 85 plots in 15 stands in CIRO, was sampled in 2008, 2011, and 2016, and panel 3 consisting of 49 plots in 10 stands was sampled in 2009, 2012, and 2017. Stand #13 and #50 were not sampled during the first sampling period because they were mistakenly thought to be located on private land. The current panels (2 and 3) in CIRO consist of 134 plots in 25 stands (Figure 5). Detailed maps for the stands in CIRO are in Figures 6–12 by sampling unit. Sampling units are only used for mapping purposes.



Aspen stands and sampling units

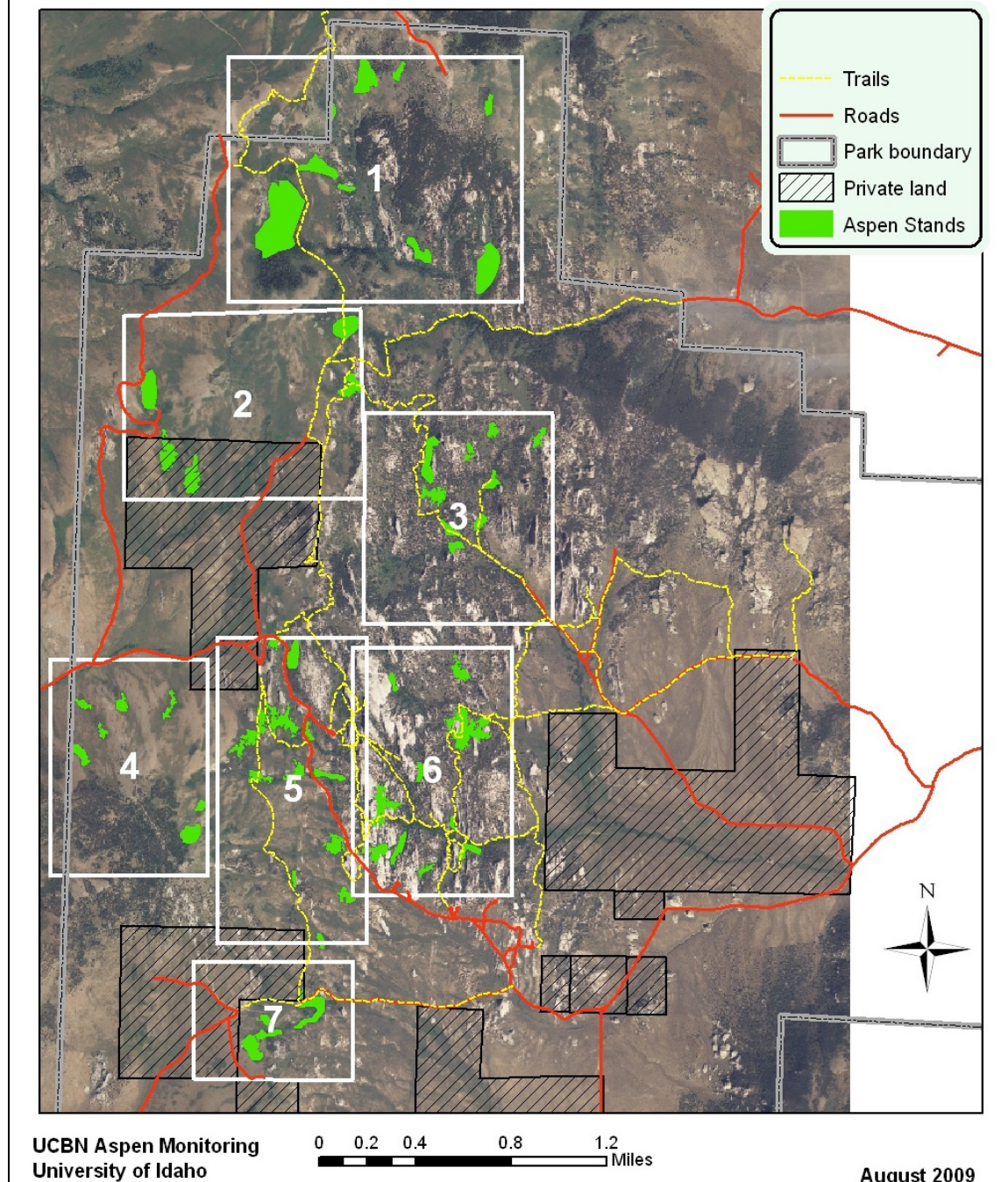
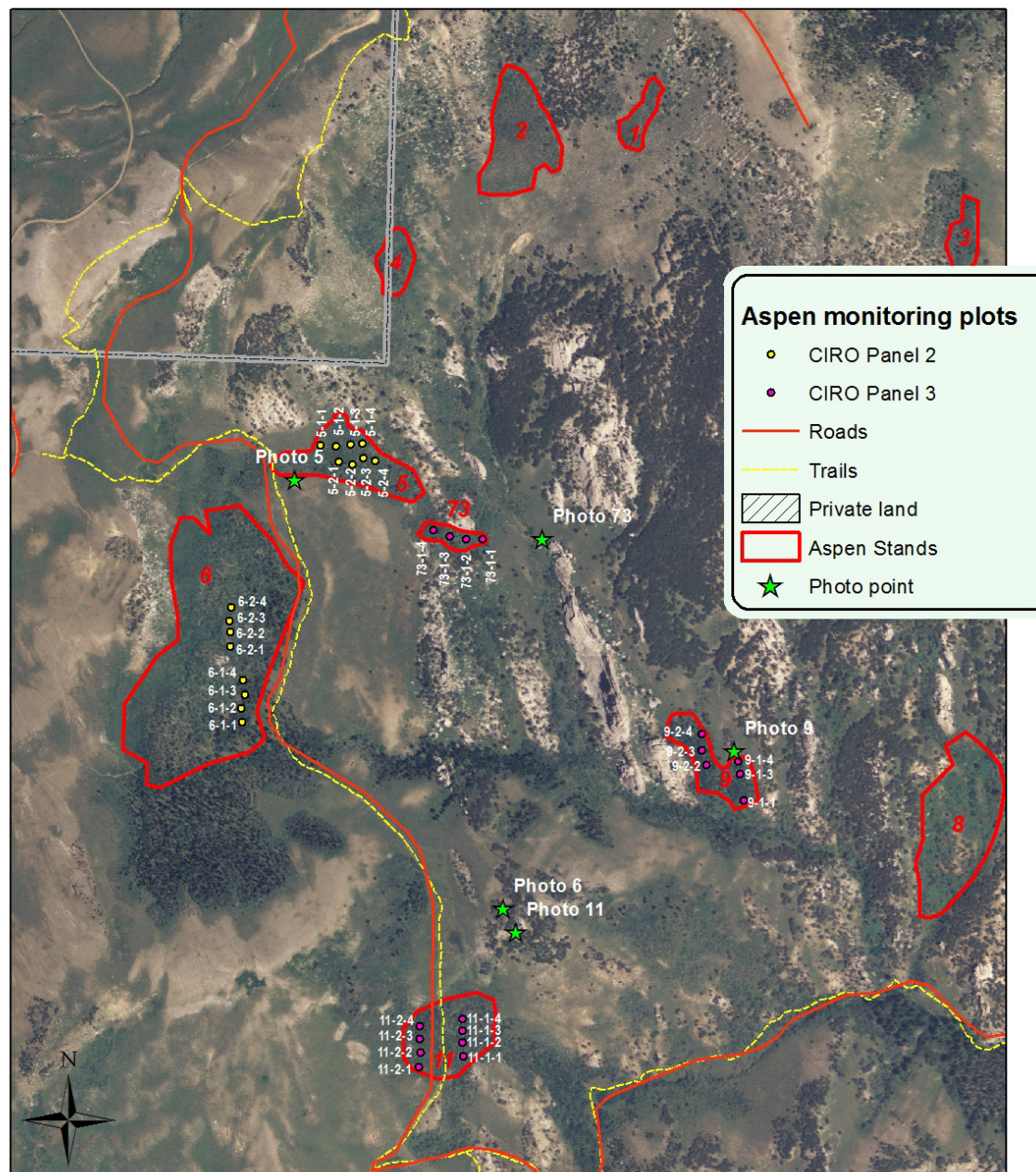


Figure 5. Map of aspen stands in CIRO. A total of 57 aspen stands have been identified of which 25 stands are selected for sampling. The stands in CIRO are divided into 2 panels and 7 sampling units. The panels are not shown.



Aspen stands - Unit 1



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0 0.125 0.25 0.5 Miles

October 2012

Figure 6. Aspen stands and plots in CIRO, sampling unit 1. Stands with no plots are excluded from sampling based on criteria described in the objectives.



Aspen stands - Unit 2

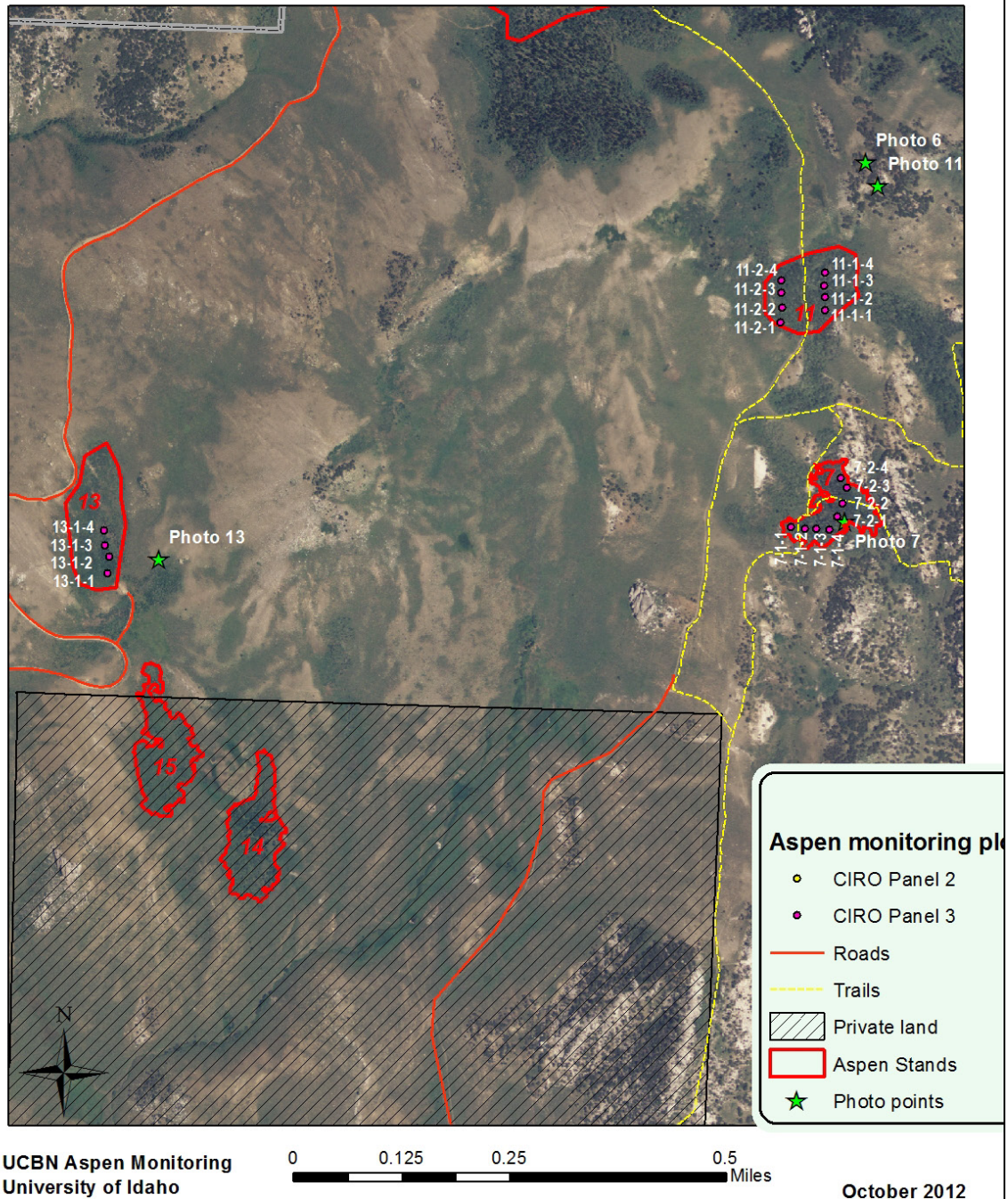


Figure 7. Aspen stands and plots in CIRO, sampling unit 2. Stands with no plots are excluded from sampling based on criteria described in the objectives.



Aspen stands - Unit 3

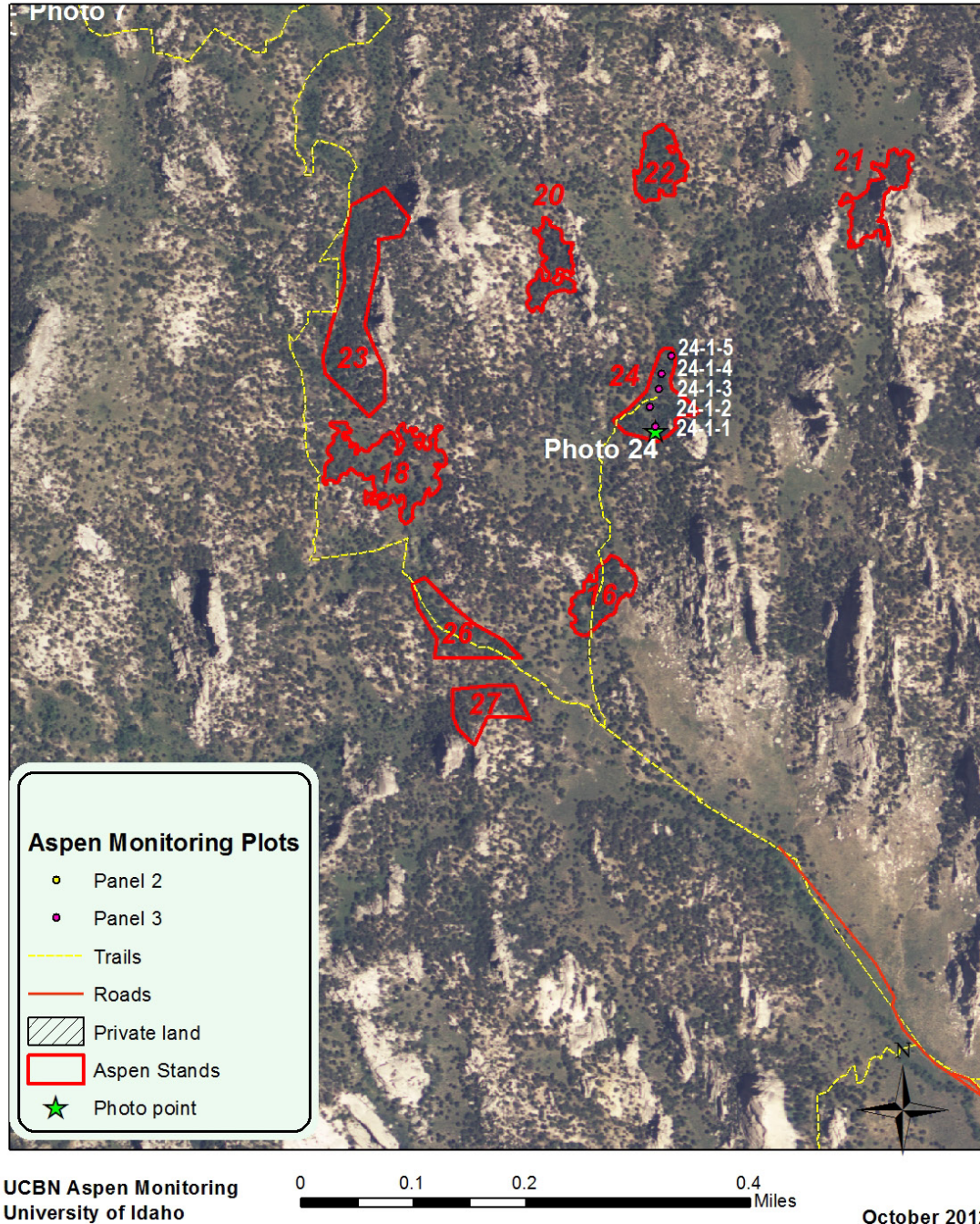
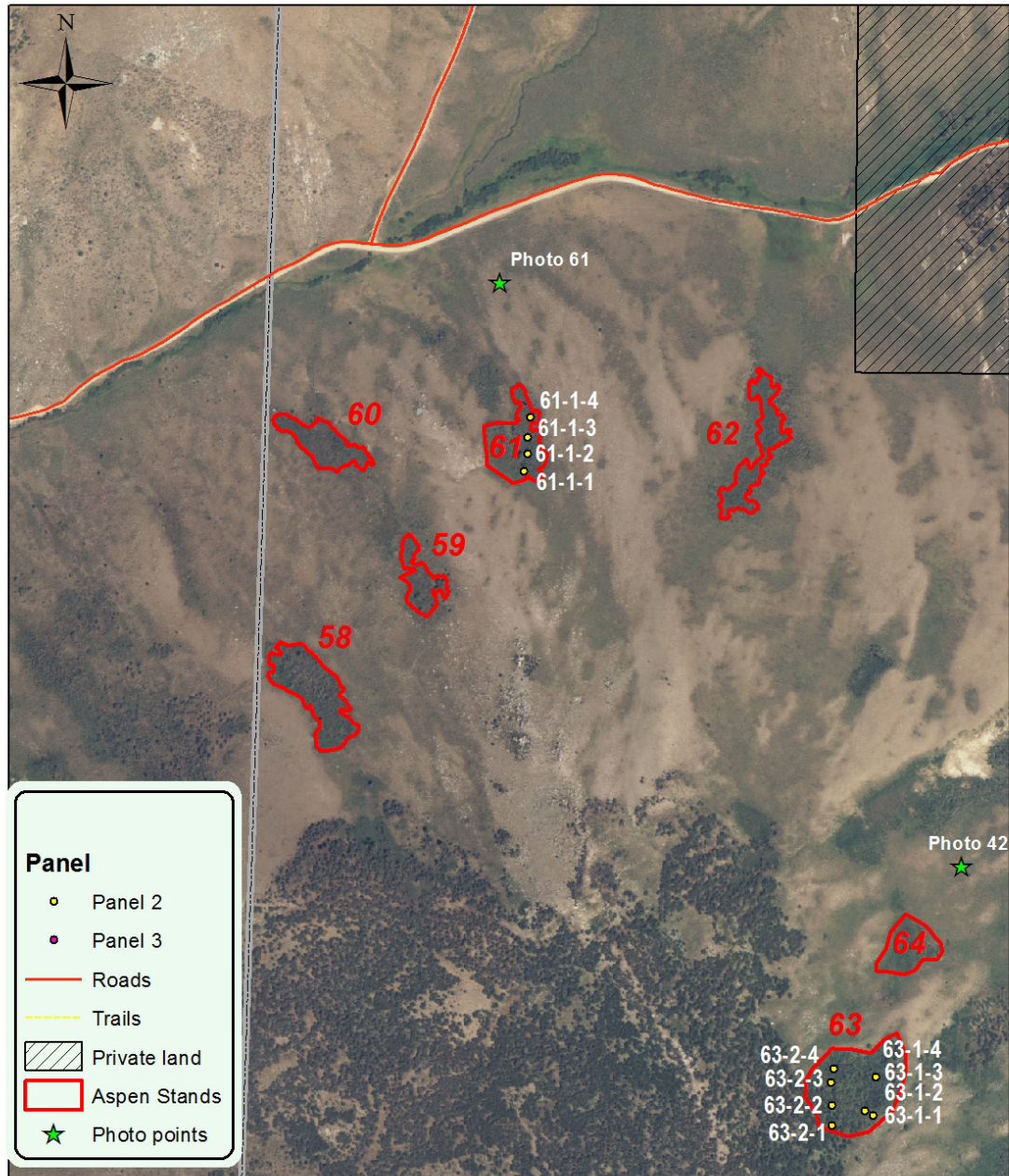


Figure 8. Aspen stands and plots in CIRO, sampling unit 3. Stands with no plots are excluded from sampling based on criteria described in the objectives.



