Climatic Influences on Forests across Montana – Strategies for Conservation and Functional Retention

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Climatic variability is a topic that has received a lot of attention this past decade, in part because new technologies coupled with research allowed both measurement and reconstruction of the past climate with a degree of accuracy never before possible. As data sets developed the fact that there was a warming trend across many areas of the northern hemisphere became increasingly relevant because there seemed to be a strong correlation with an increase of forest disturbance events. Across the western United States warmer winters and earlier spring facilitated increased drought which in turn promoted wildfires and insect outbreaks of uncharacteristic size and severity. Over the past decade Montana suffered wildfires and tree killing insect outbreaks that cumulatively impacted approximately 45% of our forested landscapes which equates to approximately 11.5 million acres of the total 25 million acres of forest (Table 1). Although bad fire seasons have been documented to periodically occur over the past millennia and certainly in the past century, and episodic bark beetle and defoliator outbreaks had also been experienced as recently as the late 1970's, the combined impacts and magnitude of these events over the past decade surprised even historians. Montana was not alone in these types of events with a global 2005 fire season resulting in 5 million acres of forest burning through central Alaska forests as one large event and 50 million acres estimated to have burned across Siberia. Since then a mountain pine beetle outbreak killed over 30 million acres of lodgepole pine forest across British Columbia with additional millions of acres suffering from severe bark beetle mortality across, New Mexico, Arizona, Wyoming and Colorado. Initially the increase in wildfire impacted areas across the western United States was largely blamed on past human

Montana Forest Impacts Years 2000-2010

Acres Burned Annually		Acres with significant Bark Beetle Mortality	
Year	**Acres**	**Year**	**Acres affected**
2000	1,160,145	**2000**	103,920
2001	146,819	**2001**	223,892
2002	110,309	**2002**	450,134
2003	736,809	**2003**	493,785
2004	18,445	**2004**	730,782
2005	103,294	**2005**	1,213,602
2006	1,047,118	**2006**	1,000,289
2007	778,079	**2007**	948,517
2008	166,842	**2008**	1,905,355
2009	48,912	**2009**	3,810,080
2010	56,710	**2010**	2,205,971
Total:	***4,373,482***	***Total:***	***13,086,327***

Table 1. Reported acres from Forest Service and MT Department of Natural Resources and Conservation. This does not include significant acres impacted by Douglas-fir beetle, spruce budworm and other pests. Insect impacted acres are detected through aerial surveys every year that record recently killed (red) trees and thus total acres may represent the same acres several times depending on the speed of attack – where potentially 30% of trees were killed one year and similar proportions killed in subsequent years, doubling or tripling actual acres impacted. Actual total impacted area is estimated between 4 and 7 million acres.

interference, where a fire suppression strategy implemented following the infamous 1910 fires sought to suppress all wildfire starts before they burned more than 10 acres by 10:00AM the following morning. This policy, aggressively pursued by hard working and motivated fire crews was quite effective for over 50 years and most certainly kept most wildfires from developing into larger landscape events during that time. Fuels and tree regeneration that normally would have been consumed in some burn mosaic on the landscape accumulated to greater density than might otherwise have occurred. The other part of the human interference matrix that has since been documented with greater relevance was the displacement of Native American people into reservations by the 1870's and thereby the restriction of their widespread wildfire setting activities that had been part of their culture and the landscape development across the northern and central Rockies for multiple previous centuries. Thus by the early 1980's Montana forests had grown denser, more expansive, and woody debris had accumulated to higher levels than probably any time in previous history.

But what about climate effects and the rest of the affected northern hemisphere? Had fire suppression also been at work in Siberia, Alaska and British Columbia with similar impacts? Numerous studies have clearly shown that the Earth's climate has been in a continual state of change for as far back as it possible to measure, and based on analysis of an Antarctic ice core in the 1950's has fluctuated rather dramatically over time (Figure 1), allowing for ice ages and warm periods with relative predictable frequency.

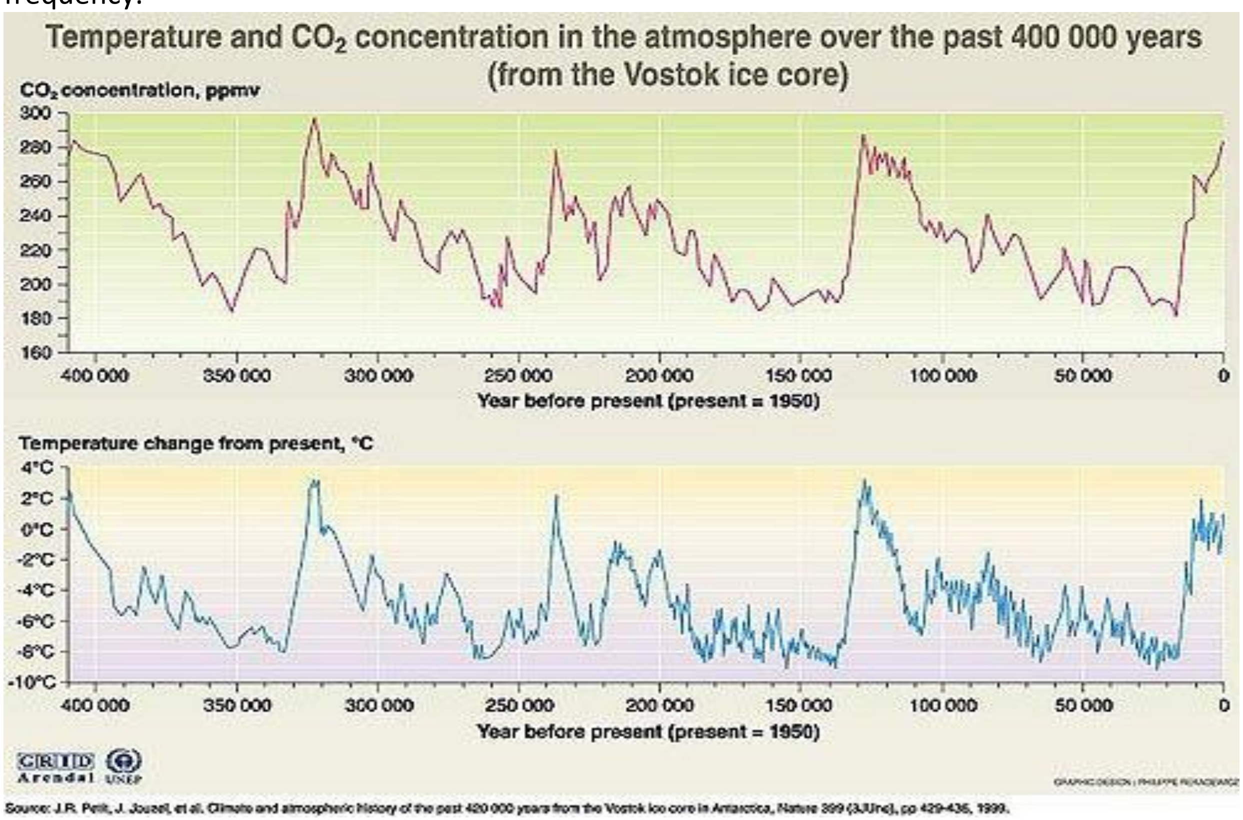

Figure 1. The Earth's climate reconstruction based on isotope analysis of gas trapped in a core of the Antarctic ice cap over a period of 450,000 years. The axis on the right shows temperature changes from our current average air temperature "0". Prolonged cold periods lasting about 80,000 years deviations between -4 and -8 colder than present are the great ice ages that have impacted the Earth, speculated to be due to the "wobble" of the Earth on its axis. The most recent 10,000 year warm period that we are still in and that allowed humans to reach their current advanced state of "civilization" is the very short plateau at the far right and, the longest stable warm epoch over the past half million years.

