REFORESTATION FRAMEWORK

Dinkey Collaborative Forest Landscape Restoration Project

Dinkey Landscape Restoration Project

The Reforestation Framework was developed through an engaged and collaborative process. The Landscape Planning Working Group, including Sue Britting, Mark Smith, Chip Ashley, Lauren Pile, Ramiro Rojas, Adam Hernandez, and Sarah LaPlante were responsible for initiating and drafting the Framework. The Framework was adopted (tentative) by the Dinkey Collaborative Forest Landscape Restoration Project in December 2017. Questions on the Framework can be forwarded to Sue Britting (britting@earthlink.net), Mark Smith (mtsmith04@comcast.net), or Lauren Pile (lpile@fs.fed.us).

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Purpose of the Framework

The interplay of past management practices, higher temperatures, extended drought, and insect outbreaks have resulted in unprecedented levels of tree mortality across the ponderosa pine and mixed-conifer zones of the southern Sierra Nevada. The restoration projects of the Dinkey Collaborative Forest Landscape Restoration Project ("Dinkey CFLRP") sought to reduce stand density and increase structural and compositional heterogeneity by promoting pine species and reducing the abundance of white fir and incense cedar through forest thinning and prescribed fire. However, the landscape-scale mortality has impacted even the areas where treatments were designed to increase resistance and resiliency. Many areas have lost reproductively mature pines. Furthermore, the regrowth of shrubs in some places is limiting the germination and growth of pine. This framework proposes planting trees, i.e., artificial regeneration, in some places in order to increase regeneration of pine and improve the chances of survival of existing regenerating pine so as to reduce the time until forests dominated by mid-sized pine are re-established.

The impact of future climate on forest composition caused by species range shifts is currently unknown. Adaptive management using guidance from the historical natural range of variation, predicted species shifts to changing climatic envelopes, and advances in silvicultural approaches will be necessary to increase future resiliency and provide habitat for critical wildlife species. Determining how to approach reforestation efforts, while also developing an evolving understanding of desired future conditions that may not be based on historical reference conditions is a priority and focus of the Dinkey CFLRP and serves as the foundation of this document.

The location of conifer reforestation activities is a landscape-level decision process that will require consideration for watershed protection and health, critical wildlife habitat, ecosystem processes and functions, and ecological goods and services. Such a decision process will also need to address restoration and enhancement of non-coniferous species common in the forest type, such black oak and other native hardwoods.[1] When reforestation is proposed, this document identifies the major goals, desired conditions and activities for the Dinkey CFLRP, including associated timelines. It focuses on where[2] and how the members of the Dinkey Collaborative will advocate for the reforestation of stands[3] in the process of ecological restoration. Scientific and technical issues associated with reforestation are addressed to the extent the Collaborative finds appropriate at this time. If the goals and desired future conditions of other interested parties, including those of private land owners, are similar to the ones outlined by the Dinkey CFLRP, the following Framework may provide guidance for reforestation activities on their lands. Monitoring and adaptive management associated with reforestation are addressed in the Collaborative's ecological monitoring plan, not in this document.

[1] We recommend developing a companion chapter to this conifer reforestation framework that focuses on the restoration and maintenance of oak and other native hardwoods due to their ecological and cultural importance.

[2] When conifer reforestation is proposed, "where" refers to the goals and landscape positions described in the following paragraphs not to the location of a proposal within the Project boundary.

[3] Areas, greater than five acres, that are stocked with varying combinations of surviving saplings and poles, natural regeneration, shrubs and planted seedlings. Much of the information in this document can also be applied to gaps which are areas from a quarter to five acres in size within stands.

The short term desired conditions developed in this Framework were heavily influenced by Collaborative members' observation and discussion of the vegetation structure and species composition of the Big Creek Restoration Project at age 20 years in 2016. In the Collaborative's view the species composition favoring pine, fire resilient stands, and heterogeneity at the scale of an acre or two will achieve the goals for reforestation and long term desired conditions described below. Further, the Big Creek Project has demonstrated the activities described in the short term desired condition section using the sequence and timing listed in the table in Appendix I are feasible.

Background and Goals for Reforestation

Over the life of a stand of trees, whether a few acres or tens of acres, tree density is an important factor in growth and resiliency. Trees compete with each other and other vegetation for moisture, nutrients, and sunlight. Any landscape is capable of optimally serving only a limited number of trees and other flora. When limiting factors are exceeded, vegetation becomes stressed and therefore less resilient and more vulnerable to disturbances. Thus, a sound reforestation strategy must include specific elements to address the limitations of stands to be reforested. To optimize heterogeneity and resiliency, planting density should be varied according to site index, microclimate, slope, aspect, and slope position. This includes taking advantage of the remaining green trees in areas of high mortality by providing an adequate seed bed for natural regeneration and reducing the need for mechanical treatments by utilizing existing openings. Subsequent cultural treatments should minimize the risk of creating overly dense and homogenous stands. Finally, lower density stands enable the use of prescribed fire to mimic natural fire regimes and reduce fuel loading. The result is resilient stands, less vulnerable to climate change and thus wildfire, insects and other disturbances. Stands managed with such a strategy contribute to forests that will provide ecosystem benefits and services including ensuring and enhancing habitat connectivity for wildlife species long into the future.

A stand has an inherent capacity to grow biomass (trees, shrubs, forbs and/or grass) that varies by the site quality and the availability of moisture. Planning for reforestation should utilize the natural range of variability for tree density stratified by site productivity and landscape position and adjusted based on the best available science for carrying capacity and future climate conditions. In the southern Sierra Nevada, when tree seedlings are planted or natural regeneration occurs, almost all the moisture must be available to the seedling for it to survive the late spring through early fall when little or no rain occurs. During this time, tree seedling, especially pine, roots grow rapidly and typically reach depths of 24 inches by the first period of winter dormancy.

From the second year through the fifth year, seedling survival and growth continues to be dependent on available moisture to develop to the extent allowed by the site quality. Shrubs and grass growing within a five foot radius of the seedling may challenge survival and suppress vertical growth. In areas where managers decide to control competing vegetation, two methods are commonly used depending on the nature of the vegetation being controlled. Non-sprouting brush and grass can be effectively controlled by hand hoeing but sprouting brush is most often controlled with an herbicide like glyphosate. Once past the fifth growing season, seedlings, especially pine, have deep roots and enough height to survive and grow satisfactorily.

To be effective, reforestation practices must work in coordination with fire and fuel management strategies. Specifically, reforestation, prescribed fire, and managed fire must not conflict with prescribed and managed fire practices. A particular concern is not to create conflicts with the prescribed and managed fire program whereby managers would resist implementing the program in or near plantations for fear of damaging an investment. Further, trees should not be planted where burning is immediately essential and where seedlings cannot be protected from prescribed fire.

As control of competing vegetation is curtailed, wildfire becomes the primary threat to the young trees. Whenever possible, the developing stand of trees should be underburned between age five and ten to eliminate as much ground fuel as possible and increase the likelihood the young trees would survive a wildfire.

Reforestation Objectives

A. Long Term Desired Condition (Stand Age 20 - 100)

In the mixed conifer and ponderosa pine forest types, stand structure would be consistent with a historic fire-adapted ecosystem. Species composition would favor pines and black oaks, which are adapted to frequent fire, rather than less fire tolerant white fir and incense-cedar. In the true fir forest type, which has a less frequent fire regime, white and red fir would dominate. In both forest types, stands would be uneven-aged, and heterogeneous, both vertically and horizontally, resulting in a variety of habitats and micro-site conditions.

Forest structure would follow the topographical effects on available soil moisture. Tree density and canopy cover would be highest in stands in drainages and riparian areas, then decrease in those on midslope and become lowest in those near and on ridgetops. Tree density and canopy cover in all three slope positions would be higher on northeast compared to southwest aspects. They would be higher on gentle slopes and more open on steep slopes as much as feasible with common management activities. Tree densities would be managed to provide resiliency to drought, desired tree vigor, and desired levels of bark beetle and other density dependent mortality.

