Appendix F
Silvicultural Systems

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The silvicultural system can be viewed as the process by which we grow a forest stand for a specific purpose. This process includes all practices over a rotation - harvest or regeneration cuttings, intermediate cuttings, and other cultural treatments - necessary for replacement and development of the forest stand.

The Chequamegon-Nicolet National Forests will utilize the two types of silvicultural systems–both uneven-aged and even-aged systems.

Uneven-aged and Even-aged Management

Uneven-aged management

Uneven-aged Management is the application of a combination of actions needed to simultaneously maintain continuous high-forest cover, recurring regeneration of desirable species and the growth and development of trees through a range of diameter or age classes to provide a sustained yield of forest products. Harvesting is usually regulated by specifying the number or proportion of trees of a particular size to retain within an area, thereby maintaining a planned distribution of size classes. Harvesting methods that develop and maintain uneven-aged stands are single-tree selection and group selection. An improvement harvest may be used to establish a desired species composition and to rid the stand of undesirable trees as the first step of moving a stand from even-aged conditions to uneven-aged conditions.

Uneven-aged management is used primarily in mixed northern hardwoods in Northern Wisconsin. Regeneration is achieved either naturally through seeding or root sprouting. Some planting occurs generally to improve species diversity. The following is the rationale for using uneven-aged management by species group:

Single-tree Selection

In single-tree selection, trees are removed either individually or in small groups based on age, size, merchantability, health, seed production capability, and potential to increase in volume and quality. Single-tree selection creates very small openings, generally less than 40 feet in diameter, to develop regeneration of a new age class. Single-tree selection is more favorable for reproducing species that can grow in the shade (shade-tolerant) over those that require direct sunlight. Therefore, the single-tree selection method is not appropriate for regenerating shade-intolerant species. The size, shape, and placement of openings can be varied to meet the light requirements of the species being regenerated. Opening size is determined by the silvical characteristics of the trees, their size, and the ease by which they can be removed without damaging other vegetation.

Group Selection

Group selection is similar to single-tree selection except trees are removed in groups based on age, size, merchantability, health, seed production capability, and potential to increase in volume and quality. While single-tree selection creates very small openings,

in group selection, the openings can be up to two acres. Group selection is more favorable for reproducing a broader range of species that can grow in the shade as well as those that require direct sunlight. Due to limiting factors in Northern Wisconsin such as periods of low moisture, frost, and competition, group selection is used only in unique situations and the size of the openings tend to be on the smaller side. The size, shape, and placement of openings can be varied to meet the light requirements of the species being regenerated. Opening size is determined by the silvical characteristics of the trees, their size, and the ease by which they can be removed without damaging other vegetation.

Even-aged management

Even-aged management is the application of a combination of actions that result in the creation of stands in which trees of essentially the same age are grown together. In an even-aged stand all trees are the same age or at least of the same age class; a stand is considered even-aged if the difference in age between the oldest and youngest trees does not exceed 20% of the length of the rotation (Smith 1986). Managed even-aged forests are characterized by distribution of stands of varying ages (and tree sizes) throughout the forest area. Regeneration in a particular stand is obtained during a short period at or near the time that a stand has reached the desired rotation age or tree size for harvesting. Regeneration cutting methods producing even-aged stands are clearcut, shelterwood and seed tree cutting. Tending or intermediate cuttings are called thinnings or pre-commercial thinning.

The rotation age under an even-aged management system is the number of years between establishment of a stand of timber and when it is considered ready for final harvesting and regeneration. If a forested area were managed on a 120-year rotation, approximately 8% of the acres would be regenerated each decade in a regulated system. Much of the Forests are similar in age due to the logging era of the early 1900s. So many types such as red pine, red oak, white spruce, and paper birch, among others are generally 70-90 years of age. There is very limited acreage in the other age classes for these species. Some of these areas will be rotated early, some on a normal rotation and some on extended rotations to spread the age class distribution.

Even-aged management is used to manage a variety of forest cover types in Northern Wisconsin including: aspen, jack pine, balsam fir, red pine, white spruce, white pine, hemlock, paper birch, oak and mixed northern hardwoods (in certain species combinations or locations). Even-aged management includes harvest treatments such as thinning, shelterwood preparation cut, shelterwood seed cut, shelterwood removal cut and clearcutting. Regeneration is achieved either naturally through seeding, root sprouting; or artificially through planting or seeding. The following is the rationale for using even-aged management by species group:

Clearcutting

Clearcutting harvests all merchantable trees on an area at one time with the exception of trees left for wildlife, visual or ecological purposes. Unmerchantable trees are also felled to eliminate competition with regeneration. Depending on the tree species, thinnings may or may not precede the clearcut. Regeneration develops from natural seeding, root/stump sprouts or from hand planting or seeding. This regeneration method favors the establishment and development of shade intolerant species. Clearcutting slows the change towards more climax tree species caused by natural processes while maintaining earlier successional forest types.