The climatic stability we all seem to believe exists due to our extremely limited lifetime experience is in fact a myth. Even climatic reconstructions of the past “stable” centuries show rather profound natural fluctuations. Figure 2 is a climatic compilation of seven different studies that examined tree rings across the northern hemisphere and reconstructed the climatic history of each location for the past 1000 years. Although there are minor variations across locations, just as occur today (a heat wave in Montana may occur simultaneously with a cold summer in Europe), the greater trends are remarkably the same showing global and episodic climatic changes. The impacts of these fluctuations on human populations where severe and what were mysteries of human civilization collapse until recently can now be better explained. For example, the period from 900 AD until 1200AD, known as the “medieval dark ages” is also known as the “medieval optimum” to climatologists. During this time agriculture in northern countries flourished resulting in a human population explosion and resulting wars over territory and exploration for new lands, most dramatically documented by the colonization Iceland and Greenland by Vikings. However, for equatorial countries such as Egypt and India the warmer temperatures resulted in documented drought and famine. As the medieval optimum started to transition into the cooler mini-ice age, profound climatic fluctuations occurred that can further be correlated with additional collapses of civilizations such as the disappearance of the Anasazi culture during a 300 year drought across the present day SW United States, the infamous famine and bubonic plague across England and Europe during which 75% of the European population perished, and the death and retreat of the Vikings from Greenland and Iceland.

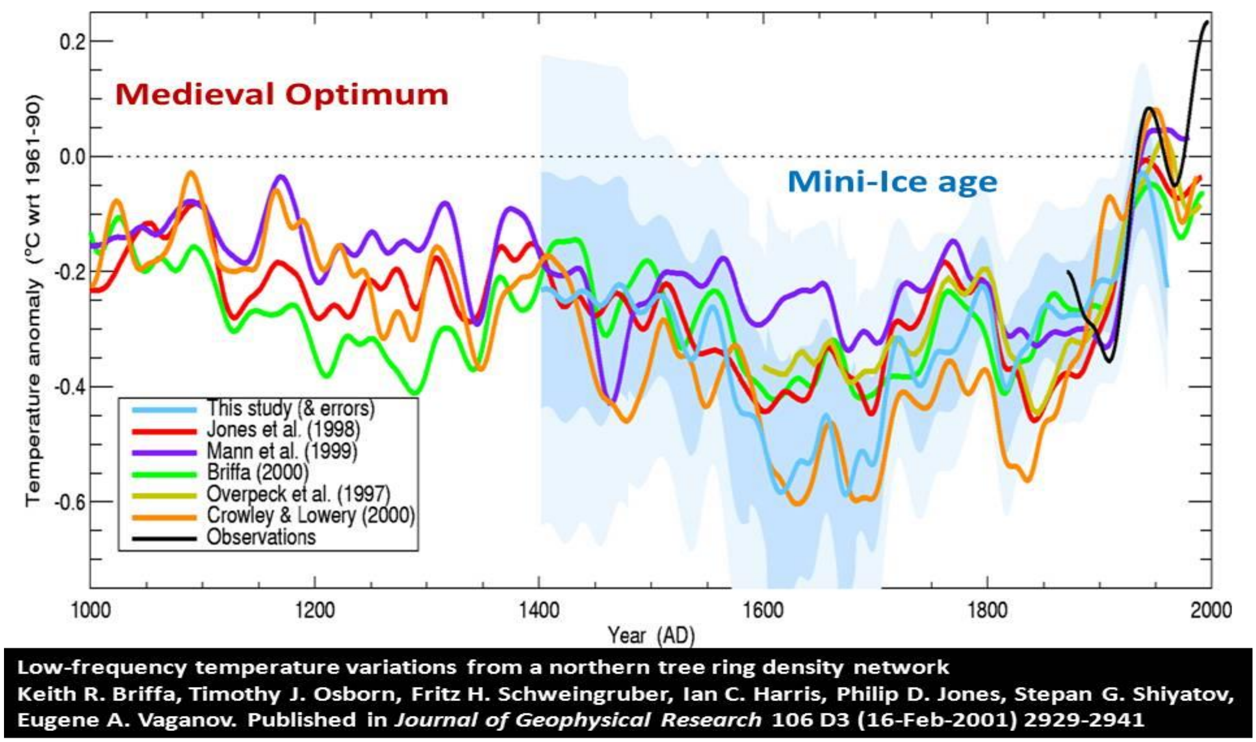

Figure 2. Compilation of tree ring analysis for the northern hemisphere showing climatic fluctuations over the past 1000 years. Lines are averages and shaded areas are data variations, showing that individual years or decades may actually have varied tremendously from the average. For example, although on average the year 1400 was cooler than present, individual years or multiple year periods may have been much warmer than present.

A summary of the past 10,000 years of climate (Figure 3) further elaborates how fluctuations in temperature occurred. Correlations of human civilizations rise and fall may have depended on their ability or inability to adapt their land management practices to these changes.