Within forest stands, individual trees, small clumps, and groups of trees are interspersed with grass, herbaceous plants, and shrubs, in variably sized openings that vary with forest type and topographic position. A spatial mosaic of shrub densities, tree litter, down wood and bare ground occurs between groups of trees. Vigorous understories of heterogeneous, patchy, and diverse native shrubs, herbs, and grass species support small mammal, bird, insect, and fungal communities, as well as providing pollinator and herbivore forage. In some stands, shrub, grass and young trees grow in patches of high tree mortality with abundant snags and large logs, providing complex early seral habitat.[4]

Forest structure and function would generally resemble pre-settlement conditions. Differences between stands would result in high levels of horizontal and vertical diversity across landscapes, exemplified by clearly apparent variation in tree densities and sizes. Differences within stands would result from micro-scale variation in site productivity, disturbances, and the frequency of sprouting species like California black oak.

Differences in fire severity over decades would create and/or maintain a forest structure and composition that varies by fire patterns that are controlled by slope aspect, slope steepness, topographic position and fire frequency. Studies suggest natural forest landscapes vary depending on fire frequency and intensity, which is largely controlled by fuels and topography, such that ecosystem processes and structures are consistent with frequent low to mixed intensity fire regimes.[5]

B. Short Term Desired Condition (Stand Age 20)

The short term desired condition section addresses species composition, heterogeneity and tree spacing, sequence and timing of treatments, coordination with fuels strategy, and expected stand development.

Reforestation dictates the initial species composition of a stand and sets it on a trajectory of structure and risk of loss due to tree density, drought and fire. Treatments accomplished in the first 20 to 35 years post reforestation can largely determine the structure in the next 80 years (Oliver and Larson 1996).

The reforested stands would resemble the range of vegetation structure and species composition of the Big Creek Restoration Project at an age of 20 years in 2016. The Big Creek Project serves as one example of management intervention to accelerate the progress toward the long term desired conditions for a landscape at 4,000 to 7,000 feet elevation on a west aspect at mid-slope with varying site productivity. The results are used as a guide and provided as examples throughout this description of the short term desired condition.

The most evident elements of the short term desired condition at this age would be species composition favoring pine[6], fire resilient stands, and heterogeneity at the scale of an acre or two. Controlling the tree and brush density with various management activities, natural regeneration

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[4] Adapted from the desired conditions for montane forests in the draft revised forest plan for the Sierra NF (p. 17) (http://a123.g.akamai.net/7/123/11558/abc123/forestservic.download.akamai.com/11558/www/nepa/3403_FSPLT3_3083749.pdf

[5] Ponderosa pine and mixed conifer forest types are dominated by ponderosa pine species. In these forest types the frequent fire regime historically created a relatively small high severity patch size of less than 25 acres covering approximately 10 percent of the fire area (Kane et al. 2013). Fir dominated forests with functioning fire processes were characterized by most high severity patches being less than 25 acres and one or two patches greater than 120 acres (Collins and Stephens 2010, Kane et al. 2013). These fir forests with functioning fire processes had approximately 13 percent of the fire area in high severity acres (Collins and Stephens 2010, Kane et al. 2013).

[6] Ponderosa pine and sugar pine are shade-intolerant and do not flourish under an intact forest canopy. Reforestation of these species will require openings (gaps or stands).

(ingrowth) of pine and brush species and sprouting of black oak stumps has created the heterogeneity seen at Big Creek. Similar efforts would be made to increase within stand-level heterogeneity by using an appropriate mix of species and relying on both natural and artificial regeneration when necessary.

Approach to Achieving Objectives

A. Species Composition

Species composition is affected by site preparation, planting, and release treatments. Natural regeneration of both conifers and oak species creates opportunities to enhance species composition. Desired species composition following large scale disturbance should provide a bridge to the long term desired condition which is described above.

As an example in the Big Creek Restoration Project, pine was planted and naturally occurring California black oak and incense cedar were purposefully retained. However, due to the lack of seed source for incense cedar, this species is found at a frequency lower than desired. Thinning and release guidelines adequately protected black oak. A lesson learned is that little or no natural regeneration for species with few or no seed sources causes a need to include the species in the planting treatment. Project planning will need to consider the available seed sources, including those from natural and artificial regeneration, to maximize species diversity within an appropriate elevational zone or topographical feature.

Species planted should reflect the natural range of variability in species composition and the greatest genetic diversity of individuals to foster adaptation to current and future climatic conditions. Inclusion of seed from other seed zones or species typically found at low frequency in the forest type and slope position where the stand is located should be considered to promote resilience. Any planting with seed from different zones should be done mixed with seed of locally adapted genotypes. However, in order to effectively monitor new genotypes, small single plantings may provide the best method with limited resources. Effective short- and long-term monitoring will be important to ensure survival and help determine seed genotypes for future reforestation projects.

B. Fuel Loading and Continuity

The short term objective should be to maintain fuel loads of less than 10 to 20 tons per acre within planted areas. Young tree seedlings, especially those less than five years old, are particularly vulnerable to direct impacts of fire. However, prescribed burning in the fall when the buds of pine seedlings are dormant is likely to result in less overall mortality compared to spring burning in young ponderosa pine stands. Lower fuels should be maintained along strategic fire suppression roads and bridges. Higher fuel loads may be allowed in the interior of stands or away from values at risk.

The fuels and other treatment strategies within planted areas should seek to reduce the exposure of planted and natural trees to fire. Treatments should be timed to prolong lower fuel loads and lower vulnerability of young trees to fire. In the first five years after planting, grasses and forbs should contribute the greatest proportion of the fuel load. Shrubs should be less than 15 percent plant coverage on moderately and highly productive sites. This level of shrub cover promotes the fastest tree crown and diameter growth resulting in thicker bark that provides increased resistance to fire. Prescribed burning as a site preparation treatment prior to planting may also contribute to reduced fuel loads allowing seedlings a few years to develop fire-resistant traits (i.e., thick bark, self-pruning of lateral branches) during a fire free period.

After five years shrub cover will likely increase and should be maintained below 30 percent for the first 20 to 30 years depending on site productivity as a discontinuous layer with space between shrubs and tree crowns.

The Big Creek Restoration Project offers an example of both desirable and undesirable levels of shrub cover. Within planted and burned or thinned and piled areas after 22 years shrub cover is 20 to 25 percent plus forbs. Within areas not piled or unburned areas, shrub cover is nearly continuous, exceeding 60 percent cover.

C. Heterogeneity and Tree Spacing

Controlling the tree and brush density with various management activities and promoting the natural regeneration (ingrowth) of conifers and shrub species and sprouting of California black oak stumps can lead to desired heterogeneity through prolonging the stand initiation phase of stand development. Lower tree and shrub density allows for rapid individual tree crown growth, which promotes faster trunk diameter growth and early viable seed production.

In the Big Creek Restoration Project, tree and brush density and canopy cover does not yet vary significantly by elevation, aspect, and slope position but does by site productivity within the stand and the frequency of sprouting species, including California black oak. Heterogeneity in this stand could be increased in the future through disturbances such as wild and prescribed fire, insect irruptions, natural regeneration and management intervention.

Heterogeneity can also be introduced through variations in planted seedling spacing at the stand scale or microsite scale. At the stand scale planting density can be varied by site productivity, landscape position, aspect, or fuels objectives. Within a stand horizontal heterogeneity can be introduced early by creating clumps of three or more small trees by directing planters to create a clump of trees planted at less than the standard wide spacing. An example would be a cluster of 10 trees planted 10 feet apart in an otherwise 20 foot planting spacing scheme. Horizontal heterogeneity was achieved in the Big Creek Restoration Project through establishment of natural regeneration in addition to the trees established by planting.

Objectives that may drive wider spacing (20 feet apart) include fuels and fire suppression objectives that require low crown continuity or objectives for higher shrub component, resulting in initially widely spaced conifers with retained oaks dispersed throughout the stand. However, this wide spacing creates space for shrubs and conifer ingrowth which can move stands away from the fuels objective of low crown continuity. Narrower tree spacing would be used where tree size (denser, smaller trees) are desired to lessen shrub and conifer ingrowth.

The Big Creek Restoration Project offers an example of this type of tree spacing heterogeneity. Within 250 feet of the Stump Springs Road or key ridges, tree planting was less dense (20’ x 20’ spacing). Beyond roadsides, planting spacing was determined so that crown closure occurred at

35 to 45 years after planting. It was either 16' x 16' or 18' x 18' depending on the site quality. Crown closure is higher than expected at 20' x 20' spacing due to very fast crown growth.