The National Forest Management Act (NFMA) directs the Forest Service to: “Insure that clearcutting ... and other cuts designed to regenerate an even-aged stand of timber will be used as a cutting method on National Forest System lands only where for clearcutting, it is determined to be the optimum method ... to meet the objectives and requirements of the relevant land management plan.”

The Report of the U.S. Senate Committee on Agriculture and Forestry on the National Forest Management Act of 1976, to accompany S. 3091, states that: “The term optimum method means it must be the most favorable or conducive to reaching the specified goals of the management plan. This is, therefore, a broader concept than silviculturally essential or desirable, terms considered and rejected by the Committee. The Committee had substantial discussion over how to define when it was appropriate to use even-aged management systems. There was full agreement that the decision should not be based solely on economic benefits, i.e. dollar benefits or return dollars. Rather, the full scope of environmental effects (natural, economic, and social) should be evaluated and even-aged systems should be used only when they best meet forest management objectives for the individual management plan. Further, the monitoring, evaluation, and research processes will be used in the process.”

The Chief of the Forest Service has established policy on clearcutting as follows: “Apply clearcutting only where it has been found to be the optimum method of regeneration to meet multiple-use objectives and is essential to meet forest plan objectives, involving one or more of the following circumstances:

1. To establish, enhance, or maintain habitat for threatened, endangered, or sensitive species.
2. To enhance wildlife habitat or water yield values or to provide for recreation, scenic vistas, utility lines, road corridors, facility sites, reservoirs, or similar development.
3. To rehabilitate lands adversely impacted by events such as fires, wind-storms, or insect or disease infestations.
4. To preclude or minimize the occurrence of potentially adverse impacts or disease infestations, windthrow, logging damage, or other factors affecting forest health.
5. To provide for the establishment and growth of desired trees or other vegetative species that are shade intolerant.
6. To rehabilitate poorly stocked stands due to past management practices or natural events.”

Adherence to the above policy will be decided on a project-specific basis and is not part of the revised Forest Plan.

Clearcutting is the most appropriate system for effectively regenerating those species of trees which naturally grow in even-aged stands and which cannot regenerate in the shade of other trees. Clearcutting has been determined to be the optimum method for the following species: aspen, jack pine and red pine.

Shelterwood Harvest

In a shelterwood harvest, the mature stand is removed in a series of two to three cuts. The early cuts are designed to structure the species composition, improve stand vigor and improve the seed production capability of the residual trees while preparing the site for new seedlings (natural or planted). This method provides a partial cover of mature trees, which provide partial shade, increased ground moisture, frost protection and allows

additional growth on quality residual trees. When the shelter becomes a hindrance to the growth of the developing seedlings rather than a benefit, it is necessary to remove the remainder of the mature stand. This may occur as soon as 3 years or as long as 20 years depending on the regenerating species needs.

Shelterwood harvests are most appropriate for species or sites where the shelter of a partial overstory is needed for reproduction or to give desirable regeneration an advantage over less desirable species. Shelterwood harvest is most appropriate for the following species: white spruce, balsam fir, paper birch, white pine, red oak and other hardwood species such as white ash, yellow birch, basswood and red maple.

Seed Tree Harvest

In a seed tree harvest, all trees are harvested except for a few well distributed trees of the desired species to provide seed for natural regeneration. After adequate regeneration has been established, the seed trees are normally harvested or left as reserve trees for future snag and coarse woody debris. Generally, a shelterwood is preferred over the seed tree harvest. The shelterwood provides more protective cover and is more sensitive to visual concerns. However, there are a few cases where the seed tree regeneration method would be useful. Examples would include jack pine or paper birch areas to be regenerated with prescribed fire.

Intermediate Thinning

Thinning is the cutting of individual trees within an immature stand to improve growth and quality of the remaining trees, to improve species composition, and/or to remove damaged or suppressed trees.