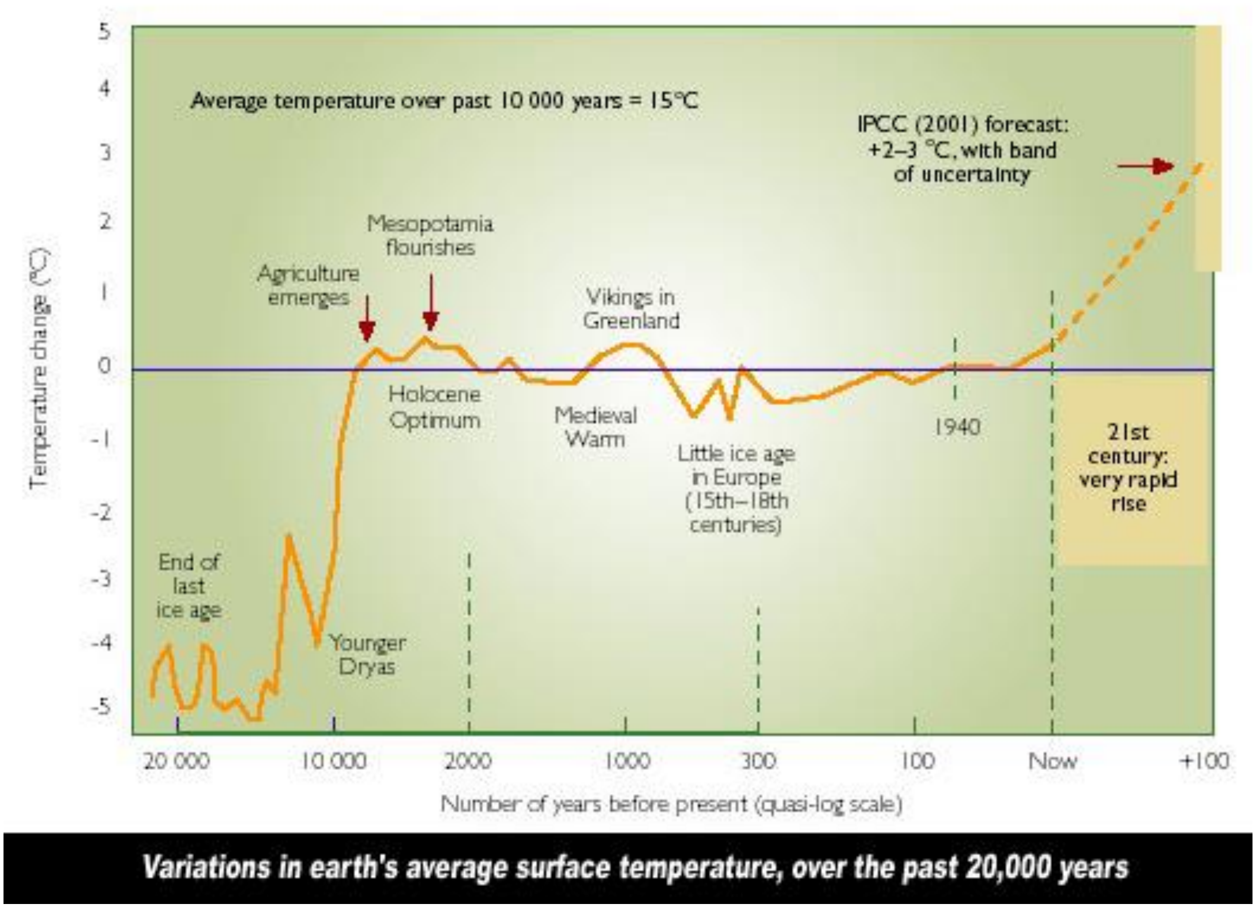

Figure 3. A historical chart showing last 10,000 years climate trends and human history. A projection of the future climate based on human caused global impacts is dashed line on right.

Climatic trends, however, are not as simple as is shown on long term graphs of average temperatures. In the case of the northern and central Rockies, moist Pacific air masses moving eastward provide most of the regions moisture though can collide with dry and often cold continental air masses that are drawn south and west from Alberta by clockwise rotating atmospheric high pressure cells. To further complicate the weather, hot dry air moving north-east from California across Nevada and into southern Idaho create dry volatile lightning storms that can be drawn further northward by a shifting jet stream. Which of these three weather patterns dominates the region is associated with larger global influences emanating from the Pacific Ocean. Forests across Montana have thus historically been subjected to highly variable weather and a great deal of climatic variability.

Surrounded by dry prairie ecosystems where annual precipitation averages 11 inches per year, Northern Rockies forests are largely a result of wet air masses from the Pacific being lifted by various North-South mountain ranges and the rain and snow condensation that results. One of the most drought adapted tree species, ponderosa pine, starts to occur where annual precipitation reaches a minimum of 16 inches with other species finding survivable conditions as increasing precipitation occurs. The wettest forests in the region are characterized by western red cedar and hemlock that require 30 inches precipitation or more per year and relatively humid air. Water and temperature are the key elements that determine where tree species can grow and how well, as well as what types of disturbance occur and potentially with what magnitude. All of the western United States is most influenced by east moving air masses that develop over the Pacific ocean. As has become common knowledge over the past decade, the Pacific ocean surface temperatures fluctuate in what is known as El Nino and La Nina events – also refered to as El Nino Southern Oscillation (ENSO). These roughly 10-year cycles determine rain and drought events across western South America and south-western North America, and are reported to influence north Pacific water temperatures in an opposite though much less predictable effect called the Pacific Decadal Oscillation (PDO). It is the PDO that has greatest influence on temperature and moisture effects across the northern Rockies and this influence can vary significantly over time (Figure 4).

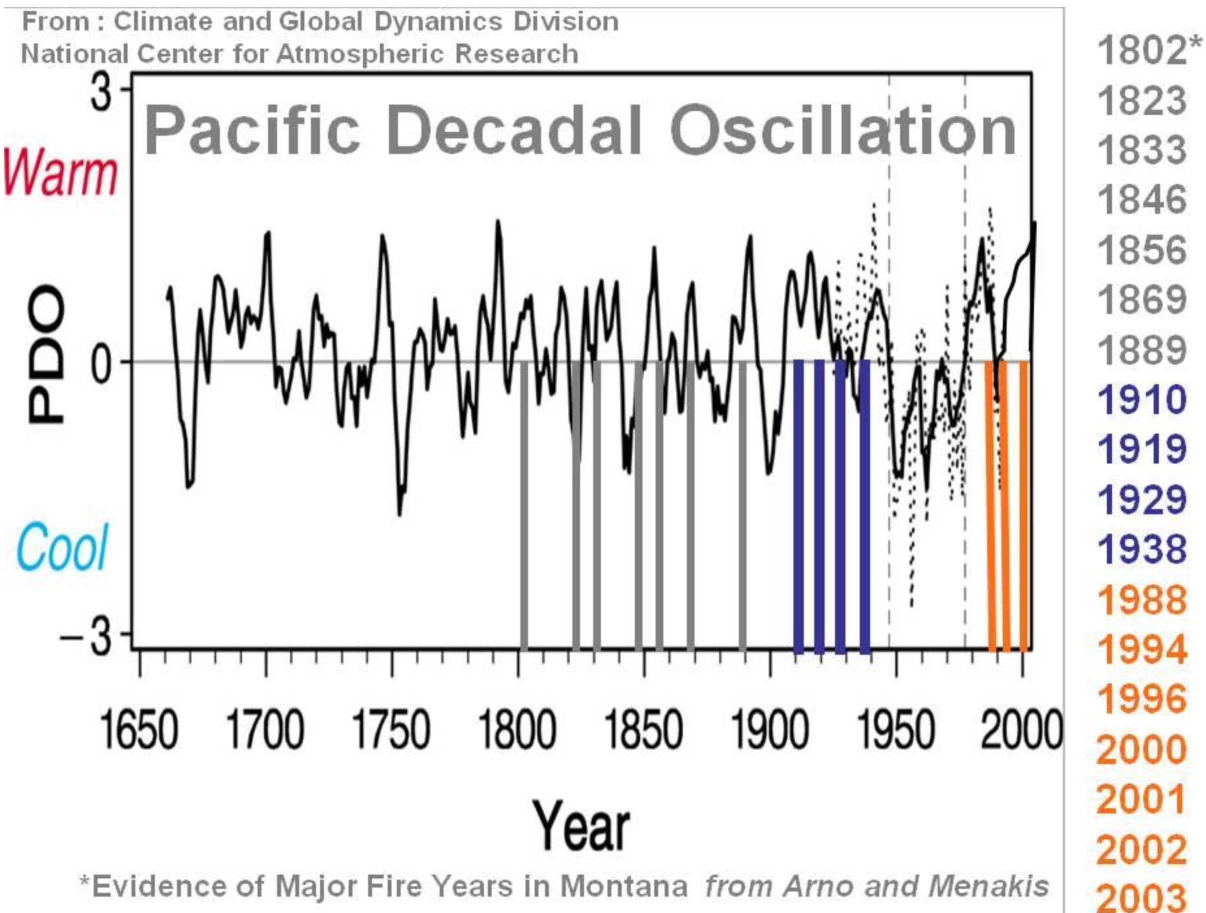

Figure 4. A graph of the Pacific Decadal Oscillation which is the largest climatic influence on the northern Rockies. The extended cool period from 1945 until 1976 is one of the longest cool periods on record. Cooler and wetter periods promote greater tree growth and regeneration, leading to denser forest, and may reduce wildfire frequency and severity. Major wildfire years (right column) determined by tree fire scar analysis across the Northern Rockies superimposed on the graph of PDO shows a correlation between major fire years and warm spikes in air temperature.

