REFORESTATION-REVEGETATION CLIMATE CHANGE PRIMER

Incorporating Climate Change Impacts into Reforestation and Revegetation Prescriptions

USDA FOREST SERVICE, NORTHERN REGION

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Reforestation – Revegetation Climate Change Primer for the Northern Region

Incorporating Climate Change Impacts into Reforestation and Revegetation Prescriptions

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I. Introduction and Objectives

Reforestation and revegetation practices on National Forest lands can influence the future resilience of those lands when artificial regeneration is used to enhance the establishment of a select set of species. Depending on the species selected, their survival, growth, the presence and abundance of these species, artificial regeneration will alter species composition leading to changes in vegetation dynamics, carbon sequestration, and ecosystem services (e.g. water quantity and quality, wildlife habitat, forest products). Given that our climate is changing, it is paramount that we develop and incorporate a strategy that includes consideration of climate drivers in our future reforestation and revegetation efforts; recognizing that the decisions we make today will influence how forest communities will function in the future.

The Northern Region (R1) is committed to incorporating adaptation strategies to changing climates into management actions based on the vulnerability of resources to climate change. This primer provides management recommendations on addressing climate change in the forest regeneration and native plant revegetation programs in Region 1. Specifically the objectives are to provide guidance for developing sound reforestation and revegetation prescriptions based on current science and professional interpretation of ecosystem function. In this primer, we are addressing reforestation specific to conifer regeneration in the forest setting. Revegetation incorporates the host of shrubs, herbs and forbs in forest and grassland ecosystems.

Silviculturists, botanists, and other field practitioners should find this guide useful for developing reforestation and revegetation prescriptions that are successful in both the current climate and a warmer and potentially drier future climate. It should guide species and site selection during planting or seeding to assure that sensible investments are being made, and lands move to a more resilient condition and are able to adapt to changing conditions. We want to incorporate actions that are beneficial given a variety of climate futures and desired future conditions (Erickson *et al*. 2012).

Knowledge in climate change research is continually evolving, thus we consider this Primer as one step in our Regional adaptive management process. Forest Service and academic scientists will continue to refine our understanding of ecological impacts from climate change and improve our ability to prepare and implement prescriptions for the future. As a result, this primer will evolve as we learn more about reforestation and revegetation strategies within the context of a changing climate.

II. Climate Change Assumptions

There are several assumed climate driven factors that will influence species shift and composition in our future forests. These include rising temperatures, shifts in distribution between snow and rain, changes in depth and duration of snowpack, and drier summers. Subsequently the consequences of these changes most likely will result in longer summer droughts, potentially more severe insect infestations, and longer fire seasons.

The forests of the Northern Rockies are highly sensitive to projected climate change (Running 2010). Consequences from a shifting climate will likely cause plant communities to undergo shifts in species composition and/or changes in densities at landscape levels (Fig. 1). Species range shifts are expected to be species specific rather than collections of currently associated species shifting as a community (Shafer 2001, Rehfeldt *et al.* 2006, McKinney *et al*. 2007). Communities will not adjust to the climate in a synchronous fashion, but the composition of species within a community will change. Species with poor dispersal ability or narrow biophysical niches will not tend to adapt easily to climate changes; leading to the potential for localized loss of biological diversity if environmental shifts outpace species migration rates (Aitken *et al*. 2008, Littell *et al*. 2009).

Figure 1. Climate Change Assumptions

- *Rising temperatures*
- *Changes in precipitation cycles:*
  - *Less snow, more rain*
  - *Less water stored in snowpack*
  - *Earlier spring snowmelt and peak runoff*
  - *Lower stream flow in summer*
  - *Longer summer drought*
  - *Alter site water balances*

These changes could lead to potential consequences:

- *Increase water stress to some species*
- *Favorable climate to sustain insect infestations*
- *Longer fire seasons with favorable burning conditions.*
- *Changes in growing season*

Increased temperatures and changes in precipitation cycles

As stated in the Northern Rockies Climate Change Primer (USDA 2012), all global climate change models (GCMs) project surface temperature warming in the Northern Rockies in all seasons, regardless of the uncertainties in modeling greenhouse gas emissions. This synthesis projects that by the 2040s, we can expect temperature increases of around 3.2°F (1.8° C) in winter, spring and fall, but an increase of 4.3°F (2.4°C) in summer, compared to 1970-1999 averages. Precipitation projections are more variable. Over the next 40 years, precipitation is predicted to increase during the winter (+8%), spring (+7%) and fall (+3%) but decrease in summer (-7%) compared to 1970-1999 averages. These temperature and precipitation shifts are based on averages across B1 (18 GCMs), A1B (19 GCMs), A2 (15 GCMs) emission scenarios (USDA 2012).

The Northern Rockies is already experiencing increased winter temperatures, earlier spring snowmelt, longer growing seasons, higher summer temperatures, and higher water stress. This tendency is expected to continue (Running, personal conversation 2013) and will have a major effect on reforestation and revegetation efforts. These changes are demonstrated in the following diagrams.

Figure 2 below shows an increasing trend in warmer temperatures as demonstrated by the greater frequency of higher maximum temperatures and a lesser frequency of low minimum temperatures in 2000-2009 compared to 1950-1959.

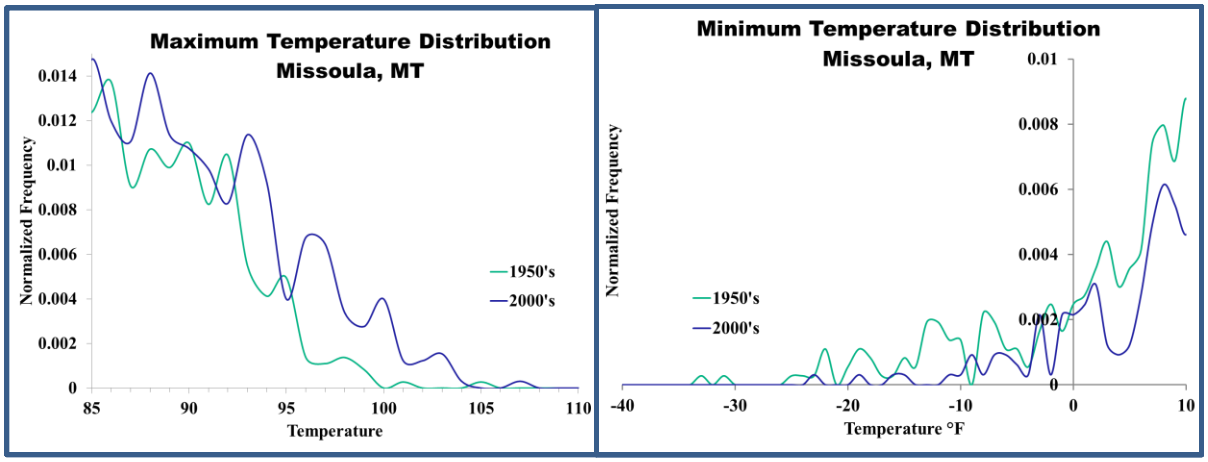


Figure 2. Frequency of maximum and Minimum Temperatures in 1950 and 2000. **(Running 2012)**

Spring snowmelt is also beginning earlier and finishing earlier in most part of the Region. This affects the Region's stream flows as well as increases the length of the fire season. Soil moisture also decreases when runoff occurs while the ground is still frozen.

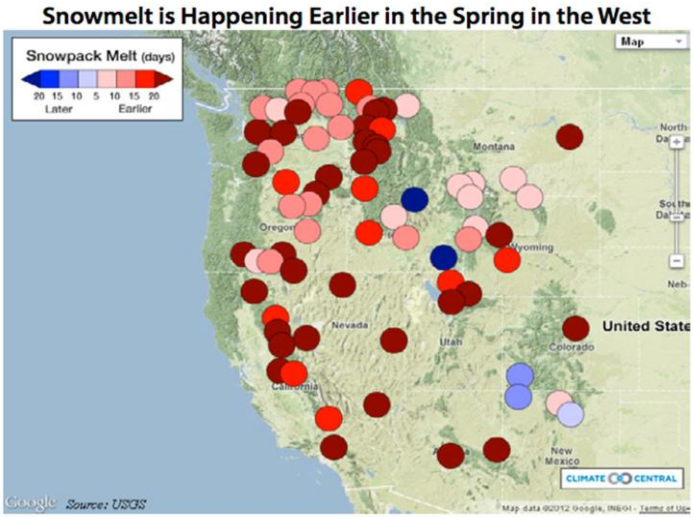


Figure 3. Snowmelt is occurring up to 30 days earlier particularly in the western portion of the Region.
Running 2012

Extreme weather events may also be more frequent. The distribution of weather events around the climatic average often results in a bell shape curve. An increase in annual temperatures shifts the distribution, resulting in a much larger relative effect at temperature extremes than near the mean (Running 2012) as seen in Figure 4. For example, what may have been a 1 in 40-year hot weather event may become a 1 in 6 -year event with a shift of one standard deviation in mean temperature. Even small increases in average temperatures will result in more frequent hot growing seasons and more variability in the temperatures (Running 2012).

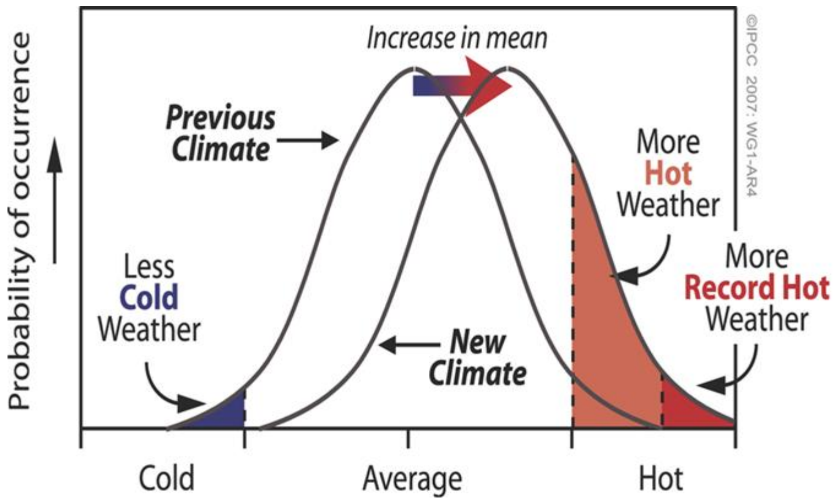


Figure 4. Predicted shift in mean climate conditions. (IPCC 2007 ARY:WG1) (Running 2012)

Winter temperatures are expected to increase more than other seasons, affecting shoulder season snowpack (snow in the fall and spring). The growing season is expected to lengthen by two months, with spring snow melt occurring four to six weeks earlier and the summer drought period lasting six to eight weeks longer. Precipitation, run off, and stream flow patterns will change in both the quantity and the timing of runoff. The longer and more intense summer drought period will negate the positive effect of the longer growing season due to diminished water availability to plants (Running 2010).

Water availability will be a major limiting factor amplifying already relatively dry conditions common to Region 1. Using an ensemble mean of climate models, it is predicted that the growing season soil water deficit will increase throughout the Northern Region (FS Climate Change Resource Center), as shown in Figure 5. The eastern portion of the Region shows less of a shift in future soil water deficits because many areas currently are more arid and have a negative water balance. However, the western portion of the Region shows a large increase in future soil water balance deficits. Populations will respond in differing ways, depending on a species ability to adapt to drier conditions.

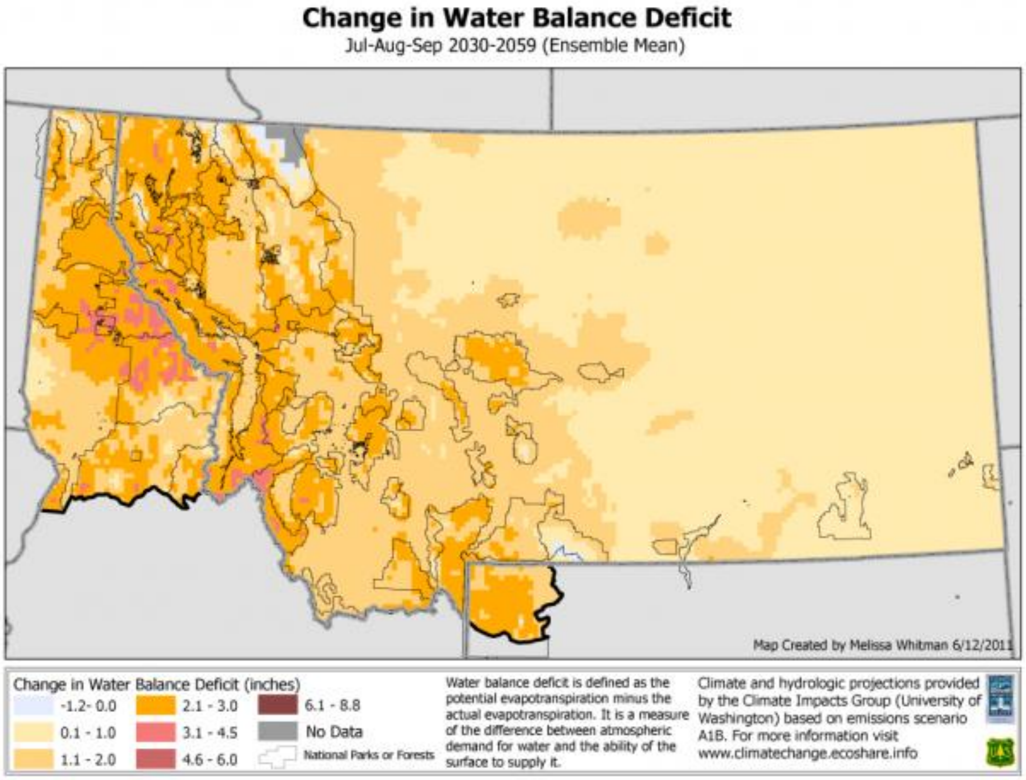


Figure 5. Change in Water Balance Deficit. The difference between potential and actual evapotranspiration (PET-AET) is water balance deficit. Increases in the water balance deficits are caused by a greater demand for water by plants than what is supplied by precipitation and snowpack. It is a measure of the difference between atmospheric demand for water and the ability of the surface to supply it. [From CRCC website]

How Forests Might Respond to Climate Change

The range of some species may expand covering a greater proportion of a landscape, while others may retreat. Climate effects on vegetation will be dictated by moisture requirements of individual species, water holding capacity of the soil, solar energy inputs across aspect and slope, current landscape structure and composition, and the complicating factors caused by increased intensity of disturbances resulting from more arid conditions. Site specific soil moisture conditions will affect tree establishment and growth, as well as processes such as cone and seed development, bud phenology, insect and disease susceptibility, and size and intensity of wildfires. Reforestation prescriptions need to bridge the gap between landscape level forest responses and fine scale effects caused by topography, aspect, soil properties, fire and other disturbances. Ecotones are likely to be most sensitive to change (Hampe and Petit 2005).

Daubenmire's simplified diagram (Fig. 6) illustrates the relationship between topography and habitat type on the south face of the Palouse Range in Idaho (Daubenmire 1980, Cooper 1991). It shows the complex vegetation patterns resulting from the range of microclimates caused by topography. In a more arid future climate, we would predict that the wettest habitat types (solid shading, *Thuja plicata*) will recede and the drier habitat types would expand. Elevation is commonly used as a proxy for minimum temperatures affecting species distribution; however niche distribution is much more complex. Ultimately, the change in cover type will be driven by biotic factors such as competition, and abiotic factors including soils, topography, moisture availability, and temperatures (Soberon and Peterson 2005).

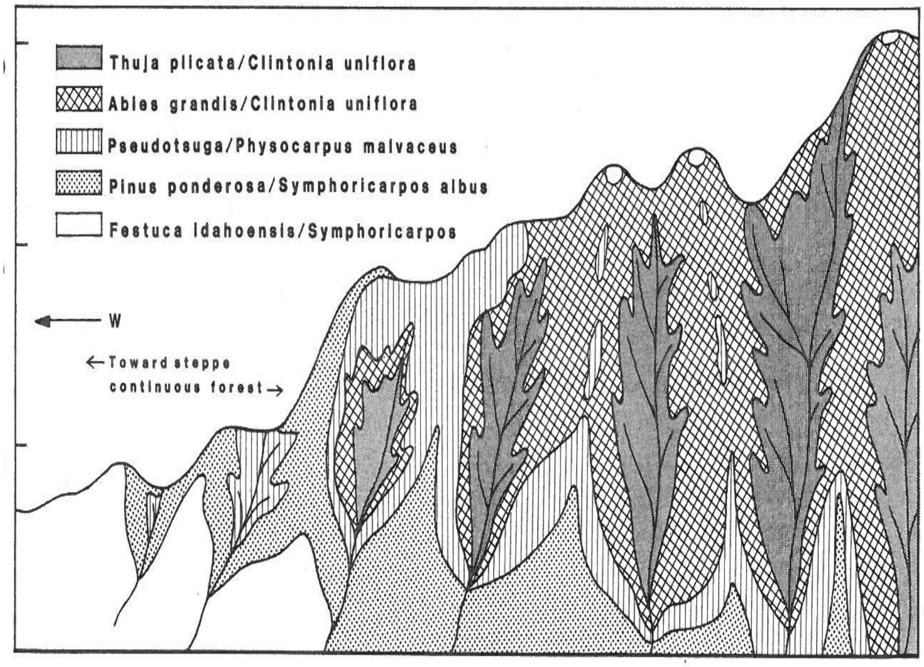


Figure 6. Habitat Type-Topography Relationships

Thuja plicata/Clintonia uniflora representing most mesic of this drainage.

Abies grandis/Clintonia uniflora representing relatively moist sites

Pseudotsuga/*Physocarpus malvaceus* is increasingly drier

Pinus ponderosa/Symphoricarpus albus represents the dry sites.

Festuca idahoensis/Symphoricarpus represents the dry site that does not support tree cover.

(Daubenmire 1980)

Considerations for Reforestation and Revegetation

Given the prospects of a changing climate, resource managers are challenged to develop reforestation and revegetation prescriptions that have the best chance for success. To make the most of current investments, plans should incorporate adaptations for warmer and drier future conditions and adopt strategies that support plant vigor through the rotation or lifecycle. Reforestation and revegetation strategies now should consider the best sites for investments, keeping in mind areas previously selected for planting may be poorer opportunities in the future.

There are four factors that influence species distribution (Soberon and Peterson 2005):

1. Abiotic conditions, which include the climate, physical environment, soil characteristics, and disturbances that impose physiological limits for a species to be able to persist in an area.
2. The interactions with other species such as competition that will modify the ability of a species to grow and develop. These interactions can be either positive (e.g., whitebark pine and Clarks Nutcracker) or negative (e.g., competitors, predators, diseases), affecting species distribution.
3. Seed dispersal and regeneration establishment. This factor is useful in distinguishing between a species actual distribution from its potential distribution based on landscape configuration and other species' dispersal abilities. Even if seed is present, or artificial

regeneration is applied, the ability of a species to establish for the long-term is crucial, and within a changing climate establishment may be the most sensitive period influencing future species distributions.

4. The evolutionary capacity of populations of the species to adapt to new conditions. This factor, usually reserved from analyses or assumed negligible, is nevertheless an additional and important consideration in outlining the distributional possibilities of species.

Tree growth responds more to water stress than any other seasonal factor on the forest site. Thus soil water is fundamental to forest productivity for many species in many parts of the world (Spurr *et al.* 1973). Since height, radial, and reproductive growth of trees as well as seedling establishment is highly correlated with environmental stress, the soil-water properties are increasingly important in considering climate change. The physical soil features combined with the topographic position influences soil moisture and air drainage. Understanding how water behaves in soil, how plants use water, and how management practices, wildfire and changing climatic conditions may affect plant available water in different soils can greatly increase planting success. Reforestation and revegetation efforts must match moisture requirements of specific plant species with factors controlling available soil water.

There is also very close relationship between a site's abiotic factors and the ability of a species to establish there. Region 1 plantation survival surveys (stake row surveys) are valuable in displaying general trends. As seen in Figure 7, ponderosa pine and western larch survival was lower in the drought years of 1994, 2000, 2003, and 2006 (USFS 2012). While survival after the first growing season is highly variable, the correlation between seedling survival and drought is seen in the graph for all species. Some species, like ponderosa pine and western larch, appear more sensitive to soil moisture deficits in the first few years after planting. Based on this knowledge, it is critical to match species and planting sites in anticipation of an increased frequency of drought during the growing season. The greatest seedling mortality occurred when the June and July growing seasons were unusually dry. Although these plantation survival surveys are not statistically rigorous, they provide valuable information about survival trends across all Northern Region planting sites.

A failure to adjust reforestation prescriptions to future climate conditions may result in more frequent planting failures. Thus, silvicultural practices informed by regional research efforts should continually be evaluated to guide investments in tree planting and to improve regeneration success.

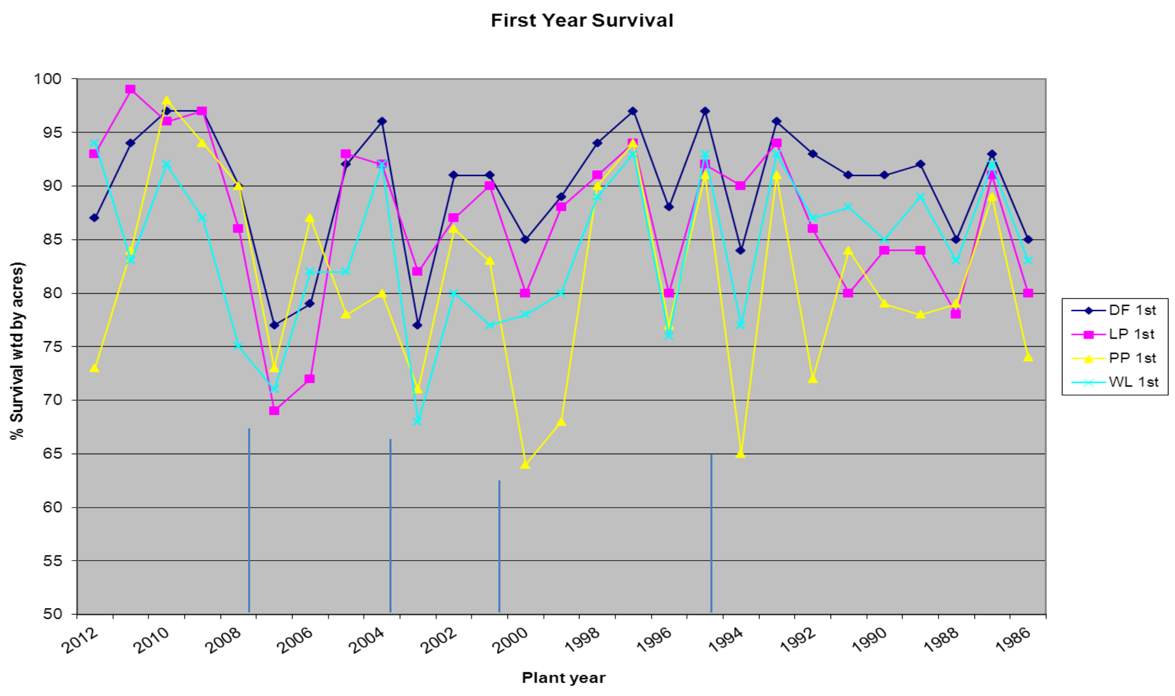


Figure 7. Trends in seedling survival over time in Region 1.

The effect of climate change on reforestation is more than seedling survival. There are multiple feedback loops including the effects of disturbances, climate, and species attributes that impact planting and natural regeneration success. Reforestation results hinge on several key factors such as (1) seed production, (2) seed germination, (3) genetically adapted seed sources, (4) nursery practices, (5) stock handling techniques, and (6) soil moisture conservation including the reduction of competing vegetation. For example, water stress can cause a decline in the vigor of seed producing trees, triggering an increase in insect infection and thus reduced cone and seed production. An increase in fire size and intensity with more frequent droughts may fragment forest cover impacting a range of processes from pollination to seed distribution. To be able to respond to these complex interactions, forest managers (silviculturists, botanists, foresters, soil scientist, and biologists) must prepare prescriptions that are flexible and adaptable to the full range of potential climates.