Species managed under an even-aged system

Aspen

Aspen is common tree species in the forested ecosystems in the Lake States. Aspen is a shade intolerant species and is considered "pioneer" tree species on sites that are recovering from intense disturbance. Under natural conditions, aspen is regenerated by natural disturbance such as wildfire, windstorms followed by high intensity fires or other events that leave a site devoid of vegetation. Ground conditions as a result of these events are favorable for aspen root suckering and seeding.

Aspen is not a long lived species. By age 50, decay pathogens start to become a concern. The fungus *Phellinus tremulae* is the chief cause of decay in aspen and is the major deterrent to growing aspen on long rotations (Perala and Russell, 1983). After 50-70 years, these stands will begin to deteriorate. The deterioration of the aspen stand begins when the crowns of older trees can no longer grow fast enough to fill voids in the canopy left by dying trees. By age 60-80 years, many aspen trees will have died and succession to more shade-tolerant species will begin (Katovich, McDougall and Chavez, 1998). Deteriorating clones will produce significantly fewer root suckers following harvest or catastrophic disturbances than their healthy counterparts.

Wildfires have largely been eliminated from the Great Lakes landscape through active fire suppression. Man-caused disturbance events need to be considered to maintain aspen in the absence of wildfire. Without disturbance, stands currently dominated by aspen will be replaced by species more shade tolerant (Stone, 1996). Prescribed burning, as an

alternative to natural disturbance, is possible but not practical in many locations due to the concern for the safety of firefighters, landowners, and the protection of adjacent private properties. Stand replacement fires which are required to regenerate aspen, create too many negative resource values and human safety issues.

Where regeneration of aspen types is the objective, clearcutting is the optimum method for regenerating fully stocked sucker stands and maximizing growth (Perala, 1990) by stimulating suckering on the greatest number of roots and minimizing shade on the site (Bates, Blinn and Alm, 1991). Aspen needs full sunlight for vigorous growth and successful competition with shade tolerant species (Perala, 1977). Soil temperature is the most critical environmental factor affecting suckering. Initiation and development of suckers is optimum at about 74° F (Perala, 1990). As little as 10-15 square feet of basal area of residual overstory will slow aspen sucker growth by 35-40% (Perala, 1977). Thus, the shelterwood, seed tree, and individual selection methods of harvest would not be effective in regenerating these stands.

The overstory left behind in seed tree, shelterwood, and individual selection harvest methods shade the ground and reduce or eliminate suckering, reduce growth rates, and reduce the aspen's competitiveness with shade tolerant species such as sugar maple and other hardwood or conifer types. Group selection (a method that removes small groups of trees during harvest) would also not be as effective in regenerating aspen because with the small size of the openings (less than 2 acres). The perimeter trees shade the regeneration opening. In general, the number of suckers produced is proportional to the degree of cutting. More suckers develop - and grow best - in full sunlight. For this reason, clearcutting is used to harvest and regenerate aspen (Wooden, Locey and Cummingham).

A standard and an extended rotation age have been set for the aspen types is 45 years and 70 years of age respectively. Desired age class structure of the aspen type is set in the Forestwide Standard and Guidelines.

Jack Pine

Jack pine is common tree species in the forested ecosystems in the Lake States. Jack pine is one of the most shade intolerant trees in its native range (Rudolph and Laidly, 1990) and is considered “pioneer” tree species on sites that are recovering from intense disturbance. Under natural conditions, jack pine is regenerated by natural disturbance such as wildfire, windstorms followed by high intensity fires or other events that leave a site devoid of vegetation. Ground conditions as a result of these events are favorable for jack pine seeding. Over much of its natural range jack pine bears predominately sertinous cones (Rudulph and Laidly, 1990).

Seed stored in sertinous cones remains viable for many years, but special measures are often necessary to secure release of this vast quantity of seed after cutting. Jack pine is adapted to regenerate after forest fires. When hot fires melt the cone scales, the seeds are released onto the bare soil left by fires. Because it is rarely feasible to duplicate the severe crown fires that bring these stands into being in nature, the effects of the fire must be simulated by other means (Smith, Larson, Kelty and Ashton, 1997).