Furthermore, fluctuations in the PDO are highly correlated with fluctuations in wildfire activity and bark beetle activity (Figure 5). In summary, the key factors in Northern and Central Rocky Mountain forest development and function over the past 10,000 years might be described as: A conglomeration of multiple tree species, each with different and unique life strategies and advantages for surviving on a highly varied geologic and topographic substrate that interacts with highly variable climatic patterns that are driven by north Pacific ocean temperatures. The persistence of these tree species is in turn due to their continual evolution through natural selection to take advantage of and possibly become dependent on periodic environmental changes including natural disturbance events such as wildfires, coevolved insects and diseases, floods, avalanches, landslides and interactions with mammals and birds such as but not exclusively bison, elk, deer, bears, rodents, finches and other specialized birds such as Clark's nutcracker, and human populations. So what does this mean in the context of modern day climate change, wildfires, insects and diseases, human caused events and the future of the northern and central Rockies forests?

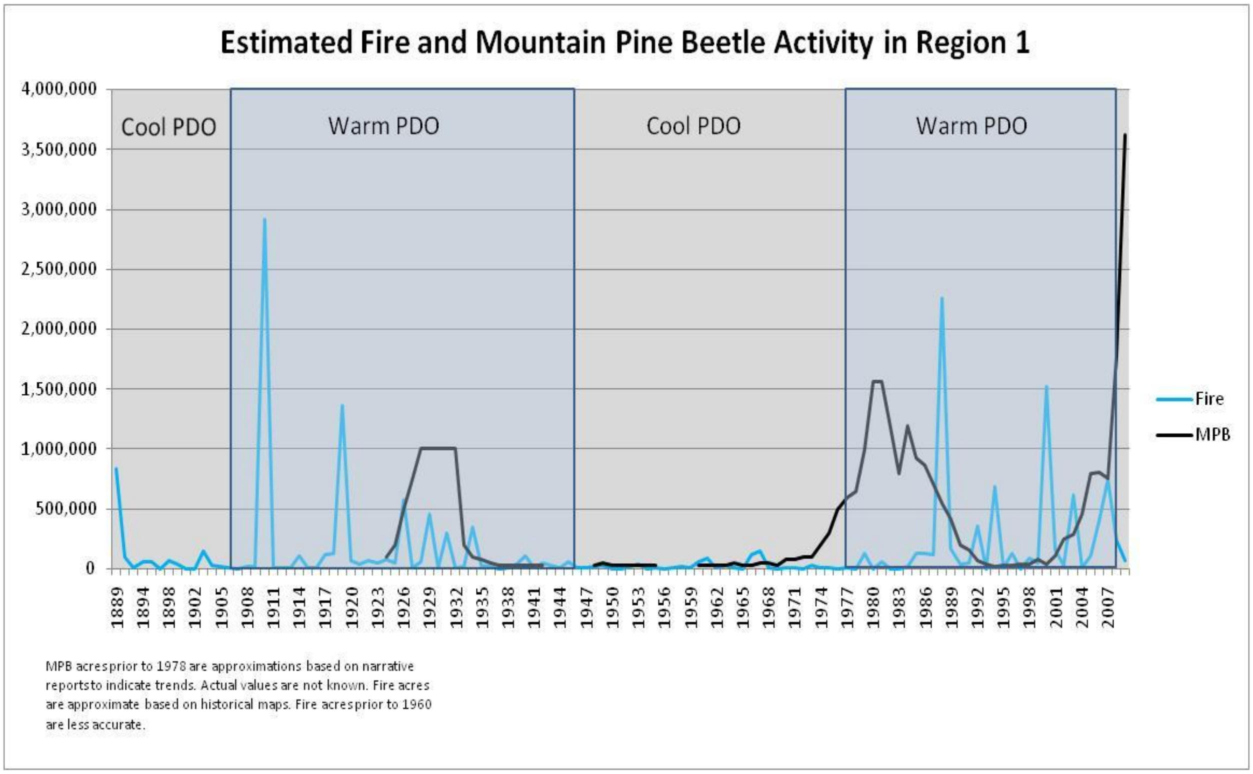

Figure 5. Historical fluctuation in the PDO and severe fire years as determined from coinciding wildfire scars from across the northern Rockies. Severe fire years occur during warm periods of the PDO. (From Barry Bollenbacher – silviculturist Forest Service Region 1)

The history of the forests across our region indicates that they have survived because of their great resilience to changes in key environmental drivers, and in fact are defined in every microsite by the local history of site specific disturbance processes. The documentation of local disturbance histories, however, should not mean that such disturbances are required for the system to continue to function. Many alternate forest species combinations and interactions are often possible on any given site and disturbance history simply tells us what forests encountered in the past and survived, not what they can survive in the future. Forest resilience may be defined as "the ability of a landscape to remain occupied by local tree species in a variety of densities, sizes and species combinations". It would be fair to speculate that based on the past climatic reconstructions and the accumulated knowledge of each individual species physiological abilities and genetic diversity that northern Rockies forests have varied tremendously in their expansiveness and species composition across the last 10,000 years, more than likely covering much less area and being more transient across most landscapes. Starting with the past ice age forests existed as small pockets of trees between ice fields and lakes. As the climate transitioned to a rapid warming period trees expanded their ranges as seed production and movement allowed, tempered to sites where water was available. As shown by Figure 3, the first 8,000 years (Holocene optimum) following the past ice-age was quite warm, perhaps analogous to our future warmer climate, followed by a 1,000 cool period when tree species could have expanded their ranges based on water availability and another 500-year warm period (medieval optimum) when species ranges again shrank due to drought, wildfires and insects. Based on climatic history, the actual present day forests that we expect to function and exist into perpetuity only developed into their present day distribution and function during the past 700 years and may now be naturally transitioning into an entirely new configuration across the landscape. So what role can management play and how will human populations have to adapt to the "new forests" of the future?

Current Forest Conditions

The climatic changes that have been occurring across the Northwestern United States have put Montana forests into a state of transition. Although all forested lands are subjected these climatic influences, most often manifested as wildfires, bark beetle, and defoliator outbreaks (Figure 6), the most severely impacted areas are usually found on federally managed lands. National Forests experienced the least stand-replacing disturbance of any ownership over the past century with some records indicating only 20% of this land base had an active timber harvesting program (U.S. Forest Service records) and all lands active fire suppression. Alternatively, harvesting on private lands was extensive and most likely more than 75% of all private lands across Montana have been logged at some level. Railroad and timber industry lands, accounting for less than 10% of Montana forests, produced more than 50% of the state harvest over the more recent several decades and much of this land is currently in a forest regeneration phase (young trees). Family owned tracts of private land account for 19% of all forested land and provided 30% of total annual timber harvest across the past decades. Family forest harvesting practices have been highly variable as determined by individual management goals, leaving a mosaic of forest species and age classes, including groves of ancient trees that landowners valued and wished to protect. Thus some private lands still support original forest and other lands have been harvested at varying levels including conversion of forest to pasture. During more recent decades "thinning" has been the most prevalent practice on family forest lands as a promoted practice to reduce wildfire risk and increase forest vigor against insect attack. Another example is Tribal forestry, which is also considered "private land". Because of their unique status, tribal forestry has consisted of a more traditional forestry approach where a sustained yield mosaic of different harvesting techniques ranging among clearcut, seedtree, shelterwood cuts, and thinning practices was implemented. Although originally administered by Bureau of Indian Affairs foresters who were utilizing classic forestry practices in concert with tribal needs and wishes at varying levels, most tribal lands these days are actively managed by tribal councils and foresters. Using a historic reference to forests provided by tribal elders, these forests remain very actively managed and harvested to provide for the many habitats, plants and wildlife that elders recall from times prior to forests reaching their current day densities. Both Tribal and family forest lands across Montana are being managed with some of the most progressive forest management philosophies and techniques available. These include quick responses to salvage recently killed trees as well as preventative harvesting to reduce densities of select tree species determined to be at high risk to insect attack of severe wildfire impacts.

