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Survey of Aspen Dieback in the Intermountain Region

John Guyon and James Hoffman

Quaking aspen (*Populus tremuloides*) is a keystone tree species in North America, where it exerts a significant influence on the structure and function of subalpine and boreal forest systems (Bartos, 2000). Aspen is the most widely distributed tree species in North America, extending across diverse topographical, edaphic, temperature and moisture gradients (Jones, 1985). However, recent patterns of aspen decline and dieback suggest that current management strategies and changing environmental conditions may impose constraints on aspen vigor across portions of its western range (Worrall et al, 2008; Fairweather et al, 2008; St. Clair et al, 2010). Forest Inventory and Analysis (FIA) data, suggest decreasing aspen cover in some regions of its western range (Rogers, 2002; Bartos and Campbell, 1998). Aspen dieback has been observed from western Canada (Hogg et al, 2008) south through the Rocky Mountains (Bartos and Campbell, 1998) including recent, large scale aspen mortality events in southwestern Colorado (Worrall et al, 2008) and Arizona (Fairweather et al, 2008). Additionally, recent aerial survey results in the USDA Forest Service Intermountain Region (the states of Utah, Nevada, Idaho south of the Salmon River, and western Wyoming) and elsewhere (Figure 1) has recorded substantial dieback in aspen forests in the western U.S.

Funding was provided by the USDA Forest Evaluation Monitoring program (Project INT-F-06-1) to conduct ground surveys and determine the agents responsible for the decline, dieback and mortality of aspen forests in the Northern (northern Idaho and Montana) and Intermountain Regions. This report summarizes the findings from surveys in Utah and Nevada in 2006 and the southern/central Idaho

survey in 2007. In 2008, Montana and northern Idaho were also surveyed and those results have been previously reported (Steed and Kearns, 2010).

Figure 1. Areas of aspen dieback symptoms reported from USFS aerial detection surveys 2003 to 2008.

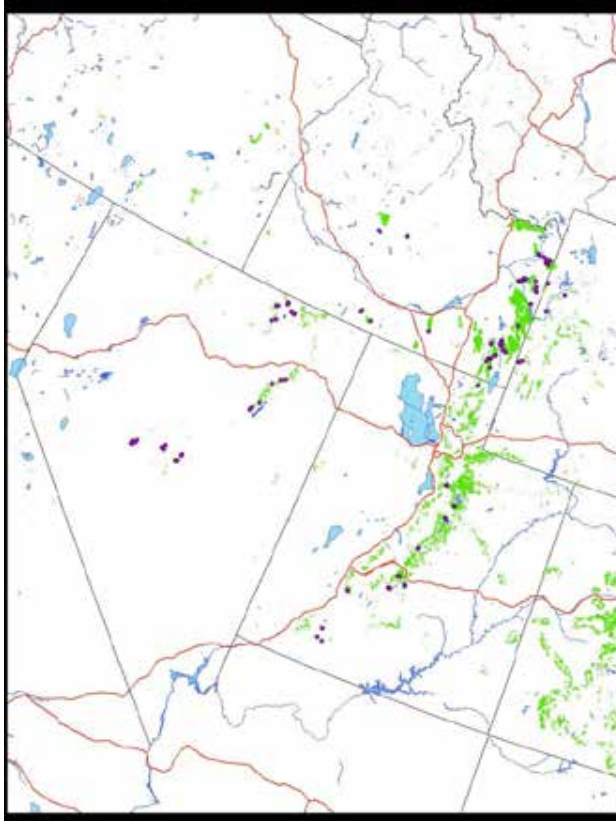


Methods

For the 2006-7 survey, aerial survey polygons of aspen dieback were used to determine potential plot locations. Within the polygons of dieback, any polygons within one mile of a road were considered potential plot locations. Within stands marked as having dieback within one mile of road access, plot locations were selected from all stands having at least seven overstory aspen stems where plots were randomly located. The survey objective was a detection survey of the agents damaging aspen. This procedure involves two significant biases. The survey selected areas with aspen dieback recorded during aerial surveys and stands sampled were close to roads with primarily an aspen overstory. Given these biases only descriptive statistics are used to summarize the data.

Permanent plots were located on ten National Forests in the Intermountain Region (Figure 2). Survey methods were identical to those previously reported (Steed & Kearns, 2010). All plot locations were documented using global positioning system (GPS) devices and monumented with a metal fence post at plot center. Plot level data taken included: slope, elevation, topographic position, primary and secondary tree species, clone stability (retreating, expanding, stable), successional status (stable, successional) and expected successional pathway. If species other than aspen (primarily conifers) were present and successfully regenerating on the site, the probable replacement species was recorded.

Figure 2. Purple dots represent locations of permanent aspen plots in the Intermountain Region. Due to the scale of the map, some dots are obscured by others that are located nearby.



All trees over 5-inches diameter breast height (dbh) were tagged with numbered aluminum tags starting north and moving clockwise in a 1/20th acre plot. Data taken on trees over 5 inches dbh included: species, dbh, crown dieback in three classes (<33%, 34-66%, and >67%), tree condition (live, new dead, older dead), crown class (dominant, codominant, intermediate & suppressed), the three most damaging agents, and damage severity (low, moderate, high). The term, “new dead” was defined as stems that appeared to have died within the last few years but still maintained fine branches and most of their bark. “Older dead” was defined as trees that were not as above with bark beginning to slough off. Older dead trees that had already sloughed off most of their bark were not recorded.