Reasonable success of natural seeding of jack pine in the absence of severe fire has been achieved in the Great Lake Region (Smith, Larson, Kelty and Ashton, 1997). The melting temperature of the resinous bonding material of the cone scales is 122° F (Rudulph and Laidly, 1990). These temperatures can be achieved when cones are within 15 centimeters of the ground (Smith, Larson, Kelty and Ashton, 1997). For best results, mineral soil should be exposed by either the logging operation itself or scarification prior to or after

the harvest. Sometimes the dense little clusters of seedlings that arise from the opening of cones on the ground pose a difficult kind of pre-commercial thinning problem (Smith, Larson, Kelty and Ashton, 1997). Planting seedlings or sowing seed from a known local source is recommended in situations where the parent stand seed source is unknown, such as in the case of many CCC-era plantations.

Jack pine requires full sunlight for optimal development. Vegetative competition seriously inhibits seedling development. Competition reduction improves survival and enhances the growth of seedlings (Schone, Bassett, Witter and Montgomery, 1984). Because of jack pine's intolerance, especially to shade, even-age management using the clearcutting, shelterwood, or seed tree silvicultural system is the only practical method to maintain the forest type (Rudolph, 1983). Clearcutting is the recommended silvicultural system for harvesting mature trees where the new stand will be established by planting improved seedlings, direct seeding, or scattering serotinous cones from high quality trees (Benzie, 1977).

Red Pine

Red pine is less tolerant of shade than its common associates except the aspens, paper birch, and jack pine. A light overstory of only 30 square feet of basal area per acre will reduce volume growth by 70% (Benzie and McCumber, 1983). Because of its shade intolerance, red pine grows best in even-aged groups or stands and is well adapted to even-aged management. Depending on conditions either the shelterwood system or clearcutting followed by planting or seeding maybe used (Rudolf, 1990).

Seed production in mature red pine is irregular; bumper crops are produced only once every 10 to 12 years. Several factors may reduce red pine seed crops: prolonged rainy weather at the time of pollination; fire injury; insects which consume the flowers and seeds or damage the cones, squirrels, mice and other animals and songbirds which eat the seeds or damage the cone bearing branches (Rudolf, 1990). Since seed crops are so unreliable, seed is collected during good years for growing container or bare root planting stock. Seedling establishment requires site preparation on areas where slash or vegetation, particularly sod or shrubs cover the planting site.

One of the major diseases of red pine is the shoot blight caused by the fungus *Sirococcus conigenus*, formerly called *Sirococcus strobelinus*. This fungus has become increasingly widespread since the late 1970's. It commonly kills red pine seedlings and saplings growing under infected overstory trees. Spores are spread to nearby hosts by water drops from rain. The best control is to avoid two-story or uneven-aged stands in northern areas where Sirococcus is a potentially serious problem (Nicholls, Prey and Hall, 1984).

Thinning of plantations is necessary to develop larger crowns and vigorous trees. Dense plantations that have not been thinned will have trees with small crowns that are prone to wind and ice damage. In addition, these trees are prone to bark beetle outbreaks during drought (Katovich, McDougall and Chavez, 1998).

Although it is possible to grow red pine in either even- or uneven-aged silvicultural systems, even-aged systems give better results. Even-aged management of red pine, specifically thinning, clearcutting and planting, is the optimum method for maintenance and regeneration due to the factors cited above.

White Spruce

White spruce is intermediate in tolerance to shade. It is equally or less tolerant than black spruce, hemlock, balsam fir, and sugar maple. It is more tolerant than aspen or paper birch (Nienstaedt and Zasada, 1990).

White spruce is capable of reproducing under mature stands of spruce and early successional tree species; however, the response is highly variable and density and percent stocking are low. Good seed years can occur at 2- to 6-year intervals but may be as many as 10 to 12 years apart (Nienstaedt and Zasada, 1990). For these reasons, planting white spruce is the most reliable method of regeneration.

Young white spruce stands, especially those established in open areas, low areas, or along forest edges can be very susceptible to spring frost injury. Frost kills the new growth on trees, and repeated frost injury can stunt trees significantly (Katovich, McDougall and Chavez, 1998). A high light overstory of other forest types such as aspen or paper birch, which reduces full sunlight by 25-30%, protects the spruce seedlings from frost injury and allows maximum height growth of the seedlings.

Beyond the first 10-12 years, overhead cover has a negative effect on height growth. Once the seedlings are above the height that frost damage occurs, growth is greatest at full light intensity. Damage from frost is less serious after trees reach from 13 to 19 feet in height. White spruce shows a significant response to release resulting from natural causes or silvicultutural treatment. Reducing light intensity to 50% of full light reduces height growth by 25%; shoot weight by 50% and rooting depth by 40% (Nienstaedt and Zasada, 1990).