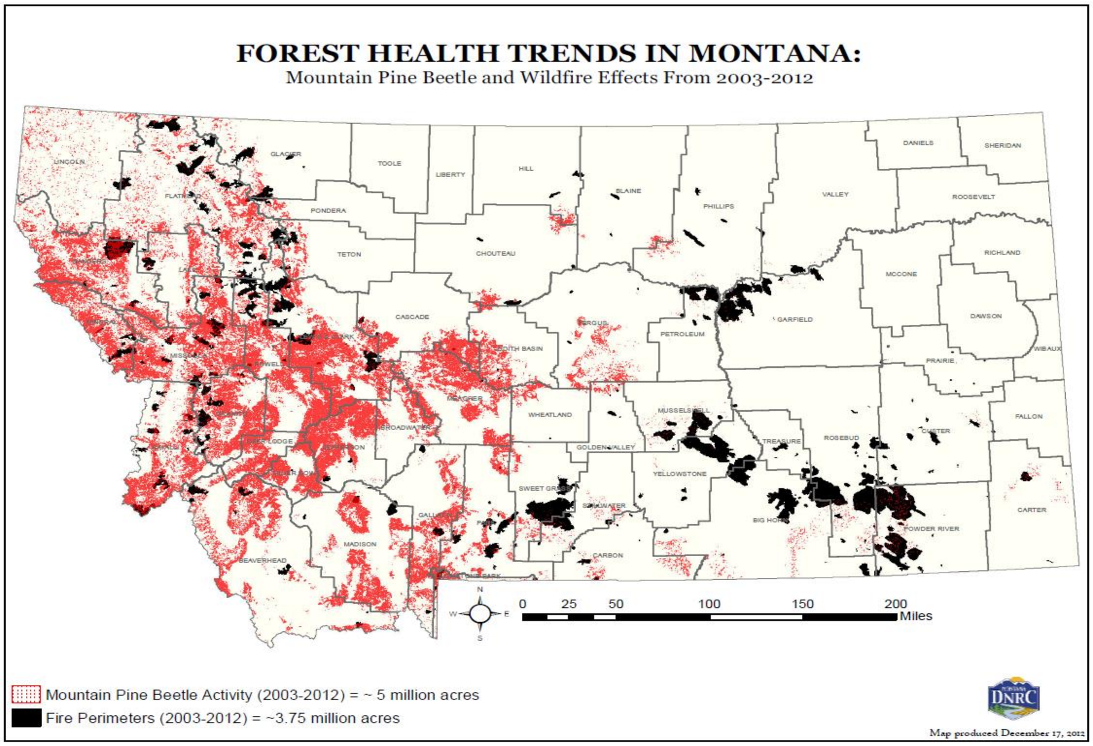

Figure 6 – statewide impact of wildfires and mountain pine beetle over past decade – does not include the 1.4 million acres that burned or the 700,000 acres of bark beetle impacted lands from 2000-2002.

To put the current forest condition into perspective with past forest management practices, an examination of research conducted on bark beetle biology, climatic changes and other historical influences, the bark beetle outbreaks Montana and other states are experiencing across the entire western portion of North America can be considered a result of multiple ecological factors converging at the same time, most notably warmer winters, summer drought and expansive landscapes with tree species and age classes that are most susceptible to beetle attack. Beetle outbreaks, similar to wildfires can be considered a natural phenomenon, perhaps having been exacerbated in certain situations by past human activities. Alternatively, other human activities such as forest thinning and regeneration harvesting have also acted to reduce the expansiveness and severity of both wildfire and beetle activity. The former might be expansion of even-aged lodgepole pine forests enhanced by logging for mining timbers in the Helena and Butte regions at the turn of the century, or in the later case the extensive salvage logging that increased the age class mosaic within extensive lodgepole pine forests of the Kootenai National forest during the mountain pine beetle outbreak in the late 1970's to 1980's. Management activities that were heavily criticized because of the often square clearcuts, large harvest volumes and extensive access networks, in part because they were perceived by emerging environmentalism as landscape degrading, today have proven to be among the most resilient to landscape level disturbances brought by recent severe wildfires and epidemic bark beetle activity. Although the original intent was to remove timber volume before it degraded and to maximize tree growth potential as outlined by classic forestry texts from Europe, chasing tree mortality also inadvertently caused human management to mimic to some extent the mosaic that insect and wildfires might naturally have created during milder fire seasons consistent with the climate of the mini-ice age. The biggest difference one might find between human caused management and the natural mosaic that historic disturbance processes created would be the geometric shapes of human surveying and thus harvest units versus the more irregular patterns created by wildfires acting on topographic and weather constraints. The end result has been the same, however, where mosaics of tree species and age classes, either natural or human created have proven to be much more resilient to the severe disturbances of today that are largely driven by milder winters, longer summers and the associated drought (Figure 7). It might also be noteworthy to point out that management practices that fell

Figure 7. The difference between wildfire that burned through a homogeneous landscape of even aged lodgepole pine and subalpine fir on left, and wildfire that burned during similar circumstances but through a mosaic of different species and age classes created through management by previously harvests.

outside of what might be considered "natural ranges of variability" such as treating harvest units for excessive woody debris and reforesting with seral (pioneer) tree species that may have been lost from the landscape due to the longer term absence of stand replacing disturbances, also has helped prepare these landscapes for greater stresses associated with climatic variability. In some cases this added species diversity to the landscape and fuel reduction has caused both wildfire behavior and bark beetle infestations to vary more in severity and intensity thereby leaving behind a more functional forest ecosystem. To be fair, a significant number of forest harvesting operations did not leave behind a more functional or resilient forest. The science of forest management and harvesting was in many cases focused only on harvesting the greatest volume and regrowing the fastest volume, sometimes resulting in overharvesting certain areas and reforesting with trees that were perceived to grow the fastest, and not with the best resilience. Much has been learned and it important to utilize that knowledge to help moderate the natural "boom and bust" cycles that is more typical of natural processes than the "steady state" modern human society desires and in many cases needs. Thus past harvesting, where it occurred in the right combination of harvest unit sizes, timimg and mosaics, also promoted greater species diversity and forest resilience whereas many unmanaged areas converged into a similar density, species composition and age class distribution. An apt analogy is if the population of a city ages uniformly to the point where most people are over 65 years of age and of similar genetic background. It is much more susceptible to catastrophic failures.

Forest Conservation and Resilience

Active forest management practices can help forests of the Northern Rockies increase their resilience to large scale disturbances and adapt to the current and predicted climatic trends by using silivicultural practices specifically targeted to lessen the magnitude of drought, insect outbreaks and wildfires. Of these, managing for soil water retention is a key component (Figure 8). It is well established with numerous studies and empirical observations spanning the last century that trees with adequate water availability are less likely to die from fire related injuries, be attacked by insect pests, or even contribute to severe fire behavior because a high leaf moisture is more resistant to combustion. Drought stress is a function of water deposits through rain and snow, soil water holding capacity, and water loss through direct surface water evaporation, leaf transpiration and snow sublimation. Manipulating forest leaf area (tree density) is the only cultural practice though which the overall water deposit and utilization of a stand of trees can be influenced. In addition, the decomposing root system of harvested trees

