Silvicultural recommendations for the management of ponderosa pine forest

ENGLISH

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In a nutshell

Ponderosa pines are the most important timber producing species in Mexico, and they also represent a major portion of the USA and Canada timber production. These pines form near pure stands with simple and stable stand structure. They suffer only occasional disturbances, and they sustain a limited capacity to hold biodiversity and other senvironmental services. The driving force in the stand dynamics is a need for direct light during all their lives. Most ponderosas can successfully regenerate under partial shade, but they must be released soon afterwards. Seedlings appear almost immediately after upper canopy removal, even in years of poor seed production, as long as a thin litter and duff layer forms a proper seed bed. If no such organic layer in the soil is present, leaving partial shade of 40 to 60 % from the overstory will provide protection until vigorous and uniform regeneration can close crowns.

The high demand of light by ponderosa pines tend to require low stocking with all trees in the dominant or codominant class. Low stocking can occur naturally, or it can be the outcome of thinnings. Ponderosa pines are prone to large periods of stagnation from overstocking. Shoot borer damage is common in overstocked stands. These problems can be prevented by opportune thinnings. Other health conditions are of no special concern. Ponderosa pines resist fire, and they are less susceptible to bark beetles than most other pines they associate with. Their capacity to thrive in very low stocking conditions, with grass in the understory maintained by frequent fires, creates low timber productivity scenarios that can sustain considerable amounts of game, and high yield of high quality water runoff. Ponderosa extensive distribution and the diverse species and varieties in the group suggest a formidable capacity to adapt to sites. They might fare well under climatic induced changes.

This work is intended a set of ideas and tools to help in the decision making of ponderosa pine forest management of North America. Emphasis has been given to Mexican management situations.

Foreword

The aim of this work is to become a practical tool to help manage ponderosa pine forest. This work is sponsored by the North American Forest Commission. Prescriptions suggested in this document have benefited from published research, and they are close to the state of the art. None the less, the value in this document stems from suggestions from experienced foresters that designed and currently practice these ideas. In this context, the recommended silvics of ponderosa pine forests is described next.

Contenido

Core concepts

Silviculture is an art, a technology, and a science with a long history and a global scope. Tradition runs deep into silvicultural thinking, more so than its scientific foundations. Siliviculture began in the Middle Ages in central Europe. From this cradle all internationally important ideas started. Today silviculture still follows closely the logic of its roots, namely tradition, experience, custom, law, and cultural trends from each region where it is practiced.

If silviculture were merely a rational process to produce wood or any basket of products and services, or if silviculture were a means to preclude exposure to risks coming from the forest, then in no time silviculture would be replaced by agronomic schemes like those used for perennial crops such as fruit orchards. To a great extent plantation forestry and tree farming already are more agronomic than forestry schemes, they even can be considered agrarian in nature. Efficiency conveyed by agronomic designs reduces competitiveness of products from natural and artificial forests.

Products that ponderosa pines yield are forest products, not agronomic products, and it is this form of natural production that this document is designed for. By no means productivity and stability of ponderosa pine production in Chihuahua or British Columbia will ever outrun the competitive edge of exotic plantations in Brazil, as for example those in Fearnside (1998). Eucalypt plantations in Brazil have reached an annual yield of 80 m^3/ha in the best sites, and 35 m^3/ha per year is considered standard yield in the typical site. These figures are off the chart for ponderosa pine anywhere it is planted.

Recent world forest history conveys the message that something must be done with the millions of hectares of ponderosa pine forests in the Americas. It is not only a matter of how extensive and essentially inexhaustible they are, but it is because of the many very special combinations of products and services they can render to society. This opportunity is enhanced by forestry thinking. According to forestry ideas, natural variability is to be ruled, not vanished as in agriculture.

This is why silviculture is a way of production where rationality yields way to cultural preferences. Silviculture is more an art, a way of thinking, a style that allow individuals live with, and enjoy the varied responses displayed in the wide spaces where forests respond to environmental, cultural and political processes.

A different factor that defines trends for ponderosa pine silviculture is land tenure. In the case of Canada and the USA, although there is quite a bit of private and corporate forest land, by and large most ponderosa pine forests are in public lands. In the Mexican case practically all ponderosa pine forests, and most other kind of forests, are privately owned. In Mexico there are two forms of private ownership: groups (ejidos, comunidades), and individual property (small private land). In absence of extensive areas in the hands of individuals, small businesses, international corporations, and most of all in absence of public ownership, silviculture possibilities are reduced to those schemes that can offer a continuous flow of income to the owner, whether or not there is any profit from growing timber, and regardless of the patterns in cash flow or investment needs that may arise.

Harvest revenues must pay for daily expeditures in a Mexican forestry business, since there are no financial instruments for forestry. There is no specific regulatory restriction on financial institutions limiting their involvement in forestry, it is only a matter of cultural expectations. Hence, forest planning ought to consider unfeasible those silvicultural regimes that have a need for continuous expenditures early in the rotation, and revenues latter on. These limitations are implicitly accepted in the national goals where forest is not an economic activity but a support for rural communities.

Land tenure also shapes a certain profile of the forest owner. Multiple roles for the owner as manager, entrepreneur, worker, logger, and even assistant to the forester, they all explain that important silvicultural decisions are constantly revolving around diverse considerations on self-employment, working only on certain seasons in the year, ups and downs in the market, and legal strategies. Silvicultural treatments stand a better chance of being implemented if they are compatible with the forest owner’s multiple criteria and concerns.

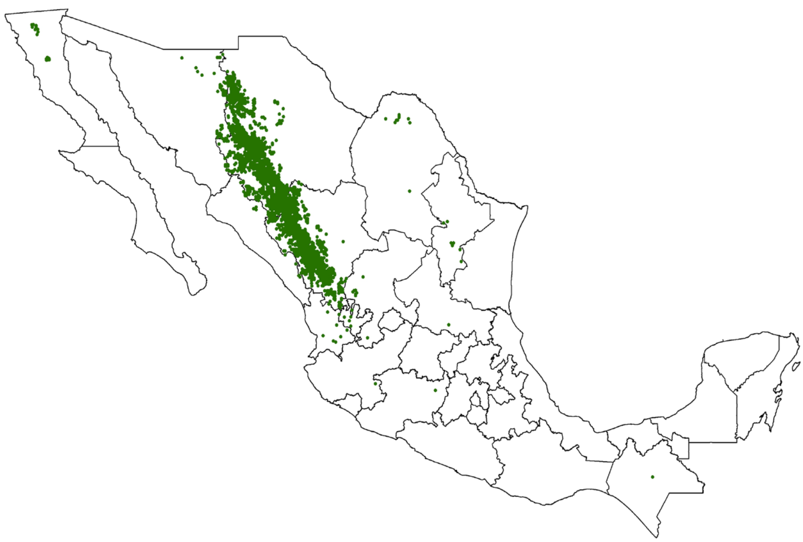
Creating a catalog of silvicultural possibilities for ponderosa forests, with special attention to Mexican conditions, but including the rest of the subcontinent, is a process of exploration about regional forest knowledge and tradition. The aim in this document is to offer a select set of practices that fit into today's natural, cultural and legal scenarios.

This work refers specifically to the sylvics of *Pinus arizonica*, P. durangensis, P. engelmannii, *P. ponderosa*, and P. jeffreyi, and to the species associated in the same forest type where ponderosa pines occur.

Figure 1. *Pinus durangensis* cones.

Distribution and communities where ponderosa pines grow

Ponderosa pines are part of the temperate conifer forests in mountain ranges, particularly Sierra Madre Occidental, and the Rockies. Typical *Pinus ponderosa* grows with the coastal pines in the Pacific coast, including Baja California. *P. ponderosa* var *scopulorum* is a frequent component of the conifer mix in the Rocky Mountains of the Usa and Canada. (figure 2).