In some situations, planting in multiples has been beneficial for achieving management objectives without increasing stand densities. An example of conifer reforestation adaption on the Aspen Fire, two to three conifers were planned per planting per spot at a spacing of 18 inches apart. The spots were spaced to reduce the need for future pre-commercial thinning at 14 to 19 feet apart depending on site quality and GTR-220 topographic zone which resulted in 125 to 225 trees per acre. Cultural treatments will remove all but one of the seedlings per spot by age 3, prune the lower third of the branches at age 6 and under-burn at age 9.

The objective was to establish 90 percent of planted areas with the desired numbers of trees within five years. The approach almost assures survival of at least one seedling at each planting spot. In the likelihood that one seedling dies, the survival of one of the remaining seedlings will ensure that site occupancy and dominance is held by trees. It is especially useful with species like sugar pine and true fir that typically suffer about fifty percent seedling mortality during the three years after planting. Obviously, there is a cost to planting the second or third seedling at a spot but it is offset by rarely having to endure the much greater cost of replanting to reach the desired number of trees. If there are one or two live seedlings to be removed at age three, the cost is negligible or non-existent because aggressive release would be occurring around the planting spots so the excess seedlings would be removed as part of that treatment.

In areas that are key for fire suppression based upon topographic features (e.g. slope, aspect) and road locations, spots planted were done at extra-wide spacing. A consequence of extra-wide planting is the need for additional release treatments.

D. Sequence and Timing of Treatments

The general sequence of stand treatments and anticipated stand development and fire risk across the Big Creek Restoration Project is shown in the table in Appendix I. The Framework developed here from the Big Creek Restoration Project is intended to guide future Dinkey CFLRP reforestation activities once a reforestation area is determined.

Site preparation should occur within five years of disturbance. Delayed site preparation allows for increased shrub competition. Delays past five years can incur significant costs to allocate growing space from shrub species to desirable tree species. In addition, without additional treatments, high mortality in the overstory may increase the difficulty of controlling the shrub layer. Planting typically occurs within one or two years of site preparation.

Site preparation in the Big Creek Restoration Project reduced fuel loads and shrubs, but a significant grass crop increased the risk of loss to fire for 1 and 2 year old seedlings. In order to reduce the susceptibility of mortality from fire, a hand release treatment by hoeing between 3 and 5 years after planting resulted in a six-foot diameter cleared area around each tree. Also, once planted trees were taller than 3 to 6 feet, the hazard from burning grass was greatly reduced. Between year 6 and 10 stands were treated once with either a late fall prescribed fire or by cutting and piling brush. Additionally, key areas for strategic fire suppression along ridges and roadsides were pruned to reduce crown fire in young trees.

The potential for the use of prescribed fire depends on fuel load, time of year, tree species and planting density. The table in Appendix I describes the potential for the use of prescribed fire in a widely spaced plantation. In pine dominated areas, fall/winter dormancy of seedlings offers an opportunity to consume surface fuels and reduce shrub cover. In fir or incense cedar dominated stands, young seedlings and saplings remain vulnerable to fire until bark thickness and tree height reduces exposure of cambium and crown to heat injury and scorch. Prescribed fire has had some success in reducing the density of young fir and incense cedar. Around 10 years of age, fir or incense cedar saplings and poles may survive prescribed fire with low flame lengths (less than 1 foot).

The presence of noxious weeds or shrubs (i.e. yellow star thistle, Spanish broom) may require additional steps to achieve dominance of native conifers and shrubs.

The Big Creek Restoration Project also offers an example of how treatments might vary across a large landscape. Site preparation and removal of fuels varied by fuels objectives. Along strategic fire suppression roads various techniques were used to almost eliminate down woody debris. Away from main roads, fuels were piled and burned, removed with prescribed fire or left to deteriorate naturally such as after early pre-commercial thinning.

Natural regeneration of conifers and oaks is found across the Dinkey CFLRP. Both planting and prescribed fire strategies should identify areas where natural regeneration can be enhanced. Release from competing vegetation, thinning, piling, and pruning can increase the opportunity to reintroduce fire and accelerate tree growth and stand structure in planted as well as naturally established seedlings.

E. Stand Development

Widely spaced planted trees and natural regeneration can result in trees staying in the stand initiation phase of stand development for the first 35 to 50 years. That means the stand remains receptive to the continued establishment of new seedlings. With aggressive release from shrubs, conifers and California black oaks can dominate stands. However with only one hand release treatment understories can be dominated by aggressive shrubs like manzanita by year 10. Especially in strategic fire suppression areas, it is preferable to have an understory dominated by grasses and forbs for at least 5 to 10 years.

Age 6 - Tree Height is 6 feet

Age 11 - Tree Height is 9 feet

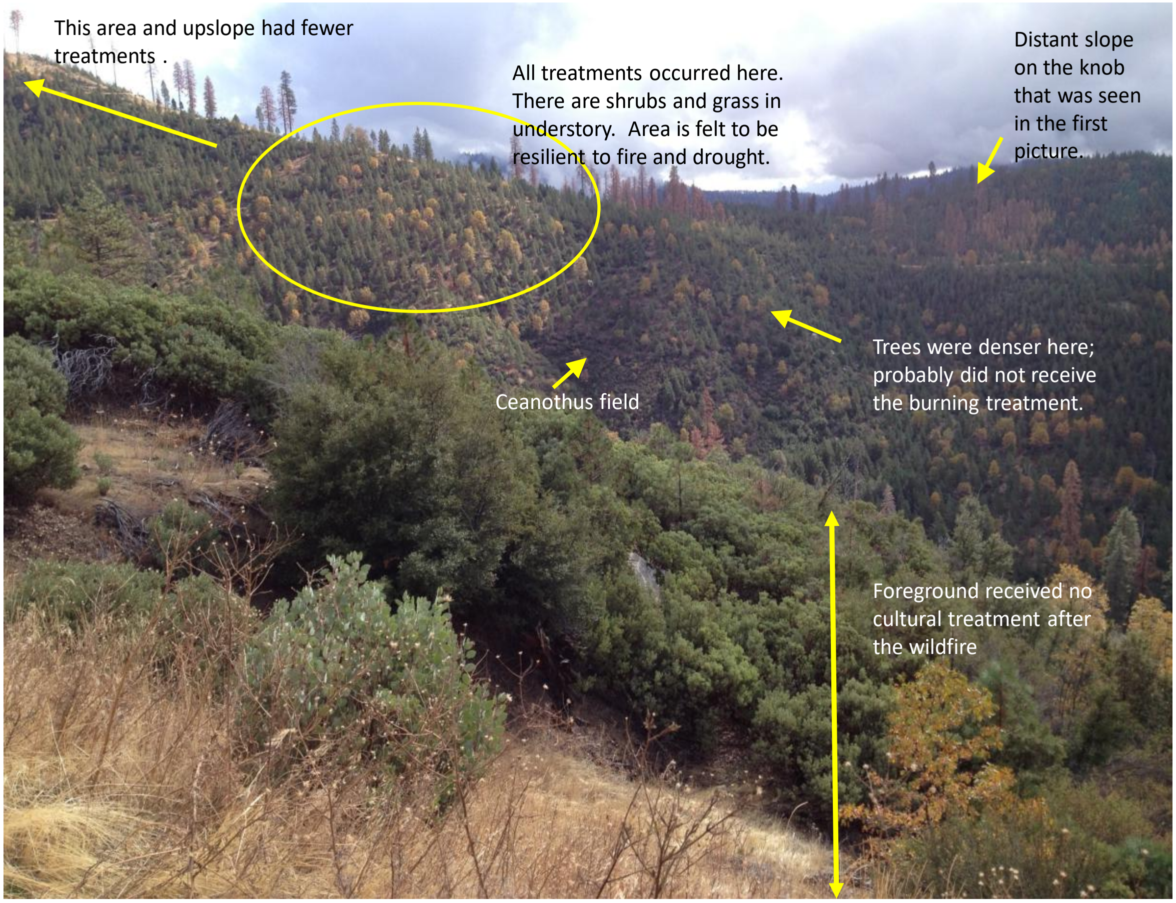
Within burned or thinned and piled areas, the vegetation structure and species composition of the Big Creek Restoration Project at an age of 22 years is one dominated by ponderosa pine 8 to 25 feet high, mostly 15 to 25 feet apart, and with height growth rates of 12 to 24 inches per year. The trees mainly occur in dense clumps or patches spaced about 20 by 20 feet. Among and within the clumps and patches are groups of 2 to 8 black oak sprouting from one stump that are 10 to 25 feet in height. There are occasional young incense cedar that are 6 to 8 feet in height and remnant large live and dead ponderosa pine that are 50 to 100 feet in height. The understory consists of varying densities of whiteleaf manzanita shrubs 5 to 8 feet high and 6 to 8 feet wide and patches of grasses and forbs of about a tenth of an acre in size.