Aspen stands - Unit 4



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0 0.1 0.2 0.4 Miles

October 2012

Figure 9. Aspen stands and plots in CIRO, sampling unit 4. Stands with no plots are excluded from sampling based on criteria described in the objectives.



Aspen stands - Unit 5

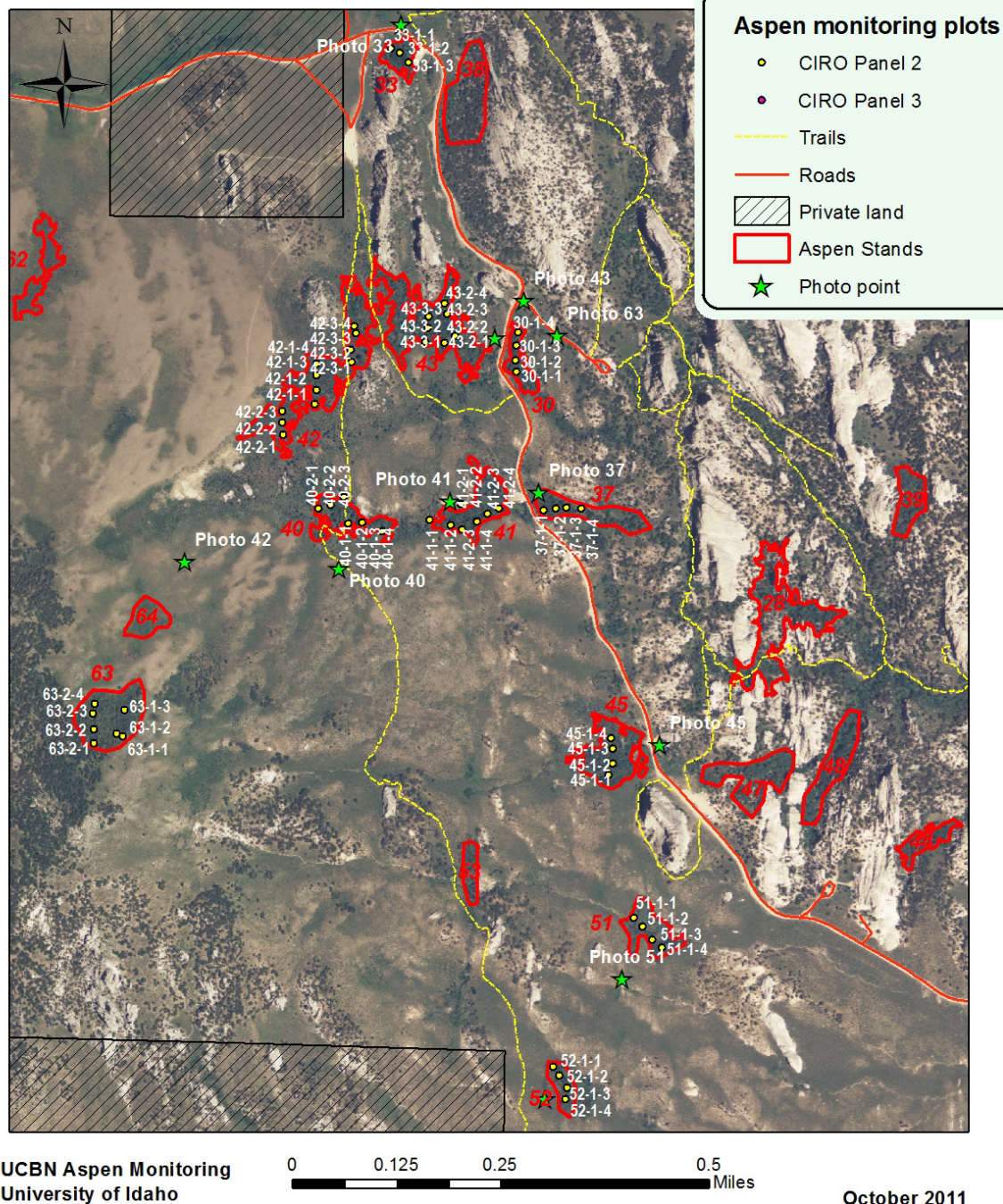


Figure 10. Aspen stands and plots in CIRO, sampling unit 5. Stands with no plots are excluded from sampling based on criteria described in the objectives.



Aspen stands - Unit 6

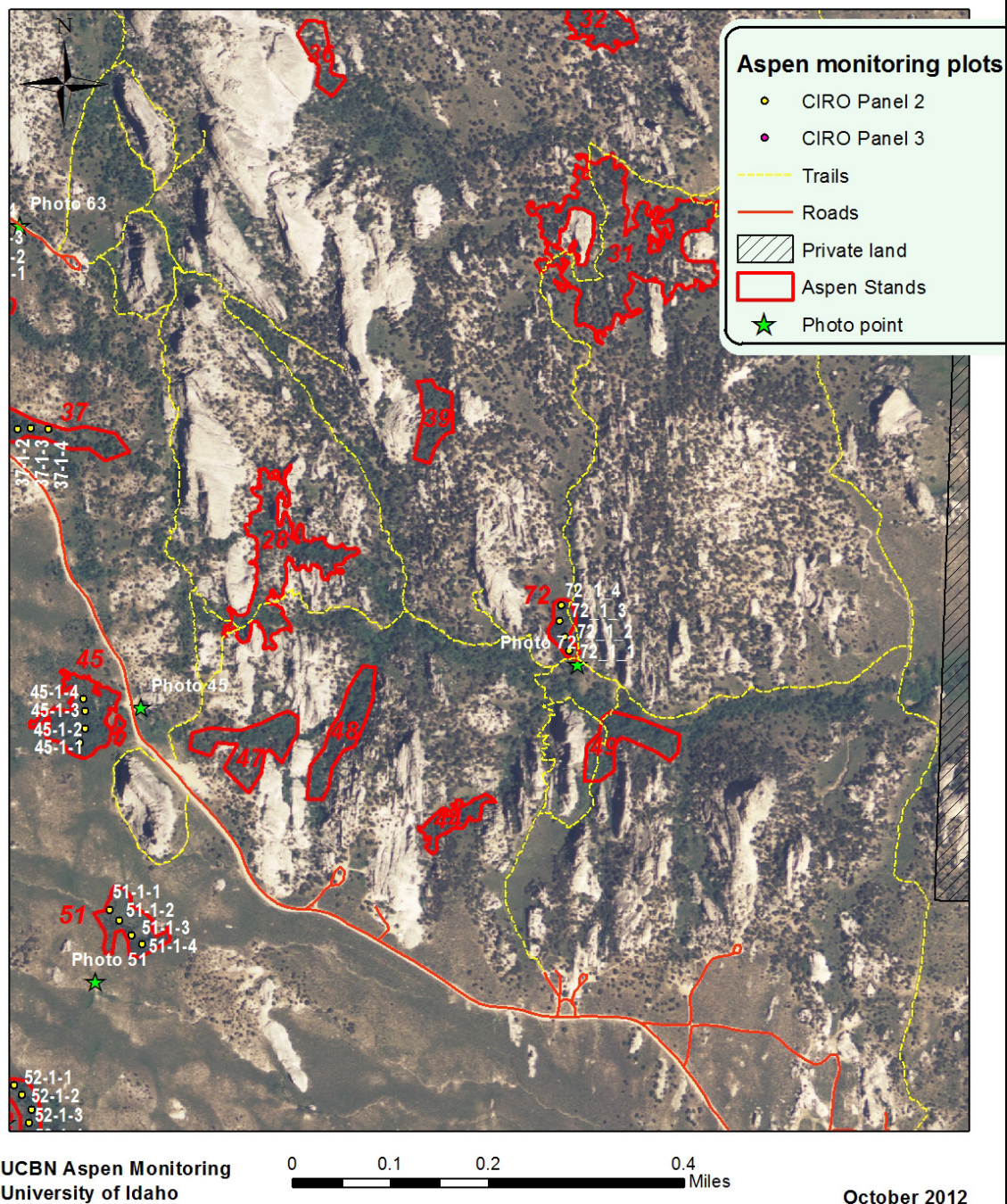
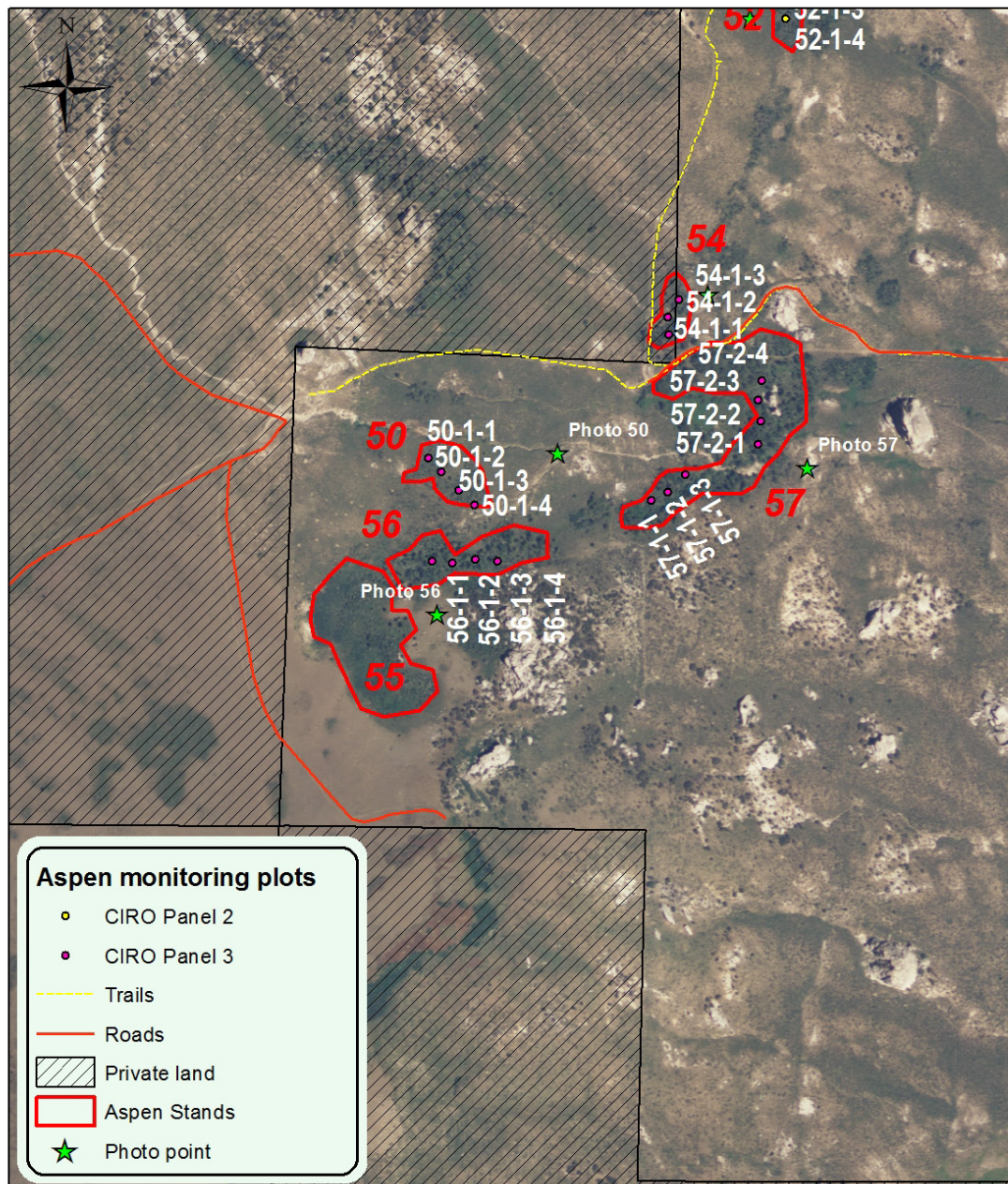


Figure 11. Aspen stands and plots in CIRO, sampling unit 6. Stands with no plots are excluded from sampling based on criteria described in the objectives.



Aspen stands - Unit 7



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0 0.05 0.1 0.2 Miles

October 2012

Figure 12. Aspen stands and plots in CIRO, sampling unit 7. Stands with no plots are excluded from sampling based on criteria described in the objectives.

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 plots were counted. Aspen suckers or conifer seedlings shorter than 15 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.

Table 2. Size classes of aspen and conifer stems.

Class	Description
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

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 Figures 2–4 for CIRO and Figures 6–12 for CIRO.

Relocation rate and bearing trees

Relocation rate of plot center was overall about 95%. Even though the relocation rate of plots was high, we decided to add bearing trees in locations where we had difficulties relocating the rebar monument at the plot centers. Bearing trees are tagged with a circular aluminum metal plate with a unique engraved number. The tag is fastened around the tree with metal wire, loosely tied around the trunk of the tree to allow for tree growth until the next sampling instance which will occur in 5 years. The wire may need to be replaced if it is tight around the tree at the next sampling event. A new entry has been made in the aspen database for bearing tree specifications which includes: distance from plot center, direction from plot center (azimuth), bearing tree species, bearing tree tag number.

Statistical analysis

UCBN personnel plan to monitor trends in counts of aspen and conifer tree stems within four size classes in CRMO and CIRO. In CRMO, 21 stands were visited in 2007, 2010 and 2015 (panel 1). In CIRO 15 stands were visited in 2008, 2011, and 2016 (panel 2) and 10 stands were visited in 2009,

2012, and 2017 (panel 3). Data from these aspen stands were used to test for a change between the three sampling periods.

The response design incorporates one to three transects per aspen stand with the number of transects chosen proportionally to the size of each stand. Three to twelve plots were located within each stand. The outcome of interest is the number of aspen and conifer stems, and these counts are obtained within each 4-m radius plot and summarized to the stand level. Analysis is not performed at the transect level.

Aspen and conifer stem counts were summarized by park unit (CRMO and CIRO) and were statistically compared by panel by sampling period for four size groups: suckers/seedlings, regeneration, mature trees, and dead trees. Average stem counts per stand and standard deviations were calculated for each combination of tree type (aspen and conifer), park unit, and sample year. Stands included in panel 2 in CIRO are #5, #6, #30, #33, #37, #40, #41, #42, #43, #45, #51, #52, #61, #63 and #72 and stands in panel 3 are #7, #9, #11, #13, #24, #50, #54, #56, #57, and #73. The year effect is examined independently within each size group by tree type with a linear mixed model (lmer) in the R statistical software. A test of the null hypothesis of no difference ($\alpha=0.05$) in aspen stem counts versus the two-sided alternative hypothesis of a difference in either direction is conducted to assess change in stem counts between time periods. The R-code for the computations is included in Appendix A.

Results

Park and stand level stem density

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 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 CRMO during the sampling seasons 2007, 2010, and 2015 and CIRO 2008/09, 2011/12, and 2016/17 (Table 3).

Table 3. Park stem density (stems/ha) by size class for aspen and conifers during the three sampling periods 2007–2017.

Park	Panel	Year	Aspen Stem Density				Conifer Stem Density			
			Suckers ¹	Regen ²	Mature ³	Dead ⁴	Seedling ¹	Regen ²	Mature ³	Dead ⁴
CRMO	1	2007	4,839	1,545	818	1,009	48	6	14	20
CRMO	1	2010	5,723	2,001	741	1,001	68	14	8	0
CRMO	1	2015	3,955	2,668	683	724	59	43	6	0
CIRO	2&3	2008/09	2,463	2,235	416	316	27	103	31	4
CIRO	2&3	2011/12	5,204	2,441	760	342	67	112	31	21
CIRO	2&3	2016/17	3,912	2,557	840	230	141	67	59	0

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

² Regeneration includes trees taller than 5 feet 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 that are greater than 2.5 cm (1 inch) in dbh.

Aspen and conifer stem density by stand is summarized by sampling period for CRMO (Table 4 and 5) and for CIRO (Table 6 and 7). Most of the aspen stands sampled in CRMO and CIRO 2015–2017 are suckering, regenerating and contain a distribution of age classes. Regeneration lower than 1000 stems/ha was recorded in three stands in CRMO in 2015: stand #5 (796 stems/ha), stand #26 (663 stems/ha), and stand #27 (597 stems/ha). Density of mature aspen stems lower than 100 stems/ha was recorded in four stands in CRMO in 2015: stand #5 (50 stems/ha), stand #12 (66 stems/ha), stand #13 (0 stems/ha), and stand #20 (0 stems/ha). The aspen stem density in stand #5 has been decreasing through time from 348 stems/ha in 2007 to 99 stems /ha in 2010 to 50 stems/ha in 2015. The regeneration in the stand has increased from 348 stems/ha in 2007 to 796 stems/ha in 2015 and the suckering has been constant (2188–3432 suckers/ha). The density of mature aspen stems in stand #13 has been 0 since monitoring started, but the stem count in the regeneration class has increased from 796 stems/ha in 2007 to 3714 stems/ha in 2015. The density of mature aspen stems in stand #20 has been decreasing through time from 547 stems/ha in 2007 to 249 stems/ha in 2010 to 0 stems/ha in 2015, while the regeneration has steadily increased from 2835 stems/ha in 2007 to 8405 stems/ha in 2015 with strong suckering (> 8000 suckers/ha). Density of dead aspen stems is variable between

stands ranging from 0 to 2387 dead stems/ha. Density of dead aspen stems is also variable through time within stands as live stems die and dead stems fall to the ground.

Table 4. Aspen stem density (stems/ha) in CRMO stands sampled in 2007, 2010, and 2015.

Stand #	2007				2010				2015			
	Sucker	Regen	Mature	Dead	Sucker	Regen	Mature	Dead	Sucker	Regen	Mature	Dead
5	2188	348	348	249	3780	647	99	398	3432	796	50	298
7	7361	2636	398	2636	2934	4128	298	945	1989	3332	647	348
9	4775	1393	895	1061	3808	2529	824	1847	2615	3212	1023	1364
10	4974	2387	1492	1790	2039	3084	945	1840	1691	3233	846	1790
11	9276	920	1219	1343	14821	995	1542	647	12136	2039	945	746
12	3846	398	663	862	4178	1658	663	398	2056	3382	66	199
13	3050	796	0	133	2056	3117	0	0	1260	3714	0	0
14	3888	597	669	723	8140	1127	713	448	3929	2089	497	547
16	7759	796	464	133	6565	2586	332	265	3581	4244	133	133
17	3647	66	1127	2188	7361	928	398	1857	8820	1857	199	464
18	5322	2537	249	448	4526	3929	348	348	3531	4228	398	249
20	14622	2835	547	1243	19894	4128	249	1094	8206	8405	0	895
21	1492	3034	796	50	4377	2288	149	647	2288	2188	298	99
23	1865	2014	1293	746	3098	1279	654	881	1790	1563	824	654
24	1393	729	862	995	995	1194	796	663	1923	1260	597	398
26	497	431	1459	1111	846	282	1376	1144	779	663	1111	912
27	2719	1459	1393	1326	1459	995	1658	597	1194	597	1857	464
29	13180	995	547	1592	11937	2039	696	2089	14772	2139	696	1492
30	2387	1790	928	531	4775	1724	862	1393	3846	1127	1194	1260
32	6913	1542	448	1194	7063	1815	547	1044	5421	2611	547	323
33	11870	8555	862	1393	10544	11539	1459	2653	4178	10279	1790	2387

Table 5. Conifer stem density (stems/ha) in CRMO stands sampled in 2007, 2010, and 2015.