III. Vulnerabilities and Management Recommendations

While there is variability between climate model projections, and there is high uncertainty of the complex response of ecosystems to a changing climate, reforestation and revegetation programs must incorporate adaptation strategies that plan increased temperatures and water balance deficits. As Running (2010) has demonstrated, even where average annual moisture does not decline, the rising summer temperatures may offset the benefits of more moisture and longer growing seasons at most elevations, causing an overall decrease in water availability. Young plants, especially those planted, are particularly affected by site conditions and moisture is generally the most limiting factor except at the highest elevations, where cold temperatures also limit successful establishment (Case and Peterson 2005).

In this section, we have described the forest vegetation (mostly conifers) that is predicted to be most sensitive or vulnerable to change in a warmer and drier climate. We need to consider these future conditions to guide reforestation investments so that trees are more adapted and forests move towards resilient conditions. The vulnerability and management direction described here are based on the expertise of Region 1 silviculturists, the regional geneticist, and Rocky Mountain Research Station (RMRS) research silviculturists. Their many years of experience in observing regeneration response and forest succession augments regional research efforts. It is this knowledge that guides the interpretation of vegetative response to changing climate. This section will continue to be refined with the advancement of knowledge about climate change and species distribution, and the addition of information on forbs, shrubs, herbs.

For the purposes of this analysis, we divided Region 1 into three broad geographic areas: Westside Forests, Central Montana Forests, and Eastern Montana Forests. A group of silviculturists, with assistance from research scientists and the regional geneticist, identified the species and habitat conditions most vulnerable to a warmer and drier climate, and provided management considerations for reforestation. The teams synthesized their knowledge of species silvics and autecology with their understanding of interactions of long term drought, insect, disease, and fire disturbances; and the complexity of soils and topography when considering the habitat conditions vulnerable to change. We must consider these biotic and abiotic stress complexes as these greatly influence the vigor of individual trees, and ultimately the sustainability of the forest ecosystems (McKenzie *et al*. 2009).

We used familiar Region 1 habitat groups (USDA FS 1997, Bollenbacher 2008) for the assessment because they represent a common frame of reference for describing forested vegetation across the Region. Habitat types are an expression of water availability, slope, aspect, and elevation which are direct drivers of vegetative processes; however we recognize these communities of species will not respond in a uniform fashion to climate change.

While mature forests have some adaptive capacity to tolerate change, young plants are more sensitive to the existing environment. We focused on expected climate changes over the next 20 years most critical for stand development when temperature increases are expected to be around 2°C rather than expanding the range of species to fit predicted distribution patterns beyond 2060 (Rehfeldt 2006, Erickson 2012, USDA 2012b). The silviculturists concentrated on conditions most vulnerable to climatic shifts, generally ecotones, and seral species most important to the Region's restoration program.

The following table (Table 1) summarizes the trends identified by the silviculturists however users of the primer should refer to the details by habitat type group (Tables 2-4) when developing prescriptions.

Douglas-fir beetle and wildfire mortality on Bitterroot NF

Table 1. Summary – Projected Changes in Forest Conditions

Forest Condition	**Description**
Dry habitats and lower tree line	Tree line may move downslope in response to greater winter precipitation, but increased temperatures in late to early summer will potentially inhibit tree establishment. Magnitude of effects will be species dependent. (Shafer *et al*. 2001, Rice *et al*. 2012).
Mesic habitats	There is considerable uncertainty and variability in the mesic sites; however, we can assume that dry summers will be extended leading to decreases in water availability. Drought stress will increase, making tree species vulnerable to root pathogens.
High elevation and tree line species	We assume the climate will alter snowpack/moisture regimes in the spring and fall. Although, there may be more precipitation, it will most likely come in the form of rain and there may be less moisture during the critical growing period. In places with shallow soils where water holding capacity is limited, there may be actually less water available for plant growth and create more arid conditions.
Fire and other disturbances	Large stand replacing disturbances will reset the successional clock and may alter the complex of species at a given site. Effects of less intense events may mimic current conditions. Disturbance and subsequent regeneration will be the driver on how fast forests change.
Ponderosa pine (*Pinus ponderosa*)	Ponderosa pine is a long lived seral adapted to soil moisture deficits in the growing season. It is the most heat and drought tolerant of the conifers in the Region due to its deep rooting capacity, thus it may expand its range into areas currently dominated by Douglas-fir (Minore 1979). Driest sites may inhibit plant establishment.
Douglas-fir *(Pseudotsuga menziesii)*	Douglas-fir is highly adapted to a large range of moisture regimes. It may be better suited on current grand fir habitat types within the lower elevations. At higher elevations and with warmer temperatures, it may expand onto sites that are dominated by cold hardy lodgepole pine, but It will be limited by growing season frosts (Heineman *et al*. 2003).
Lodgepole pine *(Pinus contorta)*	Lodgepole is adapted to heterogeneous forest landscapes in the mid- to high elevations. It is very frost resistant in winter (dormant state) and during growing season frosts. It will compete with subalpine fir where disturbance is lacking; however it will dominate following wildfire (Bartlein *et al*. 1998, Rice *et al*. 2012). Lodgepole pine will retract from the dry sites where Douglas-fir may be favored with increased average temperatures and where cold does not limit its establishment (Minore 1979).
White pine *(Pinus monticola)*	White pine grows in elevation gradients in warm and moist forests, and thus will be favored on more mesic sites where topography and soils favor good water holding capacity. Depending on the depth of soils, and length of dry summers, it may recede from the grand fir and Douglas-fir habitat types. It may, however, become the most adapted species on mesic sites if increased root disease impedes western hemlock and western redcedar success (Minore 1979). The success of future white pine plantings will be dependent on the adaptations of its competitors and the subsequent response of white pine blister rust to a changing climate. Its genetic quality as a generalist may allow it to colonize niches where other species cannot.
Western larch *(Larix occidentalis)*	Western larch is found in warm moist and cool moist settings; it will be limited to low energy aspects (easterly and northerly aspects) as the higher energy aspects, even at the same elevation, will be too hot and dry. Successful western larch regeneration will be dependent on the vigor and competitive advantage of its competitors. Thus in the more mesic sites, its ability to grow and develop will depend on how grand fir, western hemlock, and western redcedar react to climate change.
Western hemlock *(Tsuga heterophylla)* **and Western**	Western hemlock and western redcedar prefer areas that maintain consistent mesic condition. Root pathogens may increase resulting in the decline of these species and

redcedar *(Thuja plicata)*	reduction in productivity. In general, seral species will be favored especially where water deficits increase following fire or other disturbances.
Subalpine fir *(Abies lasiocarpa)* **and Engelmann spruce** *(Picea engelmannii)*	Subalpine fir and spruce are suited for high elevation cool moist settings. They may expand into areas that are currently limited by cold; however, Shrag *et al*. (2008) found that tree line conifers decreased in spatial distribution when both temperature and precipitation increased.
Whitebark pine *(Pinus albicaulis)*	Whitebark pine is specially adapted to cold, dry, high elevation sites that limit other species. Regeneration could be enhanced by longer and warmer growing seasons, however across the Region it is at risk due to white pine blister rust, mountain pine beetle, competition, drought and heat stress in the drier areas of the ecosystem (Romme and Turner 1991, Shrag *et al.* 2008, Rice *et al.* 2012). Its seed dispersal mechanisms and genetic quality as a generalist may allow it to colonize niches where other species cannot.

Tobacco Root Mtns showing 2012 fire mosaic.
Beaverhead-Deerlodge NF

Table 2: R1 Westside Forests (Kootenai NF, Idaho Panhandle NFs, Nez Perce - Clearwater NF)

The following Habitat Type Group (HTG) descriptions are adapted from **Biophysical Classification – Habitat type groups and description of Northern Idaho and Northwestern Montana, Lower Clark Fork and adjacent areas** (USDA FS 1997). The Contemporary Description (block 1) is taken from the biophysical classification, while the sections on Vulnerabilities and Management Considerations for Reforestation were developed by Region 1 silviculturists.

HTG 1: WARM and DRY

Contemporary Description: Ponderosa pine type and Douglas-fir- grass types.	This habitat type group is characterized in naturally functioning ecosystems by dry and open-grown park-like stands of ponderosa pine (*Pinus ponderosa*) or Douglas-fir with bunch grass understories. Most of the sites occur on hot and dry landscapes at lower elevations and on west and south aspects. An historical fire free interval of 5 to 25 years on these sites maintained grassy and open park-like stands dominated by large and old ponderosa pine and some Douglas-fir (Fischer 1987). These were low severity under-burning fires. Stand replacement fires were probably rare.
Vulnerabilities	In a moisture limited climate, these sites will trend toward grasslands with limited tree cover and probably support less than 10% cover. Reforestation will be particularly difficult on the steep and south facing slopes where shallow soils make it challenging for plant growth. Particularly after wildfires, Douglas-fir regeneration will decrease due to a lack of seed source and drought conditions. Ponderosa pine may regenerate where there is a seed source however it may take 7 to10 years for a good seed crop. The opportunity for seedling establishment will be limited if there is reduced cone production caused by poor tree vigor in drought conditions, or insufficient moisture for seed germination and early growth. Bunchgrass and savannah-like conditions will increase especially on sites comprised of mollisols or the fertile mollic epipedon.
Management Considerations for Reforestation	In general, planted trees are unlikely to establish and thus planting is not recommended. Expect natural regeneration where there is some soil moisture, but grasses and shrubs will tend to dominate.

HTG 2: MODERATELY WARM and DRY

Contemporary Description: Most Douglas-fir types and dry subalpine fir types	These habitat types are characterized in naturally functioning ecosystems by open-grown stands of ponderosa pine or Douglas-fir with grass and shrub understories. Most of these sites occur at lower elevations across all aspects, but are also found at higher elevation on more southerly and westerly aspects. The natural fire-free interval for underburning was 5 to 50 years (Fischer and Bradley 1987). Fires were mostly low and moderate severity fires commonly maintained open park-like stands dominated by ponderosa pine. In some cases, stand composition was dominated by Douglas-fir and western larch Little information is available for stand replacement fires, but severe intensity fires occurred only after a fire free interval probably exceeding 500 years on the drier types and 50 to 200 years on the more moist types (Smith and Fischer 1997).
Vulnerabilities	In a warmer and drier climate, vegetation on these sites will transition toward a matrix of non-forest and open forest patches. There is likely to be an increased trend toward bunchgrasses with widely spaced trees, or no trees (like current HTG 1) especially on the driest exposures, steeper slopes, and on soils with low moisture holding capacity. Expect western larch to regenerate poorly following disturbance. On the lower energy slopes, expect Douglas-fir, ponderosa pine and lodgepole pine to increase. Even on north and east slope, moisture will be limited, thus low tree density will generally be preferred. Douglas-fir root disease will likely increase where Douglas-fir vigor is declining but there may be opportunities to alter the species composition more to ponderosa pine or lodgepole pine.
Management Considerations for Reforestation	It is expected to be difficult and costly to regenerate these sites due to soil moisture deficits, high use by ungulates, high fire potential in dense stands (current condition), and savannahfication (potential for increased grasslands or sparsely populated trees). Where planting is needed to provide habitat or watershed protection, limit investments to areas that are more moderate (lower energy aspects and slopes, deeper soils where water holding capacity is greater). The species preference may include ponderosa pine and a component of Douglas-fir and lodgepole pine. Ninebark (*Physocarpus malvaceus*), ocean spray (*Holodiscus discolor*), ceanothus (*Ceanothus spp.*) and other shrubs may be strong competitors to trees. It will be important to plant larger, more vigorous seedlings, and plant only where there is sufficient site preparation to give seedlings the chance to occupy the site before the shrubs. The extent of suitable planting conditions will vary greatly by site and disturbance level and will require close evaluation of the site conditions prior to investing in planting.

HTG 3: MODERATELY WARM AND MODERATELY DRY

Contemporary Description: Douglas-fir with twin flower (*Linnaea borealis*) understory or most Grand fir types	This contains a highly variable group of habitat types. The group is a transition between the dry and moister types and includes sites characteristic of each. These habitat types were characterized in naturally functioning ecosystems by mixed species stands of ponderosa pine, Douglas-fir, western larch, lodgepole pine, and grand fir (*Abies grandis*). Understories in the absence of fire or other disturbance are composed primarily of dense Douglas-fir or grand fir thickets. The natural fire free interval for underburning was 15 to 50 years. Mixed intensity moderate and severe fires commonly created mosaics of even-aged stands with survivor individual and groups of trees (Smith and Fischer 1997). Also common are open park-like stands dominated by ponderosa pine, western larch, and Douglas-fir. These types are not found on the Kootenai NF.
Vulnerabilities	In a warmer climate, these sites will better support drier adapted species. They may be too arid for white pine particularly on the drier ecotone. The high tree density of stands in this group may subject them to large stand replacing events. After these disturbance events, it may be too dry for successful western larch regeneration except in cool protected areas, or cooler northerly aspects. Douglas-fir will gain dominance replacing grand fir, and there should be an increase in ponderosa pine. Open park-like stands are desired due to water limitations and their ability to be more resilient in wildfires. Specifically on the Nez Perce NF, lodgepole pine will likely reforest after large fires, or where cold air settling limits Douglas-fir.
Management Considerations for Reforestation	There should be increased opportunities to plant ponderosa pine especially on the drier ecotones currently occupied by grand fir and/or Douglas-fir. Low tree densities are preferred due to water limitations. On the Nez Perce NF, lodgepole pine natural regeneration should be expected after large fires where serotinous cones are present and cold air settling occurs.

HTG 4: MODERATLEY WARM AND MOIST

Contemporary Description: Grand fir-wild ginger (*Asarum spp.*) and queencup beadlily (*Clintonia uniflora*) types	These are warm and moist habitats. In western Montana and in some of the lower precipitation zones of northern Idaho, these types occur along the lower slopes and valley bottoms. In the moister environment of northern Idaho these types occur on drier aspects at mid elevations. The group is highly diverse and many of the conifer species in the area can occur on these types. Understory vegetation may be dominated by a wide variety of species. Fire-free interval is wide, from 50 years on the drier types to over 200 years on the more moist types. All fire severities are possible. Many fires are minor ground fires that create a mosaic within the stand, or mixed severity fires that create a patchy mosaic of underburn and irregular sized openings. At the other extreme with increased drying, a complete stand replacement fire will likely occur. Many times this is the result of a fire burning from an adjacent drier site. Fire exclusion on these sites has changed them primarily by reducing the number of acres in early succession vegetation, and increasing the proportion of the landscape dominated by shade-tolerant tree species.
Vulnerabilities	With a warming climate, the higher energy aspects and steeper slopes will be less suitable for western larch and white pine regeneration. Western larch and white pine will persist in cooler microsites where soils with greater water holding capacity are present. Regeneration success may be limited to moist areas creating a patch mosaic of western larch or white pine interspersed with other species. Root pathogens may increase as the vigor of grand fir declines. In Armillaria (*Armillaria ostoyae*) root disease pockets or in diffuse root disease areas, regeneration success may be reduced.
Management Considerations for Reforestation	Consider planting ponderosa pine on most of these sites. Plant western larch and white pine on selected microsites only; avoid planting them on soils with poor water holding capacity especially on southerly slopes, or steep east or north slopes.

HTG 5: MODERATLEY COOL AND MOIST

Contemporary Description: Western redcedar, Western hemlock- wild ginger and queencup beadlily types	Upland cedar and hemlock habitat types are moderately cool and moist sites. They can contain our greatest diversity of species; common tree species include western redcedar, western hemlock, Douglas-fir, Engelmann spruce, subalpine fir lodgepole pine, mountain hemlock (*Tsuga mertensiana*), western larch and white pine. Very high basal areas can be achieved on these types. Fire frequency can be low due to the maritime influence on these sites. Fire severity can be highly variable due the most common moist conditions, but is severe during periods of drought. Fire free intervals range from 50 to greater than 200 years (Fischer and Bradley 1987). Variable fire regimes are common, and often include both mixed severity fires on 50 to 85 year intervals as well as stand replacing fires on 150 to 250 year intervals. Many species, such as redcedar, do well on these sites and may thrive for centuries without disturbance.
Vulnerabilities	Currently this group is interspersed with the drier HTG 4 creating a mosaic, influenced by the complexity of topography and soils. In a drier climate, western larch and white pine will decrease in extent and ponderosa pine will expand especially on spur ridges where soil water deficits will be more pronounced. Insect and root disease infection may increase in shade tolerant species on the dry ecotones. Spruce budworm in the Douglas-fir and other diseases could also increase as vigor declines with drought stress. Differing from the other national forests, the sites in northern Montana on the Kootenai NF may exhibit less change.
Management Considerations for Reforestation	After disturbance, shrub species will rapidly invade these sites requiring prompt planting of early seral tree species. On the more exposed or high energy aspects, ponderosa pine regeneration should be preferred. On the north and east aspects and more protected sites, planting may include a mix of western larch, white pine, ponderosa pine, but be cognizant of convex topography or shallow soils. Avoid planting western larch and white pine on the drier ecotones. Mature trees with poor vigor may be an indicator of dry conditions. Specifically on the Kootenai NF, expect lodgepole pine and western larch to be successful except for the most exposed areas. Ponderosa pine is preferred on drier sites, and white pine on moist sites. After fire, lodgepole pine may naturally regenerate where there is less shrub invasion.

HTG 6: MODERATLEY COOL and WET

Contemporary Description: Western Redcedar-Athyrium, Oplopanax, and Adiantum types	These are very wet sites. They are forested riparian areas along streams and are associated with wetlands, or found in upslope sites when there is water near the surface, and soils are saturated for at least part of the year. Due to this very wet condition, the fire free interval can be very long. Intervals are probably much longer than the majority of fire groups. On the drier habitat types, fire free intervals range from 50 to greater than 200 years, and the redcedar series are commonly in excess of 250 years. Stand replacing fires on upland sites may often become patchy,-mixed and low severity surface fires, when fires burn in larger areas of these habitat types. Centuries may pass without stand replacement, severe fire (Smith and Fischer 1997).
Vulnerabilities	There is likely to be varying affects in these wet areas dependent on the topography and water dynamics. These sites are either riparian areas with abundant sub-surface moisture, or they are on upper slopes with perched water tables. Some of the upland edges of riparian areas will dry out converting to the drier shrub or forest types of the adjacent forest. After disturbance and loss of tree cover, there may be increased available water.
Management Considerations for Reforestation	In restoring or reforesting these areas, consider the resource area collectively and restore the compliment of trees and shrubs necessary to provide fish habitat cover, or other desired conditions. In addition, consider the potential for cold air settling that will limit reforestation except with cold tolerant species.

HTG 7: COOL and MOIST

Contemporary Description: Subalpine fir-Clintonia and Menziesia types	These types are characterized by cool and moist site conditions. Species diversity can be high with western larch, Douglas-fir, white pine, Engelmann spruce, lodgepole pine, subalpine fir and grand fir. Other sites are dominated by lodgepole pine after stand replacement burns. These sites are probably too cool for western hemlock and redcedar to play a dominant role, but they are not cold enough for whitebark pine to compete. Whitebark pine usually does not play a major successional role, although it may sometimes be present in minor amounts. Fire history information is scarce. Fire intervals are estimated at greater than 120 years for most sites (Fischer1987).
Vulnerabilities	These sites are quite variable and thus effects will vary in response to drier growing seasons. Overall these sites tend to be very productive, although soils may be shallow. More arid conditions may reduce competition on the higher elevations. Whitebark pine may be able to compete on shallow soils where it less suitable for subalpine fir and lodgepole pine. Cold temperatures will not be as limiting but water stress may reduce regeneration of some species. On the harsher sites on the Kootenai NF, lodgepole pine and western larch will be favored; conditions will not be suitable for subalpine fir and spruce. Western larch may be limited by moisture, and result in a more distinct patch mosaic; flatter or concave slopes and northerly aspects may be preferred. Response on the Nez Perce- Clearwater NF is similar to the more northern Idaho conditions. Douglas-fir has a high level of root disease so it will likely give way to lodgepole pine after large stand replacing fires. Expect subalpine fir regeneration on the moderate sites and grand fir on the drier sites.
Management Considerations for Reforestation	Across most of the more moderate and low energy sites, western larch and white pine should generally be preferred for planting to compliment naturally regenerating Douglas-fir and grand fir. Douglas-fir natural regeneration replacing grand fir may indicate that the site is getting too dry for successful white pine planting. Expect Douglas-fir to establish well where there is a low root disease hazard. Lodgepole pine naturals are also likely to be successful where it is too cold for Douglas-fir, and subalpine fir will be favored over grand fir on these colder sites. There are some harsher sites currently suitable for white pine on the Kootenai NF, but under drier conditions, should not be planted. Western larch may be preferred for planting only on the flatter or concave slopes and northerly aspects. Douglas-fir natural regeneration will be more prominent especially where there is little fire and more advanced succession. There should be opportunities to plant western larch on the Nez Perce NF. The Clearwater NF is generally moister and should be suitable for planting both white pine and western larch. Whitebark pine planting may be suitable on higher elevations throughout the zone where soil moisture is too low for other species and in open patches where there is reduced competition. Whitebark pine stands may be more fragmented or in limited patches than current conditions.

HTG 8: COOL and WET

Contemporary Description: Spruce– Common horsetail (*Equisetum arvense*); Subalpine fir- Bluejoint (*Calamagrostis canadensis*) and Claspleaf twisted stalk (*Streptopus amplexifolius*)	These are very wet sites. They are forested riparian areas along streams and associated with wetlands. Due to this very wet condition, the fire free interval can be very long. Intervals between severe, stand replacement fires are probably much longer than the majority of fire group nine, 90 to 130 years and are probably in excess of 150 years.
Vulnerabilities	The response of these cooler riparian habitats will likely be similar to HTG 6. The effects from climate change will be dependent on the topography and water dynamics. Some of the upland edges may dry out, converting to shrubs or the forest types of the adjacent forest. However, after disturbance and loss of tree cover, water levels will increase.
Management Considerations for Reforestation	In restoring or reforesting these areas, consider the resource area collectively and restore the best adapted compliment of trees and shrubs to provide fish habitat cover or other desired conditions. Also consider the potential for cold air settling and plant more cold tolerant species.

WP being overtopped by other species.
Idaho Panhandle NF. Photo by Terrie Jain.

HTG 9: COOL and MODERATELY DRY

Contemporary Description: Subalpine fir-Beargrass and Dwarf Huckleberry types	These are the cool and drier subalpine fir habitat types. The fire free interval of these types is 50 - 130 years (Fischer 1987). These periodic fire disturbances and high amount of low to moderate fire intensity, favors species such as lodgepole pine, Douglas-fir, and western larch. Subalpine fir and spruce commonly dominate in late succession. Stands dominated by lodgepole pine and over 80 years of age tend to build fuels to become a part of large stand replacement events encompassing thousands of acres (Fischer 1987). Whitebark pine may be present. However, although some of these sites can be frosty, especially some dwarf huckleberry (*Vaccinium caespitosum)* and beargrass (*Xerophyllum tenax*) types, they are usually not cold enough to give whitebark pine enough of a competitive advantage to play a major successional role.
Vulnerabilities	These sites tend to be the higher elevations and predicted to have lower snowpack and longer summer seasons causing greater water deficit during the summer growing season. Favored species will be Douglas-fir and lodgepole; western larch will be limited to deeper soils and cooler aspects. The Kootenai NF is moister than the more southerly national forests. Lodgepole pine, and in some cases Douglas-fir, is expected to dominate after disturbance. Poor vigor of mature western larch may indicate sites are becoming too dry. Mountain pine beetle and wildfire will be increasing disturbance agents with affects dependent on the stand age. The Idaho Panhandle and Nez Perce-Clearwater NFs may experience increased lodgepole pine dominance and possibly increasing Douglas-fir. The northerly aspects may still support western larch but not white pine. Currently western larch shows lower vigor and survival on drier sites and this could get worse.
Management Considerations for Reforestation	Natural regeneration of lodgepole pine and Douglas-fir will be the dominant regeneration process. Western larch planting may be successful but it should be limited to the more protected areas, cooler aspects, and to soils with high water holding capability. Mature trees with poor vigor may indicate areas that are too dry for planting those species. Plan for lodgepole pine and Douglas-fir on the high energy slopes and consider planting western larch with lodgepole pine on the cooler slopes. Opportunities for whitebark pine planting may be available where lodgepole pine and subalpine fir are not heavy competitors.

