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Forest Improvement Handbook

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Healthy forests provide many benefits for private landowners and for society at large. Among these benefits are aesthetic beauty, watershed protection, wildlife habitat, and timber income (Figure 1). However, many forests suffer from abuse and neglect. Livestock grazing; wildfires; poor logging practices; insects and disease; non-native invasive species; environmental stresses; and overly dense, slow growing trees all compromise forest health and diminish a forest's potential.

Through forest improvement we can protect, sustain, and improve forest health, and achieve landowner goals. Forest improvement may simply involve fencing livestock out of the forest or preventing wildfires. Commonly, however, forest improvement includes timber stand improvement (TSI). TSI increases timber value through:

1. increasing the proportion of valuable timber tree species in a forest stand;
2. increasing the proportion of trees that have good timber form, high quality, and defect-free wood volume (i.e., crop trees); and
3. reducing the time it takes for crop trees to grow to maturity by increasing growth rates.

TSI may also improve wildlife habitat; control invasive species; and enhance environmental, scenic, and recreational values of the forest. This handbook will help forest landowners, foresters, and forest contractors properly carry out TSI on many Indiana forests.

Figure 1. *Healthy forests can provide wildlife habitat, recreational opportunities, and income from timber harvests.*

Planning Forest Improvement

Forest improvement is an investment in the future and should be a part of any written forest management plan (see FNR-181, "A Landowner's Guide to Sustainable Forestry in Indiana, Part 2. Planning for the Future"). Federal and state cost-share programs may help pay for this work. A district forester can help identify and enroll properties in cost-share programs, assuming funding is available.

Regardless of the availability of government financial assistance, landowners should invest in the future health and productivity of their forest. **Often, annual rates of return from a forest improvement operation on an average to high-quality site exceed 10 to 15 percent!** An excellent example of these returns for TSI in an average woodlot is provided in Appendix A. Therefore, reinvesting a small percentage of timber sale income as forest improvement work makes good business sense.

The kind of forest improvement work needed depends on the individual forest stand's stage of development, species composition, and current tree condition. Forest improvement work should be prioritized so stands with the best potential for improvement and hence, the greatest return on the investment, are treated first. High-priority stands include those growing on productive sites and soils, and those on which a large majority of remaining trees following the forest improvement work are of desirable species and quality (see FNR-86, "The Economics of Timber Stand Improvement"). A professional forester can identify these stands and help carry out the necessary forest improvement work.

Reinvest a portion of timber sale income back into your forest through forest improvement work.

Forest Improvement Practices

Forest improvement practices range from simply cutting grape vines to the very complex task of marking trees for an improvement harvest or a commercial thinning. Often, more than one practice is done in a single operation. With a little instruction, landowners can control vines and prune young crop trees.

However, many landowners want a forester to help with most other forest improvement practices. Table B-1 in Appendix B gives an overview of the stages of forest stand development or current forest condition, and lists the forest improvement practices that may be needed for each stage or condition. Table B-2 in Appendix B provides a guide to specific, commonly used methods. Table B-3 shows herbicides commonly used for practices described in Table B-2.

NOTE!

Take care when using herbicides to prevent injury to yourself or other people, injury to wildlife, damage to water resources, or damage to non-target vegetation. ***The pesticide label is a legal document. Pesticides should not be used contrary to label directions!*** Please contact a professional forester that has been licensed by the state to apply pesticides before attempting widespread application of pesticides on your property. In addition, consider signing up for the pesticide application training available through the Purdue Cooperative Extension Service.

Pruning

Forest plantations may require pruning to help capture the investment made during their establishment. Pruning removes side branches from the lower trunk of a tree to produce clear, knot-free, and hence higher-value wood. In some cases "corrective" pruning is used to eliminate multiple stems or forks in very young trees to make one straight stem.

Since not all trees in a young stand will grow to maturity, direct your pruning to the most vigorous crop trees and limit it to the most valuable species, such as black walnut, black cherry, and oak. Do not prune species that self-prune naturally, such as tulip poplar. Normally no more than 100 trees per acre should be pruned.