White spruce can withstand overhead shade, but not without impaired height and diameter growth. White spruce plantations, if overtopped, will survive and eventually outgrow competitors on suitable sites but at the expense of excessive mortality and a prolonged rotation (Rauscher, H. Michael, 1984). Spruce having their crowns in contact with or immediately below those of aspen can be expected to double their height growth following release. The combined effect of increased diameter growth and height growth can increase spruce volume production by about 60% (Nienstaedt and Zasada, 1990).

White spruce stands should be maintained through thinning at a basal area between 100-140 square feet per acre to provide maximum volume growth and good individual tree development (Nienstaedt and Zasada, 1990).

Although it is possible to grow white spruce in either even or uneven-aged silvicultural systems, even-aged systems give better results. Even-aged management of white spruce, specifically thinning, shelterwood to 20-30% crown closure, planting and removal harvest when regeneration averages 15 feet in height is the optimum method for maintenance and regeneration due to the factors cited above.

Balsam Fir

Balsam fir has a strong ability to become established and grow under the shade of larger trees. It is classified as very tolerant, more tolerant than black or white spruce, which are common associates. Balsam fir can survive many years of suppression and still respond to release (Frank, 1990).

Within the range of suitable temperatures, moisture is more important than light for germination. In fact, light intensities of only 10% of full sunlight result in successful germination (Frank, 1990). Optimum germination temperature range from 64° to 84°, but

temperatures down to at least 54° are suitable (Johnston, 1986). If enough moisture is available, almost any seedbed type is satisfactory, but mineral soil with some shade is best (Frank, 1990). The closer the seed lies to mineral soil, the better the initial establishment (Johnston, 1986).

Balsam fir begins to produce seed regularly at about age 30; good seed crops generally occur at 2- to 4-year intervals. The effect seeding distance from a mature tree ranges from 80 to 200 feet, depending on such factors as tree height and amount of seed (Johnston, 1986).

Both even-aged and uneven-aged silvicultural systems are applicable to the balsam fir type. Even-aged systems are preferred, but uneven-aged management is possible because the tree is tolerant of shade and seedlings can and do become established in the understory. Uneven-aged management should be limited to sites where balsam fir can maintain itself as a climax type without the need for excessive silvicultural practices. On all other sites, even-aged management is generally recommended (Benzie, Smith and Frank, 1983).

Balsam fir stands break up at fairly young ages even though individual trees may live for 200 years. Root (or butt) rots begin entering balsam fir at about 25-30 years; eventually the trees are weakened, which leads to severe windthrow and wind breakage (Johnston, 1986). It is also important to recognize the risk of spruce budworm losses balsam fir is beyond 45 years of age (Benzie, Smith and Frank, 1983).

Rotation ages are generally between 45 and 60 years of age depending on the site and risk factors.

Mature even-aged stands well stocked with advance regeneration can be harvested by the clearcut method. Balsam fir seedlings about 6 inches tall can be considered to be established, especially if secondary branching has occurred. As seedlings develop, light at intensities of at least 50% of full sunlight is necessary for optimum growth (Frank, 1990). The growth rate of balsam fir at least doubles with a few years of release (Johnston, 1986).

In mature stands that do not have adequate advance regeneration, the shelterwood method applied in narrow strips, uniformly, or in groups can be used to stimulate seedling establishment. The shelterwood can be removed as soon as the seedling stand is established. The seed tree method is not recommended because of the high windfall risk before the area is successfully regenerated (Benzie, Smith and Frank, 1983).

Paper Birch

Paper birch is a pioneer type that revegetates land disturbed by natural catastrophe such as wildfire or man-caused disturbance such as clearcutting. In the absence of disturbance the paper birch type is replaced by tolerant types. Paper birch normally reproduces from seed. Stumps of trees younger than 60 years produce vigorous sprouts, which can be counted on to supplement seedling regeneration. Paper birch produces good seed crops every other year with a bumper crop 1 year in 10 (Safford and Jacobs, 1983). Paper birch seed retains limited viability for at least 2 years in the forest floor (Perala and Alm, 1989).

Seed dispersal is generally in the fall, primarily September-November (Safford and Jacobs, 1983). Practical seeding distance is less than 100 yards although some seed may travel many times farther, especially when wind-driven over crusted snow (Perala and Alm, 1989). Best germination occurs on mineral soil; germination on humus is reduced

by about 50%, and germination on undisturbed litter is only 10% of that on mineral soil (Safford, Bjorkborn and Zasada, 1990). Seeds germinate best at temperatures alternating between 68-86 degrees F. They cannot endure drought (Perala and Alm, 1989).