HTG 10: COLD and MOIST to MODERATELY DRY

Contemporary Description: Subalpine fir- Grouse whortleberry and Luzula types	These types are upper elevation cold moist to moderately dry sites. Most of these sites are above the cold limits where conifers such as Douglas fir, western larch and white pine are capable of being major stand components. On most of these sites whitebark pine has the potential to be a major stand component during some portion of the successional sequence. Common tree species are whitebark pine, lodgepole pine, mountain hemlock, subalpine fir, spruce, and alpine *larch (Larix lyallii).* High cover of grouse whortleberry *(Vaccinium scoparium)* and/or smooth wood-rush (*Luzula hitchcockii)* is often indicative of cold conditions where whitebark pine may have some competitive advantage. The fire free interval varies considerably from 35 to over 300 years. Stand replacement fires occur after intervals of more than 200 years (Fischer and Bradley 1987). Most fires are of low severity because of discontinuous fuels (Arno 1989).
Vulnerabilities	These sites are the most vulnerable to climate change due to the increase in competition and may be more influenced by water deficits than cold temperature limits. The drought effects will be further compounded by the exposure, high solarization, and poorly developed soils.
Management Considerations for Reforestation	There are limited management opportunities except in microsites where it is suitable for planting whitebark pine. Subalpine fir and spruce will decline with the water deficit but sites may be beneficial for whitebark pine establishment. Alpine larch may naturally regenerate after small fires; it is currently an important part of these forest types.

HTG 11: COLD and NEAR TIMBERLINE

Contemporary Description: High elevation whitebark pine and subalpine fir types	These types are high elevation cold sites. Whitebark pine, mountain hemlock *(Tsuga mertensiana),* subalpine fir, spruce and alpine larch are common species. These sites are near the timberline and above the cold limits of species such as Douglas-fir, grand fir, white pine and western larch. Due to severe site conditions, vascular plant species diversity in all life forms tends to be very low. The fire free interval varies considerably from 35 to over 300 years. Stand replacement fires occur after intervals of more than 200 years (Fischer *et al*. 1987).
Vulnerabilities	Similar to HTG 10, these sites will have greater water deficits during the summer growing period but a longer overall growing season due to warmer temperatures in the fall and spring. Lower snowpack will cause moisture deficits.
Management Considerations for Reforestation	There should be opportunities for planting whitebark pine in more protected areas, with deep soils sufficient for planting. The opportunities for whitebark pine planting will be best after disturbance when competition is least.

Table 3 R1 Central Montana Forests (Flathead NF, Lolo NF, Bitterroot NF)

The following Habitat Type Group (HTG) descriptions are adapted from **Biophysical Classification – Habitat type groups and description of Northern Idaho and Northwestern Montana, Lower Clark Fork and adjacent areas** (USDA FS 1997). The Contemporary Description is taken from the biophysical classification, while the sections on Vulnerabilities and Management Considerations for Reforestation were developed by Region 1 silviculturists.

HTG 1: WARM and DRY

Contemporary Description: Ponderosa pine type and Douglas-fir- grass types.	This habitat type group is characterized in naturally functioning ecosystems by dry and open-grown park-like stands of ponderosa pine or Douglas-fir with bunch grass understories. Most of the sites occur on hot and dry landscapes at lower elevations and on west and south aspects. A natural fire free interval of 5 to 25 years on these sites maintained grassy and open park-like stands dominated by large and old ponderosa pine and some Douglas-fir (Fischer 1987). These were low severity under-burning fires. Stand replacement fires were probably rare.
Vulnerabilities	In moisture limited environments, the south and westerly high energy aspects will trend toward savannah-like conditions. This will be most obvious after fire or other disturbance events and more pronounced in areas already difficult to reforest. Tree cover may remain or re-establish where the topography provides more temperate conditions, such as protected stringers. Sites will be more suitable for ponderosa pine and less so for Douglas-fir. Residual trees, especially Douglas-fir, will experience multiple stresses including bark beetle, spruce budworm and root disease that may further reduce forest cover. These types of sites are more prevalent on the Bitterroot NF and Missoula, Ninemile and Plains Districts of the Lolo NF.
Management Considerations for Reforestation	There are very limited opportunities for tree planting. Ponderosa pine regeneration will be limited by seed source and the ability to germinate and establish in open dry sites. When the desired condition is some level of tree cover, select the most protected and cooler sites, and plant with the largest, most vigorous tree stock available. Plan for and expect low tree stocking levels. Plant before grasses establish or plan to treat the competition prior to planting.

HTG 2: MODERATELY WARM and DRY

Contemporary Description: Most Douglas-fir types and dry Subalpine fir types	These habitat types are characterized in naturally functioning ecosystems by open-grown stands of ponderosa pine or Douglas-fir with grass and brush understories. Most of the sites normally occur at lower elevations on many aspects, but are also found at higher elevation on more southerly and westerly aspects. The natural fire-free interval for underburning was 5 to 50 years (Fischer and Bradley 1987). These mostly low and moderate severity fires commonly maintained open park-like stands dominated by ponderosa pine. In some cases, stand composition was high in Douglas-fir and western larch. Little information is available for stand replacement fires, but severe intensity fires occurred only after a fire free interval probably exceeding 500 years on the drier types and 50 to200 years on the more moist types (Smith and Fischer 1997).
Vulnerabilities	In a drier, warmer climate, expect ponderosa pine to be more prevalent than Douglas-fir. Drought related stress will make Douglas-fir more vulnerable to bark beetle and root disease, and greater fire disturbance will create more openings in the forest cover. Douglas-fir/ ninebark (*Physocarpus malvaceous*)- ninebark phase habitat type, may convert to grass or herbaceous cover, especially on shallow soils. Other high energy aspects, as well, will trend toward grasslands and shrubs. On cooler or low energy aspects, ponderosa pine will be favored over other species. Western larch will contract to only the most northerly slopes and soils with high water holding capacity. These habitat types are most prevalent on the Bitterroot NF and Missoula, Ninemile and Plains Ranger Districts of the Lolo NF.
Management Considerations for Reforestation	Opportunities for planting should be restricted to the best microsites. Where regeneration is necessary, good site preparation to reduce competing vegetation and prompt planting will be necessary. Big game browsing may be an issue and may limit planting opportunities. Douglas-fir/ ninebark – ninebark phase habitat types may be unsuitable for planting.

Dry DF site that was previously harvested by past landowner; regeneration will be difficult. Lolo NF

HTG 3: MODERATELY WARM AND MODERATELY DRY

Contemporary Description: Douglas-fir with Twinflower (*Linnaea borealis)* understory or most Grand fir types	This contains a highly variable group of habitat types. The group is transition between the dry and moister types and has characteristics of both habitat types. These habitat types are characterized in naturally functioning ecosystems by mixed species stands of ponderosa pine, Douglas-fir, western larch, lodgepole pine, and grand fir. Understories in absence of fire or other disturbance are composed primarily of dense Douglas-fir or grand fir thickets, though other tree species may be present. The natural fire free interval for underburning was 15 to 50 years. Mixed intensity of moderate and severe fires commonly created mosaics of even-aged stands with survivor individual and groups of trees (Smith and Fischer 1997). Also common are open park-like stands dominated by ponderosa pine, western larch and Douglas-fir.
Vulnerabilities	In a warmer climate, expect a more defined mosaic of tree species across the landscape. Douglas-fir will be favored over grand fir on the more exposed and high energy sites. Existing grand fir with poor vigor may be an early indicator of declining soil moisture. Root disease will increase where trees are stressed. The more exposed slopes will be most suitable for ponderosa pine and less so for western larch. There is likely to be breaks in the forest canopy where root disease or shallow soils impede tree establishment. The deeper draws and benches, where soils are typically deeper, may continue to support western larch and ponderosa pine. Lower soil moistures will not be favorable for white pine. Where cold air lingers, lodgepole pine may persist but the coverage is likely to decrease with warmer temperatures.
Management Considerations for Reforestation	The greatest challenges for regeneration will occur where root disease cause gaps in the forest cover. There should be increased opportunities to plant ponderosa pine to compliment natural regeneration on higher energy aspects. Be observant to the potential for cold air settling indicated by lodgepole pine regenerating with no other species. The benches and draws of dissected slopes provide planting opportunities. These areas with deeper soils may continue to be suitable for planting western larch to compliment the ponderosa pine and other naturals.

HTG 4: MODERATLEY WARM AND MOIST

Contemporary Description: Grand fir-Asarum and Clintonia types	These are warm and moist habitats that are highly diverse; many of the conifer species in the region can occur in these types. Understory vegetation are dominated by a wide variety of species. In western Montana and in some of the lower precipitation zones of northern Idaho, these types occur along the lower slopes and valley bottoms. Fire free interval is wide from 50 years on the drier types to over 200 years on the more moist types. All fire severities are possible on this type. Many fires are minor ground fires that create a mosaic within the stand, or mixed severity fires that create a patchy mosaic of underburn and irregular sized openings. On the other extreme, with drying, a complete stand replacement fire will occur. Many times this is the result of a fire burning from an adjacent drier site. Fire exclusion has changed these sites primarily by reducing the number of acres in early succession types, and increasing the proportion of the landscape dominated by shade-tolerant tree species.
Vulnerabilities	With warming climates, these valley bottoms will continue to support a diverse group of species. Although still moist, these sites will be relatively drier, and trees will be under more stress. Dependent on the moisture deficit, Douglas-fir may be favored over grand-fir. There may be an increase in acres burned due to dense stands currently common. After disturbance, more areas may be suitable for ponderosa pine, with white pine and western larch on moister and cooler sites.
Management Considerations for Reforestation	Consider planting ponderosa pine over most of these areas; natural regeneration may be limited due lack of seed source. White pine planting should be considered only on the moist microsites, benches and topographic features with high water holding capacity. Western larch may also be suitable for planting on the cooler aspects and gentler slopes.

HTG 5: MODERATLEY COOL AND MOIST

Contemporary Description: Western redcedar, Western hemlock,- Asarum and Clintonia types	These upland cedar and hemlock habitat types are moderately cool and moist sites. They can contain our greatest diversity of species; common tree species include western redcedar, western hemlock, Douglas-fir, Engelmann spruce, grand fir, lodgepole pine, mountain hemlock, western larch, and white pine. Very high basal areas can be achieved on these types. Fire frequency can be low due to the maritime influence. Fire severity can be highly variable due the most common moist conditions, but is severe during periods of drought. Fire free intervals range from 50 to greater than 200 years (Fischer and Bradley 1987). Variable fire regimes are common, and often include both mixed severity fires on 50 to 85 year intervals as well as stand replacing fires on 150 to250 year intervals. Many species do well on these sites and may thrive for centuries without disturbance; western redcedar is the most notable example.
Vulnerabilities	This group is not prevalent on western Montana national forests. It tends to be limited to deeper highly weathered soils and harbors a mix of species. Expect that it will continue to support a mix of western larch, white pine, and ponderosa pine.
Management Considerations for Reforestation	Planting ponderosa pine would generally be desirable. Planting white pine should be limited to microsites with deeper soils and greater water holding capacity and should be favored over Douglas-fir where root disease is an issue. Areas currently preferred by lodgepole pine due to cold air settling, may be suitable for Douglas-fir in the future.

HTG 6: MODERATLEY COOL and WET

Contemporary Description: Western redcedar-Athyrium, Oplopanax, and Adiantum types	These are very wet sites. They are forested riparian areas along streams and are associated with wetlands, or are found in upslope position when there is water near the surface and soils are saturated for at least part of the year. Due to this very wet condition, the fire free interval can be very long. Intervals are probably much longer than the majority of fire groups. On the drier series fire free intervals range from 50 to greater than 200 years, and may be in excess of 250 years. Stand replacing fires on upland sites may often become patchy mixed and low severity surface fires when they reach larger areas of these habitat types. Centuries may pass without a stand replacement fire (Smith and Fischer 1997).
Vulnerabilities	The effects to the riparian areas will be strongly dependent on the gradient. Steep narrow mesic areas may be less vulnerable to shifts in moisture unless the drought is really severe. Adjacent forests may trend towards drier adapted species but moisture may persist in the deep areas of the drainage. Edges of wider or flatter riparian areas may dry out. After a major fire or other disturbance and loss of surrounding tree cover, water tables will rise or be similar to current conditions.
Management Considerations for Reforestation	Management and investments in these riparian areas will depend on the desired conditions and restoration objectives which may include establishing long lived seral species or cover for fish habitat. Where restoring tree cover is desired, a nurse crop (cold tolerant trees or shrubs) may be needed.

HTG 7: COOL and MOIST

Contemporary Description: Subalpine fir-Clintonia and Menziesia types	These types are characterized by cool and moist site conditions. Species diversity can be high with western larch, Douglas-fir, white pine, Engelmann spruce, lodgepole pine, subalpine fir and grand fir. Other sites are dominated by lodgepole pine after stand replacement burns. These sites are probably too cool for western hemlock and western redcedar to play a dominant role. On the other hand, these sites are not cold enough that whitebark pine is competitive and it usually does not play a major successional role (although it may sometimes be present in minor amounts). Fire history information is scarce. Fire intervals are estimated at greater than 120 years for most sites (Fischer 1987).
Vulnerabilities	These sites will be affected by a shorter duration of snowpack, will dry out sooner in the spring, and be drier in the fall. Preferred sites for a mix of species (Douglas-fir, lodgepole pine, white pine, western larch, spruce, subalpine fir) will be dependent on topography and extent of disturbance, likely resulting in a more discrete species mosaic. Lodgepole pine is expected to be dominant after stand replacing fires with good natural regeneration. The cooler aspects and higher elevations may be dominated by spruce and subalpine fir with lodgepole pine regenerating after disturbance.
Management Considerations for Reforestation	Even under more arid conditions, western larch and white pine will be present but planting should be avoided on the southerly aspects and on soils with poor water holding capacity. Mature white pine with poor vigor may indicate poor site conditions for planting white pine. White pine can compete with lodgepole pine in managed conditions but it is limited by the competition from other tolerant species. Lodgepole pine, spruce, and subalpine fir are preferred over most of the area. Douglas-fir may be suitable on drier sites where growing season frosts are not likely.

After 2007 fires on Bitterroot NF before natural regeneration has established.

HTG 8: COOL and WET

Contemporary Description: Spruce– Common horsetail ; Subalpine fir-Bluejoint and Claspleaf twisted stalk	These are very wet sites. They are forested riparian areas associated with wetlands. Due to this very wet condition, the fire free interval can be very long. Stand replacement fires are probably much longer than the majority of fire group nine, 90 to 130 years and are probably in excess of 150 years.
Vulnerabilities	The response of these riparian areas is similar to HTG 6. Affects will be dependent on stream gradient and water dynamics. Loss of tree cover in adjoining stands may increase the water, although fringes may dry out.
Management Considerations for Reforestation	When resource objectives require planting, white pine, western larch, and spruce should be considered. If cold air settling continues to be a problem, a nurse crop may be needed as these species are not very frost hardy.

HTG 9: COOL and MODERATELY DRY

Contemporary Description: Subalpine fir-Beargrass and Dwarf huckleberry types	These are the cool and drier subalpine fir habitat types within the area. The fire free interval of these types is 50 to 130 years (Fischer, 1987). These periodic fire disturbances and high amount of low to moderate fire intensity, favors species such as lodgepole pine, Douglas-fir and western larch. Subalpine fir and spruce commonly dominate in late succession. Stands dominated by lodgepole pine over 80 years of age tend to build up fuels to become a part of large stand replacement events (Fischer, 1987). Whitebark pine may be present. Although some of these sites (especially in some blue joint and beargrass habitat types) can be quite frosty, they are usually not cold enough to give whitebark pine enough of a competitive advantage to play a major successional role.
Vulnerabilities	Expect these sites to be similar to current species composition of subalpine fir, spruce, Douglas-fir, and lodgepole pine although Douglas-fir may increase where growing season frosts are not prevalent and drought limits subalpine fir and spruce. The sites will be suitable for lodgepole pine. After disturbance, there may be a reduction of competition (too dry) and be suitable for whitebark pine regeneration.
Management Considerations for Reforestation	There are limited management opportunities, but expect lodgepole pine to naturally regeneration after disturbance. The very moist microsites may be suitable for planting western larch or whitebark pine.

HTG 10: COLD and MOIST to MODERATELY DRY

Contemporary Description: Subalpine fir-Grouse whortleberry and Luzula types	These types are upper elevation cold moist to moderately dry sites. Most of these sites are above the cold limits where conifers such as Douglas-fir, western larch, and white pine are capable of being major stand components. On most of these sites whitebark pine has the potential to be a major stand component during some portion of the successional sequence. Common tree species are whitebark pine, lodgepole pine, mountain hemlock, subalpine fir, spruce, alpine larch. High cover of grouse whortleberry and/or smooth wood-rush is often indicative of cold conditions where whitebark pine may have some competitive advantage. The fire free interval varies considerably from 35 to over 300 years. Stand replacement fires occur after intervals of more than 200 years (Fischer and Bradley 1987). Most fires are of low severity because of discontinuous fuels (Arno, 1989).
Vulnerabilities	These high elevation sties are among the most vulnerable to climate change and there are limited management opportunities. High exposure, wind and solarization, along with higher temperatures and earlier snow melt will make open slopes harsher for vegetation establishment. Open slopes may convert to grasses and forbs. On more protected areas, where cold currently limits Douglas-fir, conditions may be more favorable for Douglas-fir. Lodgepole pine natural regeneration will likely continue to be successful. With disturbance and the reduction of current tree cover and competition, whitebark pine regeneration may be favored.
Management Considerations for Reforestation	There are limited management opportunities in these high elevation forests. There should be good whitebark pine planting opportunities although microsites should be selected to protect trees from the weather and snow movement. Mountain hemlock and alpine larch are unique features in this zone that should be favored in the protected areas with deeper soils. Alpine larch should regenerate after small fires.

HTG 11: COLD and NEAR TIMBERLINE

Contemporary Description: High elevation Whitebark pine and Subalpine fir types	These types are high elevation cold sites, near timberline. Common species are whitebark pine, mountain hemlock, subalpine fir, spruce and alpine larch. This area is above the cold limits of species such as Douglas-fir, grand fir, white pine, and western larch. Due to severe site conditions, the diversity of vascular plants tends to be very low. The fire free interval varies considerably from 35 to over 300 years. Stand replacement fires occur after intervals of more than 200 years (Fischer *et al*. 1987).
Vulnerabilities	These sites, with more temperate climate, will be an ecotone in flux. An extended growing season is predicted with more water available in the fall and spring that should promote growth. Some areas may become more favorable growing conditions similar to current HTG 10 and favor lodgepole pine, subalpine fir, spruce, alpine larch, mountain hemlock, whitebark pine.
Management Considerations for Reforestation	Some of these areas should be a good investment for whitebark pine planting, particularly where competition is not heavy. The benefits of the longer growing season may be offset by a drier summer season on the more exposed slopes where wind, high solarization, and shallow soils, create harsh growing conditions. Therefore select cooler, protected aspects, and avoid the harsher aspects when selecting sites for planting.

High elevation spruce, subalpine fir and whitebark pine. Lolo NF

Table 4 R1 Eastside Forests (Lewis and Clark, Helena, Beaverhead-Deerlodge, Gallatin, Custer NFs)

The following Habitat Type Group (HTG) descriptions are adapted from **Estimate of Snag Densities for Eastside Forests in the Northern Region** (Bollenbacher *et al*. 2008). The Contemporary Description is taken from the Helena NF prescription summaries (Milburn 2012), while the sections on Vulnerabilities and Management Considerations for Reforestation were developed by Region 1 silviculturists.

HTG 1: Warm and Very Dry

Contemporary Description: Open grown dominated by Douglas-fir and Limber pine	These areas are often dominated by open-grown Douglas-fir and/or limber pine (*Pinus flexilis*), with some ponderosa pine and juniper (*Juniperus spp*). They are typically at lower elevations on dry aspects, with limited stocking. Their inclusion in suitable timber land is limited, with low to very low timber productivity. Reforestation needs arise most commonly from wildfire, in areas highly departed from a historic fire regime characterized by low severity at a 0 to 35 year frequency. Mortality may also occur from mountain pine beetle, Douglas-fir beetle, and budworm. Coarse woody debris is likely to be fairly low, less than 10 tons/ac.
Vulnerabilities	In a more arid climate, the higher energy aspects will trend towards bunchgrasses and shrubs. Douglas-fir may persist in swales or protected areas but it will be lightly stocked. There may be a shift to ponderosa pine in some cases but successful tree regeneration will be difficult on southerly and higher energy slopes especially after wildfire. Ponderosa pine seed source is lacking in many areas, and cold temperatures will limit the extent of ponderosa pine in some elevations. Areas featuring limber pine may shift to open savannah.
Management Considerations for Reforestation	Planting and successful natural regeneration should be expected only on lower energy slopes and topographic features where soils are deeper, and there is protection for young trees. Sites where there is currently a shrub component may indicate deeper soils, and be suitable for planting to achieve lightly stocked tree cover. Planting after wildfire will be difficult and will likely have poor success due to the limited moisture. There may be limited opportunities for limber pine regeneration in swales where soils are deeper and hold moisture.

HTG 2: Warm and Dry

Contemporary Description: Low elevation Douglas-fir or Douglas-fir/lodgepole pine	These areas are nearly pure Douglas-fir on dry aspects or Douglas-fir/lodgepole pine mixed on more mesic aspects. They are found on any aspect at lower elevations, and dry aspects at moderate elevations. Timber productivity is low to moderate. Reforestation needs arise most commonly from wildfire, especially in areas departed from a historic fire regime (low severity, 0 to 35 year frequency); or bark beetle outbreaks which may be exacerbated by budworm defoliation, drought, and overstocking. Coarse woody debris is likely to be low to moderate.
Vulnerabilities	The more exposed high energy sites will be similar to those in HTG 1, converting to savannah and bunch grasses. The granitic soils are well drained and currently have light tree stocking due to the poor water holding capacity. This is likely to be intensified during the growing season. The sedimentary soils with a clay and ash component are deeper than the granitic parent material and better able to hold water and support low tree density.
Management Considerations for Reforestation	There is little opportunity in a drier climate to get successful planting on most sites with granitic parent material especially after disturbance. However, the lower energy sites will probably support light stocking of trees. On sedimentary parent materials, there should be opportunities to plant ponderosa pine but evaluate each site closely. A rolling landscape is common in this zone; planting may be limited to patches or pockets where there is deeper soils and moisture, creating a more distinct patch mosaic of trees and grasslands.

Regenerating ponderosa pine within burned landscape.
Custer NF

HTG 3: Warm and Moist

Contemporary Description: Moist sites with Douglas-fir and lodgepole pine, spruce, shrubs	These areas are dominated by Douglas-fir with varying amounts of lodgepole pine, spruce, and a shrub component. Typically these sites are found on north aspects at low to moderate elevations with high amounts of available moisture. Timber productivity is low to moderate. Reforestation needs arise most commonly from wildfire, especially in areas departed from a historic fire regime characterized by low severity with 0 to 35 year frequency or a low/mixed severity with 35 to 200 year frequency; or bark beetle outbreaks which may be exacerbated by budworm defoliation, drought, and overstocking. Coarse woody debris is likely to be fairly low.
Vulnerabilities	With warmer climates, ponderosa pine will be favored in many areas currently dominated by Douglas-fir resulting from the drier growing season and decrease in cold limitations currently limiting ponderosa pine. On the upper (cooler) ecotones, Douglas-fir may be preferred over lodgepole pine, which current persists, except where there are growing season frosts. Overall root disease may expand where Douglas-fir vigor declines. These areas may revert to perpetual Douglas-fir root disease centers or convert to shrubs. On the Lewis and Clark NF, Douglas-fir may be favored (and less ponderosa pine) on the drier edges but lodgepole pine may be also present throughout the type.
Management Considerations for Reforestation	Ponderosa pine should be favored on the dry end of this type, more like HTG 2. Douglas- fir regeneration (planted and naturals) may still be favored however on the moister, cooler aspects. On the upper elevations and exposed ridges, Douglas-fir would also be preferred. Target densities should be light due to the drought conditions and desire to maintain fire resiliency.