Damage severity was defined by three categories:

- Low - unlikely to cause significant damage to the stem such as light defoliation, minor wounds and small cankers that had ceased to expand, small wounds or single insect borer attacks, etc

- Moderate -causing significant damage to the stem but unlikely to kill the stem in the next 2-3 years, such as cankers or wounds on less than 1/3rd of the stem, up to 75% defoliation, or borer attacks on over 1/3 of the stem, etc
- High – stem mortality is likely to occur within 2-3 years such as damage caused by repeated borer attacks, expanding cankers over 1/3rd of the stem, complete defoliation with serious dieback etc.

For non-aspen species only dbh, tree condition and crown- class was recorded.

Saplings (2-4.9 inches dbh) and seedlings (less than 2-inches dbh) with no minimum height requirements were recorded in nested 1/300th acre subplots located 13.2 feet from plot center at 0, 120, and 240 degrees. Data recorded for saplings was the same as the >5- inch dbh trees but they were not tagged. Seedling data included: number, damage agents, estimated percentage of the number affected by the damage agents, and damage severity. Non-aspen seedlings were noted in the count but damage was not recorded.

Results and Discussion

During 2006, 35-permanent plots were installed in Utah, 34-plots in Nevada, and six-plots in the Bridger-Teton National Forest of western Wyoming. The plots in Utah were located on the Dixie, Fishlake, Manti-LaSal, and Uinta-Wasatch-Cache National Forests. The plots in Nevada were all located on the Humboldt-Toiyabe National Forest. In 2007, 51-plots were installed in southern Idaho on the Caribou-Targhee, Salmon-Challis and Sawtooth National Forests. In terms of both forest type and geographic location, the plots on the Bridger-Teton National forest were more similar to the plots in southern Idaho, so those data were pooled together and will be referred to as Idaho plots unless designated otherwise in this report.

Plant communities are influenced by both time and their environment. Aspen ramets are short lived and shade intolerant, and are often considered to be successional to more shade tolerant conifers in the communities where they coexist. Aspen research indicates two thirds of aspen forests exist in these successional types, and one third can be considered stable (Bartos 2000). Our plots did not reflect this trend, particularly in Nevada where 73.4% of the plots fell into stable types (Table 1). Aspen in Nevada often exist in riparian sites or on slopes where snowfall accumulates that do not have conifers present. Nevada also had the highest number of stable stands that were considered expanding (Table 1). Whereas, Idaho and Utah stands were largely determined to be successional (56.7 and 51.4 percent respectively). In Idaho over half of the stands were considered to be in successional/expanding status, while Utah had no stands in this status. The successional/expanding stands in Idaho were not as densely stocked with later successional species averaging 29.4 trees/acre (TPA) non-aspen over 5 inches dbh compared to the Utah average of 124.7 non-aspen TPA over 5 inch dbh. The lower density in Idaho may account for successional/expanding status within the sampled aspen stands. There were also differences in successional patterns within the aspen component for the three states. In Nevada stands were largely succeeding towards brush vegetation types, with Idaho aspen stands succeeding towards pine, *Pinus* and Douglas-fir, *Pseudotsugae menziesii* and Utah aspen stands succeeding towards spruce/fir, *Picea/Abies*.

Table 1. Percent of plots in each type of successional pattern.

Stable					Successional			
State	No Trend	Expanding	Retreating	Total Stable	No trend	Expanding	Retreating	Total Successional
Idaho	5.9	27.5	9.8	43.2	3.4	31.5	21.5	56.3
Nevada	0	55.8	17.6	73.4	0	2.9	23.5	26.4
Utah	0	25.7	22.9	48.6	0	0	51.4	51.4

Table 2. Percentage of plots with vegetation type towards which successional aspen stands were developing.

Type	Idaho	Nevada	Utah
Sagebrush (<i>Artemisia spp.</i>)		14.7	5.7
Other brush (<i>Symphoricarpos</i> , <i>Juniperus</i> , <i>Prunus</i> , <i>Sambucus</i> , etc)	5.3	8.8	
White Fir (<i>Abies concolor</i>)			5.7
Subalpine fir/Engelmann Spruce (<i>Abies lasiocarpa/Picea engelmannii</i>)	1.8	2.9	34.2
Douglas-fir	24.6		
Pines	24.6		2.9
Grass/Forbs			2.9

A few things are readily evident from viewing the diameter distributions by state (Figures 3-5). First, none of the diameter distributions follows the expected aspen reverse J shaped curve for distribution of size classes (Shepperd, 1993). Particularly in Nevada there is a distinct drop in trees per acre (TPA) from the 2-3.9 inch size class to the 4-5.9 inch size class followed by an increase in the 6-7.9 inch size class. For the Idaho distribution, the number of trees after this mortality event remains static from 4-10 inches when a drop in TPA would be expected. In Utah, there is an increase in TPA from the 2-3.9 inch size class through the 6-7.9 inch size class. Evaluating mortality trends across all three states (Table 3), aspen mortality is lowest in the 2-3.9 inch size class then peaks in either the 4-5.9 inch or the 6-7.9 inch size class. In all states, aspen mortality follows a decreasing trend through the larger size classes up to 14 inches dbh. Over 14 inches dbh, where several diameter classes are pooled, mortality in Utah and Nevada increases but in Idaho the mortality rates fall with increasing stem diameter.