Many desirable timber species growing in dense, natural stands lose their lower branches naturally and grow straight, well-formed trunks. Under these conditions, pruning is not normally necessary and should be a lower priority than other forest improvement practices.

Grape vine control

Grape vines often grow through and over the tops of trees, often shading, deforming, crushing, and killing them (Figure 2). Wild grape vines should be controlled where trees are grown for timber, particularly on highly productive sites, and in areas soon to be harvested and regenerated under full sunlight.

Figure 2. *Grape vines can damage young trees by growing into their crowns and bending and breaking their trunks. Their leaves can also shade the crowns of host trees causing growth decline or death.*

Grape vines can be controlled at any stage of stand development. In pole, immature and mature sawtimber stands at least 3 to 5 years preceding a timber harvest, when the forest canopy is dense and the forest floor is heavily shaded, vines and vine loops—sections of vines rooted to the ground—may simply be cut at a convenient height using a saw or loppers. In sapling stands, in stands where timber will be harvested within two years, or in stands where the sun shines on the forest floor much of the day, you will need herbicide to provide adequate control of vines.

There are two options for controlling grape vines using herbicide: basal bark spraying and cut stump treatment (Figure 3).

- **Basal bark spraying** involves spraying an herbicide diluted in an oil-based carrier onto the bark at the base of the vine. It may be used anytime except during the coldest and hottest parts of the year.
- The **cut stump treatment** involves cutting vines close to the soil surface and applying an appropriate herbicide to the cut surface of the vine stump. Make a second cut of the vine at waist level, so that the vine swings freely, and/or brightly dye the herbicide mixture to make it easier to see treated areas. The cut stump method is ineffective in spring (March to May) when the sap rises, flows freely from wounds in the bark, and flushes the herbicide out from the cut vine surface.

Both options are described in further detail later in the Forest Improvement Mechanics section, and appropriate herbicides for each method are listed in Table B-3 in Appendix B.

Figure 3. *Options for control of grape vines and vine loops include cutting and treating the stumps with an herbicide (left) and basal bark application of herbicide (right).*

Never make it your goal to eliminate grape vines completely from your forest! Grape vines are an important component of wildlife habitat (Figure 4). Leave some vines on poor-quality trees growing along the outside edges of a forest. Grape vine arbors or tangles may be cut back by treating easily accessible vines along the edge of the arbor, but are usually impractical to eliminate. To maintain higher shade levels that will help prevent grape vine spread, avoid areas with grape vine arbors when marking and harvesting timber.

Figure 4. *Wild grape fruits are significant components in the diets of many forest bird and mammal species.*

Control of invasive plants

Invasive plants are undesirable, grow aggressively, and damage or interfere with the growth of desirable trees and forest plants (Figure 5). Many invasive plants threaten forest regeneration, while others can destroy existing native trees. Notable examples in Indiana forests include callery pear, Asian bush honeysuckle, Japanese honeysuckle, multiflora rose, ailanthus or "tree of heaven," kudzu, Japanese stiltgrass, garlic mustard, and oriental bittersweet. Invasive plants often lack natural enemies in their adopted environment that otherwise restrict their growth and spread.

An infestation of a few plants may go unnoticed for a number of years before reaching a critical threshold, after which the species can quickly overrun the site. For example, some invasive species (such as Norway maple) are shade-tolerant and slowly infiltrate a forest. Others, like Asian bush honeysuckle, first establish on forest edges and nearby fencerows. Following a disturbance in the forest, such as a timber harvest,

Figure 5. *Tree regeneration in this oak woodland is largely absent because of shady conditions on the forest floor from the overtopping canopy of Asian bush honeysuckle, an aggressive, invasive species found throughout Indiana.*

invasive plants may capitalize on the new open space and quickly spread into the disturbed area.