Stand #	2007				2010				2015			
	Sucker	Regen	Mature	Dead	Sucker	Regen	Mature	Dead	Sucker	Regen	Mature	Dead
5	0	0	0	0	149	0	0	0	0	0	0	0
7	0	0	0	0	149	0	0	0	149	50	0	0
9	0	0	232	0	149	0	0	0	28	0	0	0
10	0	0	0	0	149	99	0	0	249	149	0	0
11	50	0	0	0	0	50	50	0	0	0	0	0
12	133	0	0	0	133	0	0	0	66	66	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0
14	90	0	0	0	182	66	0	0	83	99	17	0
16	0	0	0	0	265	0	0	0	133	66	0	0
17	0	0	0	0	0	0	0	0	66	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0
20	50	0	0	0	50	0	0	0	50	50	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	199	0	0	0	0	0	0	0	0
26	149	50	0	0	99	0	33	0	66	66	17	0
27	199	0	0	0	265	0	0	0	398	199	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	66	0	0	0	66	0
32	75	0	0	0	25	0	0	0	25	25	0	0

Table 6. Aspen stem density (stems/ha) in CIRO stands sampled 2008–2017. ND = no data collected.

Stand #	2008/2009				2011/2012				2016/2017			
	Sucker	Regen	Mature	Dead	Sucker	Regen	Mature	Dead	Sucker	Regen	Mature	Dead
5	2700	1449	654	114	1790	1819	1108	256	2711	2512	870	174
6	2462	3506	373	124	1840	4277	224	274	1393	3631	671	174
7	1616	3855	174	771	1194	3357	696	771	696	2586	1069	298
9	3017	2918	464	398	8223	3050	232	265	1757	2752	696	166
11	1393	2537	448	547	2188	2387	572	448	881	1961	682	313
13	ND	ND	ND	ND	6864	2039	1840	149	4228	3183	1840	199
24	597	279	239	80	2905	119	438	40	2745	279	279	159
30	3233	2586	597	99	9102	4029	448	746	6515	3084	647	547
33	2188	1923	265	66	66513	3581	2056	265	65055	4576	2056	66
37	5123	2934	298	149	9500	3979	249	249	5919	4178	348	199
40	1592	1790	149	99	2735	1691	696	149	2188	2089	862	0
41	1421	1222	540	171	1790	1478	1052	256	1790	2188	966	171
42	2984	2122	619	486	2829	3316	951	265	1212	4178	850	199
43	4741	1194	564	431	8256	1260	729	332	6395	1989	597	284
45	4526	2537	448	50	4377	2387	1243	149	7162	3780	1989	66
50	ND	ND	ND	ND	1293	1641	846	149	895	1840	895	99
51	2537	995	995	249	1492	895	945	547	597	796	647	249
52	2934	2487	696	249	4228	3283	1044	597	1790	3531	1194	348
54	2852	2586	66	133	4111	729	1592	0	796	1094	1691	0
56	2437	2586	199	298	13279	1741	1243	348	7858	1592	1243	398
57	6650	3240	313	284	5713	3894	455	369	2420	2852	763	431
61	5836	1790	663	796	1459	1592	464	729	1293	2934	298	647
63	1293	1326	332	199	1592	1094	597	265	881	1592	540	85
72	1741	1194	348	0	1243	1243	199	0	1890	1243	149	0
73	2288	3332	448	895	1741	3581	348	1044	1724	1393	531	663

Table 7. Conifer stem density (stems/ha) in CIRO stands sampled 2008–2017. ND = no data collected.

Stand #	2008/2009				2011/2012				2016/2017			
	Sucker	Regen	Mature	Dead	Sucker	Regen	Mature	Dead	Sucker	Regen	Mature	Dead
5	0	0	0	85	0	0	0	0	0	0	0	0
6	25	497	75	0	25	99	50	25	50	100	100	0
7	0	0	0	0	0	0	0	0	0	0	0	0
9	0	99	0	0	33	33	0	0	0	33	33	0
11	0	0	0	0	0	0	0	0	0	0	0	0
13	ND	ND	ND	ND	0	0	0	0	0	0	0	0
24	80	80	0	0	40	80	0	40	0	80	0	0
30	0	50	50	0	0	99	50	0	50	100	50	0
33	0	0	0	0	0	0	0	0	0	0	0	0
37	50	199	298	50	298	249	249	0	348	100	547	0
40	0	149	149	0	50	99	0	0	298	133	66	0
41	28	114	57	0	85	0	0	0	455	0	0	0
42	0	0	0	0	0	111	22	0	36	54	36	0
43	99	33	33	33	99	166	133	0	853	85	199	0
45	99	99	0	0	348	50	0	0	133	199	0	0
50	ND	ND	ND	ND	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	50	0	0	0
52	0	0	0	0	0	0	0	0	0	0	0	0
54	0	199	0	0	199	398	0	0	497	398	99	0
56	99	50	50	0	249	149	50	0	298	249	50	0
57	85	369	0	0	227	341	57	0	398	365	199	0
61	0	0	0	0	0	0	0	464	0	0	0	0
63	0	0	0	0	0	0	0	0	0	0	0	0
72	99	50	0	0	0	99	0	0	0	0	100	0
73	0	50	149	0	0	99	50	0	0	66	133	0

In CIRO, regeneration lower than 1000 stems/ha was recorded in two stands in 2016–2017: stand #24 (279 stems/ha) and stand #51 (796 stems/ha). The stand with the lowest mature aspen stem count in CIRO was stand #72 (149 stems/ha). The regeneration in stand #24 has been consistently low through time, 279, 119, 279 stems/ha during the three sampling periods; the mature stem density has maintained at 279 stems/ha through time while suckering has increased from 597 suckers/ha in 2007 to 2745 suckers/ha in 2015. In stand #51 regeneration has been decreasing through time 995, 895, 796 stems/ha in the three sampling periods and so has mature aspen stem density (995, 945, 647 stems/ha during the three sampling periods) and suckering has decreased from 2537 stems/ha in 2007 to 597 stems/ha in 2015. Even though stand #72 has a low density of mature aspen stems, regeneration is still at 1243 stems/ha in 2015 and suckering at 1890 stems/ha. In summary, even

though a few stands in both parks had a low to no density of mature aspen stems, they were still suckering and recruitment of young aspen stems is occurring.

Conifer density was low in all stands in CRMO and in most stands in CIRO, however increases were observed in many stands in both parks between the start of the monitoring program in 2007 and the last sampling period 2015–2017 (Table 5 and 7). The number of stands with conifers in the seedling class in CRMO increased from seven in 2007 to eleven in 2015, with seedling density ranging from 25 to 398 stems/ha in 2015. The number of stands in CRMO with conifers in the regeneration class increased from one stand in 2007 to ten stands in 2015, with stem density ranging from 25 to 199 stems/ha in 2015. No mature conifers were recorded in CRMO. In CIRO, the number of stands with conifer seedlings increase from nine in 2008/2009 to twelve in 2016/2017 ranging from 50 to 497 stems/ha in 2016/2017 while the number of stands with conifer trees in the regeneration class stayed constant at 13–14 stands (33–398 stems/ha). The number of stands with mature conifers increased from eight to twelve in CIRO from 2008/2009 to 2016/2017, ranging from 33 to 597 stems/ha in 2016/2017. Stands with the highest mature stem density of conifers in CIRO are stand #37 (547 stems/ha), stand #43 (199 stems/ha) and #57 (199 stems/ha).

Several conifer species were present in the parks. The most common conifer species recorded in CRMO was limber pine (*Pinus flexilis*), followed by less common occurrences of Douglas-fir (*Pseudotsuga menziesii*), Rocky Mountain juniper (*Juniperus scopulorum*), and Utah juniper (*Juniperus osteosperma*). The most common conifer species recorded in CIRO was Rocky Mountain juniper followed by single-leaf pinyon, Utah juniper, and limber pine; with subalpine fir (*Abies lasiocarpa*) and lodgepole pine occurring in the highest elevation stands.

Distance photographs of the aspen stands sampled over three time periods in CRMO and CIRO 2007–2017 are compiled in Appendix B.

Statistical analysis of change, 2007–2017

Summary statistics were calculated for aspen and conifer size classes by sampling year and park. Distribution of aspen sucker count and conifer seedling count by stand in CRMO and CIRO panels 2007–2017 are displayed in Figure 13 (upper) and the estimated mean number of suckers and seedlings per plot (0.005 ha) are in Figure 13 (lower). Similar figures were created for the regeneration class (Figure 14), mature stems (Figure 15), and dead stems (Figure 16).

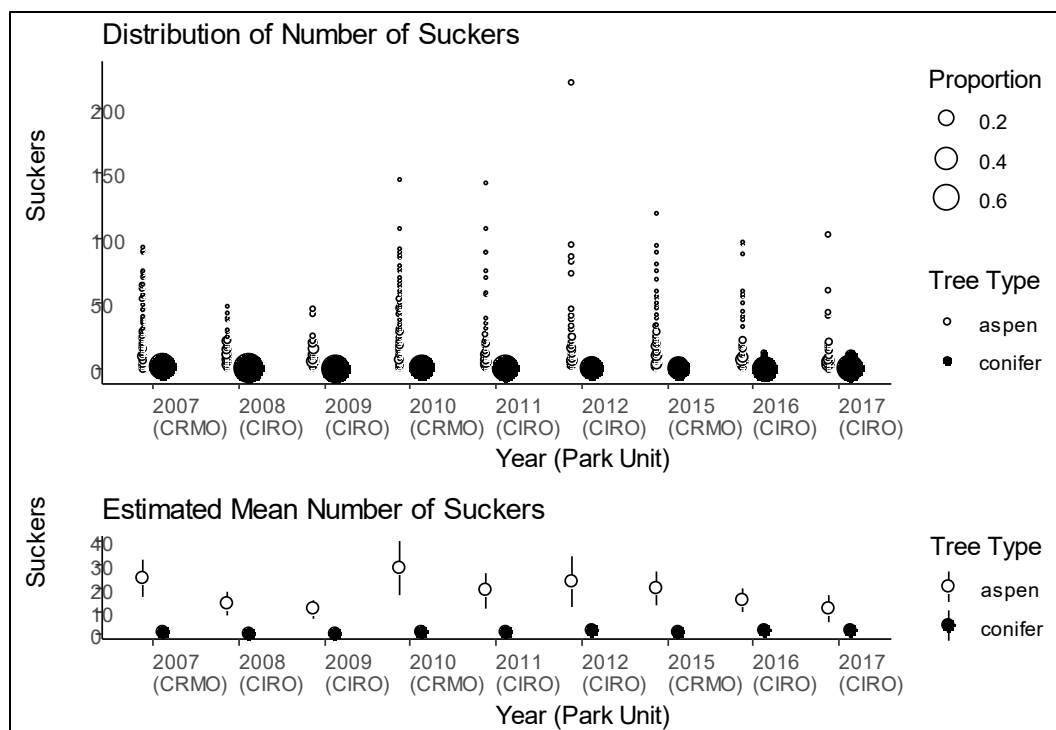


Figure 13. Distribution of aspen sucker count and conifer seedling count by stand in CRMO and CIRO panels 2007–2017; and estimated mean number of suckers and seedlings per plot (0.005 ha) by park unit and time period.

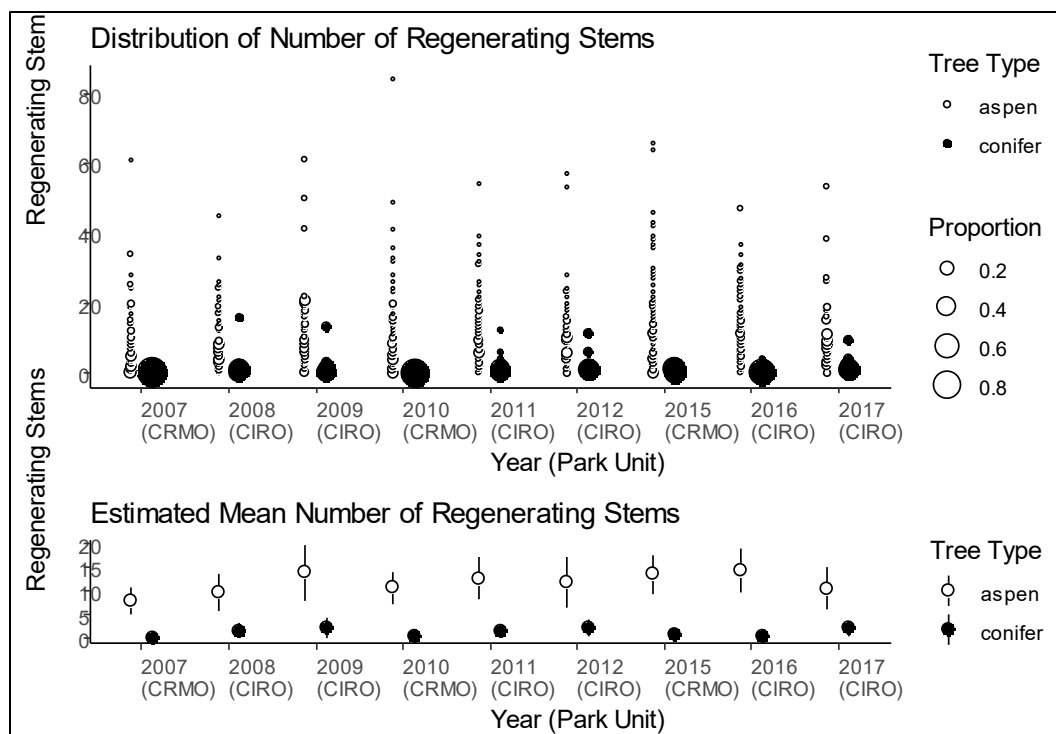


Figure 14. Distribution of aspen and conifer stem counts in the regeneration class by stand in CRMO and CIRO panels 2007–2017; and estimated mean number of stems in the regeneration class per plot (0.005 ha) by park unit and time period.

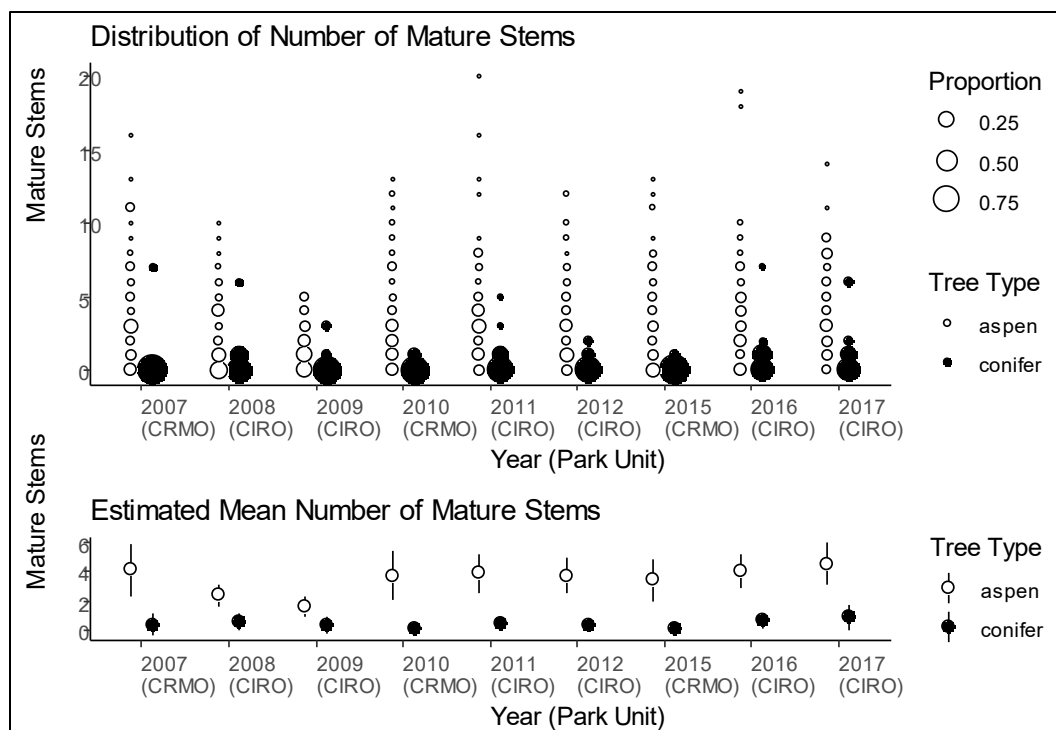


Figure 15. Distribution of aspen and conifer stem counts in the mature tree class by stand in CRMO and CIRO panels 2007–2017; and estimated mean number of stems in the mature class per plot (0.005 ha) by park unit and time period.

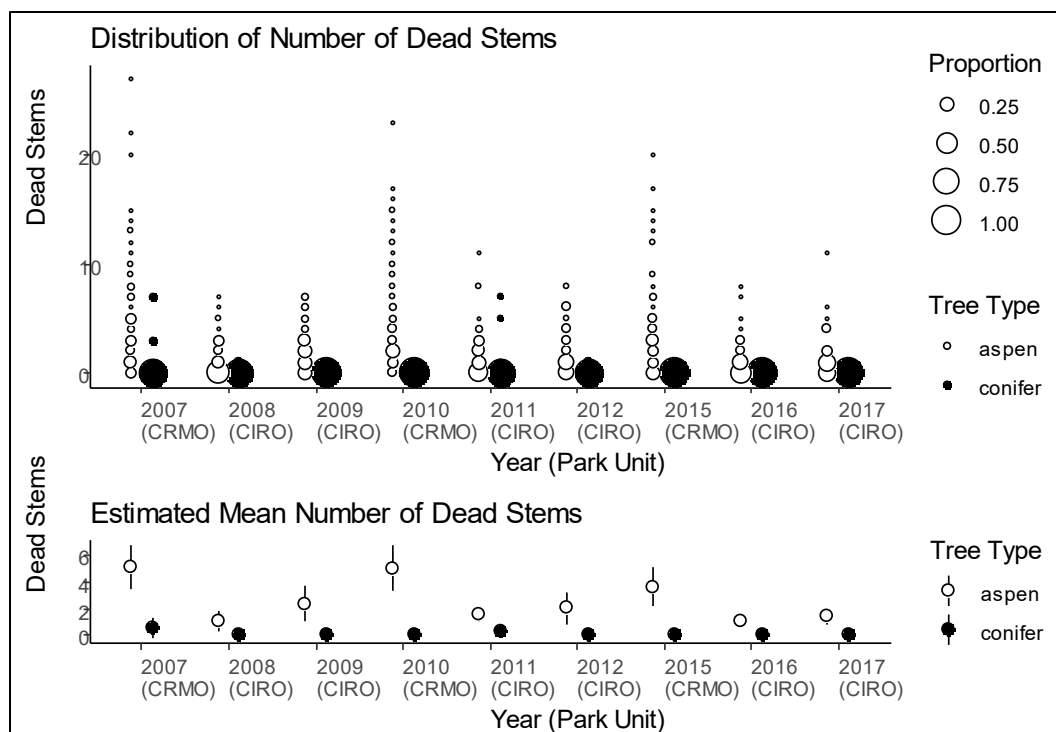


Figure 16. Distribution of aspen and conifer stem counts in the dead tree class by stand in CRMO and CIRO panels 2007–2017; and estimated mean number of stems in the dead class per plot (0.005 ha) by park unit and time period.