The following pictures provide some perspective on heterogeneity at age 22.

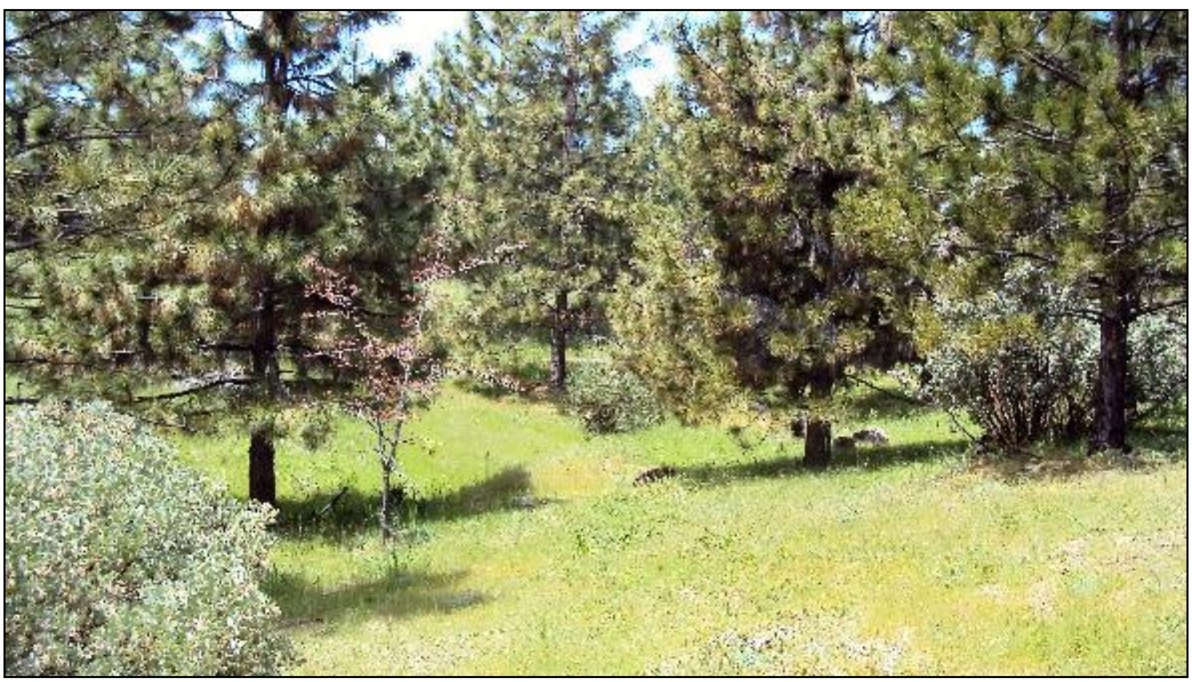
In this view from the Stump Springs Road, within 250 feet of the road, tree planting was less dense (20’ x 20’ rather than 16’ x 16’ spacing). Shrub cover is 20 to 25 % plus forbs. The area down slope was hand cut and hand piled, then sprayed to control the invasive Spanish broom. Just beyond about 75 feet from the road, the area was thinned and brush cut at year 7 and the slash scattered. Around 5 to 8 years since planting, trees are small enough and few enough that slash can easily be incorporated into soil. Additional treatments included gopher control at year 2 and pruning at year 9.

The knob on the horizon was also planted at 20' x 20' spacing and hand cut and piled. The saplings were pruned once at year 7 and again at year 12 resulting in the removal of the lower third of the crown. The knob was underburned in late fall.

The area down slope of road and including the knob is intended to act as a fuel break to stop wildfire from burning upslope. The area was felt to be resilient to fire and drought from about age 5 to 15.


This area and upslope had fewer treatments .
All treatments occurred here. There are shrubs and grass in understory. Area is felt to be resilient to fire and drought.
Distant slope on the knob that was seen in the first picture.
Trees were denser here; probably did not receive the burning treatment.
Ceanothus field
Foreground received no cultural treatment after the wildfire

The following pictures provide some perspective on diversity within the plantation at Big Creek that shows the heterogeneity at the scale of an acre or two.



F. Variation in Short Term Desired Condition by Land Management Emphasis

Reforestation Within Strategic Fire Management Zones (i.e. WUI defense zones, Defensible Fuel Profile Zones, and strategic roadside corridors)

The vegetation structure and composition on the landscape must align with the desired activities of the landscape. For example the WUI defense zone requires a low-density tree stand so that the fuels reducing underburning can be efficiently applied on a regular basis. When management objectives are to maintain strategic fire management zones, reforestation should mirror the approach described above that was used downslope of the main road in the Big Creek Restoration Project. Tree seedlings would be planted at as wide spacing as the forest type and site quality allow so they dominate the stand but limit shrub invasion. If dense tree clusters are desired they must be arranged in sizes and in locations around the primary desired activities of the landscape as to not hinder future underburning. Hoeing or herbicide application can be used to release trees from competing vegetation. To reduce sapling mortality and the risk of crown fire, prune the lower three whorls of branches when the trees are six feet tall. Underburning should occur in the fall after pruning when the buds on the trees are dormant. If underburning is not feasible, thin trees and remove excess brush by hand or mechanically to accomplish as much as possible the effects of underburning.

If feasible, underburning should occur again 20 to 25 years after planting; otherwise it is necessary to thin trees and remove excess brush by hand or mechanically.

Underburning objectives should limit mortality to planted and natural seedlings to less than 15 percent.

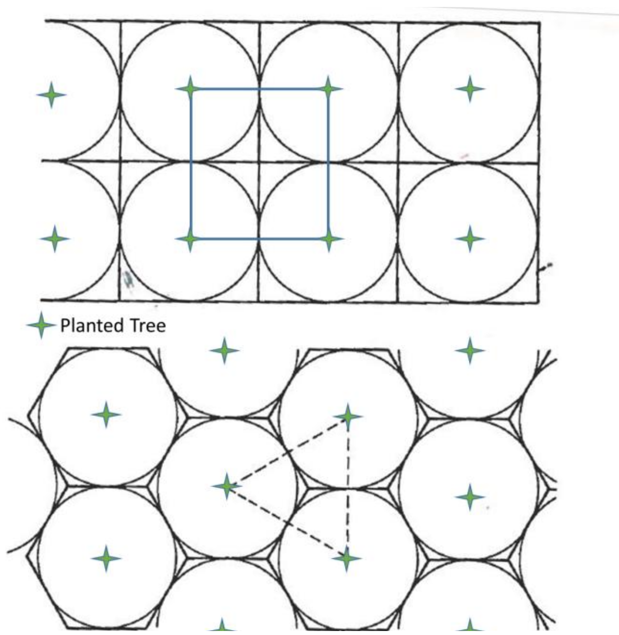
Conifer Reforestation within the General Forest including WUI Threat Zone
Conifer reforestation in the WUI Threat Zone and General forest would mirror the approach described above in the Big Creek Restoration Project. Plant seedlings according to the following table showing the number of viable saplings at age five.

Number of Live Saplings[1] at Age Five

Landscape Objective[2]	Forest Type	Site Quality[3]	Saplings per Acre	Triangular Spacing (feet)
Ridge Zone or Shaded Fuelbreak	Pine or Mixed Conifer	All	140	20 x 20 x 20
South Zone	Pine or Mixed Conifer	Moderate - high	170	18 x 18 x 18
North Zone or Canyon Zone	Pine	Moderate - high	190	17 x 17 x 17
	Mixed Conifer	Low - moderate		
North Zone or Canyon Zone	Mixed Conifer	Moderate - high	215	16 x 16 x 16
Ridge Zone or South Zone	True fir	Moderate - high	215	16 x 16 x 16
North Zone or Canyon Zone	True fir	Moderate - high	280	14 x 14 x 14

[1]The expected number of live saplings eliminates the need for a pre-commercial thinning to control stand density.
[2]Landscape objective as defined in GTR-220 (North et al. 2009).
[3]The table assumes that low quality sites not listed would not be planted.