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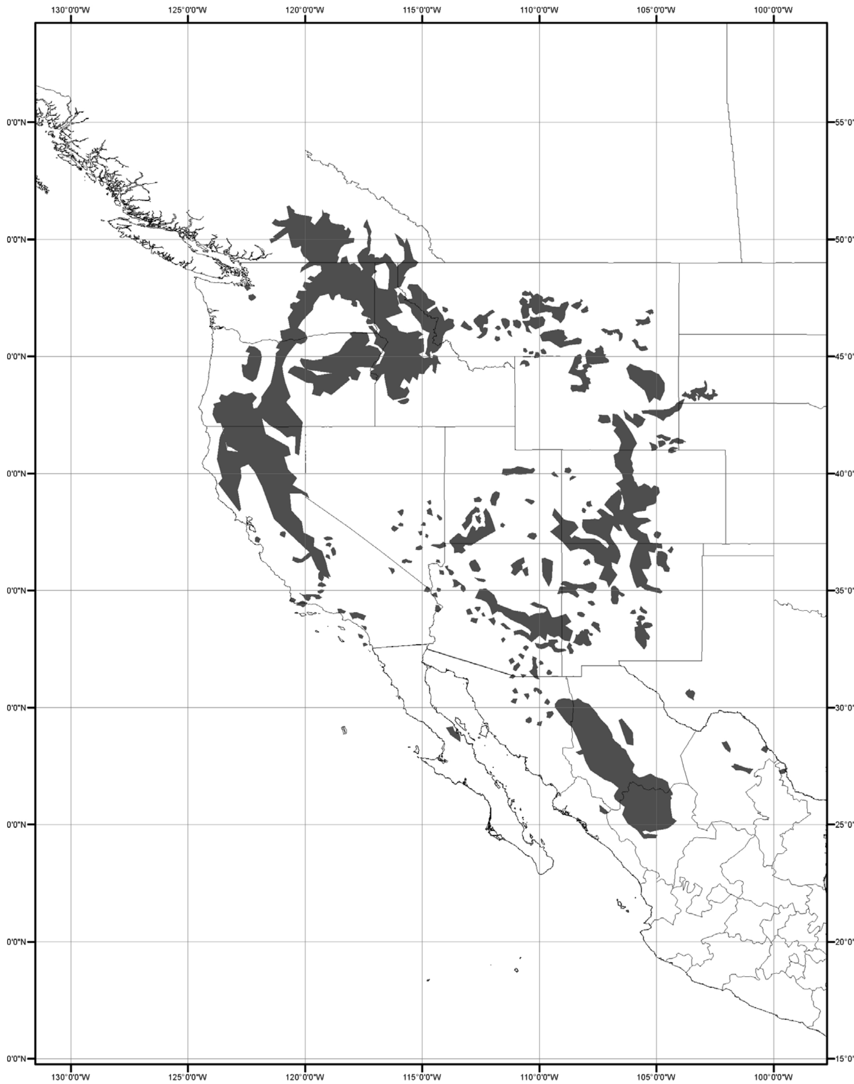

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Figure 2. Distribution of ponderosa pin especies in Mexico, A (Inventario Nacional Forestal y de Suelos, CONAFOR 2012), and North America, B (Oliver and Ryker 1990).

Composition in these forests changes within each region. Ponderosa pine from the Rockies associates with other pines (Oliver and Ryker 1990), such as lodgepole (*Pinus contorta* Dougl. Et Loud.) , and western white pine (Pinus monticola Dougl. Ex D. Don). It is also frequent to see ponderosa pine along other conifers (*Pseudotsuga, Picea, Tsuga, Abies, Larix*). Understory vegetation is characteristic of each region (Daubenmire 1968).

In Sierra Madre Occidental ponderosa pines start at the northern edge, where *Pinus arizonica* dominates, even reaching into Arizona and New Mexico. Southward this pine is replaced by P. durangensis, sometimes mixed with *P. cooperi*. Other overstory trees present include *Quercus, Arbutus, Juniperus,* and pines such as *P. lawsonii*, *P. chihuahuana*, P. ayacahuite in the dryer, sunnier sites with moderate to steep slopes. Moist, protected sites occasionally are covered with *Pseudotsuga*, *Picea*, and *Abies*. Most stands are dominated by a single species, with scarce presence of other species.

Pinus arizonica grows in all suitable ponderosa pine sites in Chihuahua, but it only appears in the northern part of Durango in sites with moderate slopes and flat ground. *Pinus cooperi* forms nearly pure stands in flat ground and high elevations. Whenever there is any slope, or in protected areas, stands are made up of *Pinus durangensis*. Transitional belts are made of rustic pines (*Pinus lawsonii*, *P. chihuahuana*), and other taxa (*Juniperus*, *Arbutus*, *Arctostaphylos*, *Quercus*) that prefer xeric conditions. Best soils are taken over by trees requiring mesic habitat (*Quercus*, *Picea*, *Abies*, *Pseudotsuga*, *Pinus ayacahuite*), and they also dominate in the most rough terrain and creeks, where they are protected from wind. Sunny places, such as flat ground, sites with southern exposures, disturbed sites, and mountain tops are also occupied by xeric conifers and broadleaves (*Pinus lawsonii*, *P. chihuahuana*, *Juniperus*, *Arbutus*, *Arctostaphylos*).

Reproduction

Reproduction is strictly by seed. When winged seeds are released from the cone, they are easily dispersed by wind. Extreme distance of seed fall is approximately one tree height (30 m), plus the effect of wind, topography, and obstacles (Oliver and Ryker 1990).

For regeneration purposes, annual seed production is sufficient even in poor years. There is a prolific seed production every 4 to 7 years, but this is not required for successful regeneration of a site, despite losses due to seed predation. Seeds need direct sun light to germinate. It is rare for seeds to germinate under closed canopy because of the change in light colors reaching the soil.

In Mexico and in the coastal USA, when a site is covered by ponderosa pines, they will be replaced by themselves after stand replacement disturbance or regeneration treatment. In the Rockies ponderosa is an early seral stage species (Alexander 1986); composition might regress to lodgepole pine (*Pinus contorta*) after severe disturbances that open wide spaces in the canopy. Usually regeneration of the next seral stage arrives if change is minor, there is partial shade and mesic environment. After ponderosa pine, the next stage is made up of firs like *Pseudotsuga mensiesii* (Mirb.) Franco.

Seedlings do well on organic soils and partial shade (20 to 40 %), constant humidity, benign winters, fertile mineral soil at no more than 15 cm (6 in) depth (figure 3). Absence of organic layer creates a risk of water freezing in the soil, killing the smaller seedlings. Frost heaving is a frequent event in frost pockets where air temperature near the ground might drop beyond freezing if canopy is removed. In frost pocket situations it is better not to clearcut but to retain some 40 to 60 % of the stocking. However, if soil is covered with organic material (less than 15 cm, 6 in), if there is some slope and the ground is broken, covered with brush, or has rocks, there will be no frostheaving, and establishment of all ponderosa pine species will be prompt, abundant, and vigorous any year if the upper canopy is removed. The use of mulching may also prevent frost heaving. Successful recruitment stops at crown closure.

Successful regeneration under partial shade.

Strong apical dominance indicates vigor and high quality of regeneration.

Natural organic matter.

Mulching applied when there is not enough organic matter.

Figure 3. Mineral soil covered with organic layer or mulch, and availability of partial shade foster abundant vigorous stablisment of *Pinus durangensis* in El Salto, Durango. Photos: MMendoza.

Wide canopy openings may lead to invasion by grasses, and hinder pine establishment. Largest advisable opening is 300 m (1 000 ft); if the opening were larger, regeneration might fail in some spots, and some trees would develop as wolf trees. Wolf trees are open grown trees with long crowns reaching down near the ground. They are slightly shorter in height for their age, prolific, prone to shoot borer damage.

The smallest canopy opening that allows at least one seedling succeed is around 15 m. For instance, for *Pinus arizonica* in central Chihuahua (San Juanito and Creel), the minimum basal area that permits successful regeneration is 6 m^2, although weak seedlings start to appear at 12 m^2 basal area. These figures also help in selecting extreme residual stocking during thinnings to avoid undesired regeneration.

For *Pinus arizonica* the best regeneration is in flat ground, or south facing slopes of less than 15 %; however, this species is capable of reproducing in any sort of slope and aspect (figures 4 and 5).

Figure 4. Shaded conditions and their effect on crown structure in *Pinus cooperi* saplings in Durango. Photo: MMendoza.

Figure 5. Sunny conditions and their effect on lush foliage in *Pinus cooperi* saplings in Durango. Photo: MMendoza.

Growth

Ponderosa pines development is defined by available light. Interference between neighbors begins about the time crowns touch each other. The levels of interference can be significant without leading to death by competition. However, interference has drastic effects on crown architecture. As soon as branches of neighboring trees touch, both stop growing; if a branch is shaded by another, it will be shedding its foliage, and eventually it will die and fall naturally (figure 6).

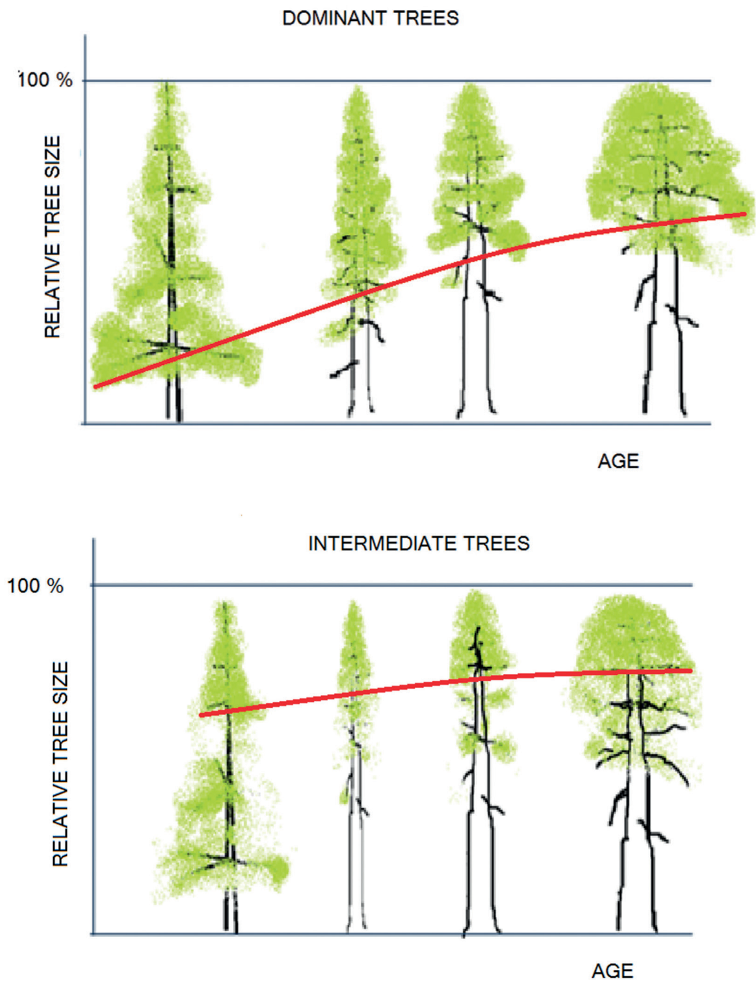

Figure 6. Dominance at different development stages, and its effect on crown length percentage.