Change in time across aspen size class

Linear mixed model analysis was used to compare aspen stem counts between time periods within parks, results are summarized in Table 8 for CRMO and CIRO. Estimates of change were calculated for the difference between a subsequent sampling year and the first sampling year within each panel. Significant increases ($p < 0.05$) were detected for the regeneration class from 2007 to 2010 and from 2007 to 2015 in CRMO. A significant decrease in dead stems was detected between 2007 and 2015 in CRMO. There were no differences in sucker counts or mature stem counts in CRMO.

An increase in suckering was observed in panel 2 and 3 in CIRO between 2008/2009 and 2011/2012, but not between 2008/2009 and 2016/2017. Increases in the regeneration class and the mature class was observed in panel 2 in CIRO from 2008 to 2011 and 2008 to 2016. A decrease in regeneration was observed in panel 3 from 2009 to 2017. Mature stems increased by 2–3 stems per plot across all sampling periods in both panels. An increase in dead stems in panel 2 occurred between 2008 and 2011 but there was no difference between 2008 and 2016 or in panel 3 either time period.

Table 8. Difference in aspen stem counts per plot (0.005ha) between sampling periods in CRMO and CIRO. The estimate is the difference in stem count, se is the standard error, lower and upper 95% confidence intervals are reported and the t-statistic and p-value. Comparisons with $p < 0.05$ are in bold.

Park	Class	Year	estimate	se	lower	upper	t-value	p-value
CRMO	Sucker	2010–2007	3.05	3.23	–3.29	9.39	0.94	0.346
	Sucker	2015–2007	–5.51	3.23	–11.85	0.83	–1.70	0.088
	Regen	2010–2007	3.61	1.38	0.91	6.32	2.62	<0.001
	Regen	2015–2007	6.23	1.38	3.53	8.94	4.52	<0.001
	Mature	2010–2007	–0.41	0.40	–1.18	0.37	–1.03	0.302
	Mature	2015–2007	–0.62	0.40	–1.40	0.15	–1.57	0.116
	Dead	2010–2007	–0.14	0.65	–1.41	1.13	–0.22	0.826
	Dead	2015–2007	–1.62	0.65	–2.90	–0.35	–2.49	0.013
CIRO	Sucker	2011–2008	10.89	4.42	2.23	19.55	2.46	0.014
	Sucker	2016–2008	5.81	4.42	–2.85	14.47	1.31	0.189
	Sucker	2012–2009	12.97	5.85	1.51	24.43	2.23	0.027
	Sucker	2017–2009	0.86	5.85	–10.60	12.32	0.15	0.883
	Regen	2011–2008	2.76	0.99	0.83	4.69	2.80	<0.001
	Regen	2016–2008	4.28	0.99	2.35	6.21	4.34	<0.001
	Regen	2012–2009	–2.46	1.31	–5.02	0.11	–1.87	0.061
	Regen	2017–2009	–3.61	1.31	–6.18	–1.04	–2.76	0.006
	Mature	2011–2008	1.59	0.60	0.42	2.77	2.66	0.008
	Mature	2016–2008	1.75	0.60	0.58	2.92	2.92	0.003
	Mature	2012–2009	2.23	0.79	0.68	3.78	2.82	0.005
	Mature	2017–2009	2.93	0.79	1.38	4.48	3.70	<0.001
	Dead	2011–2008	0.57	0.24	0.10	1.05	2.36	0.018
	Dead	2016–2008	0.05	0.24	–0.43	0.52	0.19	0.848
	Dead	2012–2009	–0.16	0.32	–0.79	0.47	–0.49	0.625
	Dead	2017–2009	–0.62	0.32	–1.25	0.013	–1.92	0.054

Change in time across conifer size class

Linear mixed model analysis was used to compare conifer stem counts between time periods within parks. Results are summarized for conifers (Table 9). A significant increase in conifers in the regeneration class was detected for CRMO between 2007 and 2015. There was no detectable difference between any other size classes through time in CRMO. A significant increase in conifer seedlings by 1.56 seedlings per plot on average was detected in panel 3 in CIRO from 2009 to 2017. In CIROs panel 2 we detected a significant decrease of conifers in the regeneration class from 2008 to 2016. No changes were detected in the mature or dead classes for conifers.

Table 9. Difference in conifer stem counts per plot (0.005ha) between sampling periods in CRMO and CIRO. The estimate is the difference in stem count, se is the standard error, lower and upper 95% confidence intervals are reported and the t-statistic and p-value. Comparisons with p<0.05 are in bold.

Park	Class	Year	estimate	se	lower	upper	t-value	p-value
CRMO	Seedl	2010–2007	–0.15	0.27	–0.68	0.37	–0.58	0.564
	Seedl	2015–2007	–0.41	0.26	–0.91	0.10	–1.57	0.116
	Regen	2010–2007	0.15	0.16	–0.15	0.46	0.97	0.331
	Regen	2015–2007	0.59	0.15	0.29	0.89	3.92	<0.001
	Mature	2010–2007	–0.48	0.53	–1.52	0.55	–0.91	0.361
	Mature	2015–2007	–0.60	0.51	–1.60	0.40	–1.18	0.237
	Dead	2010–2007	–1.00	0.54	–2.07	0.07	–1.83	0.066
	Dead	2015–2007	–1.00	0.52	–2.03	0.03	–1.91	0.056
CIRO	Seedl	2011–2008	0.10	0.49	–0.86	1.06	0.21	0.837
	Seedl	2016–2008	0.89	0.50	–0.10	1.88	1.76	0.078
	Seedl	2012–2009	1.06	0.60	–0.13	2.24	1.75	0.080
	Seedl	2017–2009	1.56	0.60	0.37	2.74	2.58	0.010
	Regen	2011–2008	–0.40	0.36	–1.10	0.30	–1.12	0.261
	Regen	2016–2008	–1.01	0.36	–1.71	–0.30	–2.79	0.005
	Regen	2012–2009	0.50	0.42	–0.33	1.33	1.18	0.239
	Regen	2017–2009	0.01	0.42	–0.82	0.85	0.03	0.974
	Mature	2011–2008	–0.11	0.27	–0.63	0.42	–0.40	0.691
	Mature	2016–2008	0.22	0.28	–0.32	0.76	0.79	0.428
	Mature	2012–2009	–0.19	0.33	–0.84	0.45	–0.59	0.556
	Mature	2017–2009	0.54	0.33	–0.11	1.19	1.64	0.101
	Dead	2011–2008	0.13	0.10	–0.06	0.32	1.35	0.176
	Dead	2016–2008	–0.04	0.10	–0.23	0.15	–0.41	0.681
	Dead	2012–2009	0.06	0.11	–0.17	0.28	0.48	0.628
	Dead	2017–2009	0.00	0.11	–0.23	0.23	0.00	1.000

Discussion

Park level changes

Park level changes in aspen and conifer stem density were detected in both CRMO and CIRO. Aspen suckering was occurring across the parks but was variable between time periods and no change was detected. This can be expected since aspen suckering depends on many factors including moisture conditions, light, the hormonal balance of the mature trees, disturbance events, and browsing pressure (Bartos and Campbell 1998; Bartos 2001; Jones et al. 2009). A significant increase in the aspen regeneration class was detected in both CRMO and CIRO. This is encouraging since the stems in the regeneration class are likely to eventually become the mature stems that maintain the stand. No significant change in mature aspen stems was detected in CRMO while a significant increase was detected in CIRO, indicating that the aspen is maintained in the parks. Dead stems decreased in CRMO from 2007 to 2015 but increased in CIRO from 2008 to 2011, with no change during the other time periods. Dead stems are created from mortality of mature stems but also eventually fall to the ground and become coarse woody debris. The lack of change in dead stems is likely an indication of a balance between creation and downfall of dead stems.

In the future, when more data are obtained, we plan to incorporate local or spatially modeled climate data as a covariate for trend analysis. The development of gridded climate data is evolving, and we will use the best sources available at the time of future analyses. Local weather data (daily temperatures and precipitation) can be accessed via the NOAA Climate Reference Network site (<https://www.ncei.noaa.gov/access/crn/station.htm?stationId=1021>). Plot-level covariates such as elevation, aspect, and slope, and dominant understory species may be useful for understanding changes in aspen stand structure.

Stands of potential concern in CRMO

Aspen stands sampled in CRMO during the last sampling period in 2015 are generally suckering, regenerating and contain a distribution of age classes. Regeneration lower than 1000 stems/ha was recorded in three stands in CRMO in 2015: stand #5, #26, and stand #27. Stand #5 is located on a southwest facing aspect in the Little Cottonwood drainage. It is one of the few stands in any of the parks that is located on the dryer south or west facing aspects. The southerly exposure and likely dryer conditions may be contributing to the low sucker density. Stands on dry sites with moisture deficit during the growing season have been found to be more vulnerable to decline, e.g., SAD (Worrall et al. 2010). Stand #26 is located at the bottom of the Leech Creek drainage. The low regeneration in stand #26 is likely associated with browsing pressure from elk or deer. There are many signs of animal use in stand #26, including bedding, browsing, and rubbing. Stand #27 is located in the Big Cottonwood drainage; it is a north-facing relatively small aspen stands, with no obvious reason for the low regeneration numbers.

In CRMO, density of mature aspen stems lower than 100 stems/ha was recorded in four stands in 2015: stand #5, #12, #13, and #20 of which stand #13 and #20 had no mature stems in 2015. The afore mentioned stands are located along the Leech Creek drainage. Density of mature stems has decreased throughout the sampling periods in these stands. Stand #5 and #13 are two of the few

stands in the park located on southwest and south facing aspects. Stand #5 also had low regeneration counts. The dryer conditions on southerly aspects may be contributing to the low stem counts in these stands. Previous research as documented higher aspen mortality on southerly aspects in Colorado (Worrall et al. 2008). Stand #12 and #20 have similar topographic placement, both are northeast facing and located higher on the hillslope than other stands. The sites are more exposed, possibly with shallower soils than other stands. Future monitoring will inform the parks whether regeneration will replace the lack of mature stems, which is necessary for the maintenance of the stands. All stands are suckering which is encouraging and also necessary for regeneration and the future maintenance of the stands. Dead stem density is variable between stands ranging from 0 to 2387 dead stems/ha. Dead stem density is also variable through time within stands as live stems die and dead stems fall to the ground.

Several conifer species were present in the CRMO. The most common species was limber pine (*Pinus flexilis*), followed by less common occurrences of Douglas-fir (*Pseudotsuga menziesii*), Rocky Mountain juniper (*Juniperus scopulorum*), and Utah juniper (*Juniperus osteosperma*). Conifer density was low in all stands in CRMO, however increases were observed in many stands between the start of the monitoring program in 2007 and the last sampling period 2015. The number of stands with conifers in the seedling class increased from seven in 2007 to eleven in 2015, with seedling density ranging from 25 to 398 seedlings/ha in 2015. The number of stands with conifers in the regeneration class increased from one stand in 2007 to ten stands in 2015, with conifer stem density ranging from 25 to 199 stems/ha in 2015. A few mature conifer trees were recorded in CRMO, decreasing from 14 stems/ha in 2007 to 6 stems/ha in 2015. Overall, conversion of aspen stands to conifer stands is currently not a concern in CRMO, however, there is a steady increase of conifer seedlings and saplings in the aspen stands of the park.

Stands of potential concern in CIRO

Most of the aspen stands sampled in CIRO during the last sampling period in 2016/2017 are suckering, regenerating and contain a distribution of age classes. In CIRO, regeneration lower than 1000 stems/ha was recorded in two stands in 2016–2017, stand #24 and #51. Both stands are located at lower elevation than other stands in CIRO. Evidence of browsing pressure has also been observed in stand #24. The regeneration in stand #24 has been consistently low through time, 279, 119, 279 stems/ha during the three sampling periods; the mature stem density has maintained at 279 stems/ha through time while suckering has increased from 597 suckers/ha in 2009 to 2745 suckers/ha in 2017. In stand #51 regeneration has decreased across the three sampling periods (995, 895, 706 stems/ha) as has the mature stem density (995, 945, 647 stems/ha) and the suckering counts (2537, 1492, 597 suckers/ha).

The lowest mature stem count in CIRO occurred in stand #72, a stand located at low elevation along Circle Creek. The stand may have had a history of heavy animal use. Even though stand #72 has a low mature stem density regeneration was 1243 stems/ha in 2015 and is suckering.

The most common conifer species recorded in CIRO was Rocky Mountain juniper followed by single-leaf pinyon, Utah juniper, and limber pine; with subalpine fir (*Abies lasiocarpa*), and lodgepole pine occurring in the highest elevation stands. In CIRO, the number of stands with conifer

seedlings increase from nine in 2008/2009 to twelve in 2016/2017 ranging from 50 to 497 stems/ha in 2016/2017 while the number of stands with conifer trees in the regeneration class stayed constant at 13–14 stands (33–398 stems/ha). The number of stands with mature conifers increased from eight to twelve in CIRO from 2008/2009 to 2016/2017, ranging from 33 to 597 stems/ha in 2016/2017. Stands with the highest mature stem density of conifers in CIRO are stand #37 (547 stems/ha), stand #43 (199 stems/ha) and #57 (199 stems/ha). In general, conifer density is low in CIRO stands, but stands with mature conifers are on a trajectory towards conifer dominance. Mature, seed producing, conifers have been documented to accelerate the establishment of conifers exponentially (see Strand et al. 2009a).

Conclusions

The UCBN long-term aspen monitoring protocol fulfills the objectives as outlined in the introduction, objectives sections, and protocol (Strand et al. 2009b). Our statistical design enabled detection of environmental change with necessary confidence, and all data collected was used in these analyses, i.e., no waste of time collecting data not used.

Changes in aspen and conifer stem densities were documented in CRMO and CIRO. All stands in the parks were suckering and establishing new stems via vegetative regeneration, however some stands had a low to no count of mature aspen stems. The few stands with low regeneration and mature aspen stem density tend to occur on south/west facing warmer and dryer aspects or higher on the hillslope further away from the riparian corridor in CRMO. One stand in CRMO is heavily used by wildlife, which is contributing to low aspen regeneration. In CIRO, low regeneration or mature tree density is likely due to historical grazing pressure or wildlife use. Even in stands with no mature stems the suckering and regeneration was occurring and even increasing and we recognize that observed changes may represent natural cycles of recruitment and mortality in aspen stands. Data collected in future time periods will inform us about the dynamic nature of stem density within age groups within CIRO and CRMO aspen stands. Conifer density is low in all stands, but a significant increase in the conifer seedlings and regeneration age group was observed. Increasing conifer dominance may change the dynamics in the aspen stands in the future.

Procedures for monumenting and re-locating permanent plots is working well, with only 5% of the plots not located and in need of remonumenting. At plots where the rebar was not possible to relocate, we installed a new rebar at the plot center coordinates and we tagged bearing trees to help with relocation during the next sampling event. Healthy trees of any species, near the plot center, expected to maintain through the next few sampling periods were selected. The bearing tree is tagged with an aluminum tag (see methods), the tag number is recorded as is the distance from the plot center, the azimuth to the plot center, and the tree species. During future sampling events the field crew can easily locate the plot center if the bearing tree is found. Bearing trees have been added to the field form and to the database. The addition of bearing trees will be included in the next update of the protocol, version 1.1. Remonumented plots will remain in the sampling frames and contribute to future statistical analysis. QA/QC procedures are satisfactory and the three-way interaction between the park personnel, the UCBN managers, and the project manager is working well.

This long-term monitoring program for detecting status and trends in aspen regeneration and population density by age group at CRMO and CIRO will provide NPS managers with a measure of the population characteristics most important to park missions, visitor experiences, and desired future conditions, and will contribute necessary data to provide feedback to adaptive management programs.

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Appendix A. R code for statistical analysis

Analysis of the Aspen and Conifer at CIRO and CRMO

Load all required packages.

```
library(ggplot2)
library(dplyr)
library(lme4)
library(trtools)
```

The **ggplot2**, **dplyr**, and **lme4** packages are in the CRAN repository and can be installed the usual way — e.g., `install.packages(ggplot2)`. But **trtools** is on GitHub and must be installed using `devtools::install_github("trobinj/trtools")`. The **devtools** package will need to be installed first, but it can be installed from CRAN using `install.packages("devtools")`.

Importing and Preparing Data

Set the working directory to the same directory containing this markdown file (note that this requires the **rprojroot** package).

```
setwd(dirname(rprojroot::thisfile()))
```

Import the data from four CSV files

```
ciroasp <- read.csv("ciro-asp.csv", stringsAsFactors = FALSE)
cirocon <- read.csv("ciro-con.csv", stringsAsFactors = FALSE)
crmoasp <- read.csv("crmo-asp.csv", stringsAsFactors = FALSE)
crmocon <- read.csv("crmo-con.csv", stringsAsFactors = FALSE)
```

Remove the variable `Period` from `ciroasp` and `cirocon` as it does not exist in the other data frames and is not used here.

```
ciroasp$Period <- NULL
cirocon$Period <- NULL
```

Create a variable `treetype` to distinguish aspen versus conifer.

```
ciroasp$treetype <- "aspen"
cirocon$treetype <- "conifer"
crmoasp$treetype <- "aspen"
crmocon$treetype <- "conifer"
```

Combine the four data frames into one.

```
trees <- rbind(ciroasp, cirocon, crmoasp, crmocon)
```

Removing the extraneous variable `Dead.1` as it is the same as `Dead`.

```
trees$Dead.1 <- NULL
```

Make a new variable for the year-parkunit combination for plotting.

```
trees$yearunit <- with(trees, paste(Sample_Year, "\n(", ParkUnit,
")", sep = ""))
```

Select the variables that are used in the analyses in the next section.

```
trees <- trees %>% select(Regen, Mature, Dead, Suckers, yearunit,
ParkUnit, Stand_Name, Plot_Name, Sample_Year, treetype)
```

Export the data in case anyone wants to use it for something else.

```
write.csv(trees, "trees.csv")
```

Analysis of Number of Mature Stems

The following is an analysis of the number of *mature* stems.

```
p <- ggplot(trees, aes(x = yearunit, y = Mature, fill = treetype))
p <- p + geom_count(aes(size = stat(prop)), shape = 21, position =
position_dodge(width = 0.5))
p <- p + theme_classic() + scale_fill_manual(values =
c("white", "black")) + scale_size_area()
p <- p + labs(x = "Year (Park Unit)", y = "Mature Stems", size =
"Proportion", fill = "Tree Type")
p <- p + ggtitle(paste("Distribution of Number of Mature Stems"))
p1 <- p
m <- trees %>% group_by(treetype, yearunit, Stand_Name) %>%
summarize(y = sum(Mature), m = n()) %>%
summarize(totally = sum(y), totalm = sum(m), s2 = var(y), m =
mean(m), n = n()) %>%
mutate(pe = totally/totalm, me = 2*sqrt(s2/n)/m) %>% mutate(lower =
pe - me, upper = pe + me)
p <- ggplot(m, aes(x = yearunit, y = pe, fill = treetype))
p <- p + geom_pointrange(aes(y = pe, ymin = lower, ymax = upper),
position = position_dodge(width = 0.5), shape = 21)
p <- p + theme_classic() + scale_fill_manual(values =
c("white", "black"))
p <- p + labs(x = "Year (Park Unit)", y = "Mature Stems", size =
"Proportion", fill = "Tree Type")
p <- p + ggtitle(paste("Estimated Mean Number of Mature Stems"))
p2 <- p
cowplot::plot_grid(p1, p2, align = "v", nrow = 2, rel_heights =
c(0.65, 0.35))
```

The confidence intervals shown in the lower plot (Figure A1) were computed using estimated standard errors based ratio estimators for one-stage cluster sampling (treating the stands as clusters). Note that it is *not* appropriate to use the overlap of confidence intervals (or the lack thereof) to make conclusions about statistical significant differences due to the lack of independence of observations from the same stand. See the analysis in the next section for inferences concerning changes over years.