The spatial arrangement of seedlings can also impact crown closure and tree development. Planting in triangles rather than squares allows for trees crowns to fit together in the horizontal dimension like hexagons and competition is better controlled due to greater occupation of space by tree crowns as shown in the following diagrams.



Planting density should consider the expected survival and be sufficient to avoid replanting.

Release, prune, and underburn as described for Strategic Fire Management Zones in years 0 to 15. Allow heterogeneity to develop naturally through variation in site quality between and within stands, openings created by insect outbreaks or unplanned fire events, and tree and brush ingrowth as they did on the Big Creek Restoration, except there were no unplanned fire events.

At age 20 to 25, underburn, if feasible, otherwise thin trees and remove excess brush by hand or mechanically. Use these activities to increase heterogeneity between and within stands if it is not sufficient to accomplish land management objectives, such as by thinning to irregular spacing. Underburning objectives should limit mortality of planted and natural seedlings to less than 15 percent.

Comparison to Other Reforestation Strategies

The following section describes other reforestation approaches used in the past or currently. Both examples tend to result in uniform stands at age 20, with the first example resulting in a higher density than the second.

A. Timber Management Approach

In the 80's and 90's it was fairly easy to figure out how to space trees when planting and thinning because the objective was to grow timber for commercial use. In stands of average site quality, the objective was to grow a 13” dbh tree, 50 feet tall by age 45 because stands that had an average size tree of 13” dbh were expected to allow a profitable commercial thinning. Similar objectives existed for stands of better and poorer site quality.

For example, the typical approach in the ponderosa pine forest type was to plant about 400 trees per acre, release aggressively and expect about 300 trees per acre to be surviving at age five. Shrub ingrowth was limited initially through aggressive release and subsequently by the dominance of 300 trees per acre. At about age 15, the acre was pre-commercially thinned to about 200 trees, the slash piled and burned, then the remaining trees left to grow until age 45 without further treatment.

B. Minimal Initial Planting Densities

The 2004 Sierra Nevada Forest Plan Amendment does not include any quantified objectives for creating and managing plantations. The objectives are qualitative, such as:

- In young plantations accelerate development of key habitat and old forest characteristics.
- In plantations, establish stocking levels that provide well-spaced tree crowns (i.e. 200 four inch trees per acre).
- In Spotted Owl HRCA’s, accelerate development of current habitat such as plantations into suitable habitat.

This type of qualitative objective has fostered the approach of planting at wide spacing to make abundant site resources available to grow seedlings fast while allowing some site resources to be utilized by shrubs, forbs and annual grass.

A typical approach would be to plant about 170 trees per acre, release aggressively around the seedlings but allow some shrubs, forbs and grass to persist and expect about 130 trees per acre (assuming 25% natural mortality) to be surviving at age five. As in the timber management emphasis example, shrub growth would be limited initially around the seedlings by the aggressive release but the trees would not dominate the site until about age 20. So, continued suppression of most of the shrub ingrowth would be necessary until about age 15. Depending on the many factors that could be encountered in an average stand, the suppression could be by hand methods, mechanical methods, herbicide and/or pruning followed by underburning. Suppressing the shrub ingrowth through about age 15 would leave the trees in good condition to grow until a thinning was feasible.

Types of Reforestation Activities

The Collaborative has identified several types of reforestation activities that it seeks to utilize in its landscape restoration projects. Some of these types of activities have been described in forest restoration and reforestation NEPA documents.

A. Long Standing Activities

These are activities that are commonly conducted and described in greater detail in project level NEPA documents. They include:

- Tree planting
- Hand release by hoeing
- Control of the gopher population
- Hand thinning trees and excess brush then piling the debris usually mechanically
- Mechanically thinning trees and removing excess brush
- Burning piles of debris
- Prescribed or managed fire every 10 - 15 years
- Releasing trees from competing vegetation with an herbicide like glyphosate

B. Uncommon Activities

These are activities that have been used infrequently or not at all on the Sierra National Forest. These could be more extensively applied when consistent with the management objectives.

- Pruning young trees
- Underburning young plantations
- Variable density and spacing of plantings
- Planting conifer species as habitat refugia for wildlife in key areas
- Prescribed or managed fire as site preparation after insect mortality
- Fertilization of conifers and/or application of pheromones in high value recreation and administrative sites and to known rust-resistant sugar pine

C. New Activities for Adaptive Management

Efforts should be made to maintain tree species at densities that allow them to be resilient and resistant under future climate conditions. This may include reduced stocking levels at initial planting, recognizing elevation and aspect effects in selecting seed for reforestation, and incorporating different reforestation approaches that have been tested and found successful in similar climates across the world. Some of the examples below have been suggested for potential incorporation in the reforestation framework above but are not specifically outlined. Because the following techniques are novel approaches in this landscape they will require substantial monitoring, a proactive approach with a level of anticipated risk, and many trials to best inform adaptive management going forward. In some of these cases, there is no consensus between and within Federal agencies, academics, and other interested parties on the best way to move forward after tree mortality and climate change.

Cluster Planting

Cluster planting or applied nucleation (figure below) may provide an economic and ecological method to restoring pine on the landscape while not establishing large areas of pine plantations with uniform spacing. The method may also be considered “applied nucleation” which uses natural pathways of forest succession whereby species create “clumps” around which other species establish (Corbin and Holl 2012). Clusters of dense seedlings are planted as either nests (very dense spacing) or groups (slightly larger spacing) which allow for natural thinning processes, without the need for intermediate treatments, and the development of a clumped forest structure. Planting clusters at fairly high densities increases intraspecific competition which may also limit the competition from shrubs and grasses. The nuclei can reduce competition from ground-level vegetation and provide a recruitment foci by enhancing seed rain of animal dispersed seeds (such as acorns or other heavy seeded species), facilitating establishment of other species, and providing structure and cover for forest sensitive species. Cluster planting or applied nucleation also has the potential to be a lower-cost forest restoration strategy when compared to plantations allowing for a potentially larger proportion of the landscape to be managed. Research suggests that larger nuclei are more effective at attracting seed dispersers and ameliorating harsh environmental conditions than smaller nuclei. Cluster planting strategies could be represented by different geometries but are often circular or square (See Appendix II).

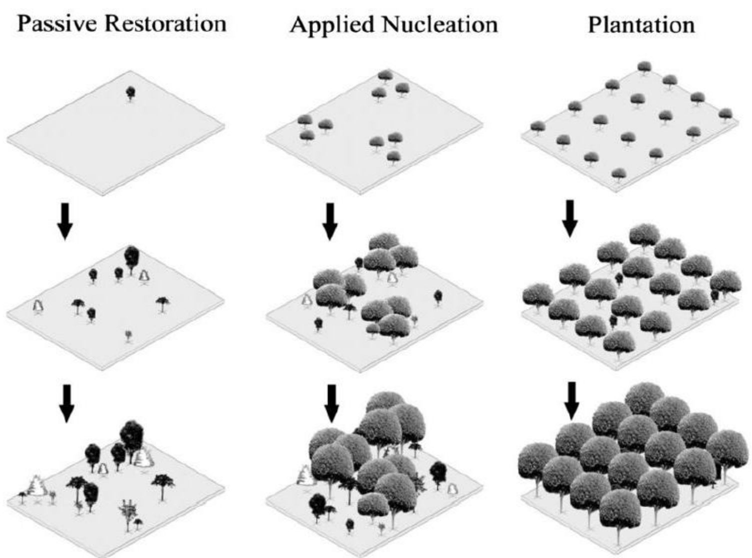


Fig. 1. Time sequence of three common strategies to restore forest cover: passive restoration, applied nucleation, and plantation. As each design ages (from top to bottom), tree cover expands via tree growth and colonization. Passive restoration produces a diverse forest community, although with the least forest cover of the three scenarios. By contrast, applied nucleation results in greater forest cover compared to passive restoration, and lower cover but a more diverse community compared to the plantation. For the sake of simplicity, only one tree type is planted in the applied nucleation and all the other species colonize naturally. In reality, nuclei and plantations could vary in species composition and the number of trees planted.