Trees that border with permanent clearings tend to develop flag shaped crowns; that is, branches expanding towards the open ground will be long, persist for extended time, and have abundant foliage. On the contrary, branches pointing towards the forest have as little foliage as any other tree in the wooded portion of the forest, and natural pruning will keep crown length close to normal for forested conditions. Edge effect gradually diminishes towards the forest interior, and it disappears about 30 m inside the stand. Border trees grow shorter because of the adverse and fluctuating environment. Their morphology is full of defects because of the environmental stress (figure 7).

Figure 7. Edge trees, *Pinus arizonica*, Chihuahua. Photo A.Quiñonez

Growth figures reported in research estimates only inner forest conditions. When managing ponderosa pines it is important to estimate area affected by edge conditions, and decrease inner forest estimates to a more realistic level that accounts for the changing and stressful environments near the tree edge. A similar provision is needed to consider differences in health, risks from animal damage, pests and diseases, weather damages, and changes in probability of death, since these factors are more important than in the forest interior. In the future it will be increasingly important to follow specific management regimes for transitional and interphase conditions because these sites are ever more frequent.

Extreme longevity in ponderosa pines reach over 300 years in the most favorable sites; it is close to 150 in most other places. Largest diameters ever recorded are close to 1.3 m (4' 3", Amilcar 2005). Extreme density can pile up a basal area of 30 m² (145 ft/ac., Chacón 1998).

Models

Among the wide variety of published quantitative depictions of ponderosa pines only one, model Arizonica, is complete enough to portrait the ponderosa pine forest in response to silvicultural treatments in a way that it displays the required diminishing returns to scale, as demanded by economic analysis. This model is an adaptation of the Prognosis model (Wykoff *et al*. 1982). Prognosis was developed for mixed conifer forest from the Rocky Mountains, and therefore it includes Pinus ponderosa. Prognosis structure is described in Mendoza (1985), Islas *et al*. (1988), and Islas and Mendoza (1989), and its parameters are presented in the Annex. Arizonica was not independently validated.

Sicremars model is the creation of Valles (2007). The model scope is limited to *Pinus cooperi* from a single permanent experimental plot named Cielito Azul, located in San Dimas, Durango. It was established in 1966. It follows an experimental design with six treatments, and six repetitions of one hectare each. Remeasurements have occurred in 1979, 1982, 1986, 1993, and 2004. Since Sicremars represents a single site, and the site is not pure *Pinus cooperi*, but a mixed conifers and broadleaves stand, it is of little value to this document. However, it can be a role model to follow in future developments that will inherit its meticulous procedures and independent validation. So far two versions have been released. Annex shows Sicremars version 2.

Although it is not published, there is one more model worth mentioning. This model is referred to as Durango´s Biometric System (Vargas *et al*. 2012a, Vargas *et al*. 2012b), and it is intended to model characteristic species and forest types of Durango. As of today selected equations have been published for two forest units: UMAFOR 1006 San Dimas, and UMAFOR 1008 El Salto, Durango. Appealing features in Durango's Biometric System include the use of permanent observation plots (so far no remeasurements yet), stem analysis, and rigorous statistical testing of goodness of fit. Equations that are known to exist for Durango's Biometric System include volume, bucking rules, and site index (Annex B).

Since fully fledged simulation models with regional coverage are not at hand, it is still practical to use preliminary parameters derived from density diagrams. In this case there is a density document for *Pinus durangensis* (Chacón 1998), and a more recent version (figure 8) by Centeno (2013). The diagram for *P. arizonica* by Zepeda (2011) is also worth mentioning.

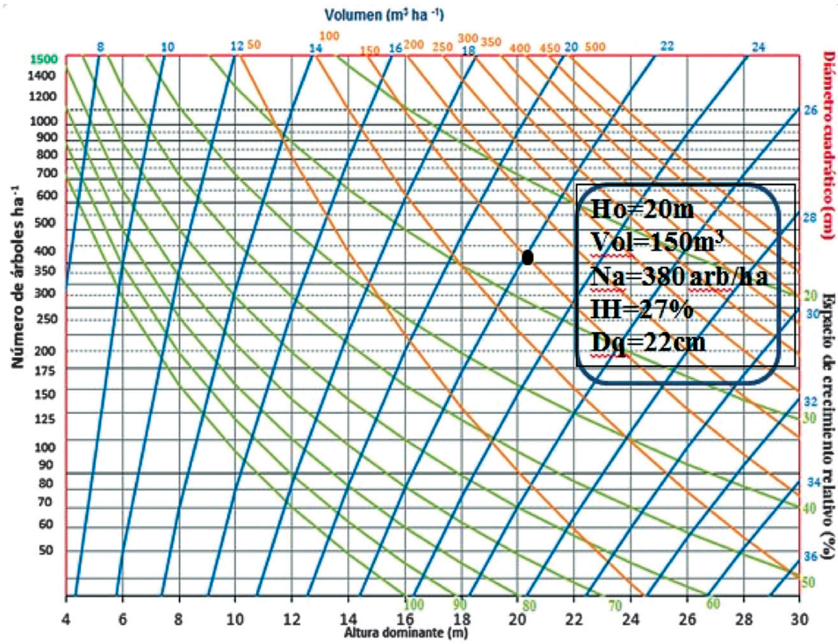

Figure 8. Density diagram for *Pinus* durangensis from Ejido La Ciudad, Pueblo Nuevo, Durango. After Centeno (2013).

Health and resilience

Ponderosa pines are susceptible to barkbeetles (*Dendroctonus rizophagus* Thomas & Bright), during their establishment. These beetles enter by the collar and the lower stem.

High density and shaded sites favor crown defects. These abnormalities are produced by shoot borer damage (Eucosma). Bud problems and rounded crowns are common to see in *Pinus arizonica* in poor sites that lack organic matter. Many times these soils also have aluminum and iron toxicity. This condition is characteristic of the Chihuahuan plateaus. Juvenile ponderosa pine species are susceptible to barkbeetles and shootborers. These problems decline with age. This is not so in the case of xeric pines (for instance *Pinus chihuahuana*, *P. lumholtzii*); these other species tend to occupy the less productive sites, and they also mix with ponderosa pines in nearby stands.

Ecology of ponderosa pines

Ponderosa pine and associated species follow dynamic patterns defined by their position in light to shade gradients. Best simulation models (e.g. Sicremars, Sat Dgo), offer growth estimates that strongly respond to crown parameters and other related variables. Crown length and other crown parameters also drive density, competition and interference indices, thus relating these indices to crown architecture. These mathematical models are only simplifications of the crown structure, and for that reason they overlook the very important statistical variability.

Quantitative representations are unable to grasp many of the important features of the crown, such as foliage exuberance, leaf color, crown symmetry, apical leadership, foliage retention, internode size and variance, branch angle (falling with age), or natural pruning. Indices best performance occurs when depicting growth and mortality in response to crowding, however, these estimates weight lightly in silvicultural decisions. Hence, in this document it is convenient to add a few more explanations about the young population dynamics as driven by crown differentiation.

Crown social status is expressed as dominance class within a single canopy layer in pure and mixed stands. In the extreme case of a tree of any size and development stage that uses as much space as it can without interference with neighbors, it will continue expanding its crown and growing without limitations. This tree is called a dominant tree. As available space shrinks with time, the tree crown will encounter other crowns and its expansion will no longer be in all directions. Crown shape will be more and more irregular, starting as dominant, then codominant, intermediate and dominated conditions relative to the rest of the crown canopy. There will be a moment when available space will be so tight that the tree would die. This space would be the minimum viable area that would allow a tree to grow. Crown dominance has a direct effect on mortality, health, growth, and anatomy of the tree. Dominance defines tree quality (figure 9).