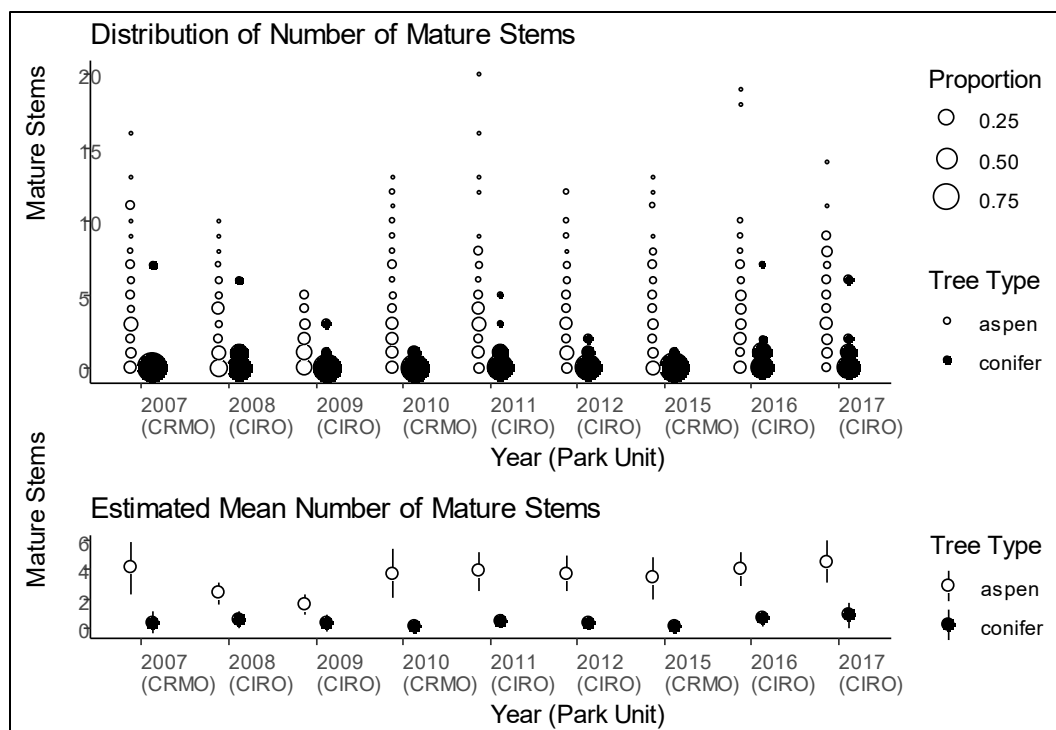


Figure A1. Example output of number of mature stems analysis.

Export the plot above as a Windows Metafile.

```
if (Sys.info()[1] == "Windows") ggsave("mature.wmf")
```

The following shows the mean, standard deviation, and number of observations (i.e., plots) for each combination of treetype, ParkUnit, and Sample_Year.

```
trees %>% group_by(treetype, ParkUnit, Sample_Year) %>%
summarize(mean = mean(Mature), sd = sd(Mature), n = n())
# A tibble: 18 x 6
# Groups:   treetype, ParkUnit [4]
treetype ParkUnit Sample_Year mean sd n
<chr> <chr> <int> <dbl> <dbl> <int>
1 aspen CIRO 2008 2.38 2.53 66
2 aspen CIRO 2009 1.66 1.57 44
3 aspen CIRO 2011 3.88 3.61 81
4 aspen CIRO 2012 3.73 3.22 52
5 aspen CIRO 2016 4.04 3.52 85
6 aspen CIRO 2017 4.55 3.23 49
7 aspen CRMO 2007 4.11 3.55 99
8 aspen CRMO 2010 3.73 3.44 102
9 aspen CRMO 2015 3.43 3.15 102
10 conifer CIRO 2008 0.591 1.30 22
11 conifer CIRO 2009 0.364 0.924 11
12 conifer CIRO 2011 0.459 0.989 37
```

```

13 conifer CIRO 2012 0.333 0.651 12
14 conifer CIRO 2016 0.644 1.13 45
15 conifer CIRO 2017 0.917 1.73 12
16 conifer CRMO 2007 0.389 1.65 18
17 conifer CRMO 2010 0.143 0.356 28
18 conifer CRMO 2015 0.0968 0.301 31

```

Analysis of Change in Number of Mature Stems

The following analysis uses average counts at the stand level (within year) as the observation for simplicity and robustness. First create a data frame of the average per stand-year observational unit, and define Sample_Year as a factor.

```

d <- trees %>% group_by(treetype, ParkUnit, Sample_Year,
Stand_Name) %>%
summarize(Mature = mean(Mature), n = n())
d$Sample_Year <- factor(d$Sample_Year)

```

Changes in the Number of Mature Aspen Stems in CIRO

Define an appropriate subset of the data and drop empty levels of Sample_Year.

```

d.subset <- d %>% filter(ParkUnit == "CIRO", treetype == "aspen")
d.subset$Sample_Year <- droplevels(d.subset$Sample_Year)

```

Estimate a basic linear mixed model.

```

m <- lmer(Mature ~ Sample_Year + (1|Stand_Name), data = d.subset)

```

Compare each subsequent year against the first year.

```

alvls <- levels(d.subset$Sample_Year)[-1]
blvls <- levels(d.subset$Sample_Year)[1]
names <- paste(alvls, "-", blvls, sep = "")
contrast(m,
a = list(Sample_Year = alvls),
b = list(Sample_Year = blvls),
cnames = names)

```

estimate se lower upper tvalue df pvalue

```

2009-2008 -0.5096 0.9533 -2.3781 1.359 -0.5345 Inf 0.592972
2011-2008 1.5919 0.5991 0.4177 2.766 2.6571 Inf 0.007882
2012-2008 1.7231 0.9059 -0.0524 3.499 1.9021 Inf 0.057156
2016-2008 1.7496 0.5991 0.5754 2.924 2.9203 Inf 0.003497
2017-2008 2.4192 0.9059 0.6438 4.195 2.6707 Inf 0.007570

```

Compare adjacent observation periods.

```

alvls <- levels(d.subset$Sample_Year)[-1]
blvls <- levels(d.subset$Sample_Year)[-
length(levels(d.subset$Sample_Year))]
names <- paste(alvls, "-", blvls, sep = "")
contrast(m,
a = list(Sample_Year = alvls),

```

```
b = list(Sample_Year = blvls),
cnames = names)
estimate se lower upper tvalue df pvalue
2009-2008 -0.50960 0.9533 -2.378 1.359 -0.53453 Inf 0.5930
2011-2009 2.10150 0.9533 0.233 3.970 2.20433 Inf 0.0275
2012-2011 0.13116 0.9059 -1.644 1.907 0.14479 Inf 0.8849
2016-2012 0.02655 0.9059 -1.749 1.802 0.02931 Inf 0.9766
2017-2016 0.66964 0.9059 -1.106 2.445 0.73923 Inf 0.4598
```

Comparison between 2009 versus 2012 and 2017.

```
contrast(m,
a = list(Sample_Year = c("2012", "2017")),
b = list(Sample_Year = c("2009")),
cnames = c("2012-2009", "2017-2009"))
estimate se lower upper tvalue df pvalue
2012-2009 2.233 0.7916 0.6811 3.784 2.82 Inf 0.0047980
2017-2009 2.929 0.7916 1.3773 4.480 3.70 Inf 0.0002158
```

Estimates for each year. Note that these will be slightly different from those obtained in the previous section as they are model-based and based on means at the stand level.

```
contrast(m,
a = list(Sample_Year = levels(d.subset$Sample_Year)),
cnames = levels(d.subset$Sample_Year))
estimate se lower upper tvalue df pvalue
2008 2.451 0.5729 1.328 3.574 4.278 Inf 1.883e-05
2009 1.942 0.7620 0.448 3.435 2.548 Inf 1.084e-02
2011 4.043 0.5729 2.920 5.166 7.057 Inf 1.703e-12
2012 4.174 0.7017 2.799 5.549 5.949 Inf 2.700e-09
2016 4.201 0.5729 3.078 5.324 7.332 Inf 2.265e-13
2017 4.870 0.7017 3.495 6.246 6.941 Inf 3.893e-12
```

Changes in the Number of Mature Aspen Stems in CRMO

Define an appropriate subset of the data and drop empty levels of Sample_Year.

```
d.subset <- d %>% filter(ParkUnit == "CRMO", treetype == "aspen")
d.subset$Sample_Year <- droplevels(d.subset$Sample_Year)
```

Estimate a basic linear mixed model.

```
m <- lmer(Mature ~ Sample_Year + (1|Stand_Name), data = d.subset)
```

Compare each subsequent year against the first year.

```
alvls <- levels(d.subset$Sample_Year)[-1]
blvls <- levels(d.subset$Sample_Year)[1]
names <- paste(alvls, "-", blvls, sep = "")
contrast(m,
a = list(Sample_Year = alvls),
b = list(Sample_Year = blvls),
cnames = names)
```

estimate se lower upper tvalue df pvalue

```
2010-2007 -0.4076 0.3954 -1.183 0.3674 -1.031 Inf 0.3026
2015-2007 -0.6208 0.3954 -1.396 0.1543 -1.570 Inf 0.1164
```

Compare adjacent observation periods.

```
alvls <- levels(d.subset$Sample_Year)[-1]
blvls <- levels(d.subset$Sample_Year)[-
length(levels(d.subset$Sample_Year))]
names <- paste(alvls, "-", blvls, sep = "")
contrast(m,
a = list(Sample_Year = alvls),
b = list(Sample_Year = blvls),
cnames = names)
```

estimate se lower upper tvalue df pvalue

```
2010-2007 -0.4076 0.3954 -1.1827 0.3674 -1.031 Inf 0.3026
2015-2010 -0.2132 0.3954 -0.9882 0.5619 -0.539 Inf 0.5899
```

Estimates for each year. Note that these will be slightly different from those obtained in the previous section as they are model-based and based on means at the stand level.

```
contrast(m,
a = list(Sample_Year = levels(d.subset$Sample_Year)),
cnames = levels(d.subset$Sample_Year))
```

estimate se lower upper tvalue df pvalue

```
2007 3.904 0.5261 2.873 4.935 7.421 Inf 1.159e-13
2010 3.497 0.5261 2.466 4.528 6.647 Inf 3.000e-11
2015 3.283 0.5261 2.252 4.315 6.241 Inf 4.337e-10
```

Changes in the Number of Mature Conifer Stems in CIRO

Define an appropriate subset of the data and drop empty levels of Sample_Year.

```
d.subset <- d %>% filter(ParkUnit == "CIRO", treetype == "conifer")
d.subset$Sample_Year <- droplevels(d.subset$Sample_Year)
```

Estimate a basic linear mixed model.

```
m <- lmer(Mature ~ Sample_Year + (1|Stand_Name), data = d.subset)
```

Compare each subsequent year against the first year.

```
alvls <- levels(d.subset$Sample_Year)[-1]
blvls <- levels(d.subset$Sample_Year)[1]
names <- paste(alvls, "-", blvls, sep = "")
contrast(m,
a = list(Sample_Year = alvls),
b = list(Sample_Year = blvls),
cnames = names)
```

estimate se lower upper tvalue df pvalue

```
2009-2008 0.08325 0.3748 -0.6514 0.8179 0.2221 Inf 0.82423
2011-2008 -0.10606 0.2672 -0.6297 0.4176 -0.3970 Inf 0.69137
2012-2008 -0.11120 0.3748 -0.8458 0.6234 -0.2967 Inf 0.76671
```

```
2016-2008 0.21930 0.2765 -0.3225 0.7611 0.7933 Inf 0.42761
2017-2008 0.62491 0.3748 -0.1097 1.3595 1.6673 Inf 0.09546
```

Compare adjacent observation periods.

```
alvls <- levels(d.subset$Sample_Year)[-1]
blvls <- levels(d.subset$Sample_Year)[-
length(levels(d.subset$Sample_Year))]
names <- paste(alvls, "-", blvls, sep = "")
contrast(m,
a = list(Sample_Year = alvls),
b = list(Sample_Year = blvls),
cnames = names)
```

estimate se lower upper tvalue df pvalue

```
2009-2008 0.083248 0.3748 -0.6514 0.8179 0.22211 Inf 0.8242
2011-2009 -0.189307 0.3265 -0.8292 0.4505 -0.57988 Inf 0.5620
2012-2011 -0.005138 0.3265 -0.6450 0.6347 -0.01574 Inf 0.9874
2016-2012 0.330502 0.3610 -0.3771 1.0381 0.91542 Inf 0.3600
2017-2016 0.405609 0.3610 -0.3020 1.1132 1.12345 Inf 0.2612
```

Comparison between 2009 versus 2012 and 2017.

```
contrast(m,
a = list(Sample_Year = c("2012", "2017")),
b = list(Sample_Year = c("2009")),
cnames = c("2012-2009", "2017-2009"))
```

estimate se lower upper tvalue df pvalue

```
2012-2009 -0.1944 0.3303 -0.8419 0.453 -0.5886 Inf 0.5561
2017-2009 0.5417 0.3303 -0.1058 1.189 1.6397 Inf 0.1011
```

Estimates for each year. Note that these will be slightly different from those obtained in the previous section as they are model-based and based on means at the stand level.

```
contrast(m,
a = list(Sample_Year = levels(d.subset$Sample_Year)),
cnames = levels(d.subset$Sample_Year))
```

estimate se lower upper tvalue df pvalue

```
2008 0.4377 0.2506 -0.05351 0.9289 1.746 Inf 0.0807293
2009 0.5210 0.2917 -0.05075 1.0927 1.786 Inf 0.0741010
2011 0.3316 0.2008 -0.06190 0.7252 1.652 Inf 0.0985969
2012 0.3265 0.2917 -0.24519 0.8982 1.119 Inf 0.2629796
2016 0.6570 0.2285 0.20913 1.1049 2.875 Inf 0.0040386
2017 1.0626 0.2917 0.49092 1.6343 3.643 Inf 0.0002695
```

Changes in the Number of Mature Conifer Stems in CRMO

Define an appropriate subset of the data and drop empty levels of Sample_Year.

```
d.subset <- d %>% filter(ParkUnit == "CRMO", treetype == "conifer")
d.subset$Sample_Year <- droplevels(d.subset$Sample_Year)
```

Estimate a basic linear mixed model.

```
m <- lmer(Mature ~ Sample_Year + (1|Stand_Name), data = d.subset)
```

Compare each subsequent year against the first year.

```
alvls <- levels(d.subset$Sample_Year)[-1]
blvls <- levels(d.subset$Sample_Year)[1]
names <- paste(alvls, "-", blvls, sep = "")
contrast(m,
a = list(Sample_Year = alvls),
b = list(Sample_Year = blvls),
cnames = names)
estimate se lower upper tvalue df pvalue
2010-2007 -0.483 0.5292 -1.52 0.5542 -0.9127 Inf 0.3614
2015-2007 -0.602 0.5092 -1.60 0.3960 -1.1823 Inf 0.2371
```

Compare adjacent observation periods.

```
alvls <- levels(d.subset$Sample_Year)[-1]
blvls <- levels(d.subset$Sample_Year)[-
length(levels(d.subset$Sample_Year))]
names <- paste(alvls, "-", blvls, sep = "")
contrast(m,
a = list(Sample_Year = alvls),
b = list(Sample_Year = blvls),
cnames = names)
estimate se lower upper tvalue df pvalue
2010-2007 -0.483 0.5292 -1.520 0.5542 -0.9127 Inf 0.3614
2015-2010 -0.119 0.4947 -1.089 0.8506 -0.2406 Inf 0.8098
```

Estimates for each year. Note that these will be slightly different from those obtained in the previous section as they are model-based and based on means at the stand level.

```
contrast(m,
a = list(Sample_Year = levels(d.subset$Sample_Year)),
cnames = levels(d.subset$Sample_Year))
estimate se lower upper tvalue df pvalue
2007 0.7022 0.3878 -0.05781 1.4622 1.8109 Inf 0.07016
2010 0.2192 0.3698 -0.50549 0.9439 0.5929 Inf 0.55328
2015 0.1002 0.3402 -0.56656 0.7669 0.2944 Inf 0.76842
```

Analysis of Number of Dead Stems

The following is an analysis of the number of *dead* stems.

```
p <- ggplot(trees, aes(x = yearunit, y = Dead, fill = treetype))
p <- p + geom_count(aes(size = stat(prop)), shape = 21, position =
position_dodge(width = 0.5))
p <- p + theme_classic() + scale_fill_manual(values =
c("white", "black")) + scale_size_area()
p <- p + labs(x = "Year (Park Unit)", y = "Dead Stems", size =
"Proportion", fill = "Tree Type")
```

```

p <- p + ggtitle(paste("Distribution of Number of Dead Stems"))
p1 <- p
m <- trees %>% group_by(treetype, yearunit, Stand_Name) %>%
  summarize(y = sum(Dead), m = n()) %>%
  summarize(totally = sum(y), totalm = sum(m), s2 = var(y), m =
    mean(m), n = n()) %>%
  mutate(pe = totally/totalm, me = 2*sqrt(s2/n)/m) %>% mutate(lower =
    pe - me, upper = pe + me)
p <- ggplot(m, aes(x = yearunit, y = pe, fill = treetype))
p <- p + geom_pointrange(aes(y = pe, ymin = lower, ymax = upper),
  position = position_dodge(width = 0.5), shape = 21)
p <- p + theme_classic() + scale_fill_manual(values =
  c("white", "black"))
p <- p + labs(x = "Year (Park Unit)", y = "Dead Stems", size =
  "Proportion", fill = "Tree Type")
p <- p + ggtitle(paste("Estimated Mean Number of Dead Stems"))
p2 <- p
cowplot::plot_grid(p1, p2, align = "v", nrow = 2, rel_heights =
  c(0.65, 0.35))

```

The confidence intervals shown in the lower plot (Figure A2) were computed using estimated standard errors based ratio estimators for one-stage cluster sampling (treating the stands as clusters). Note that it is *not* appropriate to use the overlap of confidence intervals (or the lack thereof) to make conclusions about statistical significant differences due to the lack of independence of observations from the same stand. See the analysis in the next section for inferences concerning changes over years.