Figure taken from Corbin and Holl (2012).

Assisted Migration

Assisted migration or assisted gene flow is the translocation of populations of species within their natural range (figure below). Species with wide ecological niches are often locally adapted and as climates shift maybe maladapted to new conditions requiring movement to match new habitats that maintain ecosystem health and productivity (Gray et al. 2011). It is widely recognized and practiced in forest reforestation that species perform best where they are locally adapted. However, with the potential of hotter climates expected in California, assisted migration of species within their range or somewhat beyond their leading edge may help to reduce an adaptational lag whereby there is a mismatch between the genotypes in a population and the environment resulting from relatively fast environmental change and comparably slow evolutionary response (Matyas 1990). The selection of genotypes for reforestation should be pre-adapted to near future conditions (Aitken and Bemmels 2016). Genotypes selected from warmer and drier environments should be better adapted to planting climates than local seedlings where significant higher temperature is expected to occur (Aitken and Bemmels 2016). The seedlot selection tool developed by the Forest Service may provide guidance on matching seedlots with planting sites based on climatic information (https://seedlotselectiontool.org/sst/). It is recommended that managers consider planting a composite of seedlings grown from seed from more than one source population to increase diversity and the likelihood of success on drought-prone sites (Aitken and Bemmels 2016). This should include seeds produced from large individuals that survived during the period of extreme drought and may have beneficial but unknown genetic characteristics.

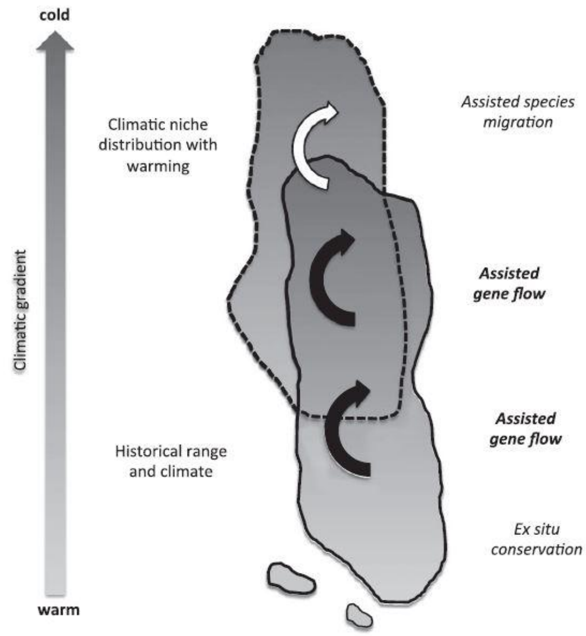


Figure 1 Schematic diagram of management options for reforestation and restoration in a changing climate. While this illustrates the northward movement of individuals, assisted gene flow may also occur along elevational or longitudinal climatic gradients.

Figure taken from Aitken and Bemmels (2016).

Increasing the use of Prescribed Fire

Moving forward with reforestation in high severity mortality areas, there is an overwhelming workload required for site preparation and to provide site maintenance using traditional practices to support reforestation. Due to the fact that there is such a large landscape to be covered and so much woody debris to be dealt with in different arrangements and configurations, as well as over an extended period of time, prescribed fire seems to be a useful approach to allow for a “clean slate” and maintenance for reforestation.

With or without high levels of standing dead and down woody debris, prescribed fire may reduce fine fuel loading, control competing vegetation, and expose bare mineral soil meeting multiple site preparation objectives by allowing for the establishment of natural or artificial regeneration (O'Hara 2014). To increase heterogeneity and reduce the need for cultural treatments (e.g., herbicides, mastication, hand hoeing) underburning could be introduced early in stand development with an understanding that seedlings will be susceptible to mortality from fire effects. Following the re-establishment of frequent fire, seedling mortality could be monitored and enrichment plantings made if mortality exceeds desired thresholds.

In order for prescribed fire to be implemented with efficiency it needs to be applied in a sequence that promotes future applications rather than just a single entry. However, the success and efficiency of the prescribed fire strategy is time sensitive in regards to the state of mortality (Stage 1: red and dead needles, Stage 2: no needles on trees, Stage 3: prominent tree failure/ heavy fuel loading). Each stage of mortality will require a different tactical effort and strategy for prescribed fire success. Ideally, prescribed fire entries will take place prior to the heavy occurrence of ground fuel loading (Stage 3). Successful understory burn treatments within "Stage 1" of the mortality phase, allows the following sequential entrees to have a higher success rate due to the reduction and maintenance of a lower ground fuel component. If the first entry is applied later during "Stage 2 or 3" control issues may hinder efficiency due to the resistance of control that will occur from the increased tons per acre and heat generation. Additionally undesired heat applied to the soils as a result of the burning of areas with high tons per acre may change the soil structure and or potential vegetation composition.

The proposed prescribed fire strategy for mortality areas is to:

1) Apply initial prescribed fire efforts during Stage 1 and the early part of Stage 2 but prior to reforestation with the objective of reducing the ground fuel component ahead of the tree failure of Stage 3. If applied under this timing, the severity and intensity of the prescribed fire effects will remain low.
2) The second entry of prescribed fire should be applied relatively soon after the initial entry in an effort to begin "jackpot" burning of the downed snags as they begin falling. At this time there should be a low accumulation of ground fuels allowing for a patchy burn pattern focusing on the jackpots of fallen trees and an easier ability to protect planted trees.
3) The third entry would mimic the second entry further reducing the new jackpots of fallen trees. This entry may produce additional spread rates as a result of the time passed since the first entry and new ground fuel from various sources.

Safety and future fuel loading will be the main factors limiting planting in stands with standing dead trees. Where feasible, underplanting of shade intolerant pines may be an effective regeneration strategy. Underplanting of pines with existing canopies has been successful in other regions of the United States following site preparation (Knapp et al. 2013, Kabrick et al. 2015, Knapp et al. 2016). However, this is not well understood in areas of high overstory mortality. Underplanting prior to the natural falling of standing dead trees will result in some inherent seedling mortality as trees begin to fall. This could be addressed either by planting at higher densities or by accepting overall lower seedling survivorship.

References

Aitken, S. N., and J. B. Bemmels. 2016. Time to get moving: assisted gene flow of forest trees. Evolutionary Applications **9**:271-290.

Collins, B. M., and S. L. Stephens. 2010. Stand-replacing patches within a 'mixed severity' fire regime: quantitative characterization using recent fires in a long-established natural fire area. Landscape ecology **25**:927-939.

Corbin, J. D., and K. D. Holl. 2012. Applied nucleation as a forest restoration strategy. Forest Ecology and Management **265**:37-46.

Gray, L. K., T. Gylander, M. S. Mbogga, P. Chen, and A. Hamann. 2011. Assisted migration to address climate change: recommendations for aspen reforestation in western Canada. Ecological Applications **21**:1591-1603.

Kabrick, J. M., B. O. Knapp, D. C. Dey, and D. R. Larsen. 2015. Effect of initial seedling size, understory competition, and overstory density on the survival and growth of *Pinus echinata* seedlings underplanted in hardwood forests for restoration. New Forests **46**:897-918.

Kane, V. R., J. A. Lutz, S. L. Roberts, D. F. Smith, R. J. McGaughey, N. A. Povak, and M. L. Brooks. 2013. Landscape-scale effects of fire severity on mixed-conifer and red fir forest structure in Yosemite National Park. Forest Ecology and Management **287**:17-31.

Knapp, B. O., G. G. Wang, and J. L. Walker. 2013. Effects of canopy structure and cultural treatments on the survival and growth of *Pinus palustris* Mill. seedlings underplanted in Pinus taeda L. stands. Ecological engineering **57**:46-56.

Knapp, B. O., G. G. Wang, J. L. Walker, and H. Hu. 2016. Using silvicultural practices to regulate competition, resource availability, and growing conditions for *Pinus palustris* seedlings underplanted in *Pinus taeda* forests. Canadian journal of forest research **46**:902-913.