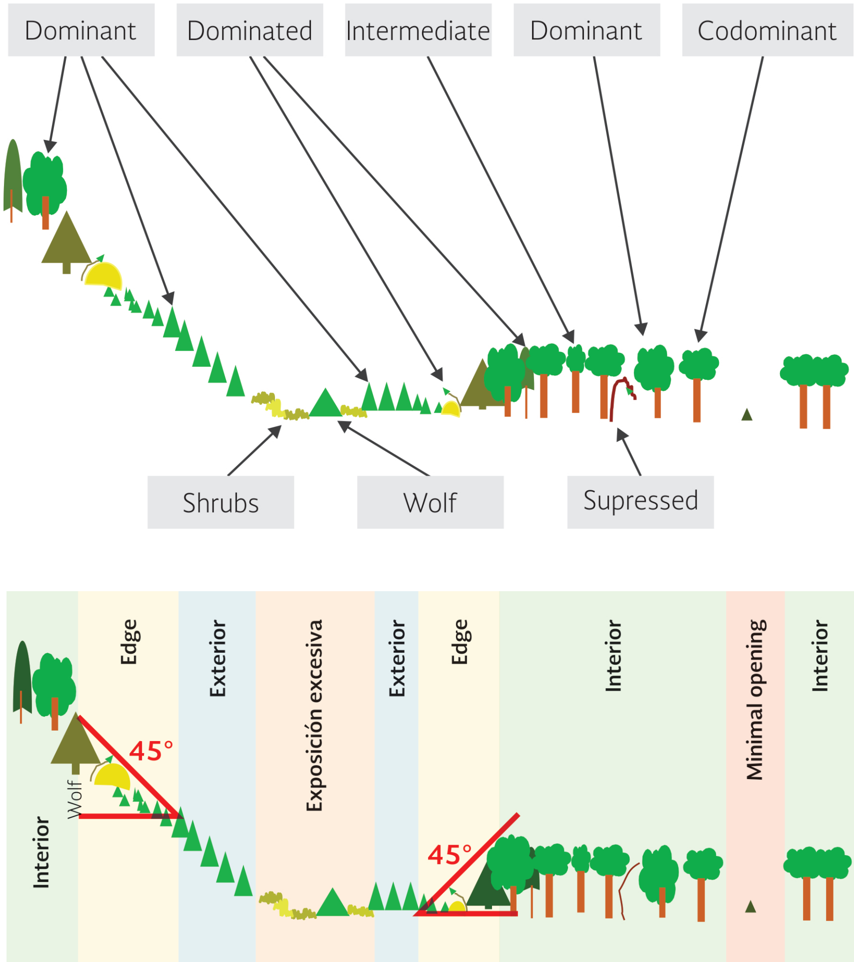

Figure 9. Border effect and gradient response to transition from interior wooded conditions to highly exposed open ground.

Terrain under a tree crown may be considered occupied. Complete occupancy means that the tree is dominant or codominant. Spaces in between crowns drive crown expansion. For instance, border trees in dense stands facing clearings after a while will tend to stop self pruning on the open side, but pruning will continue on the shaded side. Many times branches remain down to the ground on the clearing side. Stronger winds and wider environmental variability on the exposed side make border trees shorter in height than same age trees in the woods, even though foliar area of border trees might be larger.

Open grown treesw, or wolf tres, are those who has received unlimited direct sun light from all directions, their entire life. In these trees height growth is damped because of the changing and hostile environment they live on. None the less, wolf trees sustain lush foliage, branches starting from the ground up, crowns are symmetric, conic, and buds are prone to shoot borer damage.

Understory in the interior forest seldom contains ponderosa pines regeneration, even when seed fall may be considerable in fully stocked, and overstocked stands. Seeds contain physiological mechanisms that prevent germination. The few seedlings that appear are of poor quality and health, and they die shortly afterwards. There may be places where spots of sunlight allow establishment of one or a few seedlings. These seedlings tend to live for many years, some times over 70 years, but they will never reach the higher overstory. After some time, around 15 years in *Pinus arizonica*, 5 years in other ponderosas, individuals lose their ability to respond to release.

Incomplete, asymmetric crowns, scarce, grayish foliage instead of bright green leaves, are indicators of poor vigor of shaded trees. A close examination of these individuals, comparing them with similar age trees developed under open canopy conditions, reveal smaller buds. The apical bud may not be the largest or tallest bud in shaded individuals. Weak terminal dominance may produce lateral branches growing upwards and reaching a height similar to the terminal bud. Shaded trees have thinner weaker, darker shoots, numerous softer bracts crowding each other, much more than in a vigorous tree, where shoots are of lighter red or orange colors, and bracts are hard and widely spaced.

The smallest canopy opening that is suitable for high quality regeneration establishment and development until maturity, is around 15 m (50 ft); this is the recommended opening size if individual selection silviculture were to be used for ponderosa pine stands. If openings were larger, more seedlings can succeed in taking over the available space. Regeneration develops as soon as an opening appears in the upper canopy, provided suitable seed bed and seeds exist are present. The resulting new generation will then be evenaged, and it may be pure or mixed in composition. As soon as new trees shade the ground, no new incoming seedlings can get established.

The largest evenage group that ponderosa pines temperament permits is around 300 m (1 000 ft) wide, though it varies because of wind direction, aspect, and organic matter soil cover. Larger openings tend to develop adverse ecologic conditions in the central portion. Few individuals will be able to grow there even if seeds were plentiful, most seedlings would die. The few trees growing at the center of large openings will develop as wolf trees.

Ecological influences from wooded surroundings, and irregularities in terrain topography, presence of herbs, forbs, shrubs, large woody debris, litter, duff layer in the soil, all those factors define site variability and thermal insulation structures. Site variability prevents the soil water from freezing when air temperature falls below zero Celsius degrees (32° F). In the case of limited variability, regeneration establishment would occur sporadically, or grasses will take over the site preventing trees to get established.

Recomended silviculture

Ponderosa pine species have similar temperaments and behavior, as explained above. However, it is important to keep in mind that this forest type is growing in most of the North American subcontinent, and populations should be expected to fit particular features in their respective locations.

The following silviculture recommendations and specifications are meant to address all species in the ponderosa pine forests, unless otherwise indicated for specific cases. Using these general guidelines imply a need for talent, experience and creativity of professionals to adapt to local conditions. Industry and government officers should provide enough freedom for professional criteria to modify these guidelines as needed by objectives and circumstances of specific cases.

The most common silvicultural regime, as described next, involves a local species, but it can also document the development of introduced species or varieties that fit latitude, slope, aspect, soil type, and vegetation cover. For instance, the Chihuahuan plateaus are mostly covered by *Pinus arizonica*. This species also grows in the northern sierras of Durango, but it is replaced southward by *P. durangensis* if site has some slope, deep soil, humidity and fertility. On flatter less productive sites *P. cooperi* would be dominant pine. The transitional belt down the valleys in Durango and Chihuahua is covered by oak and juniper, and this is where *P. engelmannii* grows best, although the species is capable of living also at higher altitudes. These patterns suggest how far and in what direction genetic materials can be planted outside of the current range.

Regeneration

Wide plasticity and rusticity are characteristic of the ponderosa pines. They yield considerable amounts of timber and other products, and meet diverse production objectives. Although they fit well in every region they are native from, plasticity makes it possible to successfully introduce them in a wide variety of additional sites, though moving them to higher latitudes or elevations is not advisable. Ponderosa pines can be reproduced using a diversity of silvicultural treatments.

Any harvest regulation algorithm can be used to define the amount of land area to regenerate in a given year. Total regeneration area may be broken into cutting areas of sufficient size. Each cutting block will be composed of specific stands according to the scheduling procedure in the regulation algorithm. Minimum final harvest area should be no less than 20 m wide, and the maximum should be under 200 m. Regeneration treatment area can be of any shape: round, rectangular, or even irregular. All upper story trees should be removed. If the opening is larger than 60 m wide, it is advisable to leave uncut islands that contain none or few commercial size trees, but snags, large woody debris, underbrush, and top soil. These legacies can represent between 10 % up to 60 % of the treated area.

Retaining seed trees or some amount of shelter overstory may offer a more uniform seed coverage in every corner of the cutting area. They will also provide partial insulation preventing freezing in the soil and frost heaving of young seedlings. In any case, for most conditions in Chihuahua and Durango, complete removal of overstory is the default recommendation, as long as it would not lead to harsh conditions at the center of the opening.

Seed germination bed should be at least 2 cm deep (1 in), but less than 15 cm (6 in). This organic layer can be composed of litter, duff, humus, and any other form of organic matter.

Additionally, a load of 150 ton/ha of coarse woody debris would be ideal; at the least 60 ton/ha is necessary. More than two bare soil spots larger than 10 m^2 is not acceptable.

Scarification in spots around 2 m^2 (20 ft^2) is the preferred site prep method. Enough of those spots should be placed so that incoming regeneration will eventually cover completely the harvest area. Target stocking should consider preexisting seedlings, and groups of shrubs and perennial forbs that are natural components of the stand biological diversity. Prescribed burning can also be used as an alternative site prep method. Fire may be used to reduce excessive fuel load, and to reduce the relative proportion of the smaller fuels.