HTG 4: Cool and Moist

Contemporary Description:	These areas are dominated by Douglas-fir with varying amounts of lodgepole pine, spruce, and a shrub component. Typically these sites are found on north aspects at low to moderate elevations with high amounts of available moisture. Timber productivity is low to moderate. Reforestation needs arise most commonly from wildfire, especially in areas departed from a historic fire regime characterized by low severity with 0 to 35 year frequency or a low/mixed severity with 35 to 200 year frequency; or bark beetle outbreaks which may be exacerbated by budworm defoliation, drought, and overstocking. Coarse woody debris is likely to be fairly low.
Vulnerabilities	With a warmer climate and longer growing season, these sites will remain relatively productive with Douglas-fir maintaining dominance (as is current) or increasing on drier aspects. Lodgepole pine will also be the dominant tree cover in many areas and generally able to regenerate naturally. Douglas-fir habitat types may replace subalpine fir habitat types in dominance on the more exposed aspects and dry ecotone. Subalpine fir will likely easily regenerate in draws and more protected areas. Stocking densities on the drier exposed aspects should be low.
Management Considerations for Reforestation	Generally lodgepole pine would be preferred for regeneration with an increasing reliance on Douglas-fir in the planting mix. Lodgepole pine will be the dominant preferred species on the Lewis and Clark NF.

HTG 5: Cool and Wet

Contemporary Description:	This habitat type group is made up of riparian types found in stream bottoms or slopes with seeps and springs. Forests are dominated by Engelmann spruce and lodgepole pine, with Douglas-fir on drier sites and subalpine fir in some places, often with more than one age class. Timber productivity is moderate. Reforestation needs arise from mixed or high severity wildfire, especially in areas departed from a historic mixed severity fire regime; or bark beetle outbreaks which may be exacerbated by budworm defoliation, drought, and overstocking. Coarse woody debris is likely to be variable and moderate/high in stand replacement fire regime areas.
Vulnerabilities	These riparian and wetlands sites are generally draws, flat areas, or drainage bottoms. Spruce and lodgepole pine may be successfully regenerated depending on the effects of stand replacing events on the water table. Dependent on the gradient and soils, the water table may increase in if there is sufficient water, with only the fringes drying out, or in the driest portions the draws may dry out.
Management Considerations for Reforestation	The restoration will depend on the desired conditions; shrubs, willows and aspen may increase naturally after the loss of tree cover.

HTG 6: Cool and Dry to Moist

Contemporary Description:	These sites are nearly pure stands of lodgepole pine on cool sites, although stands without disturbance for over 100 years may have spruce, subalpine fir, Douglas-fir, and occasionally whitebark pine in the understory. Aspen (*Populus tremuloides*) may also be present, and on the Lincoln District, also western larch. These sites are found at moderate to moderately high elevations on gentle ground and all aspects. One or more species of vaccinium is present. Timber productivity is low to moderate. Reforestation needs typically arise from stand replacing wildfire or bark beetle outbreaks which may be exacerbated by drought and overstocking. Coarse woody debris is variable depending on disturbance history.
Vulnerabilities	In a drier climate these sites will likely still be maintained with lodgepole pine as the dominant forest cover except on the exposed aspects with granitic soils. Moisture may be a limiting factor for lodgepole pine on some of the driest exposures where Douglas-fir will dominate. Overall, the drier growing season may cause greater frequency of wildfire, with hot, stand replacing wildfires being common, along with smaller mixed intensity fires. Mountain pine beetle will continue to be a natural disturbance. There may be more of an age class diversity in the future driven by these more frequent disturbances in the footprint of the current mountain pine beetle epidemic
Management Considerations for Reforestation	Lodgepole pine will generally be suitable for planting or for natural regeneration especially where there is change of growing season frost (Heineman *et al*. 2003). Douglas-fir may be suitable for planting where competing vegetation is low and on warm exposures where frost is not a concern. Shade may be needed initially but eventually the Douglas-fir may become more drought tolerant (Poulson *et al.* 2002). Aspen will regenerate but is more limited to areas holding soil moisture, thus the extent of aspen in this zone may be reduced or be less vigorous. There may be some opportunities to plant whitebark pine or see nutcracker caching after wildfire. Lodgepole pine will be a strong competitor however, and reduce whitebark pine success.

HTG 7: Cool and Moist to Wet

Contemporary Description:	Group 7 is made up of moist sites often on north aspects near water. Lodgepole pine usually dominates with some subalpine fir, spruce, and occasional Douglas-fir, whitebark pine, and aspen. Timber productivity is moderate. Reforestation needs arise from mixed or high severity wildfire, especially in areas departed from a historic mixed severity fire regime; or bark beetle outbreaks which may be exacerbated by budworm defoliation, drought, and overstocking. Coarse woody debris is likely to be variable and moderate/high in stand replacement fire regime areas
Vulnerabilities	These are generally forested riparian areas or wetlands. The opportunities for success after planting will depend on changes in the water table following disturbance and the amount of site protection. Some areas may experience an elevated water table at least some of the year; other areas may have cold air settling that limits regeneration.
Management Considerations for Reforestation	The site specific resource goals would have to be matched to the biophysical setting prior to investing in planting trees or other vegetation.

HTG 8: Warm to Cool and Dry

Contemporary Description:	This group is made up of small scattered stands of limited acreage on moderate to moderately high elevations, on the driest spruce and subalpine fir habitat types where productivity ranges from very low to moderate. Lodgepole pine, Douglas-fir, Engelmann spruce, and subalpine fir make up the majority of tree species with whitebark pine and limber pine also found. Soil moisture is limiting. Reforestation needs may arise from wildfire or bark beetle outbreaks which may be exacerbated by drought and overstocking.
Vulnerabilities	These higher elevations sites will likely experience drier conditions during the growing season; lodgepole pine will continue to dominate but Douglas-fir may increase in abundance on the drier ecotones. The granitic soils and exposed slopes will support only sparsely forested areas especially after disturbance. Lodgepole pine will be more prevalent on the dry sites. Whitebark pine and limber pine may be more favored after disturbance, with preference dependent on soil types and cold limitations. Limber pine may expand into some microsites previously too cold.
Management Considerations for Reforestation	Generally favor lodgepole pine regeneration over most of these sites, although Douglas-fir may be preferred when planting on harsh aspects. The competition from lodgepole pine, subalpine fir, and spruce should be evaluated prior to investing in whitebark pine; select microsites less suitable to these species for planting whitebark pine.

HTG 9 and 10: Cold and Dry to Wet, and Cold and Dry

Contemporary Description:	The cold and dry to wet sites (HTG 9) are upper elevation types where trees are not stunted. Subalpine fir, spruce, lodgepole, and whitebark are the predominant species. The cold and dry sites (group 10) are the highest elevation types where trees are often wind-deformed, sometimes occurring in shrub form. Whitebark pine, subalpine fir, and alpine larch (Lincoln RD) may occupy these sites. Productivity is very low in both types, with short growing seasons where frost can occur at any time during the year. Reforestation needs may arise from wildfire, especially in areas departed from a mixed fire regime. Mortality may also occur from bark beetles. Climate change along with disturbance may cause some of these areas to transition to non-forest; thus evaluate each site prior to investing in in reforestation. Coarse woody debris is likely to be variable.
Vulnerabilities	HTGs 9 and 10 will likely be intermixed driven by the exposure and slope. A drier climate will make soil moisture the most limiting factor due to the exposed slopes, high solarization, and shallow soils thus reducing the aerial extent of tree establishment. Cold is currently a major limiting factor for and may still be on some aspects. Weather extremes (temperatures and snow loads) may continue to limit tree establishment. A warmer climate may result in more fires, or larger fires, in this zone. At least until later in the 21st century, the highest elevations may have greater snowpack caused by the increase in spring precipitation that falls as snow due to continued cold temperatures (USDA 2012).
Management Considerations for Reforestation	Although there are few management opportunities in this zone, this is probably the best opportunity for planting whitebark pine. Plant whitebark pine where it can be protected from heavy snow movement and plant soon after disturbance that reduces lodgepole pine, subalpine fir and spruce competition. Some of these areas may transition to non-forest; thus evaluate each site prior to investing in planting.

Post fire mosaic in LP AF sites; sapling stand in foreground.. Helena NF

IV. Genetics and Climate Change

The Regional genetics program provides a powerful tool for shaping the future success of our reforestation and revegetation investments. The more we understand the genetics of a species the greater opportunity to produce genetically adapted plants. We aim to develop broadly adapted populations suited for warmer and drier climates.

An understanding of the genetics of populations is important not only to predict the impacts of climate change on forests and rangelands, but also to evaluate management options for responding to climate change. For example, forest tree populations often maintain high levels of genetic variation and gene flow, which facilitate their ability to evolve in response to changing climates (Hamrick *et al.* 1992, Hamrick 2004). Yet, because populations of trees are genetically adapted to their local climates, the climatic tolerance of individual populations is often considerably narrower than the tolerance of a species across its entire range. This is especially true since the ability of forest trees to migrate and follow climate shifts is restricted by their relatively long life spans, long generation intervals and extended juvenile phases (Erickson *et al.* 2012). The underlying assumption regarding plant species is as climate continues to change, populations will become poorly adapted to the climate at their current locations; creating conditions of stress.

Elevations supporting plant species in Region1 range from under 2,000 to over 10,000 feet. Average annual precipitation varies from 10 inches to 50 inches. Temperatures during the growing season vary from 50°F to 110°F. Topographically, north to south and east to west, extremes are over 600 miles apart. Over time, plant species have developed in response to local environmental variables including temperature, frost-free periods, precipitation, fire, insects, and diseases. The combination of environmental gradients across the landscape enhances or limits survival and long-term persistence.

A plant's hardiness is determined by its genetic background (Kramer and Kozlowski 1979, Pallardy 2008). Key physiological characteristics that involve adaptability to certain sites or climatic conditions are not visible to the naked eye. These qualities become evident only when plants from different varieties, races, populations, or localities are grown under uniform site conditions in a common garden study. Common garden studies characterizing genetic variation in adaptive traits in native plants other than conifers is still relatively new. Common garden studies also assist in providing information on a species' adaptive strategy.

For species with generalist strategy, there is a large environmental component to phenotypic (visible) expression of adaptive traits; phenotypic plasticity is the means for populations to accommodate different environments. The ranges of environments where physiological processes function optimally are large and the slope of the clines for adaptive traits is flat. Species with intermediate or specialist adaptive strategies have a large genetic component that explains the phenotypic expression of traits. Genetic variation is the means by which populations respond to different environments. The ranges of environments where physiological processes function optimally are small and the slope of the clines (gradient of change of similar populations) for adaptive traits is steep. In native plants other than conifers, the steep clines may be punctuated by ecotypic variation (Rehfeldt 1994).

The underlying assumption supported by over 100 years of genetic test data for some species (e.g., ponderosa pine), is that local seed is typically better adapted to local environments (Ledig 1988, DeWald and Mahalovich 1997, DeWald and Mahalovich 2008). Adaptation and the role of seed transfer varies across the landscape and reflects a species' adaptive strategy or the unique complex of critical adaptive traits and their relationships to a suite of climatic, geographic, and physiographic factors. The vast majority of genetic variation in adaptive traits in conifers has been clinal (continuous) rather than ecotypic (discontinuous), the latter being characteristic of different parent soils.

Knowledge about the breadth of adaptation of Northern Rocky Mountain species is well documented for commercially important tree species (Rehfeldt 1994) as seen in Table 5 and is incomplete or lacking for most other native plants. It is important to remember that a species does not necessarily possess one adaptive or evolutionary strategy (Rehfeldt 1974a, 1989, 1990b, 1991), though most do (Rehfeldt 1979b, 1984, 1994a, 1995a, 1995b).

Differences in adaptive strategy can be characterized by varietal or racial differences or ascribed to changes in geography. For example, ponderosa pine var. *ponderosa* shares both an intermediate adaptive strategy at low to mid elevations (<5,000 feet) and a specialist adaptive strategy at higher elevations (Rehfeldt 1991), whereas ponderosa pine var. *scopulorum* shares an intermediate adaptive strategy at lower elevations (<7,000 feet) and a generalist adaptive strategy at mid to higher elevations (Rehfeldt unpublished data).

Additionally, interior Douglas-fir is characterized as having a specialist adaptive strategy; however, at higher elevations east of the Continental Divide, Douglas-fir behaves like a generalist (Rehfeldt 1990b). That is why there are no established elevation bands for seed transfer for the eastern Montana breeding zones 7A and 7B. Species possessing a generalist adaptive strategy are likely to fair better than their intermediate and specialist counterparts with respect to climate change.

DF seedlings in Zone 7a. Seedlings (right) are from improved seed sources from Big Fork clone bank; seedlings (left) are from general collections on the Beaverhead-Deerlodge NF.

Table 5. Adaptive Strategies

Species	Adaptive Strategy	Limiting Factors
Grand fir *(Abies grandis)*	Generalist	Root rot
Western Larch *(Larix occidentalis)*	Intermediate	Meria needle cast, cold hardiness
Engelmann Spruce *(Picea engelmannii)*	Intermediate	Spruce beetle
White Spruce *(Picea glauca)*	Intermediate	Spruce beetle
Whitebark Pine *(Pinus albicaulis)*	Generalist	Blister rust resistance, cold hardiness, mountain pine beetle tolerance
Lodgepole Pine *(Pinus contorta)*	Specialist	Western gall rust, mountain pine beetle tolerance, early fall frost tolerance, winter stress (snow damage)
Limber Pine *(Pinus flexilis)*	Intermediate	Blister rust resistance, mountain pine beetle tolerance
White Pine *(Pinus monticola)*	Generalist	Blister rust resistance
Ponderosa Pine var. ponderosa *(Pinus ponderosa* var. *.ponderosa)* (low to mid elevations)	Intermediate	Armillaria; early indication of drought tolerance, but no research to-date; western gall rust, gouty pitch midge, needle cast
Ponderosa Pine var. ponderosa *(Pinus ponder*osa var. *ponderosa)* (high elevations)	Specialist	Armillaria; early indication of drought tolerance, but no research to-date; western gall rust, gouty pitch midge, needle cast
Ponderosa Pine var. scoplulalrum *(Pinus ponderosa* var *scopulorum)*	Intermediate	early indication of drought tolerance, but no research to-date
Douglas-fir *(Pseudotsuga menziesii)* (low to mid elevations)	Specialist	Armillaria Early fall frost tolerance
Douglas-fir *(Pseudotsuga menziesii)* (high elevations)	Generalist	Armillaria Early fall frost tolerance

Seed source origin is the geographic location from which seed or other plant materials have been collected. Knowing the seed source origin guides where we plant adapted seedlings. This becomes increasingly more important with the added stressors of climate change. Seed transfer rules provide a suite of options for selecting seed source which is further refined by local silvicultural and ecological knowledge. The more difficult a site is to revegetate, the closer the seed source should be to the planting site. The notable exception is mining reclamation, where due to the extreme site conditions, non-persistent, non-natives, or seed sources outside of recommended transfer limits may be more appropriate (Ferris *et al*. 1996).

Populations that comprise forests and rangelands respond to climate change in three possible ways: adaptation, migration, or extirpation of local populations (extinction) (Aitken *et al.* 2008). The degree of adaptation depends on the interplay of natural selection, gene flow, genetic drift, mutation and demography (Shaw *et al.* 2005). Many forest tree species are long lived and have a long generation time. The connectivity of populations of species influences rates of migration, impacting their ability to keep pace with climate change, particularly for those populations on the edge of a species' range or among disjunct or isolated populations (Case and Taper 2000, Hamrick 2004).

Prior to emerging climate change concerns in the early 1990s, seed transfer based on genetic data related to adaptive traits was evaluated at the culmination of a first generation of tree improvement for conifers. The objective was to establish production seed orchards based on broadly adapted genotypes, genetic diversity, and outcrossed seed (mitigate inbreeding depression). Seed orchard seed lots now need to be evaluated to determine transfer guides in light of climate change. This is an iterative process that must be periodically revisited, rather than a one-time assessment, as seed transfer recommendations are applicable to a range of outputs.

Mean annual temperature or mean annual precipitation are considered the best climatic predictors as surrogates for seed transfer based on geography (Vogel *et al*. 2005, Bower *et al*. 2011). Climatic variables impacting the performance of a seed source however, will vary with respect to a species' adaptive strategy and geographic location from generalist, intermediate to specialist (Rehfeldt *et al.* 2006). One should not expect the same climatic variables (mean annual temperature or mean annual precipitation) to explain patterns of variation in the same fashion among different species (Newton *et al*. 1999).

A factor in the performance of a seed source when planted in a particular location is the difference in climate between the location of the planting site and location of the seed source. Historically, sources moved northward modest distances out-performed local sources, but if moved too far north (or up in elevation) they more readily suffered cold damage (Howe *et al*. 2003). If moved to the south, they did not 'perform' as well as the local seed source, but be cognizant that performance was commonly tied to growth and yield and timber volume production (Rehfeldt 1978, 1988, 1991). The frame of reference has changed in managing forested ecosystems on National Forest lands from one of volume production to one where the emphasis is on adaptation, which includes the components of survival, cold hardiness, disease resistance, and growth (but not necessarily optimal productivity). This management shift from timber production to adaptability is directly related to the [genetic] correlations among adaptive traits and it is well-established in our conifers that cold hardiness is negatively correlated or at the expense of optimal growth. We have already incorporated this relationship in our reforestation and revegetation programs and there are other objectives in establishing tree cover: watershed, wildlife and riparian habitat improvement, mining reclamation.

Seed transfer and seed source selection however, are within-species management and climate change modeling for individual species lack sufficient resolution to deal with this fine-scale movement of plant materials. Guidance for seed transfer and seed source selection needs to be presented at the appropriate scale of uncertainty, with the exception of western larch (Rehfeldt and Jacquish 2010), seed transfer recommendations are currently not available in outputs from the various climate models.

Validating Seed Transfer

The guiding principles of seed transfer have been in use for a long time (Langlet 1936, Hagner 1970, Campbell 1974). With predicted shifts in climate, the first step of seed transfer is to make the appropriate choice of species. Understanding the affects of aspect, slope, parent soil material and local knowledge of forest cover and habitat types are fundamental to the selection of species. Substituting species (type conversion) outside of current forest and rangeland cover types typically cannot be ameliorated with a seed source that appears to match a similar climate envelope, but in fact is an off-site seed source. On-going genetics research has shown an increase of 5 to 8°F would need to be attained before seed source/seed transfer changes may need to be made, particularly with species characterized as having a specialist adaptive strategy (Erickson *et al.* 2012).

The purpose of seed transfer zones is to ensure compatible seed or plant materials are used. The process of defining zones stratifies each species distribution, into areas of similar environments to ensure the intended plant material is suited for a particular site. The biological objectives of zoning in seed transfer are to:

1. Delineate those areas that minimize adverse interactions between genotypes and environments to provide consistent performance throughout the zone relative to survival, growth, and reproduction,
2. Emphasize broad adaptability, and
3. Establish a system of coding seed lots for field and nursery care.

For the native plants program, it is important, to delineate appropriate sized areas as seed zones in the absence of genetic information on adaptive traits from common garden studies. Small areas such as ecological land type, or 4th or 5th order USGS Hydrologic Unit Codes (HUCs) are too restrictive. Available information on patterns of genetic variation among and within populations of Inland West species demonstrates these fine scales unnecessarily micro-manage the genetic variation of a species. Similarly, ecological regions, 1st or 2nd order USGS HUCs, or homogenous macro climatic zones (Rauscher 1983) are too broad in scale. The seed collection zone represents a practical compromise between these fine and broad scales where both physiological and biological variation are intended to be minimized (Cunningham 1975). As genetic testing continues, zoning and seed transfer are refined.

Seed transfer guides in the form of zones or multi-dimensional seed transfer expert systems is not static. Historically, provisional seed transfer zones were revised as genetic data for adaptive traits became available from common garden studies, where customized seed transfer for individual species became the norm. As more sophisticated data for a representative sample of seed sources (greater than n=60 or range-wide) becomes available, options for multidimensional seed transfer in the form of expert systems will fine tune matching seed source selection while optimizing flexibility in utilizing seed sources. These models for seed transfer have historically been based on geographic variables (e.g., latitude, longitude, and elevation). Aspect, slope, and parent soil materials have explained little of the variation in genetic models in Inland West conifers. Habitat types have not explained any additional source of variation as long as elevation or elevation^2 (elevation-squared, nonlinear source of variation) has been parts of these models (Rehfeldt 1974a, 1974b, Campbell and Franklin 1981). However, because of climate change there is more of an immediate need to re-evaluate seed transfer.

Long-term field data in well-designed experiments are the next logical step in evaluating revisions to seed transfer. Long-term field data from genetic tests in the Region 1 are well-suited to this task. Analyses of 80-year data in 100-year old ponderosa pine and 25-year data in 30-year old lodgepole pine genetic tests demonstrate local sources or local sources from higher elevations have responded the best to environmental fluctuations, although each species has specific adaptive strategies which will limit the overall transfer. The threshold is the half- elevation transfer band which balances precipitation patterns relative to cold hardiness through 2030.

A recent example of one of six Douglas-fir long-term field tests is outlined to illustrate the use of empirical data to validate seed transfer. The Savenac test in western Montana (Fig. 8), was planted in 1974, with 24 seed sources of interior Douglas-fir. To gain an intuitive feel for the consequences of moving seed sources north in latitude and up in elevation for these broad-scale projections, survival of seed sources south of the planting location can be compared to the survival of seed sources north of the planting location using some basic descriptive statistics functions and an Excel spreadsheet. A paired t-test of southern vs. northern seed sources with unequal error variances, tests the appropriateness of emphasizing southerly seed sources. Similarly, survival from seed sources with elevations lower than the test site can be compared to seed sources higher in elevation from the test site, again, using a paired t-test with unequal variances.

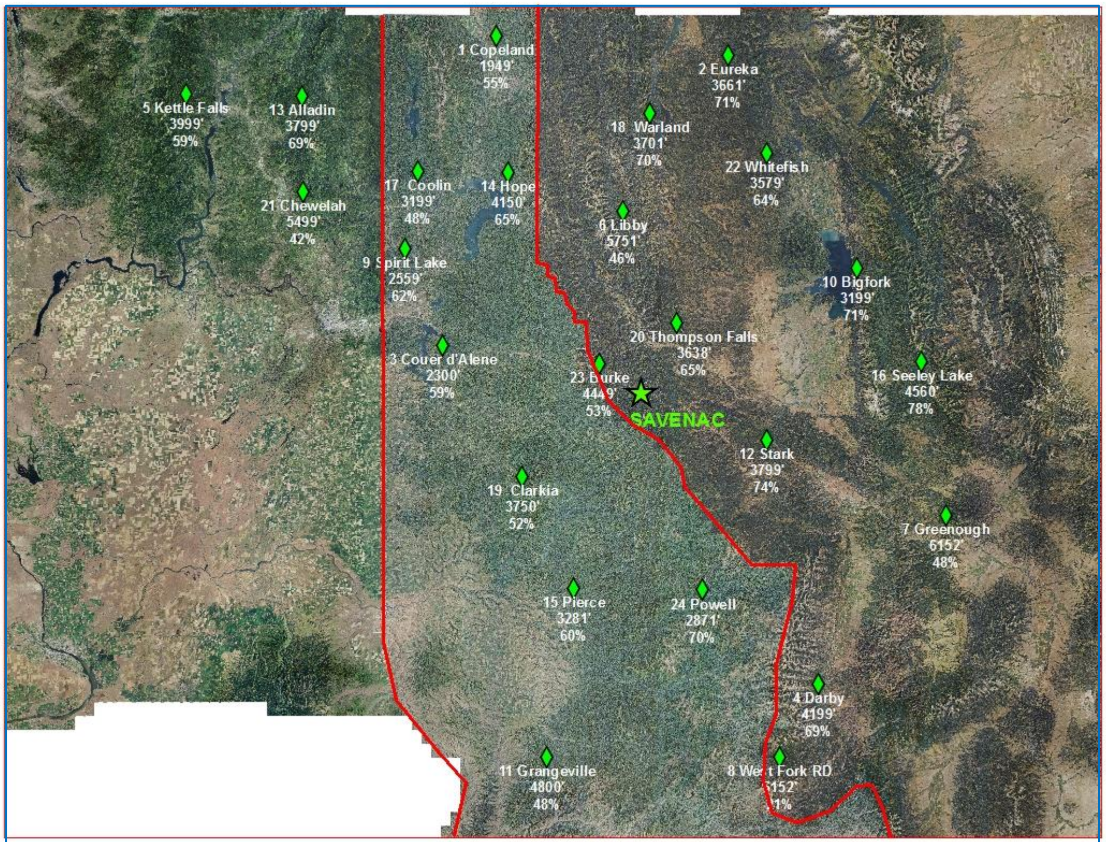


Figure 8. Thirty eight-year survival (%) among 24 provenances of interior Douglas-fir at the Savenac test site located on the Lolo National Forest. (Mahalovich unpublished data).