Figure 3. Idaho aspen diameter distribution in TPA (trees per acre) by 2" size class for both live and dead stems.

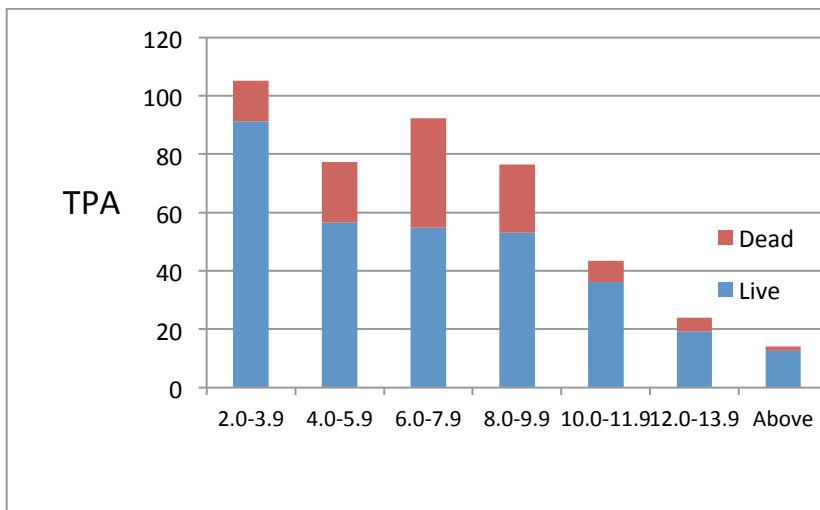


Figure 4. Nevada aspen diameter distribution in TPA (trees per acre) by 2" size class for both live and dead stems.

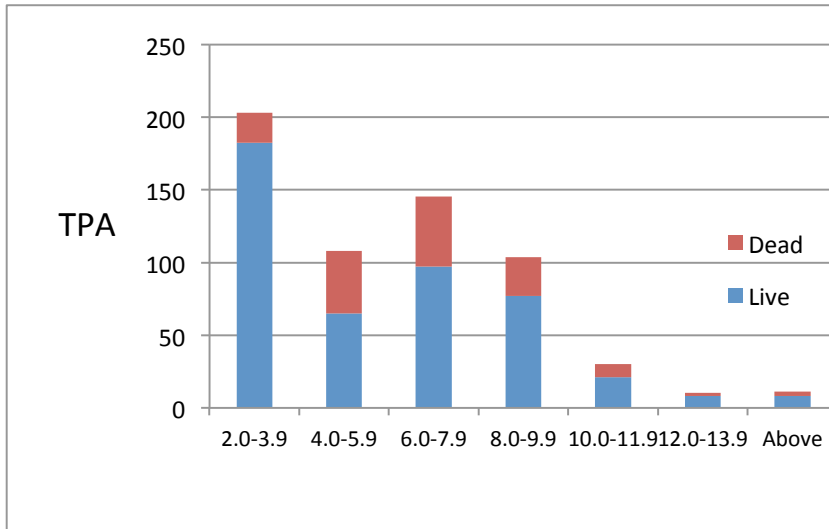


Figure 5. Utah aspen diameter distribution in TPA (trees per acre) by 2" size class for both live and dead stems.

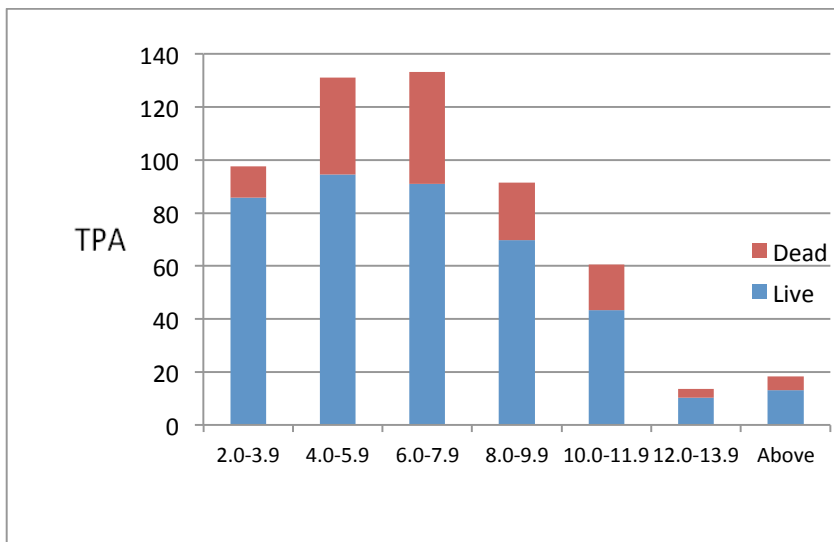


Table 3. Percent aspen mortality by diameter class.

State	2.0-3.9	4.0-5.9	6.0-7.9	8.0-9.9	10.0-11.9	12.0-13.9	Above
Idaho	13.3	26.8	40.7	30.7	17.0	19.2	10.0
Nevada	10.1	39.9	33.2	25.6	29.3	21.9	26.1
Utah	12.1	27.8	31.8	23.7	28.3	23.7	28.0

The severity of the various damage agents for all size classes of live stems is categorized in Tables 4-6. In all three states around 30% of the stems 5 inch dbh had serious damage (Severity classes 2 and 3).