Newly germinated seedlings are fragile. They are sensitive to moisture, temperature, light, and seed bed conditions. Shaded sites can produce twice as many germinants as sites in direct sunlight (Safford, Bjorkborn and Zasada, 1990). Seedlings can prosper in 50% shade and survive in up to 90% shade for a few years. However, they are easily suppressed by competing vegetation (Perala and Alm, 1989).

When paper birch is the forest type objective, even-aged management is the optimum method (thinning, shelterwood, and removal cut). A two-cut uniform shelterwood having 20 to 40% crown cover can be used to regenerate paper birch. But any system using narrow shaded clearcut strips or shelterwood strips disced within 2 years after a good seed crop may be as good or better (Perala and Alm, 1989). Regardless of the regeneration method, seedbed disturbance is required (Safford and Jacobs, 1983).

Uneven-aged management, such as selection harvest, keeps enough shade on the ground that germination is unlikely due to low ground temperatures until late in the summer. Paper birch seedlings and late season germinants would be susceptible to late summer drought and heat. In a selection method of harvest, it would also be difficult to do the site preparation needed to expose mineral soil and organic material (paper birch seedbed) without damaging the roots of the trees being left. Paper birch does not tolerate root disturbance well and would start to decline. Opening up the stand along with root damage that would occur in scarification would also increase the susceptibility for subsequent damage by other agents such as the bronze birch borer.

Even though fire is a potential tool for regenerating paper birch, the existing paper birch stands do not generally have enough fuel to carry a fire that would produce an adequate seedbed. There was also a concern for the protection and safety of fire fighters, adjacent landowners, and the public using the area.

White Pine

White pine is intermediate in shade tolerance, and vegetative competition is a major problem. Although it will tolerate up to 80% shade, tree growth increases as shade is reduced. It can achieve maximum height growth in as little as 45% full sunlight (Wendel and Smith, 1990).

White pine trees begin to bear cones before age 20, but the optimum seed-bearing period is between the ages of 50 and 150 years. Good white pine seed crops occur at intervals of 3 to 10 years. A seedbed condition is important in regenerating white pine. Partial shade, mechanical scarification, and burning improve the seedbed. However, frequent and severe fires can eliminate white pine from natural stands (Wendel, Della-Bianca, Russell, Lancaster, 1983). Normally 3 to 5 years are required for white pine to become established. Mineral seed beds plus light intensities greater than 20% full sunlight but less than full sunlight support vigorous seedling growth by reducing surface soil temperatures and providing better soil moisture conditions (Wendel and Smith, 1990).

White pine grows slowly during the first 5 years of establishment (Wendel, Della-Bianca, Russell, Lancaster, 1983). After the establishment period, light intensity becomes critical to the survival and growth of white pine seedlings. At least 20% of full sunlight seems to be required to keep seedlings alive. As light intensity increases above this point, growth increases proportionately up to full sunlight unless some other condition becomes

limiting (Wendel and Smith, 1990). A major damaging agent to young white pine is the white pine weevil. The white pine weevil kills the terminal shoot, which may include the last 2 or 3 years of growth. Growing seedlings in partial shade reduces the terminal diameters, which makes them less susceptible to weevil damage.

Growth characteristics of white pine indicate that it can be managed best under even-aged stand conditions, though considerable leeway is allowed in choosing regeneration methods. White pine has been regenerated by clearcutting in blocks and strips, and by seed-tree, shelterwood, and group selection methods. Single tree selection cutting has usually not proven satisfactory and the seed-tree method has little to recommend it (Wendel, Della-Bianca, Russell, Lancaster, 1983).

The most versatile reproduction method is the shelterwood method. By control of overstory density with a series of shelterwood cuts, seedbed conditions may be improved; an accumulation of advanced seedlings is obtained over a period of years; protection of seedlings on hot, dry aspects is afforded; weevil attacks are reduced; and competition from herbaceous and hardwood sprout vegetation is suppressed. Two, three, or more cuts spread over a number of years may be used, but usually white pine can be regenerated successfully with a two-cut shelterwood system (Wendel and Smith, 1990).

In areas where the weevil is present and white pine is to be planted in open situations, seedlings should be planted at very tight spacing (1000 trees+ per acre) so the trees can “correct” themselves by forcing new leaders to grow straight.