After 38 years of responding to climate change, sources *north* of the Savenac (MT) location have higher survival 60.8% than those south of Savenac 55.3% (p<0.29). Comparing survival of seed sources both lower and higher in elevation from the test site, sources originating from locations above 3,200 feet had higher survival (63.7%) than lower elevation seed sources (60.8%, p<0.61). Though both comparisons are not statistically significant, it indicates in this part of the Northern Rockies where there are large topographical differences, the better performing seed sources are geographically local, from more northerly latitudes, or from higher elevations. Cross-validation of climate change projections using empirical data is more complex involving several adaptive traits in combination with key geographic and climatic variables (Schmidtling 1994, Carter 1994, O'Neill *et al*. 2008). Though this approach is over-simplified, it illustrates the negative consequences of planting with lower latitude and lower elevation seed sources.

We also have an example of using western larch field data to validate seed transfer; western larch is a species at risk in a warmer and drier climate. In two Montana genetic test plantations, high levels of mortality occurred after persistent drought (2003-2006) even though it was planted in suitable habitat. Though mortality was high, it allows us to identify how seed sources selected for improved growth, cold hardiness and meria needle cast resistance, behave under drought conditions. In another instance, two Idaho western larch genetic tests sustained high levels of mortality due to an early, deep temperature drop in October 2009. Again, this affords us the opportunity to evaluate those seed sources that survive extreme climatic events.

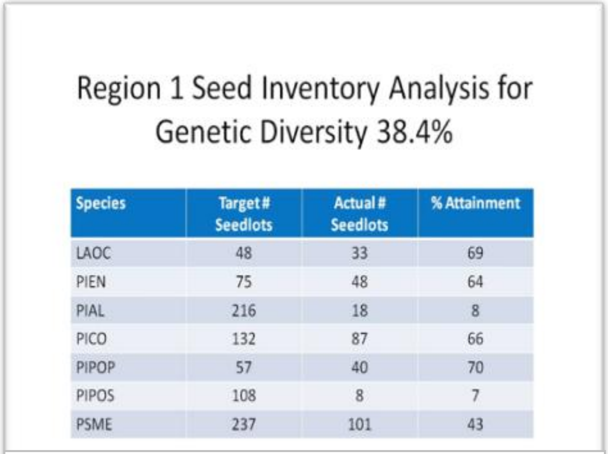
Seed Procurement Plans

Planning for large-scale disturbance is analogous in many ways to planning for climate change. Therefore, having an action plan to collect cones and seeds across the species' range is crucial for successful reforestation and revegetation efforts. The 10-year forest-level seed procurement plan is a tool to identify an adequate seed supply for planned operational and unplanned large-scale disturbance seed needs. Each forest's 10-year plan should reflect a genetically diverse seed inventory considering both spatial and temporal components. Genetically diverse seed lots translate to an appropriate effective population size of self-sustaining planting units if future management direction relies on natural regeneration.

Region 1 Forests reviewed and revised conifer seed needs for seed and breeding zones in 2010. Individual forests have made further updates. Periodic reviews should be used as a dynamic planning tool to reflect planting needs based on changed conditions, predictions of large-scale disturbance, and as progress is made in seed collection.

Genetic Diversity

In times of broad-based climatic change, there is a persistent suggestion to increase and maintain diversity (Ledig and Kitzmiller 1992). Genetic diversity imparts a species' ability to adapt to changing environments, colonize new areas and occupy new ecological niches, and produce substantial and robust progeny that persist in the long-term. Research in plants with an outcrossing mating system (open-pollination) that avoid inbreeding (mating among relatives) need a minimum of 50 reproductively mature individuals contributing to the progeny of the next generation (Franklin 1980). Achieving sufficient spatial genetic diversity to meet a minimum population size of 50 individuals translates to three, seed lots per seed zone per half elevation band. Among the 60 individuals, there may be unequal representation in seed quantity, or some lots may not have a minimum of 20 genotypes; therefore, having 60 individuals per species, per seed zone, per half-elevation band provides a good buffer to meet the minimum population size of 50.



Region 1 Seed Inventory Analysis for Genetic Diversity 38.4%

Species	Target # Seedlots	Actual # Seedlots	% Attainment
LAOC	48	33	69
PIEN	75	48	64
PIAL	216	18	8
PICO	132	87	66
PIPOP	57	40	70
PIPOS	108	8	7
PSME	237	101	43

Figure 9. The number of seed lots is one measure of genetic diversity.

An analysis of a recent seed inventory shows that the Region lacks sufficient numbers of seed lots to meet the spatial genetic diversity criterion (Fig. 9); however, this is an overall average. The Regional goal is to have each species represented by three seed lots for each half-elevation band by seed zone; however 80% attainment will provide a foundation for a broad genetic base.

Off-site Seed Sources

Small expansions of current species ranges may be acceptable in planting prescriptions, but long distance expansion will result in off-site plantings that may not succeed. The goal is to deploy plant materials with more genetic diversity so they are resilient to climate change. Thus, it is important to find the threshold between optimizing genetic diversity relative to maladaptation.

An off-site seed source is defined as a native or non-native collection that violates established seed transfer rules. There are two types of off-site seed sources seed in native species:

1. Seed originating outside the recommended geographic area (e.g., Black Hills ponderosa pine (variety *scopulorum*) planted in northern Idaho (variety *ponderosa* cover type), and
2. Seed originating from a local geographic area or within the correct seed zone, but planted outside a recommended range of elevation (e.g., low elevation lodgepole pine planted in the same geographic area but at a higher elevation).

Off-site plantings in trees are typically characterized by a stress response. Off-site plantings tend to exhibit one or more of the following symptoms:

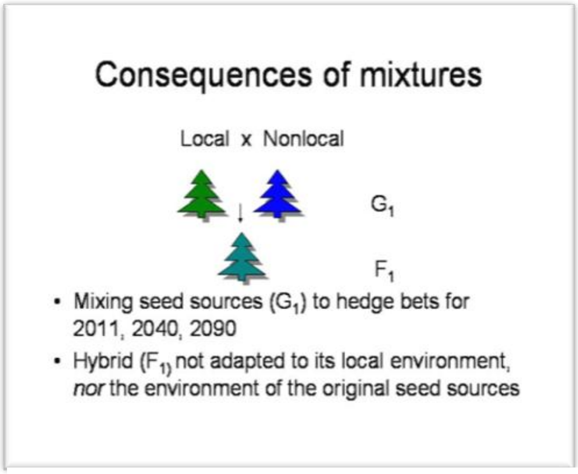
1. Poor survival immediately or in later years particularly after an extreme weather event
2. Reduced growth rate and cold hardiness
3. Increased susceptibility to insect and disease
4. Sparse crowns
5. Broken tops (low elevation or low latitude sources planted at higher elevation or higher latitudes)
6. Increased fuel loads
7. Increased pollen, stress cone or seed production

Neither the perceived biological or administrative short-term benefits of using off-site seed sources in anticipation of climate change will outweigh the negative consequences and increased costs of outright plantation failures or managing these areas over time due to poor forest health conditions and increased fuels hazards.

Plantings of nonlocal seed sources dating as far back as the late 1910s indicate a lack of awareness regarding genetic principles; genetics as a science was in its infancy. Monitoring survival and performance of these early plantings indicates early senescence and the near absence of natural regeneration. These off-site plantations are a living laboratory to observe the effects of wide transfers and offer a clear warning on how far species as well as seed sources can be moved and adapt to changing climates. The key to seed transfer in the context of climate change involves survivorship, performance, and the ability to produce self-sustaining offspring.

Natural populations of outcrossing species exhibit inbreeding depression (poor survival, growth, and loss of fecundity) if a small sample of highly related trees or other native plants are used as a seed source for reforestation and restoration.

Outbreeding depression also results in lower fitness. Figure 10 demonstrates that the progeny are intermediate to their parental seed sources, each from two different environments. The progeny are not adapted to the local environment and are not well adapted to either parental environment. At the genetic level this is attributed to breaking up of adapted gene complexes or allelic associations. These new allelic mixtures have not sorted themselves out through natural selection to favor those adapted to the local environment. Whether mixing of seed sources from wide geographic or elevational transfers or movement of species (type conversions), it takes several generations for new land races to adapt and occur at the planting location.

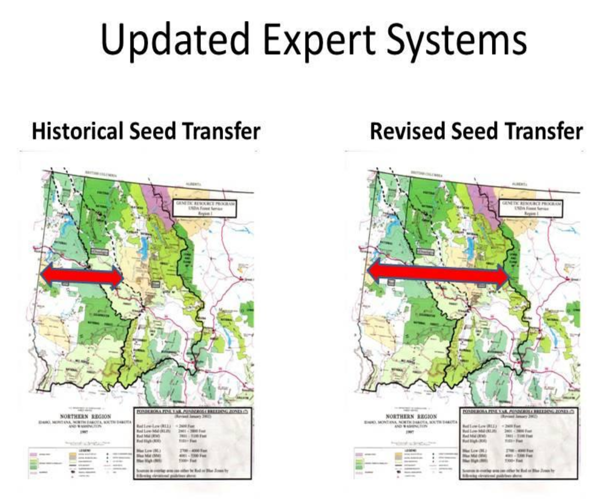


Consequences of mixtures

- Mixing seed sources (G_1) to hedge bets for 2011, 2040, 2090
- Hybrid (F_1) not adapted to its local environment, *nor* the environment of the original seed sources

Figure 10. Mixing local and nonlocal seed sources results in poorly adapted offspring.

How Climate Change is Being Addressed in Seed Transfer



Updated Expert Systems

Historical Seed Transfer

Revised Seed Transfer

Figure 11. Seed transfer for Douglas-fir. Historic and revised seed transfer guides shown to compare the expanded transfer guides to accommodate climate change effects.

The seed transfer Expert System has been revised to remove the geographic restrictions which historically confined seed source movement to accepted seed or breeding zone boundaries. However these limits are artificial and revised guides show the full extent of transfer potential.

Long-term field tests provide cross-validation data to assess recommendations for *within-species* management relative to the appropriate scale characterized by a species' adaptive strategy. Generalist species might be suitable for planting across the landscape, intermediate species limited to large watersheds, and specialist plants at small watersheds; conifer and other native plant seed transfer guides incorporate these adaptive strategies.

The Region 1 genetics program provides a vast source of information in replicated, long-term field tests dating as far back as 1903 and encompassing seven key conifer species (western larch, white pine, lodgepole pine, ponderosa pine var. ponderosa, ponderosa pine var. scopulorum, Douglas-fir, whitebark pine). This pedigreed plant material provides a valuable resource to evaluate seed source performance under operational conditions and varying climates (DeWald and Mahalovich 2008, Mahalovich 2009). Re-measurement of existing long-term field tests captures insect and disease incidence, drought tolerance and cold hardiness which are traits not always available from earlier genecological research in short-term greenhouse or farm field trails evaluating physiological or phenological data. Genetic analysis of these empirical data will be utilized to test and reconfirm current seed transfer and to readdress species-specific adaptive strategies under different climate scenarios.

Another way to monitor climatic changes is to establish long-term tests or assisted migration trials where trees or plants of know genetic background are planted in many different climates. Traits are measured over several years preferably well past reproductive maturity, because stress increases with age and competition.

V. Adaptation Strategies for Reforestation

To retain stand resiliency, we should maintain as much species diversity as possible, recognizing the long-term ecosystem processes that have created the current landscape conditions. All prescriptions should evaluate a range of management options that are reasonable in light of changing site conditions, particularly the assumption of warmer, more arid conditions. The following strategies should be incorporated in the reforestation process to increase the adaptive capacity of the young forest.

1. Alter planting prescriptions

Planting is beneficial for increasing species diversity and species distribution and is a recommended method for building resiliency in forest stands (Aubry *et al*. 2011, Millar *et al.* 2009). Consider the sensitivity of seedlings to extreme heat events and water deficit conditions; incorporate the silvicultural recommendations for species and site selection described in section III Vulnerability. Evaluate the soil conditions with assistance from soil scientists. Reduce planting density to mitigate for competition and future moisture stress. The resulting vegetative patterns may be a more defined patch mosaic where soil water conditions define establishment. Invest in planting on sites where trees will be most vigorous throughout their rotation.

2. Favor early seral species

Select early seral species as the dominant species for reforestation as often as possible; these species are more resilient to fire, insect and disease epidemics. Favor white pine, western larch and ponderosa pine west of Continental Divide, and ponderosa pine and Douglas-fir east of Continental Divide, when possible. Species, however, should be matched to the preferred sites for the best tree vigor and populations matched for adaptive capacity.

Managing for WL and WP; seedlings were planted in 2013 on Idaho Panhandle NF. Photo by Art Zack.

3. Limit stand density of established trees

At all developmental stages, maintain lower stand density to maintain tree vigor in moisture-deficit conditions.

a. Maintain lower stocking levels in the overstory where regeneration is desired.

The overstory density will affect the establishment and vigor of early seral species. Manage the overstory at lower densities to assure growing space in a water limited environment for both the establishing seedlings and residual trees. This will also benefit growing conditions for light dependent early seral species.

b. **Plan early stand thinning to limit stand density and provide diversity.** The vigor of young trees will decline when moisture is limiting. Thinning young stands will be critical to giving more growing space to fewer trees. Growing space will be determined by water availability, assuming overstory (light) is not limiting establishment. Provide species diversity in thinning prescriptions for building resiliency (Millar *et al.* 2007). It will be beneficial to select resilient species best adapted to relatively more arid conditions and against species that will be at higher risk to root pathogens.

4. Manage the seed bank

a. Manage the seed bank inventory at Coeur d'Alene Nursery to provide planting flexibility after disturbance and to maintain genetic diversity among seed lots. Expect seed needs to increase as conditions become more favorable for large wildfires and other disturbances (Westerling 2006). Cone collections should focus on meeting the following needs:

- Ponderosa pine seed inventory is not adequate to meet current planting needs. This increases the importance of making cone collections across multiple zones to increase our inventory and capture genetic diversity.
- Western larch and Douglas-fir (eastern Montana) seed is limited and is high priority for collection based on current and expected planting needs.
- White pine cone collections from seed orchards produce sufficient rust resistant seedlings without wild cone collections. There is currently a 7 to10-year supply of white pine in the seed bank (based on the current planting program).
- Whitebark pine seed is in short supply and will continue to be needed for restoration. We anticipate that the whitebark pine orchards being established for producing rust resistant seed will reduce the reliance on wild cone collections.

b. Review and update Seed Procurement Plans for each species of concern to identify known and future planting needs relative to the seed necessary to meet these needs. The procurement plan should be used as a dynamic planning tool to review seed needs, and to allow time for cone collections to provide sufficient genetic diversity. The 2010 procurement plans are available at: O:\NFS\R01\Program\2400TimberMgmt\2470SilvPractices\Reforestation\seed\2010_seed_analysis.

c. Maintain clear and concise data on the seed source of all collections. This data should include specific location data (GPS location) and elevation of each collection. Then, whether a species proves to be more narrowly or broadly adapted, the silviculturist can reliably predict the suitability of the seed lot for a specific planting site.

5. Follow seed transfer guides

a. Use the Expert System or Seed transfer maps for determining seed transfer from origin to planting site. Seed transfer maps are available at: O:\NFS\R01\Program\2400TimberMgmt\2470SilvPractices\TreeImprovement\Seed Handbook FSH2409.26f\Breeding and Seed Zone Maps\R1 Zone Maps. Silviculturists should not expand seed transfer elevation bands, however should emphasize movement from the seed source in the direction of cooler rather than warmer sites, within the geographic transfer guides (Erickson *et al.* 2012). Be aware some species may benefit from downhill shifts to warmer but wetter conditions where precipitation increases (Crimmins *et al*. 2011, Erickson *et al.* 2012). Short range expansions especially on ecotones may be considered.

b. Operational planting is not suitable for evaluating the success of seed transfer, particularly in comparing responses from various seed sources, because these plantings lack the experimental design and replication necessary for experimentation (Aubrey *et al*. 2011). Thus seed transfer guides will be modified by the Regional Geneticist, when necessary, driven by results from long-term genetic tests, similar sites of known genetic parentage, and research.

c. Regionally, we will utilize the genetic analysis from experimental data sets to test and confirm seed transfer, and to address species-specific adaptive strategies under different climate scenarios.

6. Maintain high genetic diversity in each seed lot

Each seed lot should be comprised of cones from at least 20 different trees to minimize the negative consequences of inbreeding depression. It is acceptable to use multiple seed lots for a single elevation transfer band to plant any one unit. Select one seed source from the mid-elevation of the planting unit and one from the lower elevation band. This will increase future stand resiliency and diversity with the expectation that some offspring will compete better in a warmer or drier climate or where fluctuations in weather conditions occur.

7. Use seed from genetically improved seed sources

It is preferable to use seed from genetically improved seed sources (seed orchards, clone banks, test plantations) when available. These seed sources provide a broadly adapted, genetically diverse base. Increased production of cones is projected in the near future due to a combination of factors: trees have reached reproductive maturity, floral stimulation is being employed on grafts of sufficient diameter (> 4 inches), and the application of supplemental mass pollination during strobili receptivity to ensure fertilization and subsequent seed set. Rust resistant white pine is currently available in sufficient quantities to meet the Region’s needs. Whitebark pine seedlings with known rust resistance are in the development phase. Areas with evidence of rust resistance should be preferred for cone collection until seed orchards provide operational levels of seed.

8. Monitor natural regeneration and cone production trends

Natural regeneration and cone production trends may provide an early detection signal for localized climate change. For example, if observations indicate that the extent of ponderosa pine regeneration after fire is significantly lower than the distribution of mature ponderosa pine in spite of abundant cone crops over multiple years, such as in the Frank Church study (Clippinger 2009) we may suspect that moisture deficits are reducing seed germination, or early growth. Likewise, the lack of cone production at low elevations or the lower latitudes of the range such as low elevation western larch on the Nez Perce NF, could be a sign of climatic conditions unsuitable for regeneration. Similarly, cold snaps or unusual freezing patterns can kill pollen catkins, impeding fertilization and seed set, which is a common problem in western larch. Longer growing seasons (frost-free periods) and milder winters allow insect populations to increase sometimes to epidemic levels; both larval and adult stages of some of these insects feed on cone and seeds reducing yields and possible regeneration success.

9. Be alert to savannahfication

An increase in grasses, forbs and shrubs on previously forested sites may be an indicator of decreased soil moisture that established trees are not yet sensitive to. Emerging vegetation adapted to drier or warmer conditions provides an early warning signal of increasing moisture deficits. Savannah-like conditions are characteristically grassland ecosystems and may include sparse tree stocking. This may be evidence that species selected for planting on these sites need careful consideration.

10. Practice the very best tree handling, storage, and planting techniques

The most vigorous trees will be capable of surviving stressful field conditions. Poor handling and planting techniques will reduce tree vigor significantly, although it can be rarely quantified. Tree vigor decreases with each step in the reforestation process (e.g., seedling production, transport, storage, planting, and condition of the planting site). When the seedling vigor drops below the survival threshold for a specific site, mortality increases. Refer to FSH 2409.17, Ch. 2 (R1 Supplement) for tree handling and planting practices.

11. Plant promptly after disturbance

When natural regeneration is not expected, planting promptly is the best tactic to restore tree cover. Seedling survival and growth is favored where there are lower levels of competition from grasses and shrubs. Most seedlings benefit from shaded microsites to reduce evaporative demand during the first few critical growing seasons. Maintaining soil protection that acts to mulch or cool the soil will conserve limited water reserves. In certain cases, herbicide treatments to reduce competition may be desirable. Hexazinone has provided effective control of grass and herbaceous vegetation for three to four growing seasons (Haase *et al*. 1993, Harper 2005).

12. Plant vigorous seedlings

Moisture stress is a primary cause of transplant shock, and seedlings with larger root volumes should prove less susceptible (Haase 1993). Maintaining large root systems promotes water acquisition increasing survival during the most vulnerable phase of establishment (Grossnickle 2005). As well, seedlings grown in longer containers and bareroot seedlings may have an advantage by accessing moisture deeper in the soil horizon.

Good root growth on container DF seedling during first growing season. Gallatin NF

13. Cold hardiness testing

Continue to monitor and test for cold hardiness at the nursery to adjust lifting windows based on local climate shifts. Trees and other plants that are freezer stored must be cold hardy to prevent killing the plants during storage.

14. Conserve soil moisture

The soil characteristics that control available moisture and can be influence by management activities are duff thickness, bulk density, and surface temperature. Silviculturists and soil scientists should work closely to identify options for addressing soil moisture issues.

a. Duff thickness- Duff quality and thickness control available moisture by increasing infiltration of rain, reducing evaporation of soil water, and reducing soil temperature. A continuous, decomposed thick duff will increase available water. Management activities that reduce the continuity or thickness of the duff will reduce available water. Some species require bare mineral soil in order to successfully establish.

b. Bulk density -Many management activities increase bulk density through compaction. Compaction will increase available water in coarse textured sites and decrease available water in fine textured sites. Compaction may also create an impermeable layer, reducing translocation of soil water. This may result in drying down slope soils and ponding in upslope soils. Consult with the soil scientist to determine how managing compaction can improve the available water at the stand level. Short term vs. long term strategies could be chosen based on time frames, management options and objectives. Short term options may include; ripping, scarification, adjusting site prep to retain OM or limit bare soil (may affect species selection), modifying residual coarse woody debris to aid in retaining surface moisture, etc. A long term option may be designing a successional planting strategy (e.g., initiate grasses/shrubs followed by trees after site amelioration).

c. Surface temperature (microsite shade)- Warmer soil temperatures increase evapotranspiration, which will accelerate the depletion of soil water and increase the time of summer drought. Studies have shown that slash and down woody material provide sufficient shade to reduce evapotranspiration (Harrington *et al.* 2013). In addition, the slash and down woody material can reduce surface wind speeds, which further reduces the effects of evapotranspiration.

d. Upslope through-flow- -In some cases it is possible to increase available water on lower slopes by decreasing evapotranspiration upslope through vegetation management.

WP planted in microsite shade
Idaho Panhandle NF
Photo by Art Zack

VI. Adaptation Strategies for Revegetation (herbs, forbs, shrubs)

The Forest Service is investing considerable time and resources into promoting the development and use of native plant materials for restoration. For instance, USFS national policy direction on vegetation management requires "selection of genetically appropriate plant materials [based] on site characteristics and ecological settings, using the best available information and plant materials" (USDA Forest Service 2008).

Implementation of this policy should have positive benefits under changing climate scenarios predicted for Region 1. The use of local genetic material is thought to maximize plant survival and growth, maintain local gene pools and reduce outbreeding depression (McKay *et al*. 2005), all of which are likely to improve restoration outcomes. These advantages, however, need to be balanced with the ecological realities that revegetation efforts will have greatest success in the long term if native plant materials are competitive against highly aggressive invasive plants and under novel environmental conditions expected to result from climate change.

The following strategies will move the Region towards more resilient ecosystems.

1. Develop seed management plans

Develop and implement 10-year seed management plans for each forest/grassland in Region 1. Each plan should identify the type, species, and quantity of plant materials needed for project restoration as well as time needed. Plant materials should also be developed for contingency purposes such as emergency fire rehabilitation (Burned Area Emergency Rehabilitation- BAER). From 2008 to 2011, the following forests have completed seed management plans: Beaverhead-Deerlodge, Bitterroot, Nez Perce-Clearwater, Flathead, Gallatin, Idaho Panhandle, Kootenai, Lewis and Clark, and Lolo. All forests and grasslands need to develop plans and all plans need to be kept current.

2. Develop seed transfer zones

Develop seed transfer zones for priority revegetation species for 20 priority species by 2021. Region 1 has an on-going Seed Transfer Zone Study which began in 2008. Common garden studies have been established for seven priority revegetation species (e.g., native grasses, forbs, shrubs) at the Coeur d'Alene Nursery. Continue with the analysis of preliminary data in support of development of seed transfer guidelines.

3. Manage the seed bank

Maintain a well-stocked seed bank for priority species for emergency revegetation (BAER) as well as forest/grassland restoration projects to ensure that the types, species, and quantities of material are available as needed. Currently some plant materials are stocked by the Coeur d'Alene Nursery for contingency purposes. However the seed cache needs to be expanded for increased emergency preparedness especially in light of the expectation of greater levels of fire in the future.

4. **Increase skills of practitioners**

Conduct revegetation activities by certified and trained revegetation practitioners. The Region needs to protect its investment in restoration by developing a cadre of skilled and trained revegetation specialists.