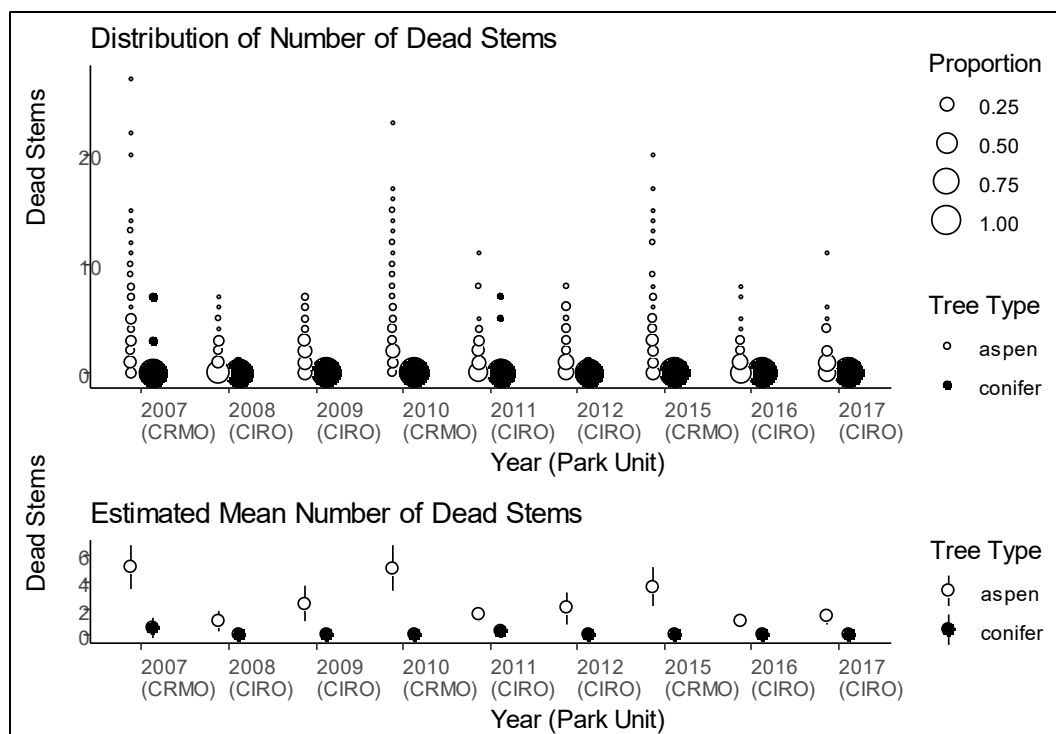


Figure A2. Example output of Estimated Mean Number of Dead Stems analysis.

Export the plot above as a Windows Metafile.

```
if (Sys.info()[1] == "Windows") ggsave("dead.wmf")
```

The following shows the mean, standard deviation, and number of observations (i.e., plots) for each combination of treetype, ParkUnit, and Sample_Year.

```
trees %>% group_by(treetype, ParkUnit, Sample_Year) %>%
summarize(mean = mean(Dead), sd = sd(Dead), n = n())
# A tibble: 18 x 6
# Groups:   treetype, ParkUnit [4]
treetype ParkUnit Sample_Year mean sd n
<chr> <chr> <int> <dbl> <dbl> <int>
1 aspen CIRO 2008 1.09 1.62 66
2 aspen CIRO 2009 2.34 2.07 44
3 aspen CIRO 2011 1.53 2.01 81
4 aspen CIRO 2012 2.02 2.22 52
5 aspen CIRO 2016 1.01 1.52 85
6 aspen CIRO 2017 1.41 2.01 49
7 aspen CRMO 2007 5.07 5.04 99
8 aspen CRMO 2010 5.03 4.81 102
9 aspen CRMO 2015 3.64 3.98 102
10 conifer CIRO 2008 0.0909 0.294 22
11 conifer CIRO 2009 0 0 11
12 conifer CIRO 2011 0.351 1.40 37
```

```

13 conifer CIRO 2012 0.0833 0.289 12
14 conifer CIRO 2016 0 0 45
15 conifer CIRO 2017 0 0 12
16 conifer CRMO 2007 0.556 1.76 18
17 conifer CRMO 2010 0 0 28
18 conifer CRMO 2015 0 0 31

```

Analysis of Change in Number of Dead Stems

The following analysis uses average counts at the stand level (within year) as the observation for simplicity and robustness. First create a data frame of the average per stand-year observational unit, and define Sample_Year as a factor.

```

d <- trees %>% group_by(treetype, ParkUnit, Sample_Year,
Stand_Name) %>%
summarize(Dead = mean(Dead), n = n())
d$Sample_Year <- factor(d$Sample_Year)

```

Changes in the Number of Dead Aspen Stems in CIRO

Define an appropriate subset of the data and drop empty levels of Sample_Year.

```

d.subset <- d %>% filter(ParkUnit == "CIRO", treetype == "aspen")
d.subset$Sample_Year <- droplevels(d.subset$Sample_Year)

```

Estimate a basic linear mixed model.

```

m <- lmer(Dead ~ Sample_Year + (1|Stand_Name), data = d.subset)

```

Compare each subsequent year against the first year.

```

alvls <- levels(d.subset$Sample_Year)[-1]
blvls <- levels(d.subset$Sample_Year)[1]
names <- paste(alvls, "-", blvls, sep = "")
contrast(m,
a = list(Sample_Year = alvls),
b = list(Sample_Year = blvls),
cnames = names)

```

estimate se lower upper tvalue df pvalue

```

2009-2008 0.96666 0.5379 -0.08759 2.0209 1.7971 Inf 0.07231
2011-2008 0.57202 0.2426 0.09645 1.0476 2.3575 Inf 0.01840
2012-2008 0.80917 0.5231 -0.21608 1.8344 1.5469 Inf 0.12189
2016-2008 0.04651 0.2426 -0.42906 0.5221 0.1917 Inf 0.84800
2017-2008 0.34714 0.5231 -0.67810 1.3724 0.6636 Inf 0.50692

```

Compare adjacent observation periods.

```

alvls <- levels(d.subset$Sample_Year)[-1]
blvls <- levels(d.subset$Sample_Year)[-
length(levels(d.subset$Sample_Year))]
names <- paste(alvls, "-", blvls, sep = "")
contrast(m,
a = list(Sample_Year = alvls),
b = list(Sample_Year = blvls),

```

```
cnames = names)
```

estimate se lower upper tvalue df pvalue

```
2009-2008 0.9667 0.5379 -0.08759 2.0209 1.7971 Inf 0.07231
2011-2009 -0.3946 0.5379 -1.44889 0.6596 -0.7337 Inf 0.46314
2012-2011 0.2371 0.5231 -0.78810 1.2624 0.4534 Inf 0.65029
2016-2012 -0.7627 0.5231 -1.78790 0.2626 -1.4580 Inf 0.14485
2017-2016 0.3006 0.5231 -0.72461 1.3259 0.5747 Inf 0.56548
```

Comparison between 2009 versus 2012 and 2017.

```
contrast(m,
a = list(Sample_Year = c("2012", "2017")),
b = list(Sample_Year = c("2009")),
cnames = c("2012-2009", "2017-2009"))
```

estimate se lower upper tvalue df pvalue

```
2012-2009 -0.1575 0.3225 -0.7896 0.47462 -0.4883 Inf 0.62531
2017-2009 -0.6195 0.3225 -1.2516 0.01259 -1.9209 Inf 0.05474
```

Estimates for each year. Note that these will be slightly different from those obtained in the previous section as they are model-based and based on means at the stand level.

```
contrast(m,
a = list(Sample_Year = levels(d.subset$Sample_Year)),
cnames = levels(d.subset$Sample_Year))
```

estimate se lower upper tvalue df pvalue

```
2008 1.023 0.3308 0.3749 1.672 3.093 Inf 1.980e-03
2009 1.990 0.4241 1.1587 2.821 4.692 Inf 2.705e-06
2011 1.595 0.3308 0.9469 2.244 4.822 Inf 1.420e-06
2012 1.833 0.4052 1.0384 2.627 4.523 Inf 6.108e-06
2016 1.070 0.3308 0.4214 1.718 3.234 Inf 1.222e-03
2017 1.370 0.4052 0.5763 2.165 3.382 Inf 7.187e-04
```

Changes in the Number of Dead Aspen Stems in CRMO

Define an appropriate subset of the data and drop empty levels of Sample_Year.

```
d.subset <- d %>% filter(ParkUnit == "CRMO", treetype == "aspen")
d.subset$Sample_Year <- droplevels(d.subset$Sample_Year)
```

Estimate a basic linear mixed model.

```
m <- lmer(Dead ~ Sample_Year + (1|Stand_Name), data = d.subset)
```

Compare each subsequent year against the first year.

```
alvls <- levels(d.subset$Sample_Year)[-1]
blvls <- levels(d.subset$Sample_Year)[1]
names <- paste(alvls, "-", blvls, sep = "")
contrast(m,
a = list(Sample_Year = alvls),
b = list(Sample_Year = blvls),
cnames = names)
```

estimate se lower upper tvalue df pvalue

```
2010-2007 -0.1431 0.6499 -1.417 1.1307 -0.2202 Inf 0.82571
2015-2007 -1.6207 0.6499 -2.895 -0.3469 -2.4938 Inf 0.01264
```

Compare adjacent observation periods.

```
alvls <- levels(d.subset$Sample_Year)[-1]
blvls <- levels(d.subset$Sample_Year)[-
length(levels(d.subset$Sample_Year))]
names <- paste(alvls, "-", blvls, sep = "")
contrast(m,
a = list(Sample_Year = alvls),
b = list(Sample_Year = blvls),
cnames = names)
```

estimate se lower upper tvalue df pvalue

```
2010-2007 -0.1431 0.6499 -1.417 1.1307 -0.2202 Inf 0.82571
2015-2010 -1.4776 0.6499 -2.751 -0.2038 -2.2736 Inf 0.02299
```

Estimates for each year. Note that these will be slightly different from those obtained in the previous section as they are model-based and based on means at the stand level.

```
contrast(m,
a = list(Sample_Year = levels(d.subset$Sample_Year)),
cnames = levels(d.subset$Sample_Year))
```

estimate se lower upper tvalue df pvalue

```
2007 5.217 0.733 3.780 6.654 7.117 Inf 1.105e-12
2010 5.074 0.733 3.637 6.510 6.922 Inf 4.467e-12
2015 3.596 0.733 2.159 5.033 4.906 Inf 9.305e-07
```

Changes in the Number of Dead Conifer Stems in CIRO

Define an appropriate subset of the data and drop empty levels of Sample_Year.

```
d.subset <- d %>% filter(ParkUnit == "CIRO", treetype == "conifer")
d.subset$Sample_Year <- droplevels(d.subset$Sample_Year)
```

Estimate a basic linear mixed model.

```
m <- lmer(Dead ~ Sample_Year + (1|Stand_Name), data = d.subset)
```

Compare each subsequent year against the first year.

```
alvls <- levels(d.subset$Sample_Year)[-1]
blvls <- levels(d.subset$Sample_Year)[1]
names <- paste(alvls, "-", blvls, sep = "")
contrast(m,
a = list(Sample_Year = alvls),
b = list(Sample_Year = blvls),
cnames = names)
```

estimate se lower upper tvalue df pvalue

```
2009-2008 0.09783 0.17622 -0.2476 0.4432 0.5551 Inf 0.5788
2011-2008 0.13257 0.09790 -0.0593 0.3244 1.3542 Inf 0.1757
2012-2008 0.15338 0.17622 -0.1920 0.4988 0.8704 Inf 0.3841
2016-2008 -0.04021 0.09801 -0.2323 0.1519 -0.4102 Inf 0.6816
```

```
2017-2008 0.09783 0.17622 -0.2476 0.4432 0.5551 Inf 0.5788
```

Compare adjacent observation periods.

```
alvls <- levels(d.subset$Sample_Year)[-1]
blvls <- levels(d.subset$Sample_Year)[-
length(levels(d.subset$Sample_Year))]
names <- paste(alvls, "-", blvls, sep = "")
contrast(m,
a = list(Sample_Year = alvls),
b = list(Sample_Year = blvls),
cnames = names)
```

estimate se lower upper tvalue df pvalue

```
2009-2008 0.09783 0.1762 -0.2476 0.4432 0.5551 Inf 0.5788
2011-2009 0.03475 0.1471 -0.2536 0.3231 0.2362 Inf 0.8133
2012-2011 0.02081 0.1471 -0.2675 0.3091 0.1414 Inf 0.8875
2016-2012 -0.19359 0.1738 -0.5342 0.1470 -1.1139 Inf 0.2653
2017-2016 0.13803 0.1738 -0.2026 0.4787 0.7942 Inf 0.4271
```

Comparison between 2009 versus 2012 and 2017.

```
contrast(m,
a = list(Sample_Year = c("2012", "2017")),
b = list(Sample_Year = c("2009")),
cnames = c("2012-2009", "2017-2009"))
```

estimate se lower upper tvalue df pvalue

```
2012-2009 0.05556 0.1148 -0.1695 0.2806 0.4838 Inf 0.6285
2017-2009 0.00000 0.1148 -0.2251 0.2251 0.0000 Inf 1.0000
```

Estimates for each year. Note that these will be slightly different from those obtained in the previous section as they are model-based and based on means at the stand level.

```
contrast(m,
a = list(Sample_Year = levels(d.subset$Sample_Year)),
cnames = levels(d.subset$Sample_Year))
```

estimate se lower upper tvalue df pvalue

```
2008 0.3877 0.4117 -0.4193 1.195 0.9416 Inf 0.3464
2009 0.4855 0.4196 -0.3368 1.308 1.1572 Inf 0.2472
2011 0.5202 0.4064 -0.2762 1.317 1.2803 Inf 0.2004
2012 0.5411 0.4196 -0.2813 1.363 1.2896 Inf 0.1972
2016 0.3475 0.4101 -0.4563 1.151 0.8473 Inf 0.3968
2017 0.4855 0.4196 -0.3368 1.308 1.1572 Inf 0.2472
```

Changes in the Number of Dead Conifer Stems in CRMO

Define an appropriate subset of the data and drop empty levels of Sample_Year.

```
d.subset <- d %>% filter(ParkUnit == "CRMO", treetype == "conifer")
d.subset$Sample_Year <- droplevels(d.subset$Sample_Year)
```

Estimate a basic linear mixed model.

```
m <- lmer(Dead ~ Sample_Year + (1|Stand_Name), data = d.subset)
```

Compare each subsequent year against the first year.

```
alvls <- levels(d.subset$Sample_Year)[-1]
```

```
blvls <- levels(d.subset$Sample_Year)[1]
```

```
names <- paste(alvls, "-", blvls, sep = "")
```

```
contrast(m,
```

```
a = list(Sample_Year = alvls),
```

```
b = list(Sample_Year = blvls),
```

```
cnames = names)
```

estimate se lower upper tvalue df pvalue

```
2010-2007 -1 0.5437 -2.066 0.06562 -1.839 Inf 0.06587
```

```
2015-2007 -1 0.5234 -2.026 0.02584 -1.911 Inf 0.05606
```

Compare adjacent observation periods.

```
alvls <- levels(d.subset$Sample_Year)[-1]
```

```
blvls <- levels(d.subset$Sample_Year)[-
```

```
length(levels(d.subset$Sample_Year))]
```

```
names <- paste(alvls, "-", blvls, sep = "")
```

```
contrast(m,
```

```
a = list(Sample_Year = alvls),
```

```
b = list(Sample_Year = blvls),
```

```
cnames = names)
```

estimate se lower upper tvalue df pvalue

```
2010-2007 -1.000e+00 0.5437 -2.0656 0.06562 -1.839e+00 Inf 0.06587
```

```
2015-2010 -9.166e-09 0.5098 -0.9991 0.99914 -1.798e-08 Inf 1.00000
```

Estimates for each year. Note that these will be slightly different from those obtained in the previous section as they are model-based and based on means at the stand level.

```
contrast(m,
```

```
a = list(Sample_Year = levels(d.subset$Sample_Year)),
```

```
cnames = levels(d.subset$Sample_Year))
```

estimate se lower upper tvalue df pvalue

```
2007 1.000e+00 0.3935 0.2288 1.7712 2.541e+00 Inf 0.01104
```

```
2010 1.043e-08 0.3752 -0.7353 0.7353 2.779e-08 Inf 1.00000
```

```
2015 1.260e-09 0.3451 -0.6764 0.6764 3.652e-09 Inf 1.00000
```

Analysis of Number of Regenerating Stems

The following is an analysis of the number of *regenerating* stems

```
p <- ggplot(trees, aes(x = yearunit, y = Regen, fill = treetype))
```

```
p <- p + geom_count(aes(size = stat(prop)), shape = 21, position =  
position_dodge(width = 0.5))
```

```
p <- p + theme_classic() + scale_fill_manual(values =  
c("white", "black")) + scale_size_area()
```

```
p <- p + labs(x = "Year (Park Unit)", y = "Regenerating Stems",  
size = "Proportion", fill = "Tree Type")
```

```

p <- p + ggtitle(paste("Distribution of Number of Regenerating
Stems"))
p1 <- p
m <- trees %>% group_by(treetype, yearunit, Stand_Name) %>%
  summarize(y = sum(Regen), m = n()) %>%
  summarize(totally = sum(y), totalm = sum(m), s2 = var(y), m =
  mean(m), n = n()) %>%
  mutate(pe = totally/totalm, me = 2*sqrt(s2/n)/m) %>% mutate(lower =
  pe - me, upper = pe + me)

p <- ggplot(m, aes(x = yearunit, y = pe, fill = treetype))
p <- p + geom_pointrange(aes(y = pe, ymin = lower, ymax = upper),
  position = position_dodge(width = 0.5), shape = 21)
p <- p + theme_classic() + scale_fill_manual(values =
  c("white", "black"))
p <- p + labs(x = "Year (Park Unit)", y = "Regenerating Stems",
  size = "Proportion", fill = "Tree Type")
p <- p + ggtitle(paste("Estimated Mean Number of Regenerating
Stems"))
p2 <- p
cowplot::plot_grid(p1, p2, align = "v", nrow = 2, rel_heights =
  c(0.65, 0.35))

```

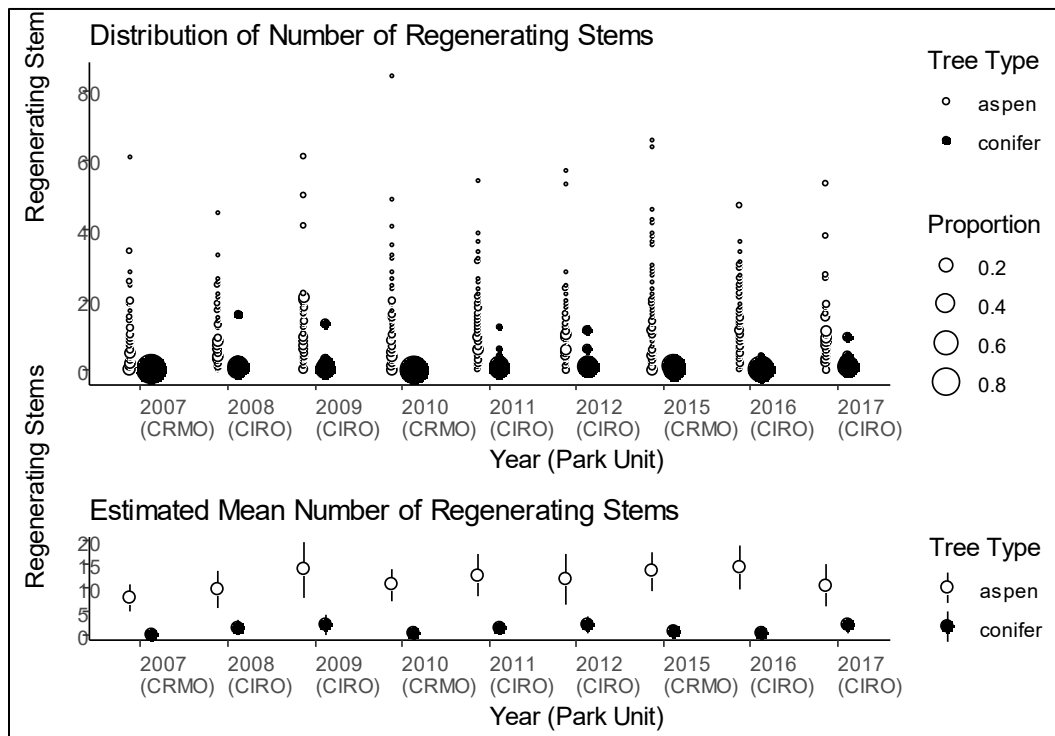


Figure A3. Example output of Estimated Mean Number of Regenerating Stems analysis.