If invasive plants are present in the stand or in adjoining stands or areas, include their management and control in the forest management plan. It is particularly important to assess the presence and extent of invasive plants well in advance of a timber harvest. If caught early, an infestation can easily be treated at little extra cost in conjunction with normal forest improvement work. Control costs can escalate rapidly if a small infestation goes unnoticed or is ignored even for a few years, and if the infestation becomes well established. By the time the invasive plants cause ecological and economic damage, control costs can reach several hundred to one thousand dollars per acre. Invasive plant control should be completed prior to a timber harvest to prevent their further spread and damage to forest regeneration.

Control of invasive plants varies greatly depending on the life history traits of the species or mix of species being targeted. A knowledgeable landowner can easily control some species early in the infestation by using

Control invasive species early and before you harvest timber to avoid economic and ecological damage to your forest.

only mechanical approaches. Commonly, however, a combination of treatments is required, most often with multiple treatments of cutting and applying herbicides over successive years. Methods described in the Forest Improvement Mechanics section may control some invasive plant species. However, a comprehensive set of recommendations for treating the many varied invasive forest plants is beyond the scope of this handbook. Visit the Midwest Invasive Plant Network for information on specific control methods for several of the most problematic species and for links to authoritative sources of invasive plant species information.

Cull trees

Severely damaged, excessively branchy, deformed, and diseased trees are often referred to as **cull trees** by foresters, meaning that they have little to no current or future commercial timber value. Cull trees include those that are hollow or with extensive decay in the trunk. They may also include "wolf" trees that have very large crowns and branches and short trunks, probably because they grew with few or no neighboring trees while maturing (Figure 6).

Cull trees affect stand growth because they occupy valuable growing space and compete with more desirable crop trees for water, nutrients, and sunlight. Such trees should be removed if they significantly limit crop tree growth or inhibit the establishment of desirable tree seedlings when regenerating the stand. Cull trees are removed by a variety of mechanical and chemical methods, including chainsaw felling, girdling, and herbicide injection. These methods are explained in the Forest Improvement Mechanics section of this guidebook.

However, cull trees can be valuable. Cull trees of desirable species may be retained to provide an important seed source for future forest regeneration. A cull beech or oak tree provides beech nut or acorn mast for turkeys, deer, and squirrels, while also providing valuable wildlife cover (Figure 7) such as dens for raccoons and nesting owls. Current Indiana Division of Forestry guidelines for state forests suggest leaving between 4 and 6 cull trees per acre for cavity-dwelling wildlife species. Such trees should be at least 11 inches in diameter, measured at "breast height," approximately 4½ feet above the ground (referred to hereafter as "**dbh**"). An additional 4 to 7 standing dead trees (called **snags**) per acre, which can be created from cull trees, may be left for bird- and bat-roosting sites.

Retaining cull trees for wildlife may be a tradeoff with timber management objectives for some forest landowners. Where large cull trees may be present, you may decide to keep fewer than the suggested minimum of four per acre. Please see FNR-102, "Woodlot Wildlife Management" and FNR-175-W, "Assessing Your Land's Potential for Wildlife" for more information on forest management options for wildlife.

Figure 6. *A wolf tree (left) grows in open conditions early in its life and develops many large branches low on the main trunk. This makes the tree of little or no value for timber, and thus, the tree is considered a cull. The sugar maple on the right is also a cull tree due to its poor bole quality and possible internal decay and defects.*

Figure 7. *This cull tree provides valuable foraging and nesting habitat for woodpeckers and other bird species.*

Figure 8. *This previously high-graded stand is now marked for an improvement harvest.*

Improvement cutting

Forest improvement may be accomplished through a timber harvest. Forest stands with a history of high-grading, where only the higher-value trees were harvested in the past, may benefit from an improvement cutting or harvest (Figure 8). Maturing forest stands that have had little or no management may also benefit from improvement cuttings.