Increase the revegetation training curriculum. The Region has developed a "Soil Bioengineering with Native Plants" training which is offered intra-agency to resource specialists, as well as interagency to other land management agencies, to enhance restoration collaboration and partnership. The Region needs to expand this training into a multi-course curriculum which addresses the full scope and technical complexities required for successful revegetation.

Shrub planting-Robbins Gulch Road Rehab Bitterroot NF

5. **Monitor the use of native plant materials**

Increased species-specific and project-specific information is needed on a variety of topics including the adaptive ability of native species under a broad range of environmental conditions, species establishment and success under highly disturbed conditions, effectiveness of locally adapted materials vs. native cultivars, identification of native plant materials that are competing against highly aggressive invasive plants, and similar topics. Monitoring and understanding these relationships will guide adaptive management.

6. **Practice the best planting practices**

Utilize best planting practices and techniques when using native grasses, forbs, and shrubs with an emphasis on utilizing natural regeneration as a first choice when suitable conditions exist. However, with increased wildfire severities under climate change, herbaceous ground cover may increasingly be reduced or lost. Natural regeneration may not occur under certain fire scenarios. Artificial revegetation may become more critical for reducing soil erosion, stabilizing slope movement, and improving the water holding capacity and productivity of soils.

7. **Evaluate role of pollinators**

Identify and evaluate the role of pollinators in native plant revegetation. Climate change will alter ecosystem function including the mutualistic relationships between plant species and pollinators. Native plants and their pollinators have evolved under synchronistic interrelationships however climate change will affect how plant blooming periods are correlated with insect pollination. An understanding of the resulting interrelationships between plants and their pollinators will be needed to ensure we are establishing self-sustaining plant communities.

8. Develop a Regional revegetation species list

Develop and implement a restricted (non-native) revegetation species list for Region 1. The USFS National Native Plant policy (2008) established guidelines for determining specific suitability of certain species for revegetation. For example, the policy restricted use of persistent, non-native, non-invasive plant materials to only those situations when timely reestablishment of a native plant community, either through natural regeneration or with the use of native plant materials, is not likely to occur. Region 1 has developed a list of species meeting these criteria. The list, " Non-natives Restricted List", was developed in collaboration with the R1 National Forest native plant coordinators and is currently under review by forest resource managers. Once approved by the Regional Forester, the list should provide guidance for commercial seed producers, seed companies, and agency revegetation practitioners regarding selection of revegetation species for use on National Forest System lands in Region 1.

9. Evaluate the role of assisted migration for specialized species

Research has increasingly considered the role of assisted migration as a tool for maintaining the viability of some species under climate change (Vitt *et al.* 2009). Threatened and endangered species and others may be candidates for active planting and re-establishment under changing environmental conditions.

Collecting grass seed on the Helena NF

VII. Gaining more Knowledge

There are many unknowns about how changing climates will affect disturbance processes, soil moisture deficits, tree species growth, mortality, regeneration and ultimately species distribution and the role of genetic diversity in tree survival. With this suite of uncertainties, forest management, including regeneration and revegetation activities, requires adaptive management techniques to restore forests to a resilient condition. This section provides an outline of on-going or planned research and studies for the Region 1 specifically addressing reforestation and revegetation. It is not however intended to be all inclusive.

R1-RMRS Adaptive Management Research Framework.

The Northern Region and the Rocky Mountain Research Station have adopted an Adaptive Management Framework for developing resilient forests. Adaptive management in concept, consists of iterative monitoring, review and decision-making to validate or improve future management . The need to collaborate and incorporate the best available science to make informed decisions is directed by the 2012 Planning Rule *(36 CFR 219).* We believe this framework will provide technology transfer of research findings to guide land management decisions within the context of the best science, public values and effective land management practices. Practitioners should review the framework document for a full discussion of the key questions that are best addressed by collaboration among researchers, managers (line) and practitioners (staff) on National Forests.

The framework addresses research questions at various scales: Regional, Forest, landscape, and project level, for six key tree species of the Northern Region. The following are a subset of the research questions designed to further the basic science and adaptive management knowledge that are specific to reforestation and forest succession.

Species	Regional Level Questions	Forest Level Questions	Landscape/Stand Level Questions
Western Larch	• Where is larch currently regenerating (trees < 5” dbh) compared to the biomass (trees >5” dbh). ? • Is tree migration already occurring as a result of changing regional climate? • How can fire management be adapted to promote larch regeneration and 2-aged larch forest?	• Is tree migration occurring, on what land types within large landscapes is this happening? • How might climate change effects be important to larch successional pathway?	• Where is larch regeneration and large trees distributed, and where do they it thrive, relative to fine scale factors (moisture, temperature, soil type, soil moisture holding capability, topographic features, fire regime) ? • Where is larch persisting and regenerating?. • Does variation in bio-physical habitat influence success of second cohort?

Species	Regional Level Questions	Forest Level Questions	Landscape/Stand Level Questions
Lodgepole Pine and Mixed Aspen	• Where is lodgepole pine and aspen currently regenerating (trees < 5” dbh) compared to the biomass (trees >5” dbh) ? • Is tree migration already occurring as a result of changing regional climate? • How can we improve projections of future distribution of lodgepole pine and aspen? • How can fire management be adapted to promote uneven-aged structure and diverse landscapes of lodgepole pine and aspen?	• Is tree migration occurring, on what land types within large landscapes is this happening?	• Where is lodgepole pine and aspen regeneration and large trees distributed, and where do they thrive, relative to fine scale factors (moisture, temperature, soil type, soil moisture holding capability, topographic features, fire regime) ? • Where is lodgepole pine and aspen persisting and regenerating • How will multiple disturbances affect regeneration capacity? • What will the successional pathway be post mountain pine beetle? outbreak for lodgepole/aspen types • How will recent mountain pine beetle affect lodgepole pine and aspen regeneration and future disturbance processes?
White Pine	• How do biophysical characteristics mitigate potential effects caused by climate change and subsequent influence on white pine distribution? • What are adaptive strategies that favor white pine, is it tied to its regeneration mechanisms? • How will climate change affect blister rust? • How successful is artificial establishment of white pine in a changing climate?	Covered by Regional and Landscape level Questions.	• What are biophysical factors that enhance or diminish blister rust? • How does biophysical attributes (forest opening, geologic features, and water potential) influence white pine and blister rust? • Are there seed source of sufficient quantity to take advantage of regeneration opportunities after disturbance? • Where should the future seed source be?
Ponderosa Pine	• What are biophysical factors that influence broad scale distribution of ponderosa pine? • What adaptive strategies favor ponderosa pine resilience in a changing climate?	• What are the key biophysical elements that favor ponderosa pine natural regeneration? • What is the timing of regeneration establishment cycles to sustain resilience ponderosa pine? • How is root disease going to alter ponderosa pine abundance? • What is preventing ponderosa pine from regenerating- is it climate? • Are biomass strongholds of ponderosa pine regenerating ?	• What is the regeneration, growth and development of ponderosa pine in variable density shelterwood treatments? • Is Armillaria root disease infecting young ponderosa pine more abundantly than what occurred in the past? Does it play a role in creating regeneration opportunities?. • Should ponderosa pine be planted on historically less favorable north facing aspect and wetter sites?

Species	Regional Level Questions	Forest Level Questions	Landscape/Stand Level Questions
Whitebark Pine	• Can whitebark pine be restored in the face of climate change? • What are biophysical factors that influence broad scale distribution of whitebark pine?. • What adaptive strategies favor whitebark pine resilience in a changing climate? • What are the frequency, genetic basis, and geographical distribution for blister rust resistance? • What do we produce less costly whitebark pine seedlings for planting? • What are effective methods for planting whitebark pine seeds? • How do we balance genetics gains in blister rust resistance and correlated response in other adaptive traits? • What is best strategy for an effective genetic program for whitebark pine?	• What are key biophysical elements that favor whitebark pine natural regeneration ? • What is the time period between regeneration establishment cycles for sustaining resilience white bark pine? • What is preventing whitebark pine from regenerating-climate, nutcracker dynamics, cone crop abundance? • Are biomass strong holds of whitebark pine regenerating?	• How do we create resilient and resistant whitebark pine forests? • How do we effectively monitor treatments for whitebark pine so we can adjust prescriptions? • What key climatic factors create optimum environment for rust inoculation, will climate change alter this environment? • How do we effectively plant whitebark pine? • How long should whitebark pine plus trees be maintained? • What are criteria for selecting artificial regeneration vs. natural regeneration? • At what rust infection level does natural regeneration become effective?

Based on the Adaptive Management Framework, RMRS and Region 1 scientists and silviculturists will examine existing research projects at experimental forests to maintain (and modify if necessary) the research to meet current and future research needs. In addition, they will utilize past studies that are useful to address current issues. Some of the studies are more than 50 years old and can provide important insights into succession and physical attributes after treatment. A given study might have been implemented for one study objective, but contain measurements that from a different perspective address new research objectives.

Genetic Resource

- Continue on-going long term genetic test measurements to provide empirical data for the validation of current seed transfer guidelines.
- Evaluate tolerances of where orchard donors can be transferred relative to future climate projections.
- Establish long-term genetic tests or assisted migration trials where trees or plants of known genetic background are planted in many different climates. Measure traits over several years preferably well past reproductive maturity, because stress increases with age and competition. Limit assisted migration trials to a maximum of 10% of planted acres.

- Initiate genecological research for more non-traditional traits, e.g., bud phenology, water use efficiency and drought tolerance.
- Evaluate patterns of genetic variation in key adaptive traits with down-scaled climate data to potentially improve models of seed transfer.
- Develop revegetation seed mixes for diversity and appropriate low and high elevation seed transfers.
- Evaluate phylogeographic and ecological niche modeling (landscape genetics) for key species.

Tree Planting and Nursery Stock

Leverage opportunities to test stock under limited moisture conditions to better forecast field performance (Folk *et al*. 1996). This may lead to exploration of drought adapted populations (genotypes) or growing regimes that make seedlings better adapted to arid field conditions. We should support research that advances knowledge of the mechanisms affecting water use efficiency or drought tolerance in nursery stock and the relationships to genetic seed source adaptability. There may be opportunities to continue research on the relationship between water use efficiency, drought tolerance and dormancy triggers to aid in stock production.

Coeur d'Alene Nursery bareroot nursery beds.

There are many enhancements promised by commercial manufacturers for increased seedling survival; however, in actual practice few are effective. We should support further studies of polymers or other amendments that will increase a seedling's ability to establish during drought conditions.

Focus on improving seedling handling and planting techniques that reduce stress and unnecessary carbohydrate use, ensuring more vigorous seedlings at time of planting. Continue practices to evaluate stock types, cold hardiness testing, and growing regimes that produce seedlings with good root systems and suitable calipers to improve the ability for tree establishment.

Microclimate Studies

The Region 1 analysis team and the University of Montana are studying the current distribution and potential redistribution of tree species in the Northern Rockies using Forest Inventory and Analysis (FIA) data. This work will likely provide insights into how recent shifts in climate may have already impacted tree regeneration, as well as how projected future climate change will impact tree regeneration. These studies are using high resolution, sub-regional climatic water balance models that incorporate fine-scale variation in surface air temperature and humidity. Preliminary results suggest that regenerating trees occur in relatively mesic sites relative to adult populations and thus may already reflect shifts in regeneration patterns with recent climatic change. The analysis may ultimately provide managers with improved guidelines for optimizing site selection for tree planting.

Revegetation Specific Data Needs

1. Given anticipated changes in climate what is the adaptive ability of native species under the broad range of environmental conditions that may become more commonplace? Are there certain characteristics or strategies that allow certain species or suites of species of to adapt better under the changing northern Rocky Mountain or northern Great Plains conditions? Information on this issue is critical in developing plant materials to vegetate disturbed areas following wild or for revegetation during road decommissioning, oil and gas reclamation, mine reclamation, and riparian restoration projects.

2. With predicted rapid changes in climate over the next 50 to 100 years, it is possible that the benefits of local adaptation may be offset by maladaptation to the warmer conditions of the future. The Region needs to examine among-population differences in climate sensitivity (e.g., drought tolerance) and the relative importance of local adaptation versus climate sensitivity for priority revegetation species. Data acquisition and analysis is needed to develop baseline information for the Region's native plant material needs.

3. The effects of climate change are expected to provide competitive advantages to certain invasive plant species in the Northern Rocky Mountains. Can some genotypes of native plants be more competitive against invasive species than local ecotypes in areas with high abundance of invasive nonnative plants such as cheat grass and knapweed? Field trials testing the competitive abilities of native species vs. cultivars are needed in habitats that provide a high potential for invasive species.

4. The ability of native plants to adapt to changes in climate requires maintenance of genetic diversity within populations. It will become important to understand the levels of genetic diversity that currently exist within source populations used for native seed collection and the impact of seed collection practices on these populations.

5. Current research often identifies the potential role of genetically manipulated native plant material for use in native plant revegetation under changing climate conditions. However specific data is not available on which local adaptive characteristics and adaptive strategies would provide competitive advantages under anticipated climate changes. Research is needed to test the competitive abilities of locally adapted species (priority revegetation species) vs. genetically manipulated material under specific climate change scenarios.

6. Climate change is projected to increase the intensity and scope of wildfire in the Northern Rocky Mountain ecosystem. Under wildfire and prescribed burn activity, herbaceous ground cover is reduced or lost. What is the role of natural plant regeneration following different fire scenarios and when does active revegetation with native plant materials (grasses, forbs, shrubs) become more critical for reducing soil erosion, stabilizing slope movement, and improving the water holding capacity and productivity of soils?

7. Climate change is also anticipated to alter ecosystem function at the species level including the potential to impact highly evolved mutualistic relationships between species. The majority of the flowering plants in the northern Rocky Mountains are insect pollinated. Specific mutualistic relationships exist between indigenous plant species and their pollinators. Native plants and their pollinators have evolved under synchronistic interrelationships where plant blooming periods are highly correlated with insect pollination activities. As growing seasons begin earlier and plant phenology stages change, what will be the resulting interrelationships between plant blooming periods and their pollinators? Also, since pollinators are needed for plant reproductive strategies, what are cascading effects of misaligned pollination/flowering periods? Will changed environmental conditions result in potentially lowered plant reproduction, loss of forb diversity and abundance, and reduced insect pollinator populations?

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Appendix 1: Key Literature References

There is a large collection of literature dealing with species distribution in future climate scenarios and an even greater library on climate change. Some of the findings provide opposing conclusions and there is a huge amount of uncertainty on what the future climate will be, how species will respond, and the structure and function of future forests. In this chapter, we have provided some of the key literature references with a brief synopsis of the paper; this literature may help in addressing climate change particularly relevant for planning reforestation. This is not intended to be an all-inclusive reference list and new studies and findings are occurring frequently.

FOREST SERVICE REFERENCES PROVIDING DIRECTION ON CLIMATE CHANGE

Peterson, D.L.; Millar, C.I.; Joyce, L.A.; Furniss, M.J.; Halofsky, J.E.; Neilson, R.O.; Morelli, T.L. 2011. Responding to climate change in national forests: a guidebook for developing adaptation options. Gen. Tech. Rep. PNW-GTR-855. USDA Forest Service, Pacific Northwest Research Station. Portland, OR. 109 p. http://www.fs.fed.us/pnw/pubs/pnw_gtr855.pdf

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Bollenbacher, B.; Kolb, P.; Morrison, J. 2013 Vulnerability, exposure, and sensitivity in restoring and maintaining the adaptive capacity of forest landscapes in the Northern Region of the Northern Rocky Mountains. (in review) USDA Forest Service, Northern Region. Missoula, MT. 82 p.

Erickson, V.; Aubry, C.; Berrang, P.; Blush, T.; Bower, A.; Crane, B.; DeSpain, D.; Gwaze, D.; Hamlin, J.; Horning, M.; Johnson, R.; Mahalovich, M.; Maldonado, M.; Sniezko, R.; St. Clair, B. 2012. Genetic resource management and climate change: genetic options for adapting National Forests to climate change. USDA Forest Service, Forest Management. Washington DC. 19 p. http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5368468.pdf

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U.S. Department of Agriculture, Forest Service. 2012 R1-RMRS Adaptive Management Framework [AMRF]: Developing Resilient Future Forests. 30 p.

U.S. Department of Agriculture, Forest Service and UW Climate Impacts Group, 2012. Northern Rockies Climate Change Primer. 20 June 2012. O:\NFS\R01\Program\ClimateChange\climate change\Jim Work\Primers\NRPrimer_2draft\NR_Primer_2draft_sm.pdf [link as of 8/22/2012-this may be temporary]

Summary: Prepared for the Northern Region by Dr. Jeremy Littell and colleagues with the Climate Impacts Group of the University of Washington. Presents observed and projected 21st century trends specific to the Northern Rockies. Based on a synthesis of the range of climate scenarios and GCMs, the primer presents current and projected tendencies in temperature, precipitation, seasonal climate and hydrologic changes. Presents graphs and maps for the Northern Rockies and a closer resolution of the Greater Yellowstone Area for each of the characteristics. Very useful downscaled climate information which further references the Climate Impacts Group (CIG) web site; maps used are available from Ecoshare interactive website on climate change http://climatechange.ecoshare.info/maps-and-data/r1/ .

INTERACTIVE WEBSITES

Climate Change Resource Center (CRCC) interactive website sponsored by US Forest Service.
http://www.fs.fed.us/ccrc/

Summary: A reference web site for resource managers and decision makers who need information and tools to address climate change in planning and project implementation on lands in the West. Provides various primers on climate change, links to important literature and other Forest Service climate change related websites, and an extensive annotated bibliography sorted by specialized topics on climate change.

Climate Impact Group (CIG) modeling sub basins overlapping USFS Northern region (R1); website sponsored by Northwest Climate Group, USDA Forest Service. Extent of Region 1 (R1) Data
http://climatechange.ecoshare.info/maps-and-data/r1/ .

Summary: Provides a large variety of maps of climate variables such as runoff, snow depth, precipitation, maximum temperatures, water balance deficit, by month or season, for several climate model projections, and time periods (past, present, future). User selects the parameters for the map display.

Relative Effective Annual Precipitation Data sponsored by USDA Natural Resources Conservation Service.
http://nris.mt.gov/nrcs/reap/index.asp.

Summary: Provides access to Relative Effective Annual Precipitation (REAP) data for all counties in Montana and provides a map by county. REAP is an indicator of the amount of moisture available at a location, taking into account precipitation, slope, aspect, soil properties, and the seasonality of the precipitation. The interactive site allows the user to select the county and compare the REAP data. It reveals that two different sites that receive the same amount of precipitation may have very different relative effective precipitation due to soils, slope or aspect. Based on NRCS soils mapping.

LITERATURE

Adams, H. D.; Kolb, T.E. 2005. Tree growth response to drought and temperature in a mountain landscape in northern Arizona, USA. Journal of Biogeography 32: 1629-1640.

Summary: Studied the tree growth response to regional drought and temperature along an elevational gradient in the San Francisco Peaks in Northern Arizona. Results showed that annual growth was positively correlated with measures of regional water availability at all sites. The response varied by species and stands but growth was reduced the most in drier, low-elevation forests and in species growing in ecotones low in their elevational range. Specifically, Engelmann spruce, limber pine, ponderosa pine and Douglas-fir had greater sensitivity to regional drought when growing in drier low-elevation stands that those of the same species in wetter high elevation stands. Evaluates some of the physiological processes that affect species adaptive capacity for changes to severe drought.

Bartlein, P.; Whitlock, C.; Shafer, S. 1997. Future climate in the Yellowstone National Park region and its potential impact on vegetation. Conservation Biology 11(3): 782-792.

Summary: Examines the scope of future vegetative responses that may occur in mountainous regions, by illustrating the potential distribution of selected tree species in Yellowstone National Park. Works from the premise that biotic responses to future climate are difficult to project and it is exacerbated in mountainous regions. The simple upward displacement of vegetation zones in response to warming is not adequate. In this study, simulated vegetation changes result in elevational and directional range adjustments based on statistical analysis of taxa and climate relationships. The range of high-elevation species decreases and some species become regionally extirpated. Projected climate changes within the Yellowstone region and individualism displayed by species in their potential range adjustments are greater than those seen in paleoecologic records during previous warming periods.

Case, M. J.; Peterson, D. 2007. Growth-climate relations of lodgepole pine in the North Cascades National Park, Washington. Northwest Science 81(1): 62-75

Summary: Examines the effects of climatic variability during the past century on growth of lodgepole pine along an elevation gradient and evaluates how the species may shift in climate-change scenarios. The study in the North Cascades in Washington showed that growth and productivity varied by elevation. Mid-elevation populations were most influenced by precipitation and high elevations were most affected by annual temperatures and winter Pacific Decadal Oscillation index. Results suggest that increased summer temperatures will decrease productivity of lodgepole pine on sites with shallow well drained soils, south and west facing aspects and steep slopes. It may increase at high elevation sites where fires provide seed cast, and the positive effects of increasing precipitation and lengthening the growing season.

Chmura, D.; Anderson, P.; Howe, G.; Harrington, C.A.; Halofsky, J.E.; Peterson, D.L.; David C. Shaw, D.C.; St. Clair, J.B. 2011. Forest responses to climate change in the northwestern United States: ecophysiological foundation for adaptive management. Forest Ecology and Management 261: 1121-1142.

Summary: Presents foundation concepts for evaluating the complex interactions that climate-change can have on the forests. Displays the benefits of elevated CO_2 and warmer temperatures on growth and productivity on forests currently limited by cold, and the effects that substantial warming has in reducing growth and survival, and predisposing forests to disturbance. Discusses the physiological processes in response to drought including gas exchange, carbon allocation, growth, survival, and regeneration. Identifies some of the uncertainties and research needs to better understand complex relations of evolutionary adaptation, and drought acclimation and hardiness.

Clippinger, Eric. 2009. Exploring altitudinal and climatic effects on coniferous seedling regeneration in burned areas in Central Idaho. DeVlieg Undergraduate Research Report. College of Natural Resource, University of Idaho, Moscow ID. 30 pp.

Summary: Study to quantify the difference in post fire seedling establishment as a function of elevation in the Frank Church-River of No Return Wilderness and Taylor Wilderness Research Station. Higher temperatures and redistribution of precipitation have influenced the distribution and abundance of important tree species. Success of regeneration was better on higher elevations which also correlate with the higher basal area of mature trees at those elevations. Ten percent of the sites sampled had mature ponderosa pine, but ponderosa pine regeneration accounted for less than 1% of the total regeneration; the remainder was Douglas-fir. Observed shifts in forested lands to grasslands at lower elevation could signify a change in vegetative biomass as well as the ability for vegetation to sequester carbon.

Crowe, K. A.; Parker, W.H. 2008. Using portfolio theory to guide reforestation and restoration under climate change scenarios. Climate Change 89:3 55-370.

Summary: Provides a conceptual model to identify the seed source portfolio of populations that minimizes the risk of maladaptation access all scenarios for a given site. Uses portfolio theory to incorporate regional provenance trial and site climate data along with general circulation models to develop a species range impact model and estimate how well adapted a specified population is to a given climate change scenario. Each climate scenario is equally probable in predicting climate change thus solutions on seed transfer and adaptability can be optimized.

DeWald, L. E.; Mahalovich M.F. 2008. Historical and contemporary lessons from ponderosa pine genetic studies at the Fort Valley Experimental Forest, Arizona. *In:* Olberding, Susan D., and Margaret M. Moore, tech cords. 2008. Forest Valley Experimental Forest-A Century of Research 1998-2008. Proceedings RMRS-P-53CS. USDA Forest Service, Rocky Mountain Research Station. Fort Collins, CO. pp. 204-213.

Summary: Presents the history of the 1910 Fort Valley Experimental Forest ponderosa pine genetics research project. This pioneer study led to the description of ponderosa pine varietal differences, genetic diversity, and genetic variability in physiology and disease resistance in mature trees. Based on current knowledge, the varietal differences are known to reflect adaptive responses associated with changes in temperature and precipitation. The early tests showed that early performance was not always a reliable predictor of later performance. Specifically, non-local seed sources may grow faster early on and tolerate average conditions of a site but they are poorly adapted to extremes of weather that occurs less frequent. The longer term data does not support the selection of southern latitude or lower elevation seed sources after 10 decades, but rather local and higher in elevation sources have survived and been more productive.

Ettinger, A.K.; Forest, K.R.; HilleRisLambers, J. 2011. Climate determines upper, but not lower, altitudinal range limit of Pacific Northwest conifers. Ecology 92(6), 1323-1331.