Similar to the pattern in stem mortality, sapling sized trees had lower damage percentages compared to larger diameter trees (Table 5). Damage in the seedling size trees (Table 6) was similar to the >5 inch dbh trees with approximately 30% of the seedling damage in the higher severity classes (Table 6). The

most common and damaging agent on sprouts (<2- inch dbh) was browsing. When trees exceeded 2- inch dbh, browsing damage declined. Decreased browsing injury on the larger diameter stems may account for the decline in damage severity between sprout and sapling size classes.

Table 4. Severity of damage agents on over 5 inches dbh stems by state.

State	Severity 1 (%)	Severity 2(%)	Severity 3(%)
Idaho	70.9	21.1	8.0
Nevada	70.0	23.2	6.8
Utah	68.6	21.7	9.7

Table 5. Severity of damage agents on saplings (2-4.9 inches dbh).

State	Severity 1 (%)	Severity 2(%)	Severity 3(%)
Idaho	82.8	11.8	5.3
Nevada	85.5	7.2	7.2
Utah	94.2	5.8	0

Table 6. Severity of damage agents on sprouts (less than 2 inches dbh stems).

State	Severity 1 (%)	Severity 2(%)	Severity 3(%)
Idaho	70.8	16.8	12.4
Nevada	72.8	17.3	9.9
Utah	69.4	23.1	7.5

We recorded the presence of over 60 different biotic and abiotic damage agents (Appendix 1). However, over 90% of all damage could be attributed to 15 principle damage agents (Tables 7 & 8). It's important to note that our survey recorded the presence of root diseases only if they were evident in the root collar area and involved in stem mortality. Consequently root diseases may have been inadequately assessed in this survey. In a few sites *Armillaria* root disease (*Armillaria spp*) was affecting trees on the plots, but often this type damage was only detectable at a very low level. A few stands appeared to be affected by *Ganoderma* rot disease (*Ganoderma applanatum*), but none of the root disease pockets fell within plot boundaries. Also, some of the insect borer damage that should have been attributed to eastern poplar borer (*Poecilonota cyanipes*) or poplar dicerca (*Dicerca tenebrica*) was misidentified in 2006 and 2007 because both insects were not positively identified until 2008 (Steed and Kearns, 2010). This damage was likely cited as bronze poplar borer (*Agrilus liragus*) and poplar borer (*Saperda calcarata*) damage.

Up to three damage agents were recorded in the survey and nearly all of the dead trees and most of the damaged trees had more than one agent causing mortality and tree injury. Also, within the surveyed area drought conditions preceded the survey. Many of these damage agents may have been more prevalent and damaging due to predisposing stress caused by drought. The most common damaging agents on live stems over 5 inches dbh in Idaho were:

- poplar borer
- unknown and other cankers

- bronze poplar borer
- large aspen tortrix (*Choristoneura conflictana*)
- aspen leaf tier (*Sciaphila duplex*)
- sooty bark cankers (*Encoelia pruinosa*)
- Phellinus decay (*Phellinus tremulae*)

The unknown and other cankers category included black canker (*Ceratocystis fimbriata*), snake canker (*Cryptosphaeria popilina*), Hypoxylon canker (*Hypoxylon mammatum*), and cankers that were too high on the stem or too early in the development of the canker to positively identify. On the dead trees in Idaho, sooty bark canker, Cytospora canker (*Valsa sordida*) and bronze poplar borer were the most prevalent damage agents recorded in the survey.

Table 7. Pest damage percentages on >5 inch dbh Aspen

Damage Agent	Idaho Live Stems	Idaho Dead Stems	Nevada Live Stems	Nevada Dead Stems	Utah Live Stems	Utah Dead Stems
Sooty Bark Canker	12.8	84.1	16.9	82.5	12.9	57.4
Cytospora Canker	8.6	37.3	29.0	57.5	19.2	75.3
Other and unknown cankers	35.3	1.6	23.8	1.1	12.1	2.1
Phellinus decay	12.4	12.3	0.2	0	9.1	8.3
Fungal foliar pathogens	2.2	0	4.8	0	2.9	0
Poplar Borer	44.4	17.7	23.7	17.7	8.6	6.3
Bronze Poplar Borer	30.8	70.6	13.3	11.6	4.2	53.7
Large Aspen Tortrix	21.3	0.4	18.4	0	46.2	0
Twoleaf Tier	18.7	0	6.6	0	11.6	0
Aspen Leaf Tier	0.5	0	2.4	0	7.4	0.5
Other foliar insects	2.9	0	30.8	0	8.8	0
Aspen Bark Beetles	2.2	6.0	0.3	1.1	1.1	3.6
Mechanical Damages	13.4	8.8	28.3	5.8	26.8	2.5

Various forms of aspen bark roughening were also noted, primarily in the comments, due to *Diplodia tumefaciens*, *Curcubita staphula*, and *Rhytidella baranyayi*. These agents were present in all three states but were more frequently noted in Idaho. Bark roughening did not appear to be damaging to aspen stems and in almost all cases there was no cambial necrosis under the infections. In Nevada, the principle damage agents were:

- other foliar insects

- mechanical damage
- Cytospora canker ,
- other and unknown cankers
- poplar borer
- large aspen tortrix
- sooty bark canker
- bronze poplar borer

The other defoliator category includes a large number of insects causing minimal damage on aspen such as aphids (*Chaitophorus spp*, *Aphis maculatae*, *Mordwilkoja vagabunda* and others), leaf hoppers (*Idiocerus spp*), aspen leafminer (*Phyllocnistis populiella*) and various blotch miners, leaf rollers (*Pseudexentera oregonana* and others,) , forest tent caterpillar (*Malacosoma distria*), poplar petiole gall (*Pemphigus populitransversus*), Eriophyid mites, gall forming mites, spider mites, aspen skeletonizer (*Phratora purpurea*), lace bugs, and various leaf beetles. Because only the three most damaging agents were recorded on plots in many cases the “Other defoliator” category would have been recorded if the most damaging agents per plot had been increased to four. At least one of these agents would have been recorded on nearly every plot. Mechanical damage includes various forms of animal damage such as debarking, antler rubbing, sapsucker damage and many unknown other wounds.