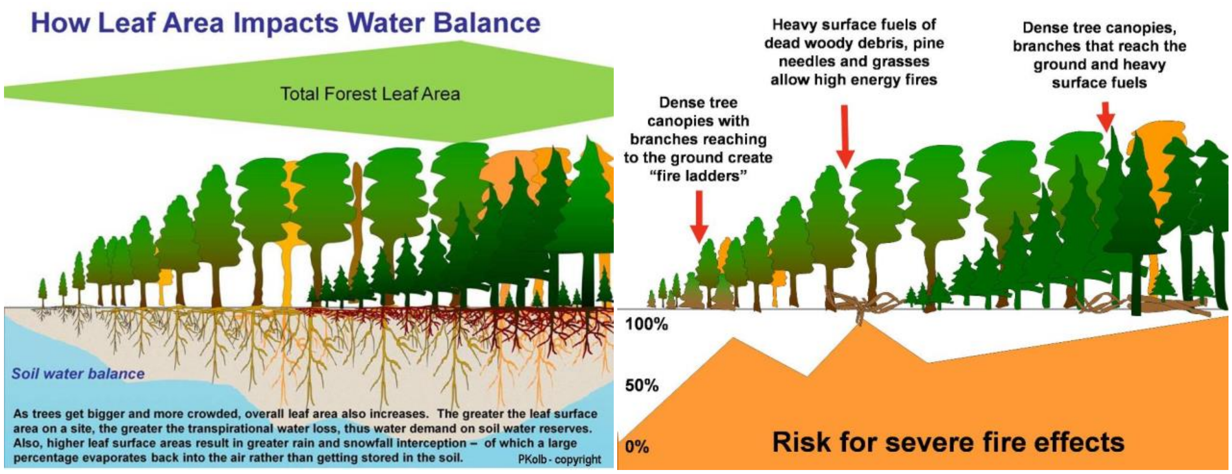

Figure 8. As a forest develops from establishing deep rooted pioneer (seral) species that are designed to reflect light and thereby shed heat, and changes to one of more shade tolerant (climax), shallow rooted and water consumptive species who's strategy is to acquire light, water and nutrients before it reaches seral species, a forests dynamics change dramatically. Denser trees result in more leaf area, which in turn loses more water through transpiration but also intercepts more rain and snow, allowing it to directly evaporate back into the air. This transition results in cumulative drought stress because dense forest requires more water, but by their very nature cause even less water to penetrate to the soil surface. The very nature of this process also promotes stand-replacing wildfires that in turn can recycle this entire process, that may occur over a century to a millennia based on the forest type. However, a very severe wildfire can also cause a forested ecosystem to cycle back past the pioneer tree phase to the moss and grass stage where tree seed sources and regeneration may be excluded for centuries.

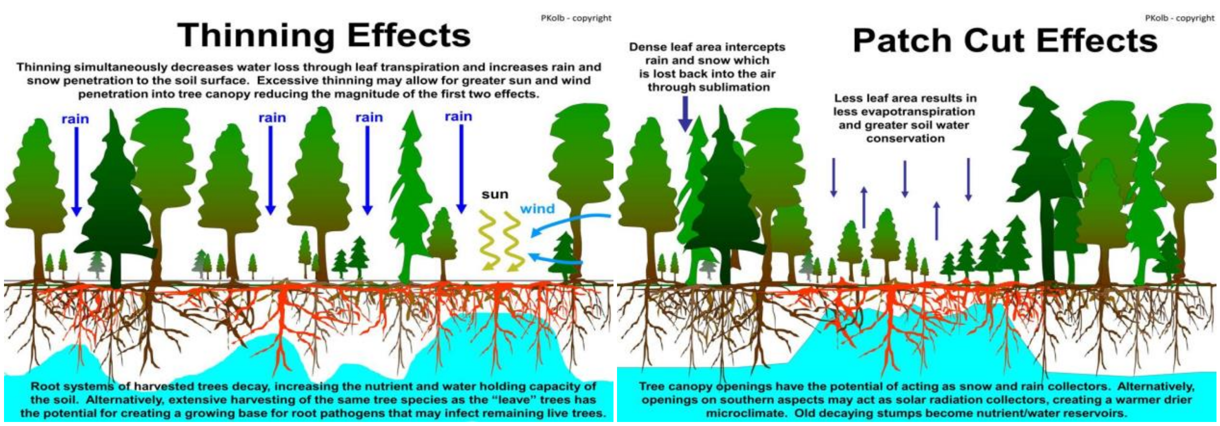

Figure 9. Diagram of the impacts of thinning (left) and patch cuts (right) on overall forest water balance and function. Thinning and patch cutting achieve the same objective of reducing overall leaf area and promoting greater hydrologic recharge from rain and snow. The only difference is how the trees are distributed where thinning promotes individual trees with an emphasis on existing or shade tolerant species and patch cutting promotes groups of trees and regenerates sun-tolerant pioneer species. Fine root turnover is the greatest source of soil organic matter and soil development as opposed to woody debris deposited on the soil surface, thus harvesting also adds to overall soil functionality by providing a dense source of decomposing roots that in turn allow for better soil water infiltration and soil water retention.

provides for better soil water infiltration and retention (Figure 9). Managing the density of trees, specifically reducing the total leaf area can be very effective in mitigating the effect of drought by decreasing total leaf transpiration, reducing direct evaporation of water and snow that has been intercepted by tree canopies, increasing snowpack within trees and reducing sublimation and spring snowmelt by retaining adequate shade through residual tree spacing. Ultimately this requires that thinning/harvesting guidelines be established for each tree species and crown condition class along aspect and elevation gradients. To affect soil water balance tree stands need to be thinned to optimize precipitation through-fall, soil surface shading for snow retention, suppression of competing understory vegetation, and evapotranspirational needs of foliage. Not only does forest manipulation for water retention benefit trees, but as

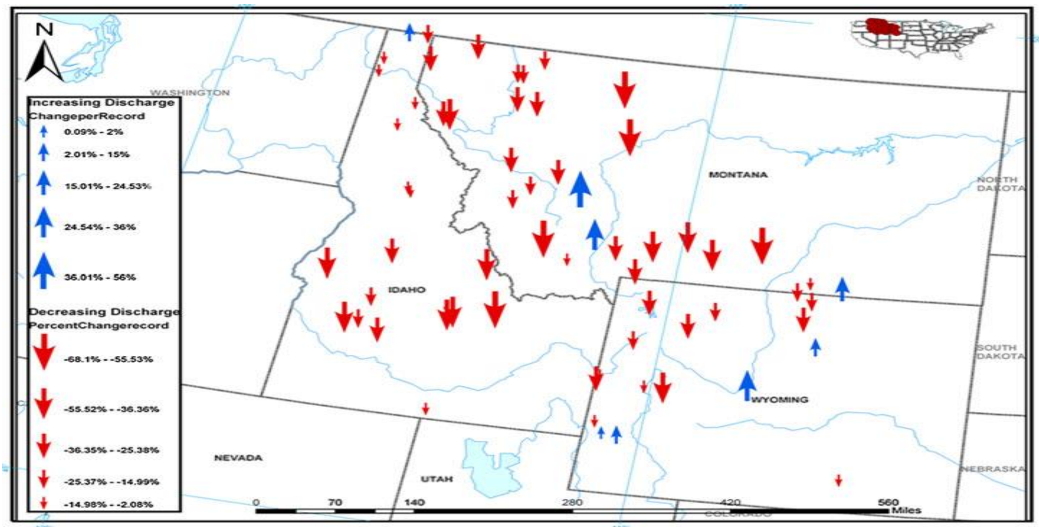

Figure 10. Amount and type of normalized discharge change per record across the Central Rockies. The downward pointing red arrows signify a decreasing slope and the upward pointing blue arrows signify an increasing slope. The Larger the arrow the larger the discharge change at each gauging station. This figures shows a decreasing trend across the study area with very few positive slopes (From: Leppi, J.C., DeLuca, T.H., Harrar, S.W. and S.W. Running. 2011. Impacts of climate change on August stream discharge ion the Central-Rocky Mountains. Climatic Change DOI 10.1007/s10584-011-0235-1)

primary watersheds forests also provide for regional stream flows and all of the ecosystem services those water sources provide. Climatic influences have been shown to have had a rather dramatic impact on major watersheds (Figure 10) as examined by Leppi et al (2011), especially for pristine watershed that have been relatively unaffected by landscape management actions or water conservation such as contributing reservoirs (Table 1).