Summary: Study to evaluate the growth-climate relationships for six species in Mt. Rainer National Park. Results demonstrated that at high elevations, species were sensitive to climate drivers. The annual growth of the high elevation conifers declined with high snow levels, low growing season temperatures, or low growing degree days at the upper range limits. All species responded similarly. At the lower ranges however, where canopy cover is tighter, the growth-climate relationships were weak. Thus other factors, likely biotic factors of competition and facilitation, were affecting the species range. This supports other studies suggesting that the importance of biotic interactions increases as abiotic conditions become less stressful. The authors state that for these reasons, climate change impacts will be difficult to accurately predict using climate change envelope models.

Gray, L.K.; Hamann, A. 2011. Strategies for reforestation under uncertain future climates: guidelines for Alberta, Canada. PLoS One 2011; 6(8).

Summary: Case study for evaluating commercial important tree species of Alberta using bioclimatic envelope modeling approach for climate projections of 2020, 2050, 2080. Results showed that genotypes adapted to drier climatic conditions will be preferred planting stock over much of the boreal forests of Alberta. The authors conclude however that forest trees are normally adapted to broad environmental gradients with substantial within-population genetic diversity and precise matching of genotypes to abiotic environment may not be necessary. Options for seed sources should represent those suitable for 1961-1990 reference, 1997-2006 and under 2020s climate projections. Planting trees appearing suitable for 2050s and 2080s climate is not sensible as trees must survive in current environments. There is too much variability in predicting actual conditions of the longer term.

Haig, Irvine T. 1936. Factors controlling initial establishment of western white pine and associated species. Yale University School of Forestry Bulletin No. 41. Yale University New Haven, CT.

Summary: Documents the premier field studies at Priest River Experimental Forest conducted in 1932-1934 with research in habitat condition and seedling mortality and development for white pine in northern Idaho.

Hampe, A., Petit, R.J. 2005. Conserving biodiversity under climate change: the rear edge matters. Ecology Letters 8: 461-467.

Summary: Reviews findings from fossil records, phylogeography, and ecology to illustrate that rear edge populations (populations residing at the current low-latitudinal margins of the distribution range) are often disproportionately important for survival and evolution of some species. While research is very limited, some studies suggest that rear margins may be more stable that high-latitude range margins. Predictions based on climate models may be unreliable, stable rear edges may not disappear as readily as forecasted by some models, as regional climate changes may be buffered by topographic heterogeneity. Conservation practices specific to rear edge species are explored.

Johnston, M. 2009. Vulnerability of Canada's tree species to climate change and management options for adaptation: an overview for policy makers and practitioners. Canadian Council of Forest Ministers. 40 p.
http://www.ccfm.org/pdf/TreeSpecies_web_e.pdf

Summary: Addresses the most important aspects of climate change on Canada's important tree species and discusses the forest management practices to improve adaptation to climate change thus reducing the vulnerability of tree species. The authors present a detailed threat assessment of various tree species and present five management options 1) reforest managed forest land, 2) conserve genetic diversity, 3) maintain species productivity, 4) maintain forest health, and 5) enhance adaptive capacity.

Keane, R. E.; Holsinger, L.M.; Parsons, R.A.; Gray, K. 2008. Climate change effects on historical range and variability of two large landscapes in western Montana, USA, Forest Ecology and Management 254: 375-389. DOI:10.1015/j.foreco.2007.08.013.

Summary: Presents the results of a simulation study using LANDSUM to generate reference landscape compositions for three climate scenarios (warm-wet, hot-dry, current) and three fire regime scenarios, to determine if future climate change has an effect on landscape dynamics. The results show that on two landscapes in western Montana, the fire regimes using future predicted climate scenarios are significantly different from simulated historic conditions.

Littell, J.D.; Peterson, D. 2012. U.S. National Forests adapt to climate change through Science-Management partnerships. Climatic Change 110(1):269-296.

Summary: Discusses the science partnerships developed on two National Forests for developing appropriate management options for adapting to climate change and integrating climate change concepts into management and planning. The authors identified general adaptation strategies that can be applied to a variety of national forests: (1) reduce vulnerability to anticipated climate-induced stress by increasing resilience at large spatial scales, (2) consider tradeoffs and conflicts that may affect adaptation success, (3) manage for realistic outcomes and prioritize treatments that facilitate adaptation to a warmer climate, (4) manage dynamically and experimentally, and (5) manage for structure and composition. Specific adaptation options include: (1) increase landscape diversity, (2) maintain biological diversity, (3) implement early detection/rapid response for exotic species and undesirable resource conditions, (4) treat large-scale disturbance as a management opportunity and integrate it in planning, (5) implement treatments that confer resilience at large spatial scales, (6) match engineering of infrastructure to expected future conditions, (7) promote education and awareness about climate change among resource staff and local publics, and (8) collaborate with a variety of partners on adaptation strategies and to promote ecoregional management.

Lo, Y.; Blanco, J.A.; Kimmins, J.P. 2010. A word of caution when planning forest management using projections of tree species range shifts. The Forestry Chronicle 86(3).

Summary: Research note to raise awareness of the risk of accepting predictions of tree shifts from climate envelope models, dendroclimatology and other models that do not account for all the major determinants of future forest composition. Thus, shifts in climatic zones, on their own, are not a suitable proxy for predicting shifts in species. More complex process based models that incorporate key determinants are needed. Major vegetation determinants include soil moisture and nutritional gradients, competition, seed production and migration rates as well as rate, type and intensity of disturbance. It is risky for future management to assume that current ecosystems will simply be displaced northwards and upwards. Actual plant communities within the climate framework will be modified by topography gradients of moisture and nutrients, fire, and the action of herbivores, insects and diseases.

McKenzie, D.; Peterson, D.L.; Littell, J.S. 2009. Global warming and stress complexes in forests of western North America. In S.V. Krupa (ed.), Developments in Environmental Science, Vol. 8, Wild Land Fires and Air Pollution, A. Bytnerowicz, M. Arbaugh, A. Riebau, and C. Anderson (eds.). Amsterdam, The Netherlands: Elsevier Science, Ltd, pp. 319-337.

Summary: Assesses the accelerated impacts of stress complexes, which is a combination of biotic and abiotic stresses, and the effect on tree vigor with increased temperatures on four forest ecosystems: pinyon-juniper woodlands of Southwest, mixed conifer forests of Sierra Nevada, interior lodgepole pine forests, and Alaskan forests. The authors build on the proposition that the effect of increased temperature predisposes forests to lethal stresses, directly by increasing negative water balances, and indirectly by increasing severity, frequency and extent of fire and insect outbreaks.

McLachlan, J. S.; Hellman, J.J.; Schwartz, M.W. 2007. A framework for debate of assisted migration in an era of climate change. Conservation Biology 21(2): 297-0302.

Summary: Deliberates the opposing conservation views of assisted migration addressing three policy options: aggressive assisted migration, avoidance of assisted migration, and constrained assisted migration. Offers views on policy issues, and a research agenda for informed policy, genetic diversity and preparing for an uncertain future for framing the debate on assisted migration policy.

Millar, C. I.; Stephenson, N.L.; Stephens, S.L.. 2007. Climate change and forest of the future: managing in the face of uncertainty. Ecological Applications 17(8): 2145-2151.

Summary: Provides a framework of options for managing forested ecosystems with a portfolio of approaches that focus on enhancing ecosystem resistance and resilience and assist ecosystems to adapt to inevitable changes in climate and the changing environment. Addresses adaptation options (create resistance, promote resilience and enable forest to respond), mitigation options (reduce greenhouse gases,) and prioritizing management under conditions of rapid change. No single approach will fit all situations and there is a need to take risks, and have the capacity to reassess condition frequently and change course as needed.

Minore, D. 1979. Comparative autecological characteristics of Northwestern tree species- a literature review. Gen. Tech. Rep. PNW-GTR-87 June 1979. USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. Portland, OR. 72 p.

Summary: Synthesis of autecological characteristics of over 40 native trees species found in the Pacific Northwest. Compiles the known information on a wide variety of environmental conditions and compares species tolerance and adaptations in detail, with citations from a broad array of resources. The author compares factors such as: tolerance to light, temperature, moisture, and nutrient conditions; processes affecting growth and reproduction; and resistance to wind throw, insects and fire.

Moore, M.B.; Kidd, F.A. 1982. Seed source variation in induced moisture stress germination of ponderosa pine. USDA Forest Service. Tree Planter's Notes 33(1):12

Summary: Investigates the effect of moisture stress on ponderosa pine seed germination. Results indicate that seeds collected across the range in Colorado differed in their ability to germinate under several artificial moisture-stress treatments. Seed sources have differentiated based on seed source. The paper emphasizes the importance of seed source selection for outplanting to assure long term survival and regeneration.

Parmesan, C. 2006 Ecological and evolutionary responses to recent climate change. Annual Review of Ecology, Evolution, and Systematics (37) pp. 637-669.

Summary: Discussions of a wide array of animal and plant species where observed changes in the species range are biased in the directions consistent with that due to global warming. Range-restricted species particularly polar and mountaintop species have been the first groups to go extinct. The chapter on trees discusses the complex interacting factors affecting growth at high elevations, comparing the increased growth during the warming climate in the late 1930s and 1940s, but a weaker growth increase in recent warm decades. The relatively dry conditions of the recent decades may be preventing trees from responding as they did before. In contrast, tree line species in the southwest US have experienced increase rainfall and corresponding increases in tree-ring growth at high elevations.

Rehfeldt, G.; Jaquish, B. 2010. Ecological impacts and management strategies for western larch in the face of climate-change. Mitigation and Adaptation Strategies for Global Climate Change 15(3).

Summary: Assesses the potential impacts of the changing climate on western larch by predicting the contemporary distribution of western larch from climate variables; and the genetic variation based on the climate of the seed source study. Projected the suitable distribution of future populations and located sources of seed with the best genetic adaptations for the future climates. By the end of the century, the climates suitable for western larch would be on lands not inhabited by the species today. Methods described provide a framework for assuring that appropriate seed sources of the best suited species are planted in proper climates. This will be particularly important to consider in reforestation after larger wildfires and climate induced vigor declines.

Rehfeldt, G.; Crookston, N.; Warwell, M.; Evans, J. 2006. Empirical analyses of plant-climate relationships for the western United States. International Journal of Plant Science 167(6): 1123-1150.

Summary: Modeled the climate profiles of 25 biotic communities of western United States and applied a correlative model to evaluate plant-climate relationships to project future plant distributions. Projections showed that unmitigated global warming should increase the abundance of montane forest and grassland communities at the expense of subalpine, alpine and tundra communities as well as arid woodlands. The model accurately portrayed the bioclimatic profile relative to species distribution, however, the climate of 47% future landscapes may be outside the contemporary community profile by 2090. Projected effects on nine species, including Douglas-fir, ponderosa pine, western larch and Engelmann spruce, are shown in detail envisioning the change in aerial extent expected through the end of the century, expansion into new areas, and the portion of the profile not expected to change through the century.

Rice, J.; Tredennick, A.; Joyce, L. 2012. Climate change on the Shoshone National Forest, Wyoming: A synthesis of past climate, climate projections, and ecosystem implications. Gen. Tech. Rep. RMRS-GTR-264 January 2012. USDA Forest Service, Rocky Mountain Research Station. Fort Collins, CO. 60 p.

Summary: Provides a synthesis of the understanding of paleo and historical climate as a reference point, an assessment of what future climate may be, and what the effects of future climates may be on natural resources. Discusses climate change trends and future projections for various ecosystems including the alpine, subalpine, montane, aspen, grasslands, and wetland zones for areas of the Shoshone National Forest in Wyoming.

Romme, W.; Turner, M. 1991. Implications of global climate change for biogeographic patterns in the Greater Yellowstone Ecosystem. Conservation Biology 5(3): 373-386.

Summary: Explores implications of climate change on the biogeographic distribution of forest communities in the Greater Yellowstone. Compares three likely scenarios: (1) warmer and drier than present; (2) warmer and drier, but with compensating increase in plant water use efficiency; and (3) warmer and wetter than present. The upper and lower timberline appears to be most sensitive, with upper timberline likely migrating upward in elevation with an overall decrease in the extent of alpine vegetation. The lower tree line may retreat under drier conditions or move down slope in wetter conditions. Climate induced fires would have major effect on the extent and age-class distribution of forest communities.

Running, S.W. 2010. Impacts of climate change on forests of the Northern Rocky Mountain. University of Montana. . Missoula, MT. (Press Handout, January 5, 2010)
http://www.cfc.umt.edu/mco/pdfs/Home/ImpactsOfClimateChangeNRMForests.pdf

Summary: Displays the results of climate projections on forest productivity, forest carbon storage and water from snowpack in the Northern Rocky Mountains. Key findings include the projections for fewer days with snow, early peak snowmelt, longer growing seasons and longer drought stress. There will be an increase in forest disturbances due to drought stress, and an economic effect to forest-urban interface caused by catastrophic wildfire. Net carbon uptake will decline and the region will switch to one of absorbing carbon to releasing it by late this century.

Schrag, A.M.; Bunn, A.G.; Graumlich, L.J. 2008. Influence of bioclimatic variables on tree-line conifer distribution in the Greater Yellowstone Ecosystem: implications for species of conservation concern. Journal of Biogeography 35: 698-710.

Summary: Evaluates the potential shift in spatial distribution of whitebark pine, Engelmann spruce, and subalpine fir, all tree line conifers in the Greater Yellowstone, under three future climate-change scenarios. Includes detailed assessment of the potential physiological sensitivity of each species to changes in both temperature and precipitation. Because tree-line conifers are believed to be limited by temperature, these may serve as important indicators of climate change. Predicts overall decrease in pine dominated subalpine forests in the Greater Yellowstone with species specific limitations.

Shafer, S.; Bartlein, P.; Thompson, R. 2001 Potential changes in the distributions of western North America tree and shrub taxa under future climate scenarios. Ecosystems 4(3):200-215.

Summary: This study projects potential vegetation response to future climate change using response surfaces to describe the relationship between bioclimatic variables and distribution of tree and shrub species in western North America. The distribution of a variety of trees and shrubs were simulated under future climate scenarios (2090-99), three general circulation models, and it focused on bioclimatic variables of mean temperature of coldest month, growing degree days, and moisture index. Demonstrates where species could exploit new areas or that will contract from current habitats. The simulated change is based on where the current bioclimatic habitat limits would not be met under future scenarios. The actual affect however will be based on controls that affect the particular species, such as physiological effect of the climate condition, life span of the species, movement of other organisms, dispersal rates, and frequency of disturbances that facilitate species establishment.

Soberon, J.; Peterson, A.T. 2005. Interpretation of models of fundamental ecological niches and species' distribution areas. Biodiversity Informatics 2: 1-10.

Summary: Examines and compares two techniques for predicting the fundamental niche of a species; the mechanistic approach and correlative approach. Both are complimentary and carry caveats in applications for predicting the distribution of a species. Discusses the elements affecting distribution as the complex expression of its ecology and evolutionary history, and the diverse factors that interact dynamically and with different strengths to produce the geographic distribution of a species. The paper is intended to clarify the interplay among factors which ecological niche modeling applications can be built.

U.S. Department of Agriculture, Forest Service [USDA FS]. 1990. Silvics of North America Volume 1, conifers. Russell M. Burns and Barbara H. Honkala, Tech Coord. Agriculture Handbook 654. USDA Forest Service, Washington DC. 672 p.

Summary: Comprehensive document of 200 conifers of the United States. A compendium of individual articles researched and written by species specific experts.

Woodall, C.W.; Oswalt, C.M.; Westfall, J.A.; Perry, C.H.; Nelson, M.D.; Finley, A.O. 2009. An indicator of tree migration in forests of eastern United States. Forest Ecology and Management 257: 1434-1444.

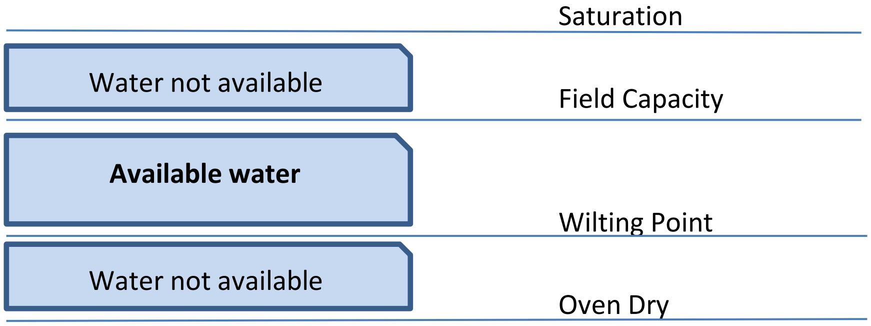
Summary: Study compares the current geographic distribution of tree seedlings against tree biomass (older trees) for sets of tree species in northern, southern, and general trees species in the Eastern U.S. Compared to mean latitude of tree biomass, mean latitude for seedlings was farther north for northern species. There was no shift for southern species, and general species showed a southern shift. Density of seedlings relative to biomass was also higher in northern latitudes for the northern species. Results of this study suggest that northward tree migration in the eastern U.S. is currently underway for many species.

Appendix 2: Soil Characteristics

HOW SOIL CHARACTERISTICS AFFECT AVAILABLE SOIL MOISTURE

Water and air are stored in soil pores. When all the pores are filled with water, the soil is saturated. When a saturated soil is allowed to drain freely for 2 or 3 days the soil has reached field capacity. Soil water between saturation and field capacity is considered unavailable to plants. Once the soil reaches field capacity, soil water continues to be withdrawn from the soil by evapotranspiration, soil biota metabolism, or continued translocation (gravity). As soil water is reduced, the remaining water is held more tightly in the soil. Eventually the soil will hold water so tightly that plants are no longer able to pull water from the soil. At this point, the plants wilt for lack of water; this is called the wilting point. Remaining water in the soil is considered unavailable to plants. The water held by the soil between field capacity and wilting point is referred to as available soil moisture or water holding capacity.

SOIL WATER AVAILABLE TO PLANTS



The amount of available water in a soil depends on several soil and site characteristics. Important soil characteristics controlling water holding capacity are texture, stoniness, chemical/physical composition and depth. Site characteristics include the position on the slope, referred to as the catena, the shape of the slope, and aspect. Lower positions on a slope may have higher available moisture by collecting water from above in the slope material. Similarly, concave or bowl areas collect water along a hill slope that increases available water. Moisture stress on warm aspects results from extended sunlight dewatering a site through evaporation. However, in the higher elevations warm aspects where moisture is less limiting have higher growth rates than cold aspects because of a longer growing season. These site conditions represent inherent characteristics that cannot be changed by management.

Dynamic soil characteristics which can be influenced by management include; alterations to the forest floor duff, the topsoil, and physical influence of nearby vegetation that can buffer from wind and temperature changes.

ROLE OF THE SOIL CATENA

A soil catena is a sequence of soils repeated in similar topographic situations. A simple catena develops in uniform parent material, where soils depth changes with topography, the amount of slope, parent material and drainage conditions (Table 1). In a simple catena the soils on the upper slopes will have shallow eroded soils that are leached and acidic. The lower slopes will be deepened by colluvial action and have more available nutrients from chemical and physical weathering. Most often, forest cover types reflect the sequence of changes along the soil catena. Deep soils along a mid-slope bench or footslope lead to high growth rates. Steeper slopes approach the limits of stable angle of repose and therefore have less soil material to store water and nutrients. Distinct changes in forest cover types may also result from geological features, management, or natural disturbance events.

SOIL CATENA

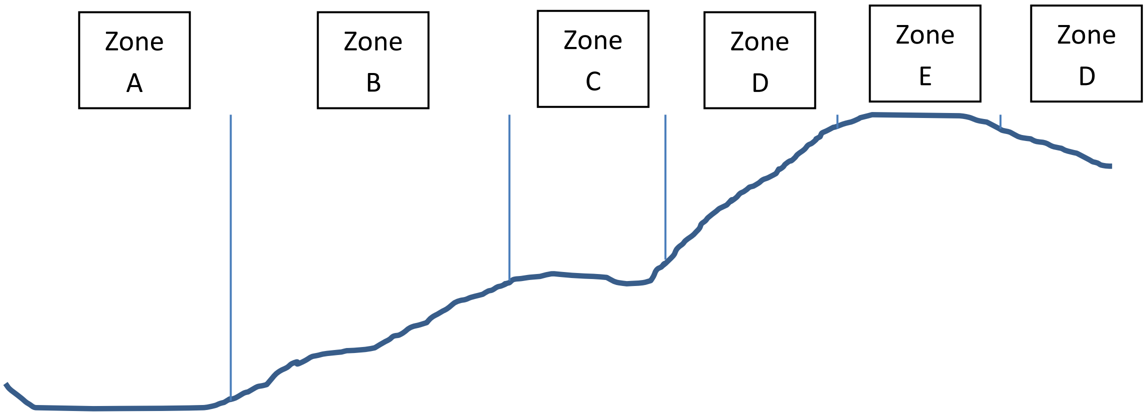


Table 1 – Soil characteristics along the Catena

Zone	Catena Position	Common Soil Characteristics
A	Stream Terrace	Deep soils, with highly sorted often coarse texture. Due to the sorting, layers may be very stony. These are very young landforms with little or no weathering. Initially these soils have no organic matter. Older soils will have some organic matter in the upper horizons.
B	Toe slope	Deep soils, with fine surface texture and moderate subsurface texture, higher organic matter, moderate stoniness, convex slopes,
C	Bench	Moderate or deep soils, with moderate to coarse texture, higher stoniness, deep organic layer
D	Steep upper slopes	Shallow soils, with coarse to moderate texture, high stoniness, concave slope, low organic matter
E	Broad Ridge top	Moderately deep soils, with fine surface texture and coarse subsurface texture, highly weathered soils, high stoniness, low to moderate organic matter

The site and soil characteristics shown in table 2 influences available water, but cannot be changed by management activities. By assessing your site with this table you can approximate available water. The columns in the left side of the table have high available water with available water decreasing moving to the right. For example, soil in Catena zone A, Valley landform, alluvium parent material, with <3% surface stone and north facing will probably have ample available water.

Table 2 – Landforms, Catenas Position and Resultant Soil Characteristics

	HIGH AW						**LOW AV**
CATENA POSITION	Zone A Stream terrace	Zone C bench	Zone B Toe-slope		Zone E Steep Upper slope		Zone D Broad Ridge top
SOIL DEPTH	Deeper soils						Shallow soils
The effect of Landforms On soil depth	Valleys	Hills and Plateaus	Frost Shattered Ridge	Mountain Slopes and Ridges	Eroded Uplands	Badlands	Mass wasted
	Glacio-lacustrine Plains	Glaciated Plains	Low Relief Hills		Erosional Plateaus and Buttes	Breaks	Colluvial
		Sedimentary Plains	Depositional Mountain Slopes		Erosional Steep Glaciated Mountain slopes		High Relief Mountain Slopes
SOIL TEXTURE	Loam		Finer Textured soil			Coarse Textured soil	
The effect of Parent Material On soil texture	Lacustrine Fine	Carbonates	Sandstone and Shale	Belt Metaseds	Quartzite	Coarse Tertiary Seds	Granitics
	Alluvium	Tertiary Fine Seds	Calc-silicates	Soft Sediments	Sandy Wind deposits	Gneiss and Schist	Glacial Outwash
	Loess	Basalt		Shale, Siltstone, Sandstone		Coarse Alluvium	
	Ash cap			Andesite, Rhyolite		Glacial Till	
SURFACE STONINESS[1]	<3%		3-15%		15-50%		>50%
ASPECT	North		West	East			South

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[1] http://sis2.agr.gc.ca/cansis/nsdb/dss/v3/cmp/stoniness.html

Appendix 3: Characteristics of Primary Tree Species in the Northern Region

Comparing Autecological Characteristics of Key Conifers

From **Comparative Autecological Characteristics of Northwestern Tree Species- A Literature Review** (Minor 1979). The following comparisons are for selected conifers common in Region 1 for characteristics most affected by moisture and temperature changes based on study results by many investigators and in a variety of environments. Minor (1979) concludes that species respond to differing conditions in complex ways that are difficult to compare but the following comparative relationships should be useful in selecting species for various conditions.