Northern Red Oak

Northern red oak is classed as intermediate in shade tolerance. It is less tolerant than some of its associates such as sugar maple, beech and basswood but more tolerant than white ash (Sander, Ivan L. 1990). Disturbances, such as fire, would have favored oak by setting back succession to an earlier stage. Many of the oak stands currently on the Forests probably originated following fires (Katovich, McDougall and Chavez, 1998). Although there is abundant evidence of a general relation between fire and the occurrence of oak, prescribed burning is not yet a viable silvicultural tool for regenerating oak stands (Crow, T. R., 1988).

Acorn production varies from year to year and from tree to tree. In northeastern Wisconsin, bumper crops occur on an average of 7 year intervals, but some bumper crops occurred as few as 2 years apart. Thinning and consequent crown expansions have the potential to increase acorn production, especially if good seed producers are reserved (Johnson, 1994). Once on the ground, acorns are quickly consumed by animals or deteriorate (generally due to desiccation) very rapidly. A regeneration system that includes direct seeding without site scarification will result in almost total loss of acorns to predators. Scarification not only helps bury the acorns in the ground, but it also removes the cover that is essential for rodents and destroys their habitat sufficiently to reduce their population levels during critical germination periods. When 435 oaks per acre more than 4.5 feet tall are present, any remaining overstory should be removed (Sander, McGee, Day and Willard, 1983).

Thinning should be an integral part of managing even-aged, reasonably well-stocked, oak stands (Sander, McGee, Day and Willard, 1983). Delay first thinnings to stand age 45. During the first 45 years, rapid height growth and the development of long, branchless boles are encouraged by maintaining high stand densities (Johnson, 1994).

If the management objective is to perpetuate oak, even-aged systems will best satisfy the reproduction and growth requirements. Clearcutting will be successful if combinations of oak advanced reproduction over 4.5 feet tall and potential stump sprouts are equivalent to 435 well disturbed, advance-reproduction stems per acre. The shelterwood method should be used when oaks are wanted in the next stand but advanced regeneration is absent (< 435 per acre) or too small (< 4.5 feet tall). A series of cuts will be necessary to establish new oak seedlings and provide conditions that will allow them or existing small advance regeneration to develop into sturdy stems (Sander, McGee, Day and Willard, 1983).

Using the single tree selection system in the oak type will not perpetuate the oaks or intolerant species. Although oak seedlings will become established, they will be unable to survive and grow into the sapling and larger size classes. Furthermore, as the existing pole and sawtimber size oaks pass through succeedingly larger size classes and are harvested, the sapling and small tree component will become dominated by whatever shade-tolerant species are present. Eventually the entire stand will be composed of these shade-tolerant species (Sander, McGee, Day and Willard, 1983).

Mixed Northern Hardwoods

We will describe mixed northern hardwoods in this discussion as a type with at least 25% of species other than sugar maple such as yellow birch, white ash, red maple, basswood, red oak and/or hemlock. Sugar maple, the most common member of the northern hardwood forest, regenerates prolifically under a wide variety of conditions and is therefore easily perpetuated after logging. Other associated species, such as yellow birch and white ash, can tolerate light or moderate shade only in the first few years after germination and then must then receive direct overhead sunlight for adequate growth. While selection harvest can be used to regenerate mixed northern hardwoods, it tends to favor sugar maple almost exclusively (Lorimer and Locey). A mixed northern hardwood stand is less susceptible to insect and disease attack than a pure sugar maple stand due to the diversity of species within the stand. Faster growing species such as basswood, white ash and northern red oak typically are larger in diameter, taller, have longer clear trunks, and are less subject to forking and branching caused defects than the maples of comparable age.

Sugar maple and red oak seed will germinate at a ground temperature of 34°F, while other associated species such as yellow birch and hemlock have a much higher minimum temperature to germinate. The heavier remaining canopy of a selection cut favors sugar maple at the expense of ash, basswood, hemlock, and yellow birch due to maintaining lower ground temperatures longer into the growing season. Shelterwood cuttings are proving to be one of the most reliable methods for establishing even-aged northern hardwoods (Godman and Tubbs, 1973). Shelterwood cuts encourage a greater variety of tree species, especially yellow birch and some faster growing species, such as white ash (Lorimer and Locey). The best result for regeneration of light-seeded shade intolerant species is a shelterwood harvest combined with soil scarification (Hutchinson).