Invasion of grasses can be avoided by retaining as many forbs as available. When grass is present, or it can be a significant threat, fire should be avoided, and silviculture should strive to produce as much shade as possible by maintaining high stocking levels. Sites already dominated by grasses can be treated mechanically in ways that overturn the grass and expose its roots to air and sunlight.

Presence of dwarf mistletoe (*Arceuthobium*) on any ponderosa pine is unacceptable at any level of damage. If mistletoes are growing in the canopy, the regeneration treatment should be a complete removal of overstory in no less than 70 m wide openings; every tree having even a single mistletoe broom must be felled. Seedlings that appear near the edge of the harvest area should be frequently monitored, every two years or so, to detect mistletoe damage in them. Pruning the mistletoe brooms or the affected branches may control lightly affected zones. Removal of regeneration and adult infected trees may be necessary to manage more intense events. Planting with any resistant suitable species is a last resort that will maintain the timber production objective in affected locations.

Mistletoe over juvenile ponderosa pines, and even mature stands not scheduled for regeneration may be ignored if severity level is less than 3 in the dwarf mistletoe rating scale (DMR, Geils *et al*. 2002). Intensely affected trees should be removed during the subsequent thinning.

Regeneration groups of any size should be visited every three years. Release should be prescribed for them if adult border trees cast any shade over the regeneration, and release should occur before damages are visible.

Spatial arrangement of regeneration groups will shape the future stand structure. Intensively managed stands generally will remain in the early successional stages, such as initiation (crowns do not touch) during the entire rotation. For many biomass or pulpwood production objectives it is reasonable that stands may reach moderate exclusion stages (partial interference between crowns that stop short of producing suppressed trees). Density in these productive stands should be regulated to maintain full occupation of the site by the minimum number of trees possible. These conditions should persist from stand formation up to final cut. This goal is easier to attain in plantations and in natural stands where spontaneous regeneration is complemented with planted stock.

On the other hand, repeated application of regeneration treatments in close proximity, after several hundred years develop complex diversified structures. In due time these structures mature and form old growth stands. Late successional conditions are identified by dead and downed materials accumulated on the ground. In functional old growth even the largest woody debris has had time to decompose, but the level of dead material is so high that it contains the most part of the nutritional stocks, so the soil may be full of organic matter but lacking in mineral nutrients. Functional old growth contains a mixture of trees in every possible age from seedling to the maximum longevity of the species and site. Tree dimensions do not reflect age, most trees will be small, but here and there very large trees or groups of very large trees are common to see. The essential condition in old growth stands is the abundance of recent regeneration in seedling or sapling stage suffering the shade of the overstory, and the scarcity of nutrients.

Intermediate cuts

Density can be controlled at any stage of development of the stand as dictated by the regulation scheme. The objective of density control is to widen spaces for tridimensional expansion of the remaining crowns. Residual trees will continue growing without impediments until the next entry, but there should be no spaces large enough for regeneration, unless so prescribed.

Marking rules follow a hierarchical priority sequence of trees to leave:

- Dominant and codominant trees remain
- Full stocking and homogeneous density. Stocking may reach 120 % occupancy, no more
- Minimum acceptable land cover is 80 %; if a stocking of less than 80 % is already present, it can be managed by removing only the excess competition in overcrowded groups. Treatment is justified where crowns already show signs of deformation
- Ending composition percentages should strive to be similar to the ideal composition for that site and forest type.

It is reasonable to leave some juvenile stands untreated, if so prescribed by the silvicultural regime or the regulation method. However, it is not wise to exceed densities that produce intermediate or dominated individuals. The stand should not reach overstocking beyond 120 % of site occupancy, else, stagnation becomes prevalent, particularly in the case of *Pinus arizonica* and *P. durangensis* (figure 10). This condition may last for decades until some severe disturbance triggers the stand replacement process. The most common of these disturbances are fire and barkbeetles.

Figure 10. *Pinus durangensis* in Madera, Chihuahua, in a stagnation phase. Photo: A.Quiñonez.

In quantitative terms the regime for maximum production, growth, and yield starts up as a regeneration stand fully covering the site. Initial stocking is such that every tree remains a dominant or codominant. Productive sites may reach crown closure at age 3, and 10 years is common for less productive timberlands.

If regeneration has reached crown closure, and seed trees and shelter canopies still persist, they should be removed at this time to prevent damages to the new generation. Release includes cutting border trees to enhance growth space for regeneration that might be shaded by those edge trees.

Consider an example with *Pinus arizonica* in Chihuahua. Recently released saplings can initiate vigorous development if a tending cut would reduce density to around 12 m^2 in basal area for trees age 10. This basal area should not contain overcrowded spots. Average basal area may drop below 12 m^2 when such harvest intensity is needed to remove intermediate and dominated trees.

From this age on, depending on the desired management intensity, thinnings may cycle as often and as intense as required to sustain a population of dominant and codominant trees. Basal area will be gradually raising until reaching between 20 m² and 24 m², at age 50. If reentry cycles go beyond 15 years, for most sites this means tolerating interference levels that create an intermediate class in the upper canopy; this excess stocking not only taxes production, it also increases susceptibility to defoliators, shootborers, even barkbeetles. Health risks can be diminished by more intense thinning, more strict marking rules retaining only the very best individuals, although more open space will be temporarily available. On the other hand, if cycle would be less than 10 years, stands would likely become understocked, or the removal would be small in volume and of little value.

This regime, designed for the best *Pinus arizonica* sites, can be modified accordingly to fit less productive stands, and other species.

Leaving the complete overstory and undestory species mix that a site grows is a policy that causes minimal impact on production. This policy relies on an educated guess that more stands will be reaching high productivity and timber yield because a diverse set of species will hold more resilience mechanisms in case of disturbance events. For a hefty portion of forests in Durango and Chihuahua, a strategy to foster healthy forests should return better results in the long run than monoculture or simplified forests. Leaving a composition similar to the one seen before intervention is a strategy that can be used under many different management methods to retain functions that those species have. Some of those functions are important in terms of forest health, for instance the role of *Quercus* and Alnus in regulating soil's nutrition, acidity, and electrical properties. Some of the herbal species also help create a favorable environment for pines. For instance, the role of ferns in regulating calcium makes them good indirect indicators of excellent soil conditions. Fire regime also affects soil nutritional capacity, and so, they must be considered as part of the silvicultural prescriptions.

This document encompasses enough of the ponderosa silviculture as to comprise all site quality spectrum if goals were efficient timber production, minimizing risks and unwanted fluctuations. These silvicultural policies promote mixed natural species vigorous and capable offering multiple products. Other objectives need a forester to exercise its professional judgment to modify parameters and fit treatments to specific aims and context. For instance, in there were interest in having diverse successional stages and their corresponding basket of environmental services, an unusually large biomass load can be tolerated for centuries until attaining sufficient number of stands in late successional scenes. These mature stands may reach close to the maximum density recorded for ponderosa pines, around 45 m^2/ha (217 ft^2/ac) (Schubert 1974). This stocking exceeds the recommended density for production stands, which runs close to 30 m^2/ha at the age of maximum average production in the best places, and around 15 m^2/ha (72 ft^2/ac) for the poor but still productive sites.

If timber production had a financial optimization role, maximum densities and rotations would be lower than those for maximum physical yield. Financially oriented regimes must adapt to the economic climate in the country. For instance, in Mexico long term (>30 years) real rate of discount fluctuates from 1 to 5 % per year. Return rates in this range imply that best physical yield rotation (nearly 50 years), should come down to around 25 to 35 years. Consequently, harvested trees diameter would not be in the 40 cm (16 in) range, but closer to 25 cm (12 in) in good sites.

Fire

Ponderosa pines are well adapted to moderate fire regimes. Normal recurrence of fire runs close to five years. The forester must consider variations around this figure that may provide the best results. It is quite normal that for a given stand that fire may return after one year, or 15.

Prescribed burning is required when wildfire is only sporadic. The target in burning is to consume most 10 hr to 100 hr fuels, but leaving intact larger pieces, and leaving a duff and humus layer between 2 cm and 5 cm; no bare soil must be exposed by the fire effect, and no mineral soil calcination is tolerable.

After intense wildfires many large trees may die, but vigorous regeneration will appear quickly and fully occupy open spaces with no additional site prep. Complementary soil treatments are expected for burned sites where erosion might be imminent.

Protection

Protective silviculture treatments need to comply with official government directives, since in Mexico responsibility for forest protection is in the hands of public agencies. The expected role of the silviculturist is limited to cooperate in the official efforts. Hence, forest protection management at the forest level occurs as preventive policies implicit in normal production silvicultural regimes.