Despite this abundance of wounds Phellinus decay was rarely found in Nevada, perhaps due to the lack of fruiting bodies in the dry climate. No internal examination of stems was conducted, only the presence of stem decay agents was recorded if they were visible on the surface of the tree. On dead aspen in Nevada sooty bark canker and Cytospora canker were the most prevalent damage agents, however bronze poplar borer and poplar borer damage were also commonly recorded. Comparing aspen damage between states, it’s interesting to note that symptoms associated with bronze poplar borer damage were less common on dead trees in Nevada than the other two states. On live aspen in Utah, large aspen tortrix was the most common damage agent, followed by mechanical damage, sooty bark canker, Cytospora canker, other and unknown cankers, aspen twoleaf tier (*Enargia decolor*), Phellinus decay, other foliar insects and aspen leaf tier. Utah had the smallest incidence of bronze poplar borer on live stems. On dead stems, Cytospora canker, sooty bark canker, and bronze poplar borer were the most frequently recorded damage agents.

The prevalence of Cytospora canker on dead stems may be related to Cytospora cankers’ role as a facultative parasite that primarily occurs on seriously stressed and dying trees (Guyon and others, 1996). Bronze poplar borer is also reported to be a secondary insect that attacks stressed and dying trees (Furniss and Carolyn, 1977). It’s noteworthy that while bronze poplar borer was more prevalent on dead trees than live trees, poplar borer decreased in prevalence on dead trees. Based on this observation of recorded damage on dead trees, bronze poplar borer could be contributing to more aspen mortality compared to trees infested by poplar borer. On several plots bronze poplar borer appeared to be the only significant mortality causing agent. Although poplar borer was quite prevalent on some plots, its presence alone did not cause significant mortality unless one of the canker diseases was also present. Poplar borer larva feed mainly in the interior wood of trees, while bronze poplar borer feeds primarily in the cambium which may account for bronze poplar borer being more prevalent on dead trees.

Sooty bark canker is the most lethal canker disease affecting western aspen (Hinds, 1985) and it has recently been associated with aspen mortality in Utah (DeWoody et al, 2008.). In thinned, heavily wounded stands, sooty bark canker can be a major element in a complex of factors leading to heavy mortality (Jones and Shepperd, 1985). In this survey, sooty bark cankers contributed to the death of many trees with wounds caused by insect borers, mechanical damage, animal damage and other causes. In Colorado, Worrall et al (2010) recorded many of the same damage agents detected in this survey, such as insect borers, and canker diseases, with the exception of sooty bark canker. They concluded that the agents that typically kill mature trees in aspen stands were unimportant in their survey. The same statement could be made for our survey except for the common occurrence of sooty bark canker.

Aspen bark beetles (*Trypophloeus populi* and *Procryphalus mucronatus*), were a significant contributor to aspen dieback and sudden aspen decline in Colorado (Worrall, 2008). Aspen bark beetles were detected at low levels within all three states, but did not play a substantial role in the dieback symptoms recorded. Recent field observations indicate that aspen bark beetles are becoming more significant agents contributing to the ongoing aspen dieback in the surveyed states.

Fungal foliar pathogens (primarily *Marssonina populi*, *Venturia tremulae*, *Melampsora medusae* and *Ciborinia whetzlii*) played a largely insignificant role on larger stem dieback. However, foliar pathogens did appear to be more prevalent on seedlings (Table 9). Insect defoliators were common in all three states, but defoliator incidence varied frequently from plot to plot. Aspen stands in southern Utah had the most prolific insect defoliation often consisting of a complex of defoliators including large aspen tortrix, aspen twoleaf tier, and less frequently, aspen leaf tier.

Forest tent caterpillar defoliation was seldom recorded in this survey. Defoliation caused by this insect is frequently detected in aerial surveys conducted within the three states surveyed, affecting aspen and other hosts. In Canada and elsewhere it is a significant contributor to aspen dieback (Hogg et al, 2002). Although forest tent caterpillar outbreaks typically last 2-3 years outbreak intervals vary for any given location (Fitzgerald, 1995).

In Nevada, aspen sunscald damage was more prevalent. Aspen clones in Nevada are often smaller discrete entities with more clonal edge exposed to the sun, compared to Idaho and Utah aspen stands which are often larger in extent and part of a larger forest canopy.

Compared to other size classes, sapling-sized trees had the lowest rate of mortality and damage. The most obvious difference between the mortality in the >5" dbh trees and the 2-5" dbh trees was the increased incidence of Cytospora canker. Both sooty bark canker and bronze poplar borer were also found in the dead saplings, but their presence was not consistent within the surveyed sites. On live saplings, fungal foliar pathogens and insect defoliators were more commonly recorded compared to larger trees (Table 8).