The confidence intervals shown in the lower plot (Figure A3) were computed using estimated standard errors based ratio estimators for one-stage cluster sampling (treating the stands as clusters). Note that it is *not* appropriate to use the overlap of confidence intervals (or the lack thereof) to make conclusions about statistical significant differences due to the lack of independence of observations from the same stand. See the analysis in the next section for inferences concerning changes over years.

Export the plot above as a Windows Metafile.

```
if (Sys.info()[1] == "Windows") ggsave("regen.wmf")
```

The following shows the mean, standard deviation, and number of observations (i.e., plots) for each combination of treetype, ParkUnit, and Sample_Year.

```
trees %>% group_by(treetype, ParkUnit, Sample_Year) %>%
summarize(mean = mean(Regen), sd = sd(Regen), n = n())
# A tibble: 18 x 6
# Groups:   treetype, ParkUnit [4]

treetype ParkUnit Sample_Year mean sd n
<chr> <chr> <int> <dbl> <dbl> <int>
1 aspen CIRO 2008 9.58 8.52 66
2 aspen CIRO 2009 13.7 12.4 44
3 aspen CIRO 2011 12.6 10.1 81
4 aspen CIRO 2012 11.8 11.0 52
5 aspen CIRO 2016 14.2 10.2 85
6 aspen CIRO 2017 10.5 9.57 49
7 aspen CRMO 2007 7.77 9.51 99
8 aspen CRMO 2010 10.6 12.1 102
9 aspen CRMO 2015 13.4 13.5 102
10 conifer CIRO 2008 1.55 3.33 22
11 conifer CIRO 2009 2.09 3.75 11
12 conifer CIRO 2011 1.32 2.22 37
13 conifer CIRO 2012 2.17 3.21 12
14 conifer CIRO 2016 0.467 0.944 45
15 conifer CIRO 2017 2 2.45 12
16 conifer CRMO 2007 0.167 0.514 18
17 conifer CRMO 2010 0.25 0.585 28
18 conifer CRMO 2015 0.710 0.739 31
```

Analysis of Change in Number of Regenerating Stems

The following analysis uses average counts at the stand level (within year) as the observation for simplicity and robustness. First create a data frame of the average per stand-year observational unit, and define Sample_Year as a factor.

```
d <- trees %>% group_by(treetype, ParkUnit, Sample_Year,
Stand_Name) %>%
summarize(Regen = mean(Regen), n = n())
```

```
d$Sample_Year <- factor(d$Sample_Year)
```

Changes in the Number of Regenerating Aspen Stems in CIRO

Define an appropriate subset of the data and drop empty levels of Sample_Year.

```
d.subset <- d %>% filter(ParkUnit == "CIRO", treetype == "aspen")
d.subset$Sample_Year <- droplevels(d.subset$Sample_Year)
```

Estimate a basic linear mixed model.

```
m <- lmer(Regen ~ Sample_Year + (1|Stand_Name), data = d.subset)
```

Compare each subsequent year against the first year.

```
alvls <- levels(d.subset$Sample_Year)[-1]
blvls <- levels(d.subset$Sample_Year)[1]
names <- paste(alvls, "-", blvls, sep = "")
contrast(m,
a = list(Sample_Year = alvls),
b = list(Sample_Year = blvls),
cnames = names)
```

estimate se lower upper tvalue df pvalue

```
2009-2008 3.5018 2.2507 -0.9095 7.913 1.55586 Inf 1.197e-01
2011-2008 2.7611 0.9861 0.8284 4.694 2.80005 Inf 5.109e-03
2012-2008 1.0447 2.1921 -3.2517 5.341 0.47658 Inf 6.337e-01
2016-2008 4.2806 0.9861 2.3479 6.213 4.34094 Inf 1.419e-05
2017-2008 -0.1104 2.1921 -4.4069 4.186 -0.05036 Inf 9.598e-01
```

Compare adjacent observation periods.

```
alvls <- levels(d.subset$Sample_Year)[-1]
blvls <- levels(d.subset$Sample_Year)[-
length(levels(d.subset$Sample_Year))]
names <- paste(alvls, "-", blvls, sep = "")
contrast(m,
a = list(Sample_Year = alvls),
b = list(Sample_Year = blvls),
cnames = names)
```

estimate se lower upper tvalue df pvalue

```
2009-2008 3.5018 2.251 -0.9095 7.91305 1.5559 Inf 0.11974
2011-2009 -0.7407 2.251 -5.1519 3.67063 -0.3291 Inf 0.74209
2012-2011 -1.7164 2.192 -6.0128 2.58008 -0.7830 Inf 0.43364
2016-2012 3.2358 2.192 -1.0606 7.53230 1.4761 Inf 0.13991
2017-2016 -4.3910 2.192 -8.6874 -0.09449 -2.0031 Inf 0.04517
```

Comparison between 2009 versus 2012 and 2017.

```
contrast(m,
a = list(Sample_Year = c("2012", "2017")),
b = list(Sample_Year = c("2009")),
cnames = c("2012-2009", "2017-2009"))
```

estimate se lower upper tvalue df pvalue

```
2012-2009 -2.457 1.311 -5.027 0.1126 -1.874 Inf 0.060915
2017-2009 -3.612 1.311 -6.182 -1.0426 -2.755 Inf 0.005866
```

Estimates for each year. Note that these will be slightly different from those obtained in the previous section as they are model-based and based on means at the stand level.

```
contrast(m,
a = list(Sample_Year = levels(d.subset$Sample_Year)),
cnames = levels(d.subset$Sample_Year))
```

estimate se lower upper tvalue df pvalue

```
2008 9.928 1.386 7.210 12.65 7.161 Inf 8.023e-13
2009 13.430 1.773 9.955 16.90 7.575 Inf 3.605e-14
2011 12.689 1.386 9.972 15.41 9.152 Inf 5.573e-20
2012 10.973 1.698 7.644 14.30 6.462 Inf 1.033e-10
2016 14.208 1.386 11.491 16.93 10.248 Inf 1.205e-24
2017 9.817 1.698 6.489 13.15 5.782 Inf 7.394e-09
```

Changes in the Number of Regenerating Aspen Stems in CRMO

Define an appropriate subset of the data and drop empty levels of Sample_Year.

```
d.subset <- d %>% filter(ParkUnit == "CRMO", treetype == "aspen")
d.subset$Sample_Year <- droplevels(d.subset$Sample_Year)
```

Estimate a basic linear mixed model.

```
m <- lmer(Regen ~ Sample_Year + (1|Stand_Name), data = d.subset)
```

Comparing each subsequent year against the first year. Compare each subsequent year against the first year.

```
alvls <- levels(d.subset$Sample_Year)[-1]
blvls <- levels(d.subset$Sample_Year)[1]
names <- paste(alvls, "-", blvls, sep = "")
```

```
contrast(m,
a = list(Sample_Year = alvls),
b = list(Sample_Year = blvls),
cnames = names)
```

estimate se lower upper tvalue df pvalue

```
2010-2007 3.61 1.38 0.9053 6.315 2.616 Inf 8.896e-03
2015-2007 6.23 1.38 3.5255 8.935 4.515 Inf 6.338e-06
```

Compare adjacent observation periods.

```
alvls <- levels(d.subset$Sample_Year)[-1]
blvls <- levels(d.subset$Sample_Year)[-
length(levels(d.subset$Sample_Year))]
names <- paste(alvls, "-", blvls, sep = "")
```

```
contrast(m,
a = list(Sample_Year = alvls),
b = list(Sample_Year = blvls),
cnames = names)
```

estimate se lower upper tvalue df pvalue

```
2010-2007 3.61 1.38 0.90534 6.315 2.616 Inf 0.008896
2015-2010 2.62 1.38 -0.08445 5.325 1.899 Inf 0.057596
```

Estimates for each year. Note that these will be slightly different from those obtained in the previous section as they are model-based and based on means at the stand level.

```
contrast(m,
a = list(Sample_Year = levels(d.subset$Sample_Year)),
cnames = levels(d.subset$Sample_Year))
estimate se lower upper tvalue df pvalue
2007 8.839 2.42 4.096 13.58 3.652 Inf 2.598e-04
2010 12.449 2.42 7.706 17.19 5.144 Inf 2.688e-07
2015 15.069 2.42 10.326 19.81 6.227 Inf 4.762e-10
```

Changes in the Number of Regenerating Conifer Stems in CIRO

Define an appropriate subset of the data and drop empty levels of Sample_Year.

```
d.subset <- d %>% filter(ParkUnit == "CIRO", treetype == "conifer")
d.subset$Sample_Year <- droplevels(d.subset$Sample_Year)
```

Estimate a basic linear mixed model.

```
m <- lmer(Regen ~ Sample_Year + (1|Stand_Name), data = d.subset)
```

Compare each subsequent year against the first year.

```
alvls <- levels(d.subset$Sample_Year)[-1]
blvls <- levels(d.subset$Sample_Year)[1]
names <- paste(alvls, "-", blvls, sep = "")
contrast(m,
a = list(Sample_Year = alvls),
b = list(Sample_Year = blvls),
cnames = names)
```

estimate se lower upper tvalue df pvalue

```
2009-2008 -0.8050 0.5948 -1.971 0.3607 -1.3535 Inf 0.175897
2011-2008 -0.4006 0.3563 -1.099 0.2979 -1.1241 Inf 0.260964
2012-2008 -0.3050 0.5948 -1.471 0.8607 -0.5129 Inf 0.608047
2016-2008 -1.0071 0.3608 -1.714 -0.2999 -2.7911 Inf 0.005253
2017-2008 -0.7912 0.5948 -1.957 0.3746 -1.3301 Inf 0.183471
```

Compare adjacent observation periods.

```
alvls <- levels(d.subset$Sample_Year)[-1]
blvls <- levels(d.subset$Sample_Year)[-
length(levels(d.subset$Sample_Year))]
names <- paste(alvls, "-", blvls, sep = "")
contrast(m,
a = list(Sample_Year = alvls),
b = list(Sample_Year = blvls),
cnames = names)
```

estimate se lower upper tvalue df pvalue

```
2009-2008 -0.80505 0.5948 -1.9708 0.3607 -1.3535 Inf 0.1759
```

```
2011-2009 0.40447 0.5015 -0.5786 1.3875 0.8064 Inf 0.4200
2012-2011 0.09553 0.5015 -0.8875 1.0786 0.1905 Inf 0.8489
2016-2012 -0.70208 0.5823 -1.8433 0.4391 -1.2058 Inf 0.2279
2017-2016 0.21597 0.5823 -0.9252 1.3572 0.3709 Inf 0.7107
```

Comparison between 2009 versus 2012 and 2017.

```
contrast(m,
a = list(Sample_Year = c("2012", "2017")),
b = list(Sample_Year = c("2009")),
cnames = c("2012-2009", "2017-2009"))
estimate se lower upper tvalue df pvalue
2012-2009 0.50000 0.4249 -0.3328 1.3328 1.17671 Inf 0.2393
2017-2009 0.01389 0.4249 -0.8189 0.8467 0.03269 Inf 0.9739
```

Estimates for each year. Note that these will be slightly different from those obtained in the previous section as they are model-based and based on means at the stand level.

```
contrast(m,
a = list(Sample_Year = levels(d.subset$Sample_Year)),
cnames = levels(d.subset$Sample_Year))
estimate se lower upper tvalue df pvalue
2008 1.9364 0.5001 0.95632 2.917 3.872 Inf 0.0001078
2009 1.1314 0.5644 0.02525 2.238 2.005 Inf 0.0449938
2011 1.5358 0.4449 0.66391 2.408 3.452 Inf 0.0005558
2012 1.6314 0.5644 0.52525 2.738 2.891 Inf 0.0038442
2016 0.9293 0.4808 -0.01307 1.872 1.933 Inf 0.0532621
2017 1.1453 0.5644 0.03914 2.251 2.029 Inf 0.0424254
```

Changes in the Number of Regenerating Conifer Stems in CRMO

Define an appropriate subset of the data and drop empty levels of Sample_Year.

```
d.subset <- d %>% filter(ParkUnit == "CRMO", treetype == "conifer")
d.subset$Sample_Year <- droplevels(d.subset$Sample_Year)
```

Estimate a basic linear mixed model.

```
m <- lmer(Regen ~ Sample_Year + (1|Stand_Name), data = d.subset)
boundary (singular) fit: see ?isSingular
```

Compare each subsequent year against the first year.

```
alvls <- levels(d.subset$Sample_Year)[-1]
blvls <- levels(d.subset$Sample_Year)[1]
names <- paste(alvls, "-", blvls, sep = "")
contrast(m,
a = list(Sample_Year = alvls),
b = list(Sample_Year = blvls),
cnames = names)
estimate se lower upper tvalue df pvalue
2010-2007 0.1521 0.1565 -0.1546 0.4589 0.9719 Inf 3.311e-01
2015-2007 0.5900 0.1507 0.2947 0.8853 3.9157 Inf 9.014e-05
```

Compare adjacent observation periods.

```
alvls <- levels(d.subset$Sample_Year)[-1]
blvls <- levels(d.subset$Sample_Year)[-
length(levels(d.subset$Sample_Year))]
names <- paste(alvls, "-", blvls, sep = "")
contrast(m,
a = list(Sample_Year = alvls),
b = list(Sample_Year = blvls),
cnames = names)
estimate se lower upper tvalue df pvalue
2010-2007 0.1521 0.1565 -0.1546 0.4589 0.9719 Inf 0.331093
2015-2010 0.4379 0.1468 0.1502 0.7255 2.9838 Inf 0.002847
```

Estimates for each year. Note that these will be slightly different from those obtained in the previous section as they are model-based and based on means at the stand level.

```
contrast(m,
a = list(Sample_Year = levels(d.subset$Sample_Year)),
cnames = levels(d.subset$Sample_Year))
estimate se lower upper tvalue df pvalue
2007 0.0600 0.11328 -0.1620222 0.2820 0.5297 Inf 5.963e-01
2010 0.2121 0.10801 0.0004314 0.4238 1.9640 Inf 4.953e-02
2015 0.6500 0.09935 0.4552737 0.8447 6.5424 Inf 6.054e-11
```

Analysis of Number of Suckers

The following is an analysis of the number of *suckers*. Note that there were a couple of extreme outliers with very high sucker counts. These are not shown in the plots.

```
p <- ggplot(trees, aes(x = yearunit, y = Suckers, fill = treetype))
p <- p + geom_count(aes(size = stat(prop)), shape = 21, position =
position_dodge(width = 0.5))
p <- p + theme_classic() + scale_fill_manual(values =
c("white", "black")) + scale_size_area()
p <- p + labs(x = "Year (Park Unit)", y = "Suckers", size =
"Proportion", fill = "Tree Type")
p <- p + ggtitle(paste("Distribution of Number of Suckers"))
p <- p + ylim(0,225)

p1 <- p
m <- trees %>% group_by(treetype, yearunit, Stand_Name) %>%
filter(Suckers < 300) %>%
summarize(y = sum(Suckers), m = n()) %>%
summarize(totally = sum(y), totalm = sum(m), s2 = var(y), m =
mean(m), n = n()) %>%
mutate(pe = totally/totalm, me = 2*sqrt(s2/n)/m) %>% mutate(lower =
pe - me, upper = pe + me)
p <- ggplot(m, aes(x = yearunit, y = pe, fill = treetype))
```

```

p <- p + geom_pointrange(aes(y = pe, ymin = lower, ymax = upper),
position = position_dodge(width = 0.5), shape = 21)
p <- p + theme_classic() + scale_fill_manual(values =
c("white", "black"))
p <- p + labs(x = "Year (Park Unit)", y = "Suckers", size =
"Proportion", fill = "Tree Type")
p <- p + ggtitle(paste("Estimated Mean Number of Suckers"))
p2 <- p
cowplot::plot_grid(p1, p2, align = "v", nrow = 2, rel_heights =
c(0.65, 0.35))

```

Warning: Removed 2 rows containing non-finite values (stat_sum).

The confidence intervals shown in the lower plot (Figure A4) were computed using estimated standard errors based ratio estimators for one-stage cluster sampling (treating the stands as clusters). Note that it is *not* appropriate to use the overlap of confidence intervals (or the lack thereof) to make conclusions about statistical significant differences due to the lack of independence of observations from the same stand. See the analysis in the next section for inferences concerning changes over years.

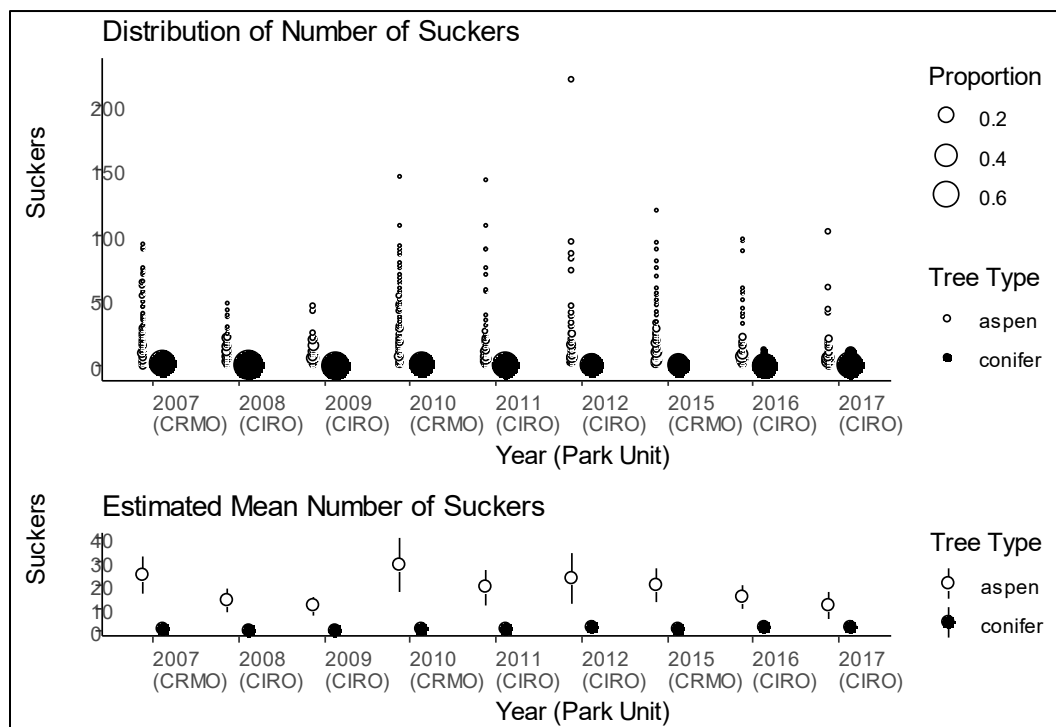


Figure A4. Example output of Estimated Mean Number of Suckers analysis.