Table 1 Comparison of gauging site groupings in the Central Rockies. The analysis indicates that the largest decreases in discharge are occurring in the pristine and un-regulated sites over the 1950–2008 period

Site classification	Number of sites	Number of significant trends		Change per record	
		Decreasing	Increasing	Mean	Median
Pristine	16	8	0	−22.87%	−22.15%
Un-regulated	49	13	2	−18.73%	−21.58%
Regulated	88	14	11	−9.44%	−11.84%

From Leppi et al 2011

Each tree species with its unique canopy architecture and physiological requirements as well as each forested landscape may need to be treated differently. Tree species with thick bark and deep root systems and thus adapted to survive fires, should have wider spacing recommendations to keep wildfires on the surface and avoid conditions for crown fires. An example would be ponderosa pine which has high survival probabilities from grass and forb fires. Species adapted to reseed after disturbances such as fire, including lodgepole pine, larch and to a lesser degree Douglas-fir should have narrower spacing guidelines for thinning that suppresses understory growth but still increases soil water balance for growth and bark beetle resistance. The rationale is that surface fires can still lead to significant tree mortality with these species (with the exception of larch). Denser stands of trees on wetter and more productive sites can act as "shaded fuel breaks" when they are maintained with high crowns and no ladder fuels as a moderately dense crown area is needed to suppress understory vegetation and thus fine fuel production. Some thinning decreases crown fire potential by decreasing the ability of a torching tree to ignite neighboring tree crowns, and by providing individual trees with greater soil water reserves and thereby potentially increasing live foliage moisture, which in turn decreases ignitability. Strategies other than thinning are, however, needed on these sites for creating maximum resilience.

The higher plant productivity of wetter ecotypes means that fuel loading will increase quickly following fuel reduction practices. This means that even frequent fires have a higher probability of having severe effects on these forests. A management strategy that only relies on tree thinning to reduce severe wildfire effects will not work as well in these forests. Since these forests often burn as stand replacing events, it is necessary to manage on a landscape level, and create zones that will not carry crown fires. This involves using patch cuts to break up continuous tree canopies in a way that presents wildfire suppression teams with the opportunity to contain crown fires versus trying to suppress them. A mosaic of fuels and structural characteristics presents more places where heat transfer through radiation or convection dissipates, thus interrupting the energy transfer required for crown fires to spread. For example a crown fire that burns into a clearcut or seedtree where surface fuels have been adequately treated will usually drop to a smoldering ground fire, which is both containable and suppressible. This same mosaic also creates a landscape that is less capable of supporting and contributing to a bark beetle epidemic. Across the wetter Douglas-fir and grand fir ecotypes, as well as the subalpine fir and cedar/hemlock types, younger stands of trees such as those found on regenerated clearcuts do not support as high a leaf area, and thus do not use or intercept as much water, maintaining higher leaf water content longer into the summer and are less flammable. They are also not good reproductive sites for bark beetles as most beetles require larger trees with thicker inner bark. There are many examples from the past decade of wildfires across Montana where extreme wildfire behavior in dense stands of mature trees converted to smoldering surface fires when they burned into clearcuts where post harvest fuel reduction treatments such as prescribed burning had taken place. Although there is much research that remains to be conducted before the exact mechanisms are fully understood and modeled, it is a common practice for fire suppression teams to link old clearcuts together into a fuel break when trying to contain a wildfire.

The biggest challenge for landowners on any particular landscape will be to determine where and what size management units will need to be employed. Each landscape is unique with different topographic features, geologic substrates, soils, species and natural histories. Intact landscapes can offer clues to past disturbances and well trained forestry specialists can also asses any landscape using understory plants (habitat types) and soils analysis to help determine potential species and their growth rates. In the end, this type of analysis offers evidence that can temper the management plan for any forested setting, that ultimately will require a subjective but educated picture to be painted based on both scientific and experiential knowledge, and the recognition that any forest is a dynamic and complex interaction of millions of organisms and processes that can change at any time (Figure 11). Forests are therefore never completely predictable and landowners and managers should not expect management plans to be the ultimate solution, but a working tool to provide thought continuity for an ecosystem that is defined as one that constantly changes.

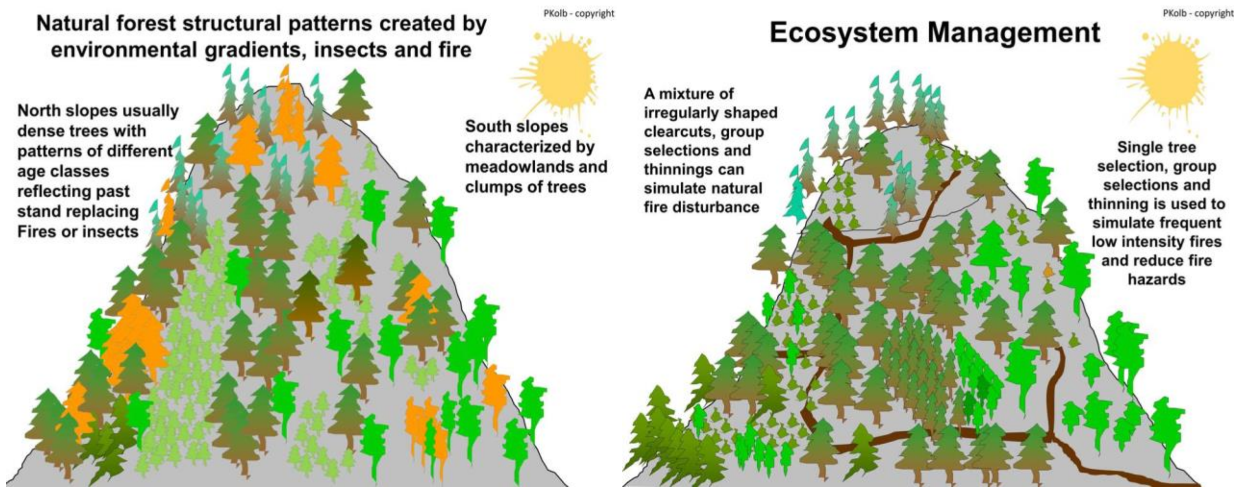

Figure 11. A natural landscape as illustrated on the left typically has tree species and age class variability that reflects both the potential of different species to grow there but also the impacts of the past natural disturbance history. Although evidence of past disturbances might indicate one reality, it should not be considered the "perfect" mosaic to be recreated as the environmental factors that created it are also dynamic and can radically change over time. Blindly emulating past processes may lead to completely novel or unwanted outcomes. The design of a management plan should foremost allow for rapid responses to unwanted outcomes and flexibility to reanalyze the landscape and alter objectives in a timely manner. Climatic fluctuations can be rapid and create new circumstances within very short time periods.