On stems less than 2 inches dbh (Table 9), the most common damaging agent was animal damage (browsing, grazing, trampling, bark striping etc) in Utah and Nevada and aspen twoleaf tier in Idaho followed by animal damage. Animal damage accounted for most (61%) of the damage severity codes rated moderate to severe damage on seedlings.

Other interesting patterns observed:

- Utah had lower shoot blight than either Idaho or Nevada

- The presence of canker diseases (primarily Cytospora canker on 2-5 in dbh stems) were fairly consistent (21.6-24.4% all cankers combined on live trees) across all three states.
- Nevada had lower levels of foliar diseases except for shoot blight.
- Twoleaf tier foliar damage was severe in Idaho.
- Eriophyid mite and aphid activity was heaviest in Nevada.

Table 8. Pest damage percentages on 2-5 inch dbh Aspen stems.

Damage Agent	Idaho Live Stems	Idaho Dead Stems	Nevada Live Stems	Nevada Dead Stems	Utah Live Stems	Utah Dead Stems
Sooty Bark Canker	9.9	0	2.9	88.0	10.8	16.7
Cytospora Canker	11.2	28.6	18.8	62.5	13.0	75.0
Other and unknown cankers	11.2	0	2.8	0	10.8	16.7
Phellinus decay	4.2	0	0	0	0	8.3
Fungal foliar pathogens	21.1	0	26.7	0	22.0	0
Bronze Poplar Borer	8.5	57.3	13.3	0	0	0
Poplar Borer	29.6	14.3	26.1	25	8.7	0
Large Aspen Tortrix	18.3	0	20.3	0	34.7	0
Twoleaf Tier	52.1	0	11.6	0	6.5	0
Aspen Leaf Tier	1.4	0	10.1	0	39.1	0
Other foliar insects	11.3	0	31.8	75	23.8	0
Mechanical Damages	23.9	0	44.8	0	19.5	8.3

Shier (1975) stated that he found the healthy clones had between 930 and 2,900 suckers per acre, while the deteriorating clones had only 159 to 441 suckers per acre. By these standards, 72% the stands we surveyed could be classified as healthy. However, we recorded the presence of any sprout that was visible above ground, and this may not be a good measure of successful regeneration, and an even poorer predictor of recruitment of small stems into a healthy forest canopy. O'Brien and others (2010) recently defined recruitment as "The rate of aspen suckers that survive to pole size ramets or stems above browse height to lower canopy". By this definition our 2-5 inch dbh class trees should be a reasonable approximation of the level of recruitment in the stands surveyed. This approximation is inexact because in some cases, trees that reached 5 inches dbh could have been classified as having reached the canopy and some of the ramets that had not reached 2 inches dbh would probably best be described as having reached recruitment size. Following this definition, 94% of the plots surveyed could be classified as below recruitment standards for healthy stands of over 500 TPA of recruitment (O'Brien et al, 2010). Steed and Kearns (2010) also suggested that the number of trees in the sapling size class might be a reasonable surrogate for successful regeneration, but didn't comment on recruitment.

Table 9. Percent of regeneration plots* with at least one sprout that had various damaging agents.

Damage Agent	Idaho	Nevada	Utah
Shoot Blight	32	26.5	6.3
Marssonina	20	5.9	6.3
Canker Diseases	30	23.5	31.3
Other Foliar Diseases	30	5.9	25.0
Large Aspen Tortrix	12	39.4	43.8
Aspen Leaf Tier	6	14.7	18.8
Twoleaf Tier	52	11.8	21.9
Leaf Hoppers	18	0	6.3
Eriophyid Mites	10	56.9	3.1
Aphids	18	58.8	0
Stem Insects	24	17.6	9.4
Other Foliar Insects	34	44.1	50.0
Mechanical Damages	12	26.5	34.4
Animal Damages	46	64.7	62.5

*Idaho had five plots with no aspen regeneration, Utah had three, and Nevada had none.

Overall, 52 plots did not have any aspen in the 2-5 inch size class. In this size class Idaho plots averaged 91.2 TPA, Nevada 182.4, and Utah 85.7 TPA. These numbers represent a 95.7, 93.8, and 97.0 percent reduction in numbers of TPA compared to seedlings (Table 9). Aspen has substantial self-thinning from seedling to sapling size classes (Bartos, 1994). Perhaps one reason the number of stems drops so dramatically from seedlings to sapling size trees is the level of damage experienced by the sprouts (Table 9). This level of damage is higher than the damage reported on seedlings for the Northern Region, Steed & Kearns (2010). Worrall et al (2010) reported low levels of regeneration but did not report heavy levels of damage caused by animals, forest insects and/or diseases in seedling size trees. In an evaluation of clearcut treatments with poor regeneration response Jacobi and Shepperd (1991) reported most of the damage was due to environmental factors and canker diseases which were present on an average of 28.2% of the seedlings in our survey.

In 1989, Mueggler reported that in the Intermountain west, two thirds of the stems surveyed were at least 96 years old. Twenty years later, these same stems would be almost 120 years old, pushing the threshold he defined for decadent stands that should be experiencing substantial dieback. Perhaps the current symptoms of dieback are just that, a correction in the canopy structure of the stand that leaves room for the sprouts to develop into a new stand replacing the old. Mueggler stated that "...suckers develop under existing stands, and more are frequently formed as the old canopy gradually breaks up. These suckers have the demonstrated potential to gradually replace a deteriorating even-aged canopy with a multi-aged replacement stand." However, the sprouts in surveyed stands were experiencing an average of 46 to 65% animal damage, primarily browsing. Mueggler's two disclaimers for the quote above were conditions where heavy grazing was present or succession to conifers was occurring, similar to that reported by Steed and Kearns (2010).