Yellow birch is the major gap phase component of the forest cover types Sugar Maple-Beech-Yellow Birch and Hemlock-Yellow Birch. It cannot regenerate under a closed canopy; it must have soil disturbance and an opening in the canopy. The optimum light level for top growth and root development of birch seedlings up to 5 years old is 45 to 50% of full sunlight. In undisturbed stands, yellow birch can only regenerate on mossy logs, decayed wood, rotten stumps, cracks in boulders, and windthrown hummocks because hardwood litter is detrimental to its survival elsewhere. An allelopathic relationship between yellow birch and sugar maple seedlings has been noted (Erdmann,

1990). In other words, the presence of sugar maple seedlings will discourage yellow birch regeneration. Yellow birch seedlings are normally overtopped by faster growing species after 5 years and require complete release from overstory shading for best survival, growth and quality development (Erdmann, 1990). A shelterwood treatment to approximately 60% crown closure followed (or preceded) by scarification is the key to ensuring the best results for yellow birch regeneration. Soon after the seedlings reached 2 to 4 feet tall (approximately 5 years) they should be released through an overstory removal.

Young white ash is a shade-tolerant tree. Seedlings can survive under a canopy with less than 3% of full sunlight but grow little under these conditions. Seedlings develop best in 45% of full sunlight. White ash becomes less tolerant of shade with increasing age, and is classed as intolerant. The decrease in shade tolerance with increasing age is reflected in the fact that young white ash is abundant in the understory of northern hardwood stands, but few grow into the overstory unless provided with light from above. White ash responds readily to thinning and within a few years will increase its crown area to take full advantage of any reasonable release (Schlesinger, 1990).

Although basswood is less tolerant than its common associate, sugar maple, vigorous sprouting and rapid growth allow it to persist under the selection system. For reproduction from seed, the shelterwood system should provide the partial shade necessary to control competing vegetation, and to create a microclimate suitable for germination. Shading aids the establishment and initial survival of basswood seedlings but heavy shade limits subsequent growth and development, and vigorous growth is unlikely under the forest canopy. Likewise, higher soil temperatures found in forest openings are suitable for greatest growth of basswood seedlings. After basswood is established, the overstory should be removed (Crow, 1990).

Red maple is a pioneer or sub-climax species that is more shade tolerant and longer lived than other early successional species. Seedlings are more tolerant than larger trees and can exist in the understory for several years. Abundant 1- to 4-year old seedlings are often found under the canopy of older stands. Many of these seedlings die each year if they are not released by opening of the main crown canopy, but new ones replace them. Thus, a reservoir of seedlings and ungerminated seed is available to respond to increased sunlight resulting from disturbance. They respond rapidly to release and can occupy overstory space (Walters and Yawney, 1990).

Eastern hemlock is the most tolerant of all tree species. The tree is capable of withstanding suppression for as long as 400 years. At all ages, however, eastern hemlock responds to release in both height and diameter growth. Despite the high frequency of cone crops and the long duration of cone production by individual trees, the viability of hemlock seed is low. Germinative capacity is commonly is less than 25%. A constant temperature of 59° F is optimum for germination. These temperatures are nearly identical to those for yellow birch and help explain the association of two species differing so much in tolerance. Hemlock requires a warm, moist site for stand establishment rather than the cool, moist conditions that usually develop as stands mature. New stands of hemlock can be established under a high density overstory (from 70-80% crown cover) using the shelterwood regeneration system. The site must be prepared, however, by thorough mixing of organic and mineral soil or by prescribed fire to expose a partially decomposed layer. Under this system, optimum conditions are created for germination and seedling establishment. Seedlings are very sensitive to high temperatures and drying of the surface soil during the establishment period. Once the root system has reached a soil depth not radically affected by surface drying, usually after the second year, the

seedlings grow more rapidly without interference of overhead shade. Seedlings are fully established when they are 3 to 5 feet tall and at that time, can be released completely from overhead competition without fear of mortality (Godman and Lancaster, 1990).

Even-aged silviculture is necessary to maximize the number of light-demanding species such as yellow birch or less aggressive tolerant species such as eastern hemlock. Shelterwood cutting (in northern hardwood types) provide the greatest flexibility and consistency in establishing even-aged stands (Tubbs, Jacobs and Cutler, 1983). Regeneration of hemlock and most of the hardwood species other than sugar maple are favored by scarification. Thinning should be done to maintain vigor growth, which reduces the risk of insect and disease attack.

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