Management of associated forest values

Custodial responsibilities in timberlands represent a form of stewardship that is integrated into several decision making tiers:

- ¡ Added mandatory measures to normal silvicultural prescriptions. These schemes usually are intended to set policy, and occasionally manage legally protected species, sites, and populations. As of today, official concerns concentrate on a set aside policy for sites where certain species and vegetation types grow: *Picea* spp, *Pseudotsuga* spp, cloud forest, medium and high tropical forest, wetlands, riparian zones.
- ¡ Strive for an uninterrupted presence of as many diverse species, ecological processes, landscapes, successional stages as known to be naturally occurring in the ponderosa pine forests. Monitoring of silvicultural activities and their consequences is required to prevent normal silvicultural regimes to interfere with presence, abundance or functionality of known forest values.
- ¡ Maintain constant consultation with regional decision makers in a way as to harmonize long term policies in the forest, with regional plans that oversee populations, species, landscapes, and ecological processes.
- ¡ Forest lands surrounded by terrain with other land cover and uses, such as crop land, grazing grounds, urban and developed zones, need to be managed in a way that silvicultural activities form a proper transitional gradient between distinct environments. These interphase belts are quite diverse and they add considerable biological richness and resource management opportunities that sustain valuable life forms dwelling in these interphases. Special attention is due to the forest edge. This portion of the forest should be managed to develop low visibility structures surrounding the woods. Lush foliage of short trees, large herbs and brush should be retained and cultivated to offer this sort of green screen hiding the interior forest environment.

- ¡ Factors that trigger disturbance events must be guided to move recurrence cycles closer and closer to the natural regime. Disturbance incidents must occur in intensity, extension, and seasonal timing so that natural processes continue the desired dynamics. The return of the normal fire regime is a high priority issue. Fire effects should be foreseeable, controllable, and favorable to forest health needs of the ponderosa pine forest type, since this forest is a community that needs frequent, light and fast natural, or prescribed fire.
- ¡ When the forest owner expresses that having late successional stages is a management objective, or when certain important species need late successional environments, some portion of the forest may follow a specific silvicultural regime aiming at developing such landscapes.

For the time being (2012) the following are considered emblematic species. Please note that these species do not live inside ponderosa pine forests, they live and use resources in nearby communities, and they occasionally use the pine forest for thermal or hiding cover, perch or other purposes:

- ¡ Cotorra serrana, thick-billed parrot (*Rhynchopsitta pachyrhyncha*)
- ¡ Gorrión serrano, Sierra Madre sparrow (*Xenospiza baileyi*)
- ¡ Lobo, wolf (*Canis lupus baileyi*)
- ¡ Oso negro, black bear (*Ursus americanus*)
- ¡ Carpinteros, woodpeckers (*Picidae*)

In this document there is no prescription or policy to manage emblematic species. There is only a general guideline mandating to strive to maintain the physical continuity of forested lands, and to seek conditions approaching the conditions of wildlands.

It is now known that ancient peoples used fire extensively in the ponderosa pine forests. After centuries of constant fires, landscape changed to very large ponderosa pines isolated or in groups. These pines were surrounded by large open spaces covered by grass. Large trees have thick barks that allow them to survive the frequent ground fires.

This environment is great for deer and other large herbivores, whose presence attract large predators. These animals constitute prime game for the people that designed the landscape. Loss of timber productivity was of no concern. Today the large dimensions, and excellent quality of ponderosa pines in these fire dominated landscapes might represent a considerable economic value; however, the long time lapse needed to produce these trees and the low stocking level makes this regime financially unfeasible if sustained on timber production alone.

If tree cover could be maintained below 50 %, perennial grasses may grow well in the understory, especially with the help of frequent, light, ground fires. Then this stand structure could provide increased high quality water runoff for human consumption, domestic use, industrial use, recreation, fishing and other uses. On the other hand, silvicultural regimes that maintain full site occupancy lead to exponential reductions in water yield, moderate reduction in quality, and an increase in seasonal variability in the water output.

Resilience

Ponderosa pines constitute a group of species with a tremendous genetic value. They have colonized many mountain regions in the North American subcontinent. This genetic wealth, if intentionally managed, could provide a proper material to grow in many places that may need it because of ecologic changes from the ongoing intense global climatic dynamics. Germplasm banks such as the one in Oregon (Ryan 2012), will be important assets storing options to respond to disturbance factors that might tax the resistance and resilience of natural forests.
Ponderosa pines plasticity and rusticity are valuable advantages when these species are considered to reforest, or reclaim degraded sites. For transitional conditions in the sierra piedmont, and in places that do not have a good organic matter layer over the soil, or places with erosion signs, other pines with xeric preferences would be better choices; among ponderosas, only *Pinus engelmannii* might have a good performance in the juniper and oak forest of Durango and Chihuahua.

When reforested places are small (<10 ha, 22 ac), and if the ground still retains some fertility and resources, like when legacies are present, all ponderosa pines are excellent candidates to bring those grounds back into production, and to reintroduce high quality genes in the gene pool. Many sites in the Chihuahuan plateaus are currently covered by a degraded forest, with trees of little value and poor future perspectives. Shoot borers have damaged most trees in these sites, an indication of meager soil nutritional resources. Durango too has many stands understocked with old trees in poor shape. Degraded stands are candidates for stand replacement treatments, and if scheduled for regeneration, these stands represent opportunities to reintroduce high quality genetic materials, though species composition may not necessarily change. This is an enrichment operation, and it should be the ideal scenario to take advantage of available superior genetic materials from seed orchards.

These recommendations would end with a caveat: the immense geographic distribution of ponderosa pine species implies the existence of a considerable spectrum of different genetic materials. Responsible use of ponderosa pines potential demands careful selection of species and geographic origin. Seeds features must match site conditions and silvicultural system design. Other vegetation and animal life expected in the planting site should also be considered in plantation prescriptions so that the full potential of the planted trees can be expressed.

Trends in ponderosa pine silviculture

Diverse chronicles and reconstructions about the history of the forest industry in Mexico agree on describing ponderosa pine forests of early XX Century as the starting point of forest management practice. Forest industry begun under the influence of USA firms, particularly some from Oregon. American technology brought into Mexico included large sawmills, railroad transportation, and the emblematic Idaho jammer. Foreign presence in Mexico accelerated creation of a culture of work in the forest, including specialized jobs, administration, public policies, science, education, public culture.

Most silvicultural and technological decisions in the pioneer years were brilliant and successful. They were the reason why forestry has been operating on a continuous manner and for a long time. Public opinion, strangely, has been consistent in rejecting innovation until reality makes change unavoidable.

The central aim in this document is to speed up the innovation processes. The document offers elements of judgment about the need to constantly assess justifications and performance of decisions about the forest. At the time the Mexican forest management method and similar techniques were guiding forest management and silviculture, it seemed justified to assume the forest was an amorphous biomass, little more than a warehouse of industrial raw materials. The fundamental policy was setting the pace for timber removals. In some specific cases where options permitted a choice, it was also important to decide on locations and sequence of harvest to secure timber procurement for pulp and sawmills. Today's knowledge, economic system, information available about the forest and its dynamics and variability, and the increased technological capabilities make it irrational to continue using old tools like dividing forest land into stands, management series, estimating timber inventories or their increments, yields, and all other means to assess the legality of timber harvesting.

To deem essential that harvested trees be first marked and measured on the spot, and then match values with additional measurements along the way to the sawmill, these concerns are unneeded remains from the past. Continuation of these schemes bogs down the introduction of better ideas. Scientific and technological advances demand a swift decision making that can opportunely respond to the ever changing forest conditions. The most important innovations rely on knowledge of the forest biology. Though it may look paradoxical, quantitative schemes of the past lead to inferior, slow, incomplete solutions about the things that need to be done. Numeric figures about productivity, production, standing stock, rate of harvest, sustainability of the forest, and similar elements are no longer needed in silviculture nor forest management; moreover, continued reliance on this type of information leads to errors and results far away from the better results possible. Old ways had an inclination for average figures, whereas the new forest challenges are those involved in managing biologic variability, and matching its opportunities and limitations to varied expectations and capabilities of diverse forest users and people affected by the forest condition.

From now on it is also advisable not to spend unlimited resources in restoration of every piece of forest that loses its cover, or suffer erosion, or damages by animals, logging, fire, hurricanes, insects, diseases, pollution, nor any other kind of loss. Disturbances are a necessary element of the forest, it is the energy and motor of forest change. Disturbances maintain forest as forest. After disturbance, new elements appear on the ground, and their presence provides a larger set of options and forest pathways. When a natural disturbance occurs, to regress to the previous stage is seldom the case in nature. It is seldom the best choice in silviculture, even for instances where restoring a condition similar to the past is attainable.

The historic situation today calls for responsible, consistent decision making. Forest management must be practiced by means that are in line with regulations. In the Mexican case these guidelines basically are the ones that are meant to protect the forest owner interests, and in a second tier, to oversee public issues and concerns, and upkeep the legal rights of all forest inhabitants.