Matyas, C. 1990. Adaptational lag: a general feature of natural populations. Paper Number 2.226. . Joint Meeting of Western Forest Genetics Association and IUFRO Working Parties, Douglas-fir, Contorta Pine, Sitka Spruce, and Abies Breeding and Genetic Resources. Weyerhaeuser Company, Olympia, Washington.

North, M., P. Stine, K. O'Hara, W. Zielinski, and S. Stephens. 2009. An ecosystem management strategy for Sierran mixed-conifer forests. USDA Forest Service, Pacific Southwest Research Station, General Technical Report PSW-GTR-220.

O'Hara, K. 2014. Regenerating multiaged stands. Pages 84-97 Multiaged Silviculture: Managing for Complex Forest Stand Structures. Oxford University Press, Oxford, UK.

Oliver, C. D., and B. C. Larson. 1996. Forest stand dynamics: updated edition. John Wiley and sons, NY.

Saha, S., C. Kuehne, and J. Bauhus. 2016. Lessons learned from oak cluster planting trials in central Europe. Canadian journal of forest research **47**:139-148.

Schönenberger, W. 2001. Cluster afforestation for creating diverse mountain forest structures — a review. Forest Ecology and Management **145**:121-128.

Appendix I

Years Post Mortality	Tree Height	Treatment	Cost per acre	Rx Fire Opportunities	Fire Risk
		Big Creek Stand Development, Treatments & Fire Risk			
0	* *	Insure adequate site prep.	</= $325	May be used for Site Prep.	
1	0.5	Plant. Foster natural regen.		None	Mod - High
2	1	and surviving saplings and	$525	None	Mod - High
3	2	poles. Release.		None	Mod - High
4	3	When Cluster Planting,		None	Low
5	4.5	remove all but one seedling	$250	None	Low
6	6			None	Mod.
7	7.5	Prune lower 3rd of branches	$180	None	Mod.
8	9	Underburn in the fall	$90	Fall only	Mod.
9	10.5			Fall only	Low
10	12			Fall only	Low
15	19.5			Spring low intensity or fall	Mod.
20	27			Spring low intensity or fall	Low - Mod.
21	28.5	Underburn, if feasible,		Spring low intensity or fall	Low - Mod.
22	30	otherwise thin trees and	>/= $90	Spring low intensity or fall	Low - Mod.
23	31.5	remove excess brush by		Spring low intensity or fall	Low - Mod.
24	33	hand or mechanically.		Spring low intensity or fall	Low - Mod.
25 - 45		Underburn	$90	Spring low intensity or fall	Low
45 - 55		Commercially thin & underburn		Spring low intensity or fall	Low

* * Stand initiation begins immediately following the stand-replacing disturbance and continues for about 25 years until some plants occupy the growing space and exclude new plants from regenerating.

Appendix II

Examples of variations in cluster planting strategies with multiple species.

Fig. 1. (*a*) Szymanski's (1986) nest design; (*b*) 7 × 7 m spacing between the centres of nests were generally followed in German nest plantings; (*c*) 23-year-old nest planting in Leonberg-Stuttgart, Baden-Wuerttemberg, Germany. [This figure is available in colour online.]

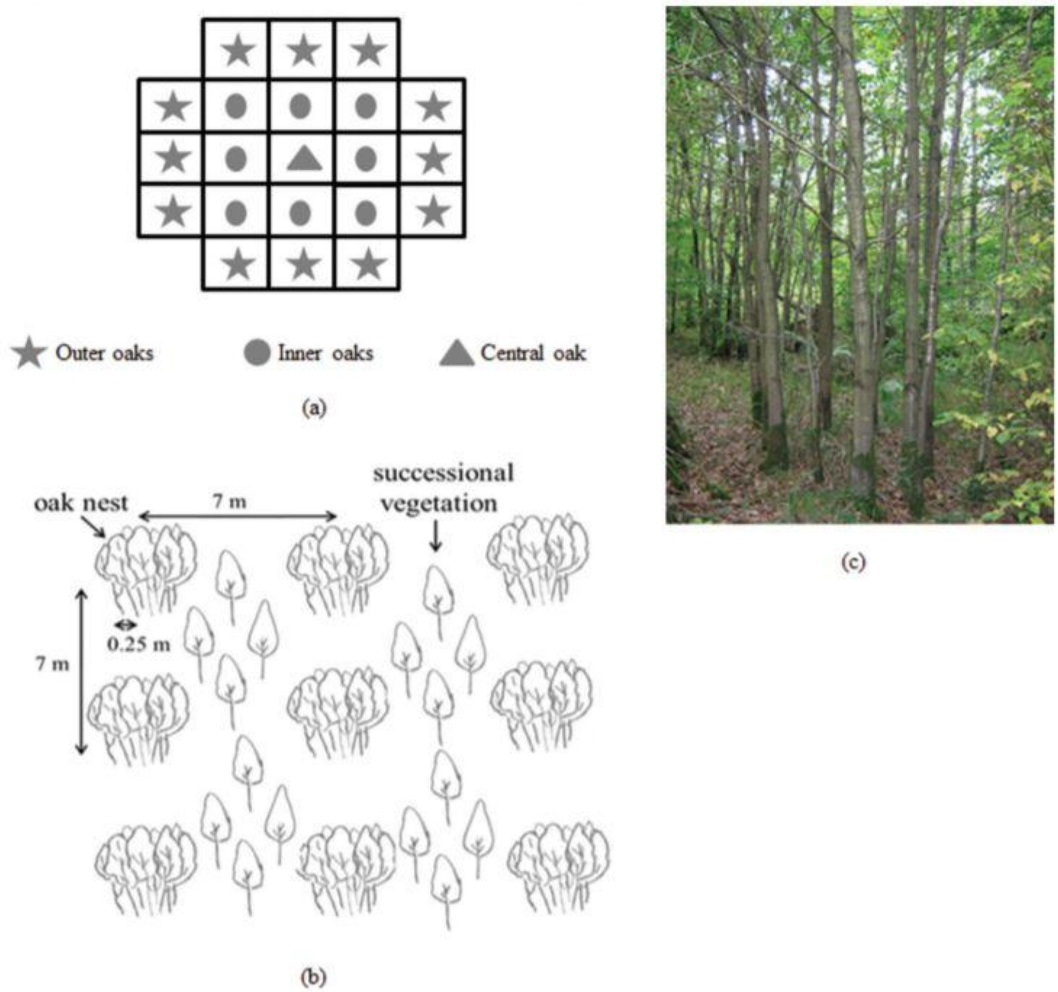
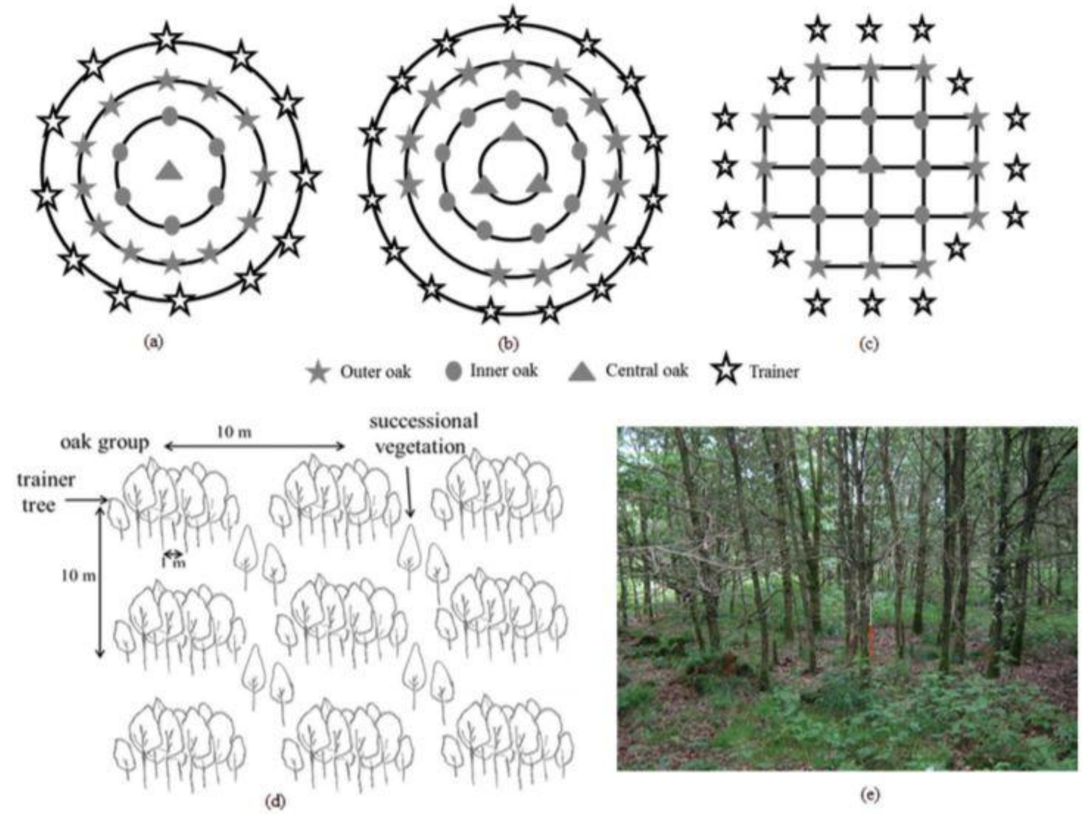