Export the plot above as a Windows Metafile.

```

if (Sys.info()[1] == "Windows") ggsave("suckers.wmf")

```

The following shows the mean, standard deviation, and number of observations (i.e., plots) for each combination of treetype, ParkUnit, and Sample_Year.

```
trees %>% group_by(treetype, ParkUnit, Sample_Year) %>%
summarize(mean = mean(Suckers), sd = sd(Suckers), n = n())
# A tibble: 18 x 6
# Groups:   treetype, ParkUnit [4]
treetype ParkUnit Sample_Year mean sd n
<chr> <chr> <int> <dbl> <dbl> <int>
1 aspen CIRO 2008 13.3 10.3 66
2 aspen CIRO 2009 11.0 9.71 44
3 aspen CIRO 2011 28.4 89.3 81
4 aspen CIRO 2012 22.6 35.2 52
5 aspen CIRO 2016 24.5 91.3 85
6 aspen CIRO 2017 11.2 17.5 49
7 aspen CRMO 2007 24.3 23.5 99
8 aspen CRMO 2010 28.8 27.4 102
9 aspen CRMO 2015 19.9 21.9 102
10 conifer CIRO 2008 0.364 0.658 22
11 conifer CIRO 2009 0.636 1.03 11
12 conifer CIRO 2011 0.730 1.17 37
13 conifer CIRO 2012 1.5 1.62 12
14 conifer CIRO 2016 1.6 2.60 45
15 conifer CIRO 2017 1.92 3.34 12
16 conifer CRMO 2007 1.33 1.19 18
17 conifer CRMO 2010 1.25 0.928 28
18 conifer CRMO 2015 0.968 1.05 31
```

Analysis of Change in Number of Suckers

The following analysis uses average counts at the stand level (within year) as the observation for simplicity and robustness. First create a data frame of the average per stand-year observational unit, and define Sample_Year as a factor. Again note that a couple of outliers have been dropped.

```
d <- trees %>% group_by(treetype, ParkUnit, Sample_Year,
Stand_Name) %>%
filter(Suckers < 300) %>% summarize(Suckers = mean(Suckers), n =
n())
d$Sample_Year <- factor(d$Sample_Year)
```

Changes in the Number of Aspen Suckers in CIRO

Define an appropriate subset of the data and drop empty levels of Sample_Year.

```
d.subset <- d %>% filter(ParkUnit == "CIRO", treetype == "aspen")
d.subset$Sample_Year <- droplevels(d.subset$Sample_Year)
```

Estimate a basic linear mixed model.

```
m <- lmer(Suckers ~ Sample_Year + (1|Stand_Name), data = d.subset)
```

Compare each subsequent year against the first year.

```

alvls <- levels(d.subset$Sample_Year)[-1]
blvls <- levels(d.subset$Sample_Year)[1]
names <- paste(alvls, "-", blvls, sep = "")
contrast(m,
a = list(Sample_Year = alvls),
b = list(Sample_Year = blvls),
cnames = names)
estimate se lower upper tvalue df pvalue
2009-2008 -1.5052 7.410 -16.029 13.02 -0.2031 Inf 0.83904
2011-2008 10.8863 4.419 2.226 19.55 2.4636 Inf 0.01375
2012-2008 11.4672 7.072 -2.393 25.33 1.6215 Inf 0.10490
2016-2008 5.8097 4.419 -2.851 14.47 1.3148 Inf 0.18859
2017-2008 -0.6449 7.072 -14.506 13.22 -0.0912 Inf 0.92734

```

Compare adjacent observation periods.

```

alvls <- levels(d.subset$Sample_Year)[-1]
blvls <- levels(d.subset$Sample_Year)[-
length(levels(d.subset$Sample_Year))]
names <- paste(alvls, "-", blvls, sep = "")
contrast(m,
a = list(Sample_Year = alvls),
b = list(Sample_Year = blvls),
cnames = names)
estimate se lower upper tvalue df pvalue
2009-2008 -1.5052 7.410 -16.029 13.019 -0.20312 Inf 0.83904
2011-2009 12.3915 7.410 -2.132 26.915 1.67221 Inf 0.09448
2012-2011 0.5809 7.072 -13.280 14.441 0.08214 Inf 0.93454
2016-2012 -5.6575 7.072 -19.518 8.203 -0.80000 Inf 0.42371
2017-2016 -6.4546 7.072 -20.315 7.406 -0.91272 Inf 0.36139

```

Comparison between 2009 versus 2012 and 2017.

```

contrast(m,
a = list(Sample_Year = c("2012", "2017")),
b = list(Sample_Year = c("2009")),
cnames = c("2012-2009", "2017-2009"))
estimate se lower upper tvalue df pvalue
2012-2009 12.9724 5.847 1.512 24.43 2.2186 Inf 0.02652
2017-2009 0.8603 5.847 -10.600 12.32 0.1471 Inf 0.88303

```

Estimates for each year. Note that these will be slightly different from those obtained in the previous section as they are model-based and based on means at the stand level.

```

contrast(m,
a = list(Sample_Year = levels(d.subset$Sample_Year)),
cnames = levels(d.subset$Sample_Year))
estimate se lower upper tvalue df pvalue

```

```
2008 12.71 4.473 3.9432 21.48 2.842 Inf 4.489e-03
2009 11.20 5.908 -0.3757 22.78 1.896 Inf 5.791e-02
2011 23.60 4.473 14.8296 32.36 5.276 Inf 1.323e-07
2012 24.18 5.478 13.4403 34.91 4.414 Inf 1.017e-05
2016 18.52 4.473 9.7530 27.29 4.141 Inf 3.465e-05
2017 12.06 5.478 1.3282 22.80 2.202 Inf 2.764e-02
```

Changes in the Number of Aspen Suckers in CRMO

Define an appropriate subset of the data and drop empty levels of Sample_Year.

```
d.subset <- d %>% filter(ParkUnit == "CRMO", treetype == "aspen")
d.subset$Sample_Year <- droplevels(d.subset$Sample_Year)
```

Estimate a basic linear mixed model.

```
m <- lmer(Suckers ~ Sample_Year + (1|Stand_Name), data = d.subset)
```

Compare each subsequent year against the first year.

```
alvls <- levels(d.subset$Sample_Year)[-1]
blvls <- levels(d.subset$Sample_Year)[1]
names <- paste(alvls, "-", blvls, sep = "")
contrast(m,
a = list(Sample_Year = alvls),
b = list(Sample_Year = blvls),
cnames = names)
```

estimate se lower upper tvalue df pvalue

```
2010-2007 3.050 3.233 -3.287 9.3860 0.9433 Inf 0.34551
2015-2007 -5.509 3.233 -11.846 0.8271 -1.7041 Inf 0.08836
```

Compare adjacent observation periods.

```
alvls <- levels(d.subset$Sample_Year)[-1]
blvls <- levels(d.subset$Sample_Year)[-
length(levels(d.subset$Sample_Year))]
names <- paste(alvls, "-", blvls, sep = "")
contrast(m,
a = list(Sample_Year = alvls),
b = list(Sample_Year = blvls),
cnames = names)
```

estimate se lower upper tvalue df pvalue

```
2010-2007 3.050 3.233 -3.287 9.386 0.9433 Inf 0.34551
2015-2010 -8.559 3.233 -14.895 -2.223 -2.6475 Inf 0.00811
```

Estimates for each year. Note that these will be slightly different from those obtained in the previous section as they are model-based and based on means at the stand level.

```
contrast(m,
a = list(Sample_Year = levels(d.subset$Sample_Year)),
cnames = levels(d.subset$Sample_Year))
```

estimate se lower upper tvalue df pvalue

```
2007 26.92 4.634 17.83 36.00 5.808 Inf 6.323e-09
2010 29.97 4.634 20.88 39.05 6.466 Inf 1.006e-10
2015 21.41 4.634 12.32 30.49 4.619 Inf 3.852e-06
```

Changes in the Number of Conifer Suckers in CIRO

Define an appropriate subset of the data and drop empty levels of Sample_Year.

```
d.subset <- d %>% filter(ParkUnit == "CIRO", treetype == "conifer")
d.subset$Sample_Year <- droplevels(d.subset$Sample_Year)
```

Estimate a basic linear mixed model.

```
m <- lmer(Suckers ~ Sample_Year + (1|Stand_Name), data = d.subset)
```

Compare each subsequent year against the first year.

```
alvls <- levels(d.subset$Sample_Year)[-1]
blvls <- levels(d.subset$Sample_Year)[1]
names <- paste(alvls, "-", blvls, sep = "")
contrast(m,
a = list(Sample_Year = alvls),
b = list(Sample_Year = blvls),
cnames = names)
```

estimate se lower upper tvalue df pvalue

```
2009-2008 0.08615 0.6788 -1.2442 1.416 0.1269 Inf 0.89901
2011-2008 0.10049 0.4875 -0.8550 1.056 0.2061 Inf 0.83669
2012-2008 1.14170 0.6788 -0.1886 2.472 1.6820 Inf 0.09256
2016-2008 0.88932 0.5049 -0.1004 1.879 1.7612 Inf 0.07820
2017-2008 1.64170 0.6788 0.3114 2.972 2.4187 Inf 0.01558
```

Compare adjacent observation periods.

```
alvls <- levels(d.subset$Sample_Year)[-1]
blvls <- levels(d.subset$Sample_Year)[-
length(levels(d.subset$Sample_Year))]
names <- paste(alvls, "-", blvls, sep = "")
contrast(m,
a = list(Sample_Year = alvls),
b = list(Sample_Year = blvls),
cnames = names)
```

estimate se lower upper tvalue df pvalue

```
2009-2008 0.08615 0.6788 -1.2442 1.416 0.12692 Inf 0.89901
2011-2009 0.01435 0.5923 -1.1465 1.175 0.02422 Inf 0.98068
2012-2011 1.04121 0.5923 -0.1197 2.202 1.75793 Inf 0.07876
2016-2012 -0.25239 0.6534 -1.5331 1.028 -0.38625 Inf 0.69931
2017-2016 0.75239 0.6534 -0.5283 2.033 1.15144 Inf 0.24955
```

Comparison between 2009 versus 2012 and 2017.

```
contrast(m,
a = list(Sample_Year = c("2012", "2017")),
b = list(Sample_Year = c("2009")),
```

```

cnames = c("2012-2009", "2017-2009"))
estimate se lower upper tvalue df pvalue
2012-2009 1.056 0.6038 -0.128 2.239 1.748 Inf 0.080455
2017-2009 1.556 0.6038 0.372 2.739 2.576 Inf 0.009993

```

Estimates for each year. Note that these will be slightly different from those obtained in the previous section as they are model-based and based on means at the stand level.

```

contrast(m,
a = list(Sample_Year = levels(d.subset$Sample_Year)),
cnames = levels(d.subset$Sample_Year))
estimate se lower upper tvalue df pvalue
2008 0.4214 0.4527 -0.4659 1.309 0.9309 Inf 3.519e-01
2009 0.5075 0.5266 -0.5247 1.540 0.9637 Inf 3.352e-01
2011 0.5219 0.3619 -0.1874 1.231 1.4422 Inf 1.492e-01
2012 1.5631 0.5266 0.5309 2.595 2.9680 Inf 2.998e-03
2016 1.3107 0.4121 0.5031 2.118 3.1809 Inf 1.468e-03
2017 2.0631 0.5266 1.0309 3.095 3.9174 Inf 8.952e-05

```

Changes in the Number of Conifer Suckers in CRMO

Define an appropriate subset of the data and drop empty levels of Sample_Year.

```

d.subset <- d %>% filter(ParkUnit == "CRMO", treetype == "conifer")
d.subset$Sample_Year <- droplevels(d.subset$Sample_Year)

```

Estimate a basic linear mixed model.

```

m <- lmer(Suckers ~ Sample_Year + (1|Stand_Name), data = d.subset)

```

Compare each subsequent year against the first year.

```

alvls <- levels(d.subset$Sample_Year)[-1]
blvls <- levels(d.subset$Sample_Year)[1]
names <- paste(alvls, "-", blvls, sep = "")
contrast(m,
a = list(Sample_Year = alvls),
b = list(Sample_Year = blvls),
cnames = names)

```

estimate se lower upper tvalue df pvalue

```

2010-2007 -0.1548 0.2684 -0.6807 0.3712 -0.5768 Inf 0.5641
2015-2007 -0.4052 0.2578 -0.9105 0.1001 -1.5718 Inf 0.1160

```

Compare adjacent observation periods.

```

alvls <- levels(d.subset$Sample_Year)[-1]
blvls <- levels(d.subset$Sample_Year)[-
length(levels(d.subset$Sample_Year))]
names <- paste(alvls, "-", blvls, sep = "")
contrast(m,
a = list(Sample_Year = alvls),
b = list(Sample_Year = blvls),
cnames = names)

```

estimate se lower upper tvalue df pvalue

2010-2007 -0.1548 0.2684 -0.6807 0.3712 -0.5768 Inf 0.5641

2015-2010 -0.2504 0.2418 -0.7243 0.2235 -1.0357 Inf 0.3003

Estimates for each year. Note that these will be slightly different from those obtained in the previous section as they are model-based and based on means at the stand level.

```
contrast(m,
```

```
a = list(Sample_Year = levels(d.subset$Sample_Year)),
```

```
cnames = levels(d.subset$Sample_Year))
```

estimate se lower upper tvalue df pvalue

2007 1.2809 0.2745 0.7429 1.819 4.666 Inf 3.069e-06

2010 1.1261 0.2671 0.6027 1.650 4.216 Inf 2.482e-05

2015 0.8757 0.2541 0.3776 1.374 3.446 Inf 5.694e-04

Appendix B. Distance Photos in CRMO and CIRO

Comparison over three sampling events

The photographs that follow show distant views of sampling sites in CRMO in 2007, 2010, and 2015 (Figures B1 through B21).



Figure B1. Photos taken at sampling site CMRO-5 in 2007 (left), 2010 (middle), and 2015 (right).



Figure B2. Photos taken at sampling site CMRO-7 in 2007 (left), 2010 (middle), and 2015 (right).



Figure B3. Photos taken at sampling site CMRO-9 in 2007 (left), 2010 (middle), and 2015 (right).



Figure B4. Photos taken at sampling site CMRO-10 in 2010 (left) and 2015 (right) (no photo taken in 2007).



Figure B5. Photos taken at sampling site CMRO-11 in 2007 (left), 2010 (middle), and 2015 (right).



Figure B6. Photos taken at sampling site CMRO-12 in 2007 (left), 2010 (middle), and 2015 (right).



Figure B7. Photos taken at sampling site CMRO-13 in 2007 (left), 2010 (middle), and 2015 (right).



Figure B8. Photos taken at sampling site CMRO-14 in 2007 (left), 2010 (middle), and 2015 (right).



Figure B9. Photos taken at sampling site CMRO-16 in 2007 (left), 2010 (middle), and 2015 (right).



Figure B10. Photos taken at sampling site CMRO-17 in 2007 (left), 2010 (middle), and 2015 (right).



Figure B11. Photos taken at sampling site CMRO-18 in 2010 (left) and 2015 (right) (no photo taken in 2007).



Figure B12. Photos taken at sampling site CMRO-20 in 2007 (left), 2010 (middle), and 2015 (right).



Figure B13. Photos taken at sampling site CMRO-21 in 2007 (left), 2010 (middle), and 2015 (right).



Figure B14. Photos taken at sampling site CMRO-23 in 2007 (left), 2010 (middle), and 2015 (right).



Figure B15. Photos taken at sampling site CMRO-24 in 2007 (left), 2010 (middle), and 2015 (right).



Figure B16. Photos taken at sampling site CMRO-26 in 2007 (left), 2010 (middle), and 2015 (right).



Figure B17. Photos taken at sampling site CMRO-27 in 2007 (left), 2010 (middle), and 2015 (right).



Figure B18. Photos taken at sampling site CMRO-29 in 2007 (left), 2010 (middle), and 2015 (right).



Figure B19. Photos taken at sampling site CMRO-30 in 2007 (left), 2010 (middle), and 2015 (right).



Figure B20. Photos taken at sampling site CMRO-32 in 2010 (left) and 2015 (right) (no photo taken in 2007).



Figure B21. Photos taken at sampling site CMRO-33 in 2007 (left), 2010 (middle), and 2015 (right).

Comparison CIRO 2008, 2011 and 2016

The photos that follow show distant views of sampling sites in CIRO in 2008, 2011, and 2016 (Figures B22 through B34).



Figure B22. Photos taken at sampling site CIRO-5 in 2008 (left), 2011 (middle), and 2016 (right).



Figure B23. Photos taken at sampling site CIRO-6 in 2008 (left) and 2016 (right) (no photo taken in 2011).



Figure B24. Photos taken at sampling site CIRO-30 in 2008 (left), 2011 (middle), and 2016 (right).



Figure B25. Photos taken at sampling site CIRO-33 in 2008 (left), 2011 (middle), and 2016 (right).



Figure B26. Photos taken at sampling site CIRO-37 in 2008 (left), 2011 (middle), and 2016 (right).



Figure B27. Photos taken at sampling site CIRO-40 in 2008 (left), 2011 (middle), and 2016 (right).



Figure B28. Photos taken at sampling site CIRO-42 in 2008 (left), 2011 (middle), and 2016 (right).



Figure B29. Photos taken at sampling site CIRO-43 in 2008 (left), 2011 (middle), and 2016 (right).



Figure B30. Photos taken at sampling site CIRO-45 in 2011 (left) and 2016 (right) (no photo taken in 2008).



Figure B31. Photos taken at sampling site CIRO-52 in 2011 (left) and 2016 (right) (no photo taken in 2008).



Figure B32. Photos taken at sampling site CIRO-61 2011 (left) and 2016 (right) (no photo taken in 2008).



Figure B33. Photos taken at sampling site CIRO-63 2008 (left) and 2016 (right) (no photo taken in 2011).



Figure B34. Photos taken at sampling site CIRO-72 in 2008 (left) and 2011 (right) (no photo taken in 2016).

Comparison CIRO 2009, 2012 and 2017

The photos that follow show distant views of sampling sites in CIRO in 2009, 2012, and 2017 (Figures B35 through B44).



Figure B35. Photos taken at sampling site CIRO-7 in 2009 (left), 2012 (middle), and 2017 (right).



Figure B36. Photos taken at sampling site CIRO-9 in 2009 (left), 2012 (middle), and 2017 (right).



Figure B37. Photos taken at sampling site CIRO-11 in 2009 (left), 2012 (middle), and 2017 (right).



Figure B38. Photos taken at sampling site CIRO-13 in 2012 (left) and 2017 (right) (no photo taken in 2009).



Figure B39. Photos taken at sampling site CIRO-24 in 2009 (left), 2012 (middle), and 2017 (right).



Figure B40. Photos taken at sampling site CIRO-50 in 2012 (left) and 2017 (right) (no photo taken in 2009).



Figure B41. Photos taken at sampling site CIRO-54 in 2012 (left) and 2017 (right) (no photo taken in 2009).



Figure B42. Photos taken at sampling site CIRO-56 in 2009 (left), 2012 (middle), and 2017 (right).



Figure B43. Photos taken at sampling site CIRO-57 in 2009 (left), 2012 (middle), and 2017 (right).



Figure B44. Photos taken at sampling site CIRO-73 in 2009 (left), 2012 (middle), and 2017 (right).

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.

NPS 003/189702, 131/189702, July 2023

National Park Service
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