Important recommendations in this document call for the repeal of unjust, old regulations, cumbersome customs, useless silvicultural practices in every issue about silviculture. Consider the fact that ponderosa pines are quite plastic, rustic, resilient. They are adapted to many different environments from Canada to Mexico. These pines grow along many other species, but not all present in the same location and moment, but a specific set of species matching the ecology of the site. Effective treatments tend to take advantage of these geographic peculiarities, while playing educated guesses about the different dynamic responses that are normal behavior of these forest communities. Hence, prescriptions in actual forestry operations are better carried out when they can be adapted to the moment's requirements for concrete sites, and their application should not be slowed down by planning targets nor policies that expect decisions defined many years in advance.

One such case needing flexibility and fast response is the frequent case of release treatments. Release of regeneration cannot be anticipated, it should be executed just before larger trees start shading the younger trees because the smaller trees are the target trees. This event might occur a year after the regeneration cut, but just as easily it could take 20 or more years and still be normal and efficient process for certain sites and certain widely spaced seedlings and saplings. Speeding up the process, or delaying treatment until it fulfills a certain schedule, both would be poor decisions. It is quite normal for ponderosa pine forests that ten or more years go away without any sign of the desired stand structure simply because most natural forests are slow changing communities. Silviculture, technology, talent of silviculturists, nor random chance are at fault in these cases.

By the same token, assessment of success in natural forest complementary planting, commercial plantations, and reforestation need not examine success, nor survival, but rather it should assess the amount of land sufficiently occupied by any form of desirable and productive land covers, and most of all, explain the reasons for those sites that failed in attaining sufficient coverage of high quality trees. Assessment should be designed for detecting failed treatments, or situations that demand further attention to reach goals. By and large, finding a large number of surviving planted trees do not necessarily means successful treatment, and many times it means that further treatments will be required to prevent overcrowding.

Today it should be quite normal to allow clearings to remain without trees when places are unsuitable for forested occupation, or when forestation might take many years to complete. It is also desirable to hold small and large permanent clearings, and forest edge transitional environments, as a means to provide spaces to nontimber vegetation needed for multiple objectives that the owner may deem important.

Situations described above tell a common story: success of the best silviculture cannot be defined by growth, yield, or successful regeneration of timber producing species. Success of the best possible silviculture means that the dynamics of site, stand, forest, and region is explained by actions that could not be more cost efficient in moving scenarios to a different and desired outcome, and when current events are widely accepted by stakeholders; the consumer of final forest products would be the preeminent of all stakeholders.

Winding down, the essentials that today distinguish ponderosa pine silviculture from the traditional ways pertain to the recognition of the many different biologically feasible methods and silvicultural systems. Each of these schemes offers a particular basket of results, products, and a certain band of spatiotemporal variability. The extended capabilities of this set of choices should be immediately available to forest managers.

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Annex

Silviculture models parameters

Prognosis

Prognosis model statistical information is outlined in Mendoza (1985), Islas et al. (1988), and Islas and Mendoza (1989). Model structure follows:

CONCEPT	VARIABLE	UNITS
diamter	D(t)	Cm
diameter without bark	DIBARK(t)	Cm
Initial bark	BARKI(t)	Cm
final bark	BARKF(t)	Cm
height	H(t)	M
crown ratio	CR(t)	.
basal area of larger trees	BAL(t)	m^2/ha
volumen	V(t)	m^3
stocking	N(t)	árboles/ha
residual stocking	RESIDUALN(t)	árboles/ha
final stocking	NF(t)	árboles/ha
final diameter	DF(t)	Cm
final diameter without bark	DIF(t)	Cm
final height	HF(t)	M
final crown rate	CRF(t)	.
increment of square diameter without bark	DDS(t)	cm^2/década
current to potencial increment rate	DDSRATIO(t)	.
aspect	ASP	grados (azimuth)
basal area	BA	m^2/ha
crown competition factor	CCF	.
distance to nearest seedling	DISTANCIAR	m
microtopography	MICROTOPO	clases
distance to nearest dead tree	DISARMU	m
diameter of death tree	DIAMUER	cm
slope	PENDIENTE	tasa 0 a 1

Equations

Diameter
DF(t)=DIF(T)+2*BARKF(t)

BARKF(t)=B0+B1*DIF(t)

DIF(t)(((D(t)-2*BARKI(t))^2) + DDS(t))^0.5

BARKI(t)=B2+B3*D(t)

DDS(t)=exp(D0+D1*ln(D(t)) + D2*CR(t) + D3*BA + D4*BAL(t) + D5*cos(ASP+45))

Ingrowth
DF(t)=I1*(H(t)-1.3)^2) + I3*CCF

Crown ratio
CR(t)=100/(1-exp(C0+ C1*D(t) + C2*H(t) + C3*BAL(t) + C4*CCF))

Height
H(t)=1.3 + 30*(1-exp(H1*D(t)))

Volume
V(t)=exp(V0 + V1*ln(D(t)) + V2*ln(H(t)))

Mortality
DISARMU = M0 + M1*Ln(DIAMUER) + M2*BA + M3*BAL + M4*PENDIENTE

Regeneration
DISTANCIAR = R0 + R1*BA + R2*PENDIENTE + R3*tan(PENDIENTE)*cos(EXP) + R4*MICROTOPO

COEFICIENT	VALUE
DIAMETER	
D0	0.242244
D1	1.072181
D2	0.017757
D3	-0.00328768
D4	-0.00923676
D5	-0.050792
CROWN	
C0	-0.676244
C1	-0.037331
C2	0.102465
C3	0.024711
C4	0.030866
HEIGHT	
H1	-0.018719
INGROWTH	
I1	3.506726
I2	-0.16543
I3	-0.614957
BARK	
B0	0.840315
B1	0.050323
B2	0.668876
B3	0.049669

COEFICIENT	VALUE
VOLUME	
V0	-9.88106
V1	1.89294
V2	1.04399
MORTALITY	
M0	3.67155
M1	0.921912
M2	-0.031269
M3	-0.00270162
M4	-0.010963
REGENERATION	
R0	-0.047007
R1	0.01511
R2	0.227216
R3	8.67727
R4	3.175519

Durango Biometric System (Vargas *et al*. 2012a, Vargas *et al*. 2012b). Currently equations for UMAFOR 1006 San Dimas, y UMAFOR 1008 El Salto, have been released for:

Above ground volume (includes branches)
modelo Schumacher Hall V=V0*DIAM^B1*ALT^B2

Where:
V = volume, m^3
DIAM = diameter, cm
ALT = height m

PARAMETERS		UMAFOR 1008 El Salto			UMAFOR 1006 San Dimas		
GENUS	SPECIES	B0	B1	B2	B0	B1	B2
Arbutus	*xalapensis*				0.000138	1.730885	0.892647
Juniperus	*depeana*				0.0000975	1.775347	0.923794
Juniperus	*spp*	8.30E-05	2.044274	0.638487			
Pinus	*ayacahuite*	5.88E-05	2.034639	0.824474	0.0000937	1.803136	0.941335
Pinus	*cooperi*	5.95E-05	2.108934	0.789586	0.0000707	1.957736	0.91877
Pinus	*douglasiana*	6.42E-05	2.179859	0.6778			
Pinus	*durangensis*	6.31E-05	1.946566	0.943014	0.0000664	2.058659	0.804969
Pinus	*engelmannii*	5.40E-05	2.095956	0.837872	0.0000697	2.143843	0.69505
Pinus	*herrerae*	7.02E-05	2.119965	0.699548	0.000103	2.047917	0.665471
Pinus	*leiophylla*	4.93E-05	2.044614	0.923022	0.0000678	1.979829	0.882221
Pinus	*lumholtzii*	6.72E-05	2.268043	0.56673	0.0000947	2.136532	0.561264
Pinus	*maximinoi*	5.89E-05	2.086931	0.797988			
Pinus	*michoacana (devoniana)*	5.32E-05	2.0629	0.878615			
Pinus	*oocarpa*	9.22E-05	2.092287	0.653552			
Pinus	*spp*				0.0000696	2.256206	0.528622
Pinus	*teocote*	6.39E-05	2.049661	0.826279	0.0000864	1.96658	0.814182
Quercus	*durifolia*	0.000063417	2.108715	0.759205			
Quercus	*rugosa*				0.0000412	2.17234	0.797945
Quercus	*sideroxyla*	6.16E-05	2.055746	0.775832	0.000076	1.881905	0.937748
Quercus	*spp*				0.000093	2.087803	0.603266

Log volume

Fang model:

d=c(1)*sqroot[H^((k-b(1))/b(1)) *(1-q)^((k-beta)/beta) * alfa(1)^(l(1)+l(2)) * alfa(2)^l(2)]

v=c(1)^2 * H^(k/b(1)) * (b(1)*r(0) + l(1)+l(2))*(b(2)-b(1))*r(1) + l(2) * (b(3)-b(2))*alfa(1)*r(2) - beta*(1-q)^(k/beta) * alfa(1)^(l(1)+l(2)) * alfa(2)^l(2))

V= a(0)* D^a(1) * H^a(3)

Where:

v = commercial volume between smaller diameter r(1) and larger diameter r(2), centimeters. Log volume in cubic meters