Figure taken from Saha et al. 2017

Fig. 2. (*a*, *b*, *c*) Gockel's (1995) group planting design with three variants; (*d*) 10 × 10 m spacing was commonly followed between the centre groups; (*e*) 20-year-old group planting in Lerchenfeld-Schwarzenborn, Hesse, Germany. [This figure is available in colour online.]



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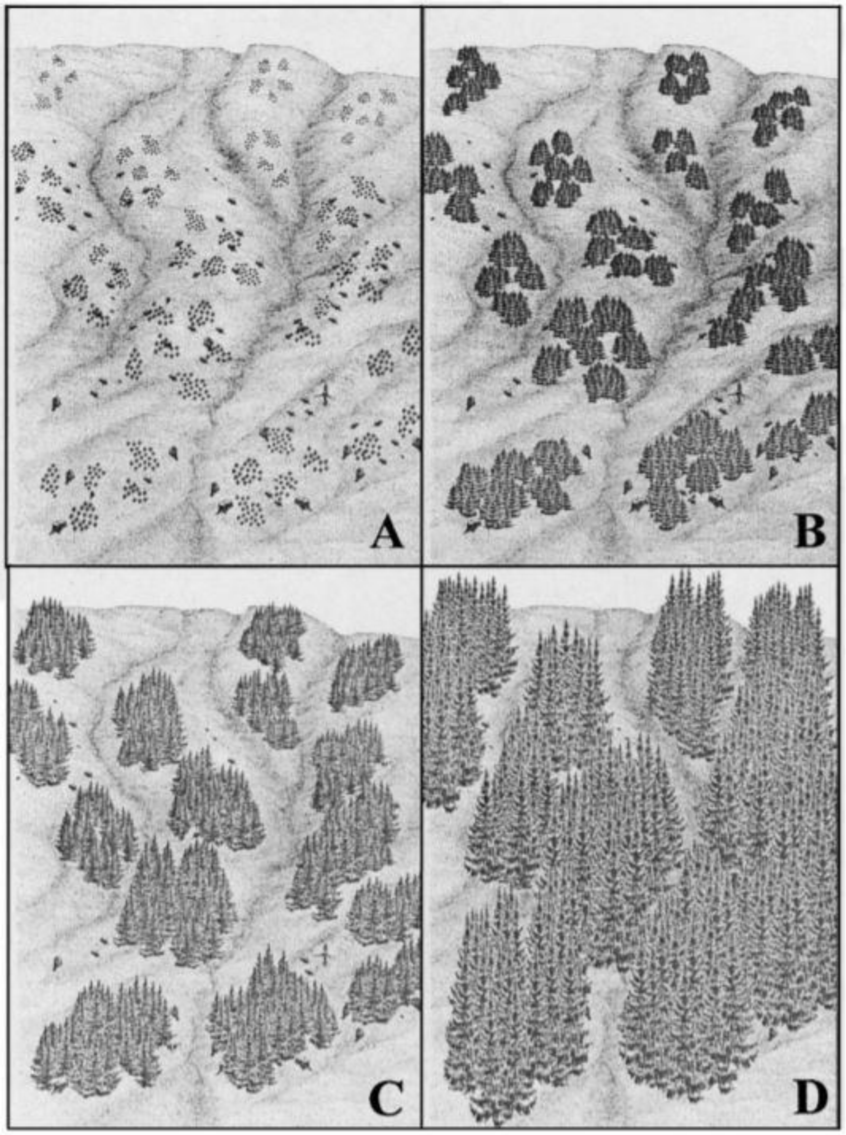

Fig. 1. A hypothetical development of a cluster afforestation with Norway spruce. (A) At the time of planting: "small collectives" of 20–30 seedlings, 2–4 m diameter and 2–3 m distant, seedling spacing 50–100 cm; (B) Five to ten years later, when seedling crowns close within the still separate "small collectives"; (C) Two to three decades later, when the "small collectives" will merge to form the final "clusters"; (D) Mature stand: the "clusters" remain distinct and touch each other only in places. The "small collectives" are no longer visible.

Figure taken from Schonenberger 2001.

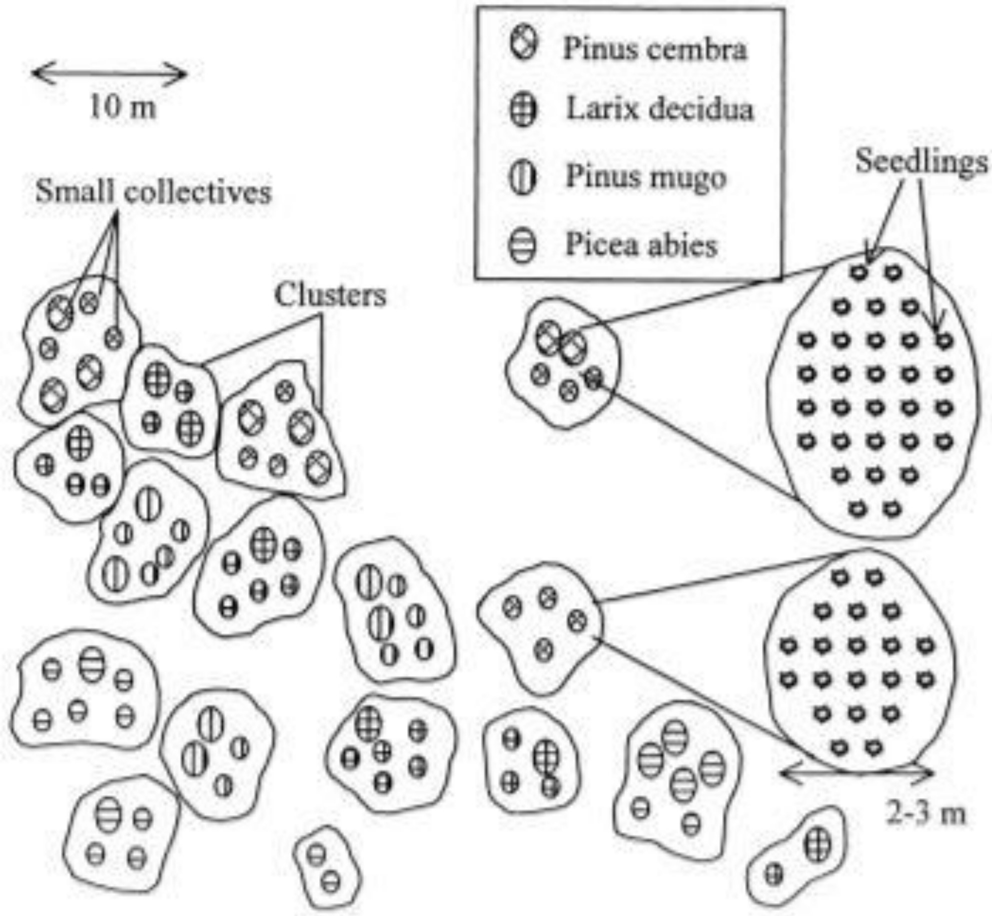

Fig. 2. Map of the cluster afforestation trial Mustair. 17 "clusters", each composed of 2–6 "small collectives", containing 20 or 30 seedlings each.

Figure taken from Schonenberger 2001.