Drought stress also can play a role in aspen dieback and decline. Worrall et al (2010) reported that the stands experiencing "SAD" (defined as "SAD is characterized by rapid, synchronous branch dieback,

crown thinning and mortality of aspen stems on a landscape scale, without the involvement of aggressive, primary pathogens and insects" Worrall et al 2010). In their survey were low elevation stands under drought stress. Hogg et al (2008), tied dieback and a collapse in primary productivity in Canadian aspen stands to climatic moisture index (CMI), a measure of drought stress. Rehfeldt et al (2008) recently published a bioclimatic model predicting the presence or absence of aspen in the western U.S. indicating a dramatic contraction of aspen range tied to variables similar to CMI. Schier and Campbell (1980) attributed deteriorating stands to physiological problems and lack of ability to withstand drought stress. The Intermountain Region experienced a significant drought from 1999-2004, immediately prior to the current episode of dieback (Appendix 2). Noted aspen biologist Wayne Shepperd has used a functional definition; when the clone or stand is experiencing dieback but is still has regeneration it is not declining (Figure 6)

Conclusions

Several authors have cited critical factors affecting the health of aspen forests. The most important factors include drought stress (Hogg et al 2008), grazing pressure (Kay 1997), and conversion of aspen forest to other vegetation types due to fire exclusion (Bartos 2000). Our survey, which was done in the aftermath of a drought, detected 46-65% (averages by state) damage to seedlings by animals, in addition to a complex of insect and disease agents causing mortality across all size classes. These factors may be facilitating succession in Utah and Idaho as over half the stands there were seral, but may have other effects in Nevada where over 70% of the stands were stable.

Overall, the aspen stands surveyed in Nevada, Utah and Idaho and western Wyoming were experiencing 32.2 percent mortality of trees over 5 inches dbh. Another 30 percent of all surveyed stems were rated as moderately to heavily damaged. Regeneration was over thresholds considered adequate in most areas (O'Brien et al 2010), but varied widely from stand to stand. Surveyed stands did not experience the top down pattern of mortality reported by Worrall et al (2010), but rather had highest levels of mortality in 4-8 inch dbh stems. Sooty bark canker, an aggressive tree killing disease was more common in our survey than in Colorado (Worrall et al, 2010). The three most common agents were poplar borer, bronze poplar borer, and *Cytospora* canker, all three of which are usually considered to be secondary agents not primary tree killers, and at least one of the three was present on a combined 60.6% of the live damaged and 100% of the recently dead over 5 inch dbh trees. Moderate to severe defoliation by insects was present in less than 8% of the surveyed stands, most of which occurred on the Dixie National Forest in southern Utah and scattered across 3 National Forests in Idaho.

In Colorado, Worrall (2010) suggested that a decline disease resulting from inciting, predisposing, and contributing factors may be responsible for "SAD", a term used to describe dying stands with little to no regeneration or recruitment. This condition was seldom detected in our survey; the stands were still capable of regenerating themselves (overall average over 2500 TPA). However, the regeneration numbers frequently did not translate into successful recruitment with an average of 124 live TPA in the 2-5 inch dbh size class, well below the threshold (500 TPA) proposed by O'Brien et al (2010) for successful aspen recruitment. Survey results indicate the importance of the relationships between various agents of ecosystem change and can provide resource managers with information that can be used to develop aspen management and restoration strategies that address disturbance agents and the long-term viability of aspen stands.

Table 10. Summary statistics for the Intermountain Region aspen survey.

	All Plots					Idaho and B-T					Nevada					Utah				
	Mean	Max	Min	ST Dev		Mean	Max	Min	ST Dev		Mean	Max	Min	ST Dev		Mean	Max	Min	ST Dev	
Elevation feet	7566.0	10363.0	5560.0	1289.3		6578.1	7518.0	5560.0	456.1		7597.9	9517.0	6473.0	936.0		9143.8	10363.0	7295.0	847.6	
TPA [#] 5+dbh*	338.5	860.0	100.0	147.6		291.4	720.0	120.0	122.2		372.4	860.0	100.0	175.7		382.3	720.0	160.0	136.8	
TPA 2-5 dbh	164.2	1000.0	0.0	214.1		135.0	900.0	0.0	221.6		226.5	800.0	0.0	202.0		151.4	1000.0	0.0	206.3	
TPA dead 5+ dbh	107.6	360.0	0.0	80.2		83.2	240.0	0.0	65.4		142.4	320.0	0.0	81.0		113.7	360.0	0.0	89.1	
TPA 2-5 dbh dead	40.3	500.0	0.0	81.7		38.0	200.0	0.0	58.9		30.8	200.0	0.0	61.8		55.0	500.0	0.0	119.1	
Percent 5+ dead	32.2	88.9	0.0	21.4		27.3	78.6	0.0	19.9		40.2	78.6	0.0	19.0		32.2	88.9	0.0	24.1	
Percent 2-5 dead	24.3	100.0	0.0	29.6		7.5	50.0	0.0	13.5		15.2	100.0	0.0	33.2		18.5	100.0	0.0	36.1	
Percent Damaged (Severity 2-3) 5+dbh	34.2	100	0.0	28.6		25.5	100.0	0.0	19.9		43.2	100.0	12.5	27.2		34.0	95.6	12.5	22.1	
Percent Damaged (Severity 2-3) 2-5 dbh	28.8	100.0	0.0	23.8		23.8	100.0	0.0	17.6		11.6	66.6	0	19.3		51.1	100.0	0.0	24.5	
TPA Regeneration [#]	2546.8	12900.0	0.0	2793.2		2121.1	12300.0	0.0	2536.8		2958.8	8300.0	100.0	2172.3		2840.0	12900.0	0.0	3597.6	
TPA Regeneration damaged*	1105.1	11700.0	0.0	2017.4		987.4	11700.0	0.0	2350.1		1244.6	7300.0	0.0	1596.0		1152.0	8200.0	0.0	1862.4	
% Regeneration damaged	52.7	1700.0	0.0	162.5		60.0	1700.0	0.0	234.7		54.6	490.0	0.0	83.3		39.0	100.0	0	36.2	