V= total tree volumen, cubic meter

D= diámetro normal cm

ALT= heigth, m

p(1)=h(1)/H

p(2)=h(2)/H

GENUS	SPECIES	UMAFOR 1008 El Salto							
		A1	A2	A3	B1	B2	B3	r(1)	r(2)
Alnus	*xalapensis*								
Juniperus	*depeana*								
Juniperus	*spp*	8.60E-05	1.885737	0.801547	8.64E-06	2.86E-05	2.68E-05	0.05049	0.0423
Pinus	*ayacahuite*	6.38E-05	1.937323	0.896294	5.84E-06	3.46E-05	3.04E-05	0.5323	0.27669
Pinus	*cooperi*	5.80E-05	1.965243	0.946191	7.05E-06	4.35E-05	3.09E-05	0.72332	0.36448
Pinus	*douglasiana*	6.26E-05	1.991174	0.873578	7.62E-06	4.01E-05	3.16E-05	0.63654	0.30562
Pinus	*durangensis*	6.52E-05	1.926791	0.936791	6.21E-06	4.16E-05	2.99E-05	0.67337	0.30463
Pinus	*engelmannii*	6.22E-05	1.91384	0.973275	9.34E-06	4.09E-05	3.03E-05	0.04951	0.08992
Pinus	*herrerae*	8.08E-05	2.023275	0.745065	7.24E-06	4.09E-05	2.77E-05	0.6543	0.27586
Pinus	*leiophylla*	5.51E-05	1.947766	0.978897	7.46E-06	4.16E-05	2.91E-05	0.58184	0.29638
Pinus	*lumholtzii*	7.86E-05	2.01415	0.76387	9.46E-06	4.27E-05	2.77E-05	0.05514	0.03415
Pinus	*maximinoi*	6.04E-05	1.959252	0.907861	7.00E-06	3.93E-05	3.20E-05	0.45765	0.26097
Pinus	*michoacana*	6.17E-05	1.933753	0.946965	8.67E-06	4.06E-05	3.14E-05	0.64587	0.37365
Pinus	*oocarpa*	7.02E-05	1.921691	0.912655	7.23E-06	4.11E-05	3.06E-05	0.63793	0.25756
Pinus	*teocote*	7.17E-05	1.92111	0.91713	8.05E-06	4.26E-05	3.08E-05	0.59374	0.28952
Pinus	*spp*								
Quercus	*durifolia*	0.0000675	1.871801	0.927753	0.00000808	0.0000281	0.000039	0.51829	0.2713
Quercus	*sideroxyla*	6.81E-05	1.914877	0.866686	6.44E-06	1.41E-05	3.08E-05	0.03069	0.04595
Quercus	*rugosa*								

GENUS	SPECIES	UMAFOR 1006 San Dimas							
		A1	A2	A3	B1	B2	B3	r(1)	r(2)
Alnus	*xalapensis*	0.00010126	1.726332669	0.92387097	0.0000098	0.000024	0.000029	0.074	0.089
Juniperus	*depeana*	0.0000633	1.91704547	0.894236965	0.0000068	0.0000282	0.0000314	0.273	0.172
Juniperus	*spp*								
Pinus	*ayacahuite*	0.0000618	1.858148889	0.9999152	0.0000049	0.000035	0.000031	0.646	0.264
Pinus	*cooperi*	0.0000705	1.907035428	0.961545898	0.0000085	0.000045	0.0000375	0.7	0.276
Pinus	*douglasiana*								
Pinus	*durangensis*	0.0000697	1.957306379	0.886116249	0.0000052	0.0000417	0.0000338	0.653	0.648
Pinus	*engelmannii*	0.0000715	2.087573154	0.719714222	0.000007	0.0000415	0.0000296	0.654	0.414
Pinus	*herrerae*		0.0000667	1.944371377	0.0000078	0.0000409	0.0000283	0.594	0.289
Pinus	*leiophylla*	0.0000956	1.809574986	0.950943516	0.0000045	0.0000464	0.0000323	0.759	0.435
Pinus	*lumholtzii*								
Pinus	*maximinoi*								
Pinus	*michoacana*								
Pinus	*oocarpa*								
Pinus	*teocote*	0.0000721	1.969258171	0.853706535	0.0000075	0.0000413	0.0000315	0.703	0.268
Pinus	*spp*	0.0000475	2.139905695	0.7723452	0.0000072	0.0000377	0.0000317	0.67	0.27
Quercus	*durifolia*								
Quercus	*sideroxyla*	0.0000511	1.945316173	0.958683126	0.0000065	0.0000334	0.0000303	0.739	0.352
Quercus	*rugosa*	0.000042	1.999498	0.948881	0.0000069	0.00003	0.000033	0.573	0.328

Site quality
Site index
GADA
Bertalanffy-Richards model

```
Y=Y(0) * [(1-e^(-b(1)*t)) / (1-e^(-b(1)*t(0)))]^((b(2)+b(3)) /
X(0))
```

Were
Y= dominant height m
t(0)= base age, years
t= current age, years

GENUS	SPECIES	UMAFOR 1008 El Salto			UMAFOR 1006 San Dimas		
		b(1)	b(2)	b(3)	b(1)	b(2)	b(3)
Juniperus	*depeana*	0.009003	1.469133	1.31048	0.018583	0.96004	1.994414
Pinus	*ayacahuite*	0.036065	8.02725	32.46379	0.045133	-2.86299	15.95811
Pinus	*cooperi*	0.020962	-2.68973	13.59772	0.02356	-1.54332	11.0775
Pinus	*douglasiana*	0.036595	3.25129	15.93742			
Pinus	*durangensis*	0.020056	-80766	21.29294	0.024063	-8.44706	34.0971
Pinus	*engelmannii*	0.026182	-2.54053	12.86391			
Pinus	*herrerae*	0.040131	-4.2038	19.42874	0.042574	-7.59415	31.69003
Pinus	*leiophylla*	0.021515	-2.1327	12.03005	0.02366	-5.78308	25.21777
Pinus	*lumholtzii*	0.021893	2.61825	11.92108			
Pinus	*maximinoi*	0.096682	256.662	805.2213			
Pinus	*michoacana (devoniana)*	0.084298	120.968	395.7362			
Pinus	*oocarpa*	0.052851	11.0388	41.96917			
Pinus	*teocote*	0.030859	-5.50645	23.33656	0.020577	-1.66798	10.44956

Site Index for *Pinus cooperi*

Chapman-Richards polimorfic model
IS=B(1)*(1-e^(-B(2)*EB))^B(3)

Where
IS= site index
EB= IS base age
HD= dominant height, m
EDAD= age, years

B(1)= 40.36514411
B(2)= -0.00781872
B(3)=ln(HD/B(1))/ln(1-e^B(2)*EDAD)

Competition (in basal area, Glover and Hool)

IAB(i)=[(suma(j,n) (pi*(D(j)/2)^2))/n)] / [pi*(D(i)/2)^2]

Where
IAB(i)= Basal area competition index for tree i
D(i)= diameter of tree i
D(j)= diameter of trees competing with i, in parcel j
n= stocking parcel j, trees per hectare

Diameter increment

ln(INC(i))= B(4)*ln(H(i)*AM) + B(5)*IS + B(6)*IAB(i) + B(7)* (D(i)/EM)

Where
INC(i)= five year increment in diameter, cm
H(i)= tree height
AM= average height
IS= site index for base age=50 years
IAB(i)= basal area competition index for tree i
D(i)= diámeter of tree i, cm
EM = mean age, years

B(4)=-0.500688
B(5)=2.06385
B(6)=-0.142535
B(7)=12.260916

Height increment

ln(INCH)=B(8)*ln(H(i)/EM) + B(9)*IS + B(10)*IAB(i) + B(11)*(D(i)/EM)

INCH(i)= annual height increment of tree i, m
H(i)= height of tree i
EM= mean age
IS= site index at 50 years base age
IAB(i)= basal area competition index for tree i
D(i)= diameter of tree i, cm

B(8)= -1.083396
B(8)= 1.659269
B(10)= -0.254507
B(11)= 12.898775

Mortality

p=1 + e^(B12+B(13)*D(i)+B(14)*IAB(i)+B(15)*IS)

Where
p= probability of death before four years for tree i
D(i)= diameter of tree i, cm
IAB(i)= basal area competition index for tree i
IS= site index at 50 years base age

B(12)= 5.818939
B(13)= -0.896119
B(14)= 1.317752
B(15)=-0.076396

Ingrowth

ln(NN)= B(16)*IS + B(17)*AB + B(18)* C + B(19)*DB

Where
NN= measurable trees ingrowth in the following five years, trees per hectare
IS= site index at 50 years base age
AB= basal area, m^2/ha
C= previous entry harvest intensity, 0 to 100 %
DB= mean diameter of trees < 7.5 cm

B(16)= 0.183474
B(17)= -1.300624
B(18)= 0.016330
B(19)= 0.001338

Tree volume

V(i)= (D(i)*H(i))^(B(20)*B(21))

Where

V(i)= volumen of tree i, m^3

D(i)= diameter tree i, cm

H(i)= height of tree i, m

B(20)= 0.980899

B(21)= 0.4197235

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