Action Recommendations

The compounding effects of climatic change, fire suppression, and natural forest succession all point towards the need for a landscape level forest management strategy for the next century. Global research on climatic trends strongly indicates that we are in a significant warming trend with more turbulent and unpredictable weather patterns in the forecast. Glacial melting indicates a tendency for reduced snow packs and a longer growing season which results in a forest predisposed to drought conditions. Forest research on the patterns and distributions of tree species of the Northwestern U.S. indicates that conifer species have dramatically expanded outside their historical ranges. We now have landscapes covered with conifer species that are not the best adapted to deal with drought stress and climatic turbulence. Wildfire suppression together with a series of wet decades has compounded the problem by allowing forests to reach high stem densities, often with shade tolerant/drought intolerant climax species crowding the more drought and fire adapted species. When the resilience to disturbance of the current forest composition is analyzed based upon projected climates, the result is a landscape of mal-adapted, drought stressed forests predisposed to wildfires of uncharacteristic proportion. Landscape level restoration of forest mosaics through active management may be the only way to conserve the dynamics and complexity of NW forests.

Specific recommendations for mitigating the effects of a changing climate on Montana forests and aid in carbon sequestration are:

1. **Increase drought resilience of forests by thinning groups of trees that are at risk of extreme water stress due to a) shallow soils, b) overcrowding, c) drought intolerant species combinations, d) at risk age distributions.** Montana forests survive droughty summers by relying on water stored in the soil. Milder winters can result in less snowpack and earlier spring runoff, with the potential of depositing less water within soil profiles. Longer summers will result in greater water needs for trees. The combination of events will result in prolonged drought stress which can directly kill trees and/or weaken them to the point of becoming highly susceptible to bark beetle attack. If individual trees are provided greater soil volume from which to draw water, they will better be able to survive extended

summers and less soil water availability. Greater soil volume per tree can be achieved by reducing the number of trees per given soil volume. In addition, selecting tree species, and age classes that have a greater tolerance for drought conditions will maximize the soil water conservation strategy. Tree water loss is a function of total leaf area, thus younger trees, that have less total needle area require less water. Alternatively, older trees may have deeper and more extensive root systems. In addition there is some evidence that older trees have slower growth rates and thus utilize less water. Given that a tree changes in its water needs and water use as it ages, and each stage has advantages and disadvantages, a landscape with an extensive distribution of tree ages would offer a greater probability of some tree survival during unpredictable climatic fluctuations yet probable drought.

2. **Promote a greater tree species and age class distribution across landscapes using a combination of tree thinning and patch cuts that emulate wildfire patterns.** This distribution should include the full complement of species and tree ages, where management actions are used to maintain a mosaic ranging from seedlings to very old trees and partial wilderness designation.

3. **Promote wildfire/bark beetle resilient forests.** Wildfire occurrence and magnitude is controlled by fuels and climate. Climate however is the larger controlling factor. Under the projected future climatic scenario for Montana wildfires will be more prevalent. On the other hand, how wildfires burn, and how difficult it is to contain them can be substantially mitigated by fuel treatments. A forest's fire resiliency (the ability of trees to minimize wildfire intensity and for the trees to survive) can be increased using several tools. As indicated earlier, tree spacing affects their water balance. Trees with abundant water are less likely to have highly combustible foliage, and more likely to tolerate intense heat. Thinning of trees (and treating logging debris) also creates a lower overall fuel load, making it more difficult for a fire to be carried through the crowns. Some tree species are more resistant to heat than others, and some species also have less flammable foliage. Discriminating against a landscape with a majority of fire intolerant and/or combustible tree species would also reduce the probability of a wildfire using trees as fuel. Finally, uniform fuels lead to uniform fire behavior. This is a problem if wildfire behavior is extreme. Promoting a landscape with diverse forest structures in the form of groups of different age classes, tree spacing, and tree species would increase the probability of a wildfire burning in a mosaic rather than a uniform flame front. Strategically placed thinned areas and harvest units where harvesting residual debris has been treated could be linked to help fire suppression crews contain wildfires. Examples of this were evident in the 2007 Mile Marker 126 and Blackcat fires. These same strategies also reduce the probability of a bark beetle outbreak.

4. **Treat fire and insect impacted forests**. Fire and beetle killed trees, when excessively abundant will fall over in 3-15 years and create high surface fuel levels. As the past decade had shown, extended drought dries even large diameter surface fuels which can impart extreme heat to soil surfaces and adjacent trees. This type of fire has a high probability of killing trees that survived insect outbreaks and may potentially have genetic resilience to future outbreaks, as well as fire resistant trees that act as a seed source following fires. The result may be vegetation shift away from forest and to brush and grassland as no natural tree seed source would remain. Fuels treatment of strategic areas, perhaps in a mosaic pattern would minimize future fire risk for some areas while maintaining down woody debris habitat for other forest organisms (wildlife, fungus, arthropods, etc.) favored by such woody debris.

Figure 12. A lodgepole pine stand (left) following a mountain pine beetle outbreak and the high risk surface fuel matrix that can develop. A forest following a severe surface fire that killed 80% of trees and the 4-ft deep surface fuel matrix that developed 7 years later. If the later burns the remaining trees will be killed.

5. **Promote local utilization of forest materials and support locally utilized wood products.** Research has shown that carbon dioxide emissions may be contributing to climatic warming. To stabilize or reverse atmospheric carbon dioxide accumulations one would ideally need a device that converts gaseous carbon dioxide into solid and stable form of carbon dioxide. In nature there exist two such mechanisms. The first are water born organisms that extract dissolved carbon out of the water and combine it with calcium to form calcium carbonate. These organisms, most of which range in size from microscopic to pint sized form exoskeletons better known as shells and coral that are responsible for the considerable limestone deposits around the world. The second are plants that extract carbon dioxide directly from the air and store it as either organic matter below ground as is the case with grasses and forbs, or above ground as woody tissue in the case of shrubs and trees. The carbon that plants store, particularly above-ground as is the case with trees can, however, be quite short lived. Upon a trees death woody tissue decays or is consumed by fire and almost all stored carbon is once again released into the atmosphere. Alternatively wood that milled for human utilization can be put into long term storage as a primary construction material for structures that have an extended utility. Although the lifespan of buildings varies, there are a considerable number that are over 100 years old, which is consistently longer than most dead wood survives in a natural setting (with some exceptions such as cold subalpine regions that do not support wildfires). Wood extracted from a forest and placed in such long term storage then acts as a carbon storage mechanism that can increase the carbon absorption capacity of a forest. There are, however, two caveats that should be adhered to maximize this form of atmospheric carbon cleansing and storage. First, harvesting and manufacturing of wood is a carbon fixing process as long as the fossil fuels consumed during the process do not exceed the carbon being stored in the wood. A carbon balance study that examined the energy requirements of wood harvesting, manufacturing and structural utilization found that transportation accounted for approximately 90% of the fossil fuel use. By utilizing local forests as the source of wood, and locally milling and building with this material the process of wood harvesting can lend itself as a significant carbon sequestration mechanism. Second, utilizing wood waste material for energy production decreases the amount of positive carbon emission from wood manufacturing and associated worker energy needs. Third, wooden structures that are built to last offer a much longer carbon sequestration mechanism than structures that have a short effective lifespan. For example, the wooden beams and framing in many European castles, churches and in some instances houses have been in place for many centuries and in some cases a thousand years.

6. **Support an integrated forest workforce.** Forestry workers, ranging from precommercial thinning contractors to high efficiency loggers have advanced experience and skills of working in forested terrain. Recruiting and providing this workforce with wildfire suppression and rehabilitation training would allow for a "reserve" workforce to be on hand when catastrophic events such as a bad wildfire season occur. This limits the financial commitment for the state and federal government of maintaining an extensive wildfire response team when wildfires are not an issue. It also limits the training expenses and risk assumed with retraining a young workforce every season. The state and federal agencies should retain a core and skilled response team that act as leaders, trainers and workforce during minimal or "normal" wildfire years.

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