Improvement cuts are not meant to maximize timber sale income in the short term, but instead to prepare a stand for improved long-term timber income. Through the harvest of saleable timber, an improvement cutting removes undesirable species and poorly formed, low-vigor, damaged, and/or diseased trees to favor desirable, higher-quality, crop trees. In addition, these cuts may remove some better quality trees within dense patches to reduce overcrowding and improve growth. Cash generated from the sale of timber generally pays for much, if not all, of the timber marking and other costs associated with the harvest. However, the benefits of an improvement cut must be weighed against potential logging damage to remaining crop trees and the timber buyer's or logger's need for some good-quality timber to make the sale profitable. Because maintaining this balance requires considerable skill in marking individual trees, it requires the skills of a forester.

Improvement cuttings will increase long-term timber income and may pay for themselves. Marking an improvement cutting requires the skills of a forester.

Preparing for forest regeneration

Forest regeneration refers to the establishment of a new stand of tree seedlings (Figure 9). When a forest stand is "regenerated," usually old, mature trees are harvested to create favorable light conditions on the forest floor for new, sun-loving tree seedlings to get established. Openings of less than three acres in the forest canopy made for the purpose of regenerating a stand are referred to as **regeneration openings** or **group selection openings**, whereas larger openings are referred to as **clearcuts** (see FNR-182, "A Landowner's Guide to Sustainable Forestry in Indiana, Part 3. Keeping Your Forest Healthy and Productive").

Following a timber harvest, areas to be regenerated still have many non-merchantable, suppressed, and otherwise cull trees casting their shade on the forest floor. Left alive, these remaining trees interfere with the establishment of desirable tree seedlings (Figure 10). They must be removed immediately following the timber harvest to ensure successful regeneration of the stand.

The stumps of felled trees of undesirable species should be treated with herbicide to prevent stump sprouting. Grape vines not controlled in advance of the timber harvest should also be controlled with herbicides at this time.

Stump sprouts of desirable tree species are an important component of the regenerating stand along with the seedlings, and are particularly important for regen-

Figure 9. *Regenerating a forest means successfully establishing a new generation of desirable seedlings and sprouts.*

Figure 10. *A regeneration opening prior to post-harvest TSI showing remaining undesirable trees occupying growing space and casting shade on regeneration (upper left). B. After post-harvest TSI is complete with dead standing trees called "snags" (upper right). C. One year after harvest and post-harvest TSI you find dense herbaceous vegetation and new tree seedlings (lower left). D. This stand has a young, dense, vigorous stand of saplings five years after harvest and post-harvest-TSI (lower right).*

To Coppice or Not to Coppice…

When regenerating trees, cut or coppice stems of desirable species to grow new stump sprouts. Follow these general guidelines for deciding whether or not to coppice a stem:

- Choose desirable species, such as most oak species, black walnut, and black cherry.
- Choose stems that do not have good stem form or "flat-topped" crowns that often indicate low crown vigor.
- Choose smaller stems, since sprouting viability decreases with parent tree diameter:
  - 1-6" dbh = viable sprout
  - 6-12" dbh = 50% chance
  - 12"+ dbh = little chance

This "flat-topped" pole-size white oak left over from logging should be coppiced to produce vigorous sprouts.

erating oaks. Cutting down trees of desirable species less than 12 inches dbh and permitting them to sprout from the stump is a practice referred to as **coppicing.**

Preparing a site for regeneration may also take place prior to the timber harvest. Oak seedlings must be large (3 ft. tall or 0.75 in. root collar diameter) and well established prior to removal of overstory trees so the oaks can successfully compete with other, faster-growing species. One way to enhance this advanced oak regeneration is to increase the amount of sunlight reaching the forest floor prior to removal of the overstory trees. This is done by removing the midstory canopy, usually composed of shade-tolerant species like sugar maple, red maple, dogwood, beech, ironwood, and black gum, five to ten years prior to a regeneration timber harvest (Figure 11). Time this midstory removal to coincide with a large acorn crop to improve oak regeneration success.

Deer browse on young trees and prefer many tree species valued for timber, such as the oaks. Where deer populations are high, significant damage occurs to