Environmental Stress	Tree Species
Comparative Shade Tolerance **Tolerant to Shade** ↓ **Intolerant to Shade**	Western Hemlock Western redcedar Subalpine fir Grand fir White pine Douglas-fir Engelmann spruce Lodgepole pine Western larch Ponderosa pine
Comparative Frost Tolerance **Tolerant to Frost** ↓ **Intolerant to Frost**	Lodgepole pine, white pine Engelmann spruce Ponderosa pine Subalpine fir Douglas-fir Western redcedar Western hemlock
Mean Temperature Relationships **Adapted to Warm Temperatures** ↓ **Adapted to Cool Temperatures**	Ponderosa pine Douglas-fir Western redcedar Western hemlock Grand fir Alpine fir, whitebark pine Lodgepole pine

Environmental Stress	Tree Species
Comparative Drought Tolerance **Drought Tolerant** ↓ **Drought Intolerant**	Ponderosa pine Lodgepole pine Douglas-fir Engelmann spruce Grand fir Western larch Subalpine fir, western redcedar, white pine Western hemlock
Optimum moisture relationships **Moist optimums** ↓ **Dry optimums**	Grand fir Western redcedar Western hemlock Douglas-fir Ponderosa pine

Silvics of Northern Region Tree Species

Adopted from Silvics of North American Conifers, Volume 1.

Grand fir	***Abies grandis***
Range and Habitat	Grand fir is found on a wide variety of sites including stream bottoms, valley and mountain slopes of northwestern United States and southern British Columbia. The average precipitation in its range is 20 to 100 inches but in northern Idaho the average is 20 to 50 inches. The average growing season temperature is 57° to 66°F. In the inland regions, grand fir grows best on rich mineral soils of valley bottoms but also grows well on shallow exposed soils of mountain ridges if moisture is adequate.
Silvics	Grand fir is either a seral or climax species. On moist sites it grows rapidly to compete with other seral species in the dominant overstory. On dry sites, it is a shade tolerant understory that eventually assumes the dominant position in the climax condition. Grand fir is a major climax species in a variety of habitat types in Montana and northern Idaho but it rarely grows in pure stands; one exception is on the Clearwater River drainage in north-central Idaho.
Special Interest	Grand fir is susceptible to fire damage in moist creek bottoms but is more resistant on dry hillsides where roots are deeper and bark is thicker. It is susceptible to heart rot and decay which influences management. Armillaria (*Armillaria ostoyae*), and Annosus (*Heterogasidion annosum*) are common root diseases causing high tree mortality (Hagle 2003).
Subalpine fir	***Abies lasiocarpa***
Range and Habitat	Subalpine fir grows in the coolest and wettest forest areas of the western continental United States. Although widely distributed, it grows within a narrow range of mean temperatures of 25° to 40°F; however, January temperatures average 5° to 25°F degrees. Cool summers, cold winters, and deep winter snowpack are more important than precipitation in determining where subalpine fir grows compared to other species. Subalpine fir grows on a variety of soils. On severe sites, it can be a nurse-crop species, or it may out-compete the establishment of other species.
Silvics	In the Rocky Mountains, subalpine fir is commonly found with Engelmann spruce and frequently extends to timberline where it may associate with lodgepole pine, alpine larch, mountain hemlock and whitebark pine. At the lower limits it associates with western white pine, Douglas-fir, grand fir, western redcedar. East of the Continental Divide, it grows with Douglas-fir, lodgepole pine, and aspen. It is a common climax species and is a pioneer on severe and disturbed sites.

Western larch	***Larix occidentalis***
Range and Habitat	In Region 1, western larch grows in the Upper Columbia River Basin of northwestern Montana, and in north and west central Idaho. It grows in the relatively moist-cool climatic zone. The limiting factors are low temperatures in the upper elevations, and lack of moisture on the lower extremes. Western larch grows on a wide variety of soils; most soils suitable for growth are deep and well drained. It is commonly found on valley bottoms, benches, and northeast-facing mountain slopes. South and west exposures are generally too severe for larch seedlings to establish, particularly in drier sites at the lower elevational limits of its range. In the mid- and northern portion of its ranges, larch grows well on all exposures.
Silvics	Western larch is a long lived seral species that always grows with other species. Douglas-fir is the most common associate, but others include ponderosa pine (lower drier sites), western hemlock, western red cedar, and western white pine (moist sites), and Engelmann spruce, subalpine fir, lodgepole pine and mountain hemlock (cool-moist subalpine forests). Seed germinates on seedbeds exposed by burning or mechanical scarification. Larch seedlings survive poorly on undisturbed litter, humus, sod or heavy root competition. High solar irradiation is the most important physical factor affecting seedling survival; seedlings germinating on duff will likely not survive. Drought is the major physical factor affecting mid- to late season survival. It is most likely to affect seedlings under heavy shade because of the heavy moisture use by the overstory and other competing vegetation. Young seedlings grow fast on desirable sites. Only lodgepole pine is similar to larch in seedling growth; Douglas-fir grows about ½ the height, and spruce and subalpine fire about ¼ the rate of larch. Site productivity however has the most affect on height growth on larch sites. Larch is the most shade-intolerant conifer in the Northern Rockies. It can tolerate partial shading only in the seedling stage. Fire is essential to the maintenance of western larch. Without fire, stands become over stocked and stagnant and are replaced by grand fir and Douglas-fir. Larch remains in the dominant position and understory trees and vegetation compete with the larch for available water and nutrients.

Engelmann spruce	***Picea engelmanii***
Range and Habitat	Engelmann spruce is widely distributed in the western United States and is a major component of the high elevation Rocky Mountain forests. It grows in humid climates with long, cold winters and short, cool summers, and occupies one of the highest and coldest environments of the western United states. The range of mean annual temperature is narrow considering its wide distribution. Spruce grows best on moderately deep, well drained, loamy sands and silts, and clay loam soils from a variety of volcanic and sedimentary materials. Good growth is also achieved on glacial and alluvial soils where the water table is accessible.
Silvics	Engelmann spruce most typically grows with subalpine fir but grows with many other conifers as a minor component or in frost pockets. Associates include mountain hemlock, whitebark pine, western larch, Douglas-fir, aspen , lodgepole pine, limber pine and western hemlock. Spruce seeds germinate on all sorts of ground cover (duff, litter, decomposed humus) and have best initial survival on duff seedbeds when sites are harsh or after fire, rather than mineral soil. It has low tolerance to high temperatures and drought, especially in the first five years of establishment. After establishment, survival is favored by adequate soil moisture, cool temperature, and shade.
Special Interest	There is evidence of natural hybridization between Engelmann and white spruce especially in the vicinity of Glacier National Park.

Whitebark pine	***Pinus albicaulis***
Range and Habitat	Whitebark pine grows in forests at the highest elevations and at timberline. The Rocky Mountain distribution extends from the high ranges in eastern British Columbia and western Alberta, and southward at high elevations to the Wind River and Salt River Ranges in west-central Wyoming. A small outlying population is found atop the Sweetgrass Hills in north-central Montana. Whitebark pine is most abundant on cool exposures and moist sites but there are sections of eastern Oregon where it is abundant on warm, dry exposures in the sagebrush mountain ranges. In general, whitebark pine grows where summers are short and cool, most precipitation comes in the form of snow and sleet, with rain only in June through September. This creates a droughty situation during parts of the summer. Whitebark pine survives strong winds, thunderstorms, and severe blizzards. Whitebark pine stands grow on weakly developed soils, although there is substantial variation in local climate, geologic substrates, and degree of soil development. Often soils lack fine material and trees may grow on talus exposed bedrock. In semiarid regions, they may have open, grassy understory and calcareous rock substrates. Whitebark pine is most abundant on warm aspects and ridge tops. It is less abundant where it is sheltered, and on north-facing slopes or cirque basins, where subalpine fir, spruce, mountain hemlock , or alpine larch are prevalent. The tallest and best formed whitebark pines are often on high basins or on gentle north slopes.
Silvics	Whitebark pine is a major component of high elevation forests and the timberline zone in northwestern and west-central Montana. It is found in pure stands in dry mountain ranges, as a co- dominant component with lodgepole pine in high elevation, and as a minor component with spruce and subalpine fir in high elevations of the Rocky Mountains. It can also be a primary long lived seral. Whitebark pine is more drought tolerant, more durable and longer-lived than its associated species on subalpine fir habitats, thus will persist as a climax or near-climax. In dry areas, it may be a co-climax with lodgepole. Growth form (erect vs. krumholtz) does not appear to be genetically controlled but rather a result of site and local climate. Whitebark pine needs light and openings in stand canopy to establish naturally. Seeds have poor germination probably due to seed coat and poor embryo development. Seed dissemination is dependent on the Clarks Nutcracker.
Special Interest	Principal damaging agents are white pine blister rust and mountain pine beetle. Resistance to white pine blister rust is the most notable phenotypic variation observed in whitebark pine. It is the most susceptible of white pines worldwide, but has strong resistance genes. Lack of wildfire has reduced the ability for whitebark pine to compete effectively and is giving way to more shade tolerant species. In 2011, the US Fish and Wildlife species found whitebark pine warranted for listing as threatened or endangered.

Lodgepole pine	***Pinus contorta***
Range and Habitat	Lodgepole pine has wide ecological amplitude, with the inland form (var. *latifolia*) found in Region 1. It grows in a wide variety of conditions with a wide range in temperatures. It is relatively resistant to frost injury and can often survive in frost pockets where other species cannot. It is found on a variety of soils, but they are generally moist. In Montana, lodgepole pine does not grow on highly calcareous soils derived from dolomitic limestone, but these soils support Douglas-fir. Lodgepole pine is found on soils developed on colluviums from other types of limestone and calcareous glacial till. Lodgepole pine has more favorable growth on northern and eastern slopes than southern and western aspects. It grows well on gentle slopes and in basins, but good stands are also found on rough and rocky terrain, on steep slopes and ridges, and bare gravel.
Silvics	Lodgepole pine grows in extensive pure stand and in association with many conifers. It has the widest range of environmental tolerance of any conifer in North America. Its successional role is dependent on the environmental conditions and on competition, although generally var. *latifolia* is seral in most forest communities. On warm, moist sites it is a seral species, and on cool dry habitats it is dominant and tends to be persistent. Fire plays a role in forest succession. Repeated fires can eliminate the seed source for other species. Lodgepole pine natural regeneration can overwhelm a site with seed from serotinous cones and exclude other species. The best lodgepole germination occurs in full sunlight and on bare mineral soil or disturbed duff, with little competition. Adequate soil moisture is required for germination and survival with the first few weeks being most critical. In southwest Montana most of the season's total germination occurs during the two weeks following snowmelt in late June when soil is saturated and temperatures most favorable. Germination is dependent on temperatures, not scarification. Young germinates are insensitive to temperature extremes. Drought is a common cause of mortality in first year seedlings. The greatest risks are soils with poor water holding capacity and the presence of duff and litter. Freezing temperatures may kill seedlings, but seedlings vary in frost resistance based on seed source. Frost heaving also causes mortality. Competition from grass can delay regeneration. Height growth begins earlier than other species it associates with except other pines and larch. Compared to other associated species, lodgepole pine is intermediate in its needs for water, requiring more then Douglas-fir or ponderosa pine but less than spruce and subalpine fir. It has a high ability to regenerate due to cone serotiny, seed viability, early rapid growth, and ability to survive a wide variety of microsite and soil situations. The serotinous cone habit is common in the Rocky Mountains but it varies over wide geographic areas as well as locally. Large quantities of seeds are available for reforesting after fire. Annual seed fall from non-serotinous cones helps in restocking relatively minor disturbances and maintaining its presence in mixed stands.
Special Interest	Mountain pine beetle is the most sever insect pest and has played a significant role in the dynamics of lodgepole ecosystems. There is genetic variation in strains of lodgepole pine, resulting in some strains to grow well in cold climate and on poor sites.

Western white pine	***Pinus monticola***
Range and Habitat	In the interior west, western white pine grows from near Quesnal Lake, BC, south through the Selkirk Mountains of eastern Washington and northern Idaho and into the Bitterroot Mountains of western Montana. Isolated populations are found as far east as Glacier National Park. The climate of the interior portion of white pine range is influenced by the Pacific Ocean, where summers are dry and the majority of the precipitation occurs in the fall and winter. White pine is limited by deficient moisture in the lower elevations and cold temperatures in the upper elevations. The southern boundary is limited by a balance of precipitation and evaporation. White pine grows on a diversity of soil types in the Inland Empire. The upper soil layers are composed of loess or loessial-like material. In this part of the range it generally grows between 1640 and 5910 feet elevation and generally where the topography is steep with v-shaped and round-bottomed valleys. It grows on a variety of slopes but is common along moist creek bottoms, lower benches, and northerly slopes. White pine grows in association with a variety of species, and in the western hemlock/*clintonia uniflora*, western redcedar/*clintonia uniflora* , and grand fir/*clintonia uniflora* habitat types.
Silvics	All factors considered, white pine seedling establishment is favored on partial shade on severe to moderately severe sites. On north slopes, little or no shade is best. Once established, white pine grows best in full sunlight on all sites. Western white pine requires 20 to 120 days of cold, moist conditions before germination commences. Seed germination has strong heritability. Germination occurs in the spring when soil moisture is at field capacity by melting snow. Under full sun, germination begins earlier and ends earlier than on shaded conditions. Mineral soil surfaces are preferred to duff. Seedling mortality late in the first growing season is attributed to high surface temperatures on exposed sites, and drought on heavily shaded areas where root penetration is slow and soil moisture is decreasing. Seedlings have low drought tolerance. Early root and shoot development is not rapid. White pine is almost always a seral species and is classed as intermediate in shade tolerance. It attains dominance in a stand only following wildfire or silvicultural systems that favor it. It is tolerant of cold when it is dormant, and similar to lodgepole pine in cold tolerance. White pine is more tolerant of heat than most of it shade-tolerant associated species. Genetic variation is high, but the greatest difference is among trees within a stand. Differences occur among stand and elevational zones, but the proportion of variation is smaller than that for trees within a stand. The adaptation of white pine to different conditions (topographic, climatic, geographic, edaphic) is governed more by phenotypic plasticity (ability of an organism to change its phenotype in response to changes in the environment) than by selective differences.
Special Interest	Most prominent disease is blister rust. A combination of climate, abundant ribes (*Cronartium ribicola*) as the alternate host and susceptible white pine caused significant losses in the past. Selection of naturally resistant trees as seed sources and planting of rust resistant nursery stock will reduce losses. In the absence of blister rust, white pine is long lives, commonly 300 to 400 years old.

Ponderosa pine	***Pinus ponderosa***
Range and Habitat	The Pacific ponderosa pine (var. *ponderosa*) ranges from the Fraser River drainage of southern British Columbia south through Washington, Oregon and California. In Region 1, it extends to the central part of Montana. The Rocky Mountain variety (var. scopularum) extends east of the continental Divide to North and South Dakota and south into Wyoming and further. Within the wide range of ponderosa pine, it is absent from several areas including a portion of southwestern Montana. This may be due the lack of rainfall in the summer months which prevents establishment except at higher elevations; however it is also limited by the shorter growing season at these elevations. Moisture is the factor most often limiting growth, especially in the summer. Seasonal rainfall deficiency is evident from the July and August precipitation. The distribution of ponderosa pine on drier sites is closely related to supplies of available soil moisture, which is closely related to soil textures and depth.
Silvics	Ponderosa pine can be either a climax species at the lower limits of the coniferous forests, or a seral in higher elevation mesic forests. In climax forests, there is generally a mosaic of small even-aged groups. Fires have a profound affect where competing tree species are considerably less fire tolerant; this allows ponderosa pine to maintain dominance on large areas. The major associated tree species are Douglas-fir, lodgepole pine, grand fir, and in the northwest, western larch. Ponderosa pine is an intolerant species, more tolerant than western larch but less tolerant than grand fir and western white pine. Cone crop periodicity varies with ponderosa pine; observations indicate it is a poor seeder west of the Continental Divide and a fair seeder east of the Divide. Throughout Region 1, natural regeneration is sporadic; best when there is a combination of a heavy seed crop followed by favorable weather during the next growing season. Soil texture, plant competition, and seed bed conditions have the greatest affect on seedling survival. Moisture stress reduces seed germination and limits seedling survival and growth. Competing vegetation deters seedling survival due to moisture use. Young seedlings (less than 36 days old) are susceptible to cold night temperatures, and occasionally trees suffer winter desiccation in drying winds. 110 day old seedlings can withstand higher temperatures than Douglas-fir, grand fir and Engelmann spruce. Ponderosa pine shows distinct geographic variation over its range. There is high genetic variation between var. ponderosa and var. scopularum in growth, survival, needle length, season pattern of root growth, ability to germinate under moisture stress (Moore, M. B., F.A. Kidd. 1982). Seed source variation in induced moisture stress germination of ponderosa pine (Tree Planters Notes 33(1)) nutrient status and isozymes.
Special Interest	Fires have a profound effect on the distribution of ponderosa pine, which allows it to maintain its dominance. Most aggressive enemy is mountain pine beetle, followed by other species of bark beetles *(Dendroctonus spp.).*

Douglas-fir	***Pseudotsuga menziesii***
Range and Habitat	Douglas-fir has been a major component of eastern North America since the mid-Pleistocene era. The Rocky Mountain (var. glauca) is found in Region 1. The range extends from central British Columbia through the Rocky Mountains into central Mexico. The range is fairly continuous in northern Idaho, western Montana, and northwestern Wyoming, with several outlying areas in eastern-central Montana and Wyoming. In the northern Rocky Mountains, Douglas-fir grows in the maritime influence with mild climate in all seasons except a dry period in July and August. In the central Rocky Mountains, the winters are long and severe, summers are hot and in some parts very dry. West of the continental Divide, the rainfall may be evenly divided between winter and summer. Douglas-fir in the Rocky Mountains originated from a considerable array of parent materials. The altitudinal distribution of Douglas-fir increases from north to south, due to the effect of climate on the distribution. The limiting factors are temperature in the northern part of the range and moisture to the south. Thus Douglas-fir prefers southerly slopes in the northern part of its range, and northerly exposures in the southern part of its range.
Silvics	Douglas-fir in the Rocky Mountains grows in extensive pure stands, both in an even and uneven-aged condition. The associated species are dependent on the climate. Douglas-fir gives way to mountain hemlock, whitebark pine, spruce, white pine, and on cold sites lodgepole pine. On droughty sites, it gives way to ponderosa pine. Western hemlock is more competitive on poorly drained sites as are a variety of hardwoods. The proportion of other species growing with Douglas-fir varies widely depending on aspect, elevation, soil type and past history, particularly fire of the area. Seedling growth the first year is relatively slow, limited generally by moisture, which triggers initiation of dormancy in midsummer. Competing vegetation may promote the establishment of a variety of seedlings by reducing temperature stress but may inhibit seedlings growth by competing strongly for moisture; this is most pronounced in the southern portion of the range (var. glauca). In the Rocky Mountains, it is a seral species in moist habitats and climax in the warmer, drier areas of its range. Regeneration is favored where Douglas-fir is seral, especially in the strong maritime influence in northern Idaho and western Montana. It is poor where it has attained climax status (Ryker 1975) . In the interior portion of its range, Douglas-fir ranks intermediate in tolerance, being more tolerant than western larch, ponderosa pine, lodgepole pine, and aspen. The species' rapid growth and longevity, thick corky bark of lower boles and main roots, and its capacity to form adventitious roots are adaptations that have enabled Douglas-fir to survive fire. Old growth Douglas-fir shows a wide range of age classes, indicating it established over long periods after major fires. It is gradually replaced by more tolerant hemlock, cedar and true fir. The species exhibits a great deal of genetic differentiation, which is strongly associated with geographic or topographic features. This clinal pattern of variation (clines consist of ecotypes or forms of species that exhibit gradual phenotypic and/or genetic differences over a geographical area, typically as a result of environmental heterogeneity) in growth and phenological traits have been observed in north-south, east-west and elevational transects despite the appreciable gene flow that would be expected from the seeds. There is evidence of genetic variation within local regions: for example in southern Oregon, seed collection on the more xeric southern aspects grows slower, set buds earlier, and has larger roots compared to seedlings grown from north-facing slopes. Seedlings from seed sources on southerly aspect have adaptive characteristics for a shorter growing season and drier soils and may survive under drought stress better than seedlings from north-aspect seed sources.
Special Interest	Throughout its life span, Douglas-fir is subject to serious damage from a variety of agents. Armillaria, and Annosus are common root diseases causing high tree mortality. Annosus root disease is particularly lethal in Douglas-fir. (Hagle 2003).

Western redcedar	***Thuja plicata***
Range and Habitat	The inland range of western redcedar extends from the western slope of the continental divide in British Columbia south through the Selkirk Mountains into western Montana and northern Idaho. The southern limit southern limit is Ravalli County and the eastern limit is near Lake McDonald in Glacier National Park. A few trees may exist east of the Continental Divide near St. Marys Lake. Western redcedar is abundant in many forested swamps as well as sites that are too dry for western hemlock. Western redcedar has better root penetration than western hemlock. It dominates wet ravines and poorly drained depressions. Where there is sufficient precipitation, low temperatures limit the species range. It is not resistant to frost and can be damaged by freezing temperatures in late spring and early fall.
Silvics	There are few pure stands of western redcedar; it is associated with a wide array of tree species as well as various shrubs species. Redcedar regenerates best on disturbed mineral soil although scorched soil is not beneficial. Rotten wood that is in contact with the soil is a preferred seed bed in redcedar groves. Establishing seedlings survive best in partial shade as they are not tolerant of high soil temperatures or frost. Roots of young seedling grow more slowly than Douglas-fir but faster than western hemlock; shoots have the longest growing period of any of the conifers it associated with. Young branches can sunscald. Redcedar also propagates by clones and tends to be more abundant than young trees established by seed. Only western hemlock in Region 1 is more tolerant to shade than western redcedar but can be overtopped by Douglas-fir, grand fir, western hemlock, and white pine .
Special Interest	Western redcedar is less susceptible than other associated species to root pathogens. However, due to its long life, there is still the impact of root disease, and heartwood typically resistant to decay is eventually invaded by fungi.

Western Hemlock	***Tsuga heterophylla***
Range and Habitat	The inland range of western hemlock includes the west side of the Continental Divide of the Rocky Mountains in Montana and Idaho north to Prince George, BC. It thrives in a mild humid climate where frequent fog and precipitation occurs during the growing season. Where the growing season is relatively drier, western hemlock is confined primarily to northerly aspects, moist stream bottoms, or seepage sites. Western hemlock grows on a variety of soil types, although it is a shallow rooted species and does not develop a tap root. Abundant roots, especially fine roots, are near the soil surface and easily damaged by fire and equipment.
Silvics	Western hemlock is either a major or minor component in many forest cover types, and may be either a seral or climax species. It is considered very shade tolerant and responds well to release. It is a major species as a climax or near climax condition. Seed germination and germinant survival is good when there is adequate moisture, and can germinate on a variety of materials and both organic and mineral seed beds. Decaying logs and rotten wood are often favorable seedbeds; decayed logs have the added benefit of good nutrition.
Special Interest	A variety of root and bole pathogens cause significant damage and mortality to western hemlock. It is also very susceptible to fire damage due to the shallow roots and thin bark, as well as wind throw due to the shallow roots. On droughty sites, top dieback is common; entire stands of hemlock saplings have been killed in exceptionally dry years.

Aspen	***Populus tremuloides***
Range and Habitat	Quaking aspen is the most widely distributed native tree species in North America and is found in the mountains of western Montana and northern Idaho. The habitat is limited first to areas of water surplus (annual precipitation exceed evapotranspiration) and secondly to minimum or maximum growing season temperatures. Quaking aspen grows on a variety of soils but growth and development are strongly influenced by both physical and chemical properties of the soil. The best soils are usually well drained, loamy, and high in organic matter, calcium, magnesium, potassium, and nitrogen. Quaking aspen has an important role in nutrient cycling due to its rapid growth and high nutrient demand. Aspen is limited by shallow water tables (<2 feet) and very deep water table (>8.2 ft) where roots are affected by limited water and poor aeration. Deterioration of aspen stands is related to warmer summer temperatures.
Silvics	Quaking aspen grows with a large number of trees and shrubs over its range. It is very intolerant to shade and is an aggressive pioneer readily colonizing after fire. Aspen, in the absence of disturbance, is successional and able to dominate a site until it is replaced by shade-tolerant conifers, especially when fire is less frequent. Mature stands reproduce vigorously by sprouting. Damage to parent trees alters the growth hormones (auxins and cytokinens) and stimulates sprout development. Soil temperature is the most critical environmental factor affecting suckering. Light is not needed for suckering but is needed for secondary growth.
Special Interest	Young trees are killed by small rodents, mammals as well as big game animals.