& Trees per acre

* Diameter breast height in inches

Trees less than 2 inches dbh were classified as regeneration

Appendix One

Insect and disease biology

Cytospora canker, caused by *Valsa sordida* (anamorph *Cytospora chrysosperma*), is the most common fungus found on aspen throughout its range (Hinds, 1985). It is a normal bark inhabitant and parasitizes bark and cambial tissues that have been injured (Hinds, 1985) or stress weakened stems (Guyon et al, 1996). Cytospora canker can cause generalized dieback of small stems, and annual cankers on larger stems under stress. This disease is also commonly found in association with other canker diseases, insect borer attacks, and mechanical wounds on stems.

Sooty bark canker, caused by *Encoelia pruinosa*, is the most lethal canker of aspen in the western US (Hinds, 1985). It can expand rapidly on all size classes of trees, but is seen most commonly on larger trees. It usually starts at bark wounds and expands rapidly so no distinct callous ridge is formed on the outer bark.

Armillaria root disease (*Armillaria ostoyae* and *A. sinapina*) is the most common and damaging root disease of western US forests (Shaw and Kile 1991). It causes widespread mortality in a vast variety of hosts including aspen.

Ganoderma root disease (*Ganoderma applanatum*) attacks at wounds infecting sapwood, heartwood and cambial tissues in large roots and the basal part of stems (Hinds, 1985), causing windthrow and extensive decay.

Poplar borer (*Saperda calcarata*) prefers larger, open grown or lightly shaded aspen, but can attack stems as young as three-years (Furniss and Carolyn, 1977). It mines extensively in the wood of the tree to complete its 2-5 year life cycle. The mining activity weakens stems and the wounds created by the borer serve as entry courts for wood decays and canker diseases.

Bronze poplar borer (*Agrilus liragus*) larvae girdle stems by feeding in the cambial area (Solomon 1995). It prefers stems that are weakened by environmental stress or other causes. Zigzag or meandering galleries created by this insect are frequently seen in freshly killed aspen stems in the Intermountain Region.

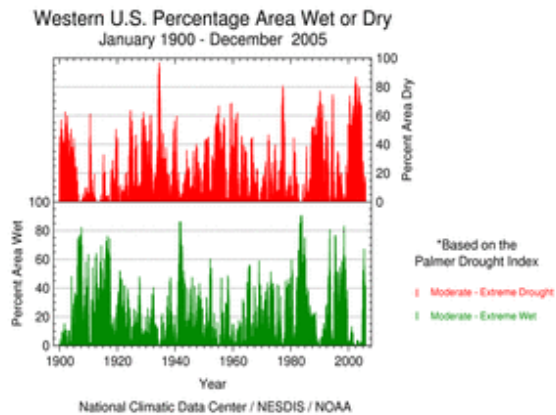
The role of Eastern poplar borer (*Poecilnota cyanipes*) and poplar Dicerca (*Dicerca tenebrica*) is not well documented in western forests, but they were identified on damaged aspen stems in a previously reported survey of aspen in Montana and N. Idaho (Steed and Kearns, 2010). Poplar Dicerca is frequently found on or near recently wounded aspen stems in the Intermountain Region.

Aspen bark beetles (*Trypophloeus populi* and *Proccryphalus mucronatus*) have been known to infest aspen in the Intermountain Region since 1977 (Petty). Information is lacking for both bark beetle species and they have not been frequently reported in the literature. However, both insects were a significant contributor to aspen decline and dieback in Colorado (Worrall, 2008)

Large aspen tortrix (*Choristoneura conflictana*) occasionally defoliates aspen across western North America (Furniss and Carolin, 1977). Outbreaks tend to last only a few years causing some growth loss.

Aspen leaf-tier (*Sciaphila duplex*) and aspen two-leaf tier (*Enargia decolor*) both periodically defoliate aspen throughout western North America with similar patterns of defoliation. Neither insect causes landscape level defoliation; however occasional larger areas of defoliation have been detected (Furniss and Carolin, 1977).

Appendix Two



“The 1999-2004 drought in the western U.S. will go down in history as one of the most severe droughts of the last 100 years.” Source: National Oceanic and Atmospheric Administration National Climatic Data Center. <http://www.ncdc.noaa.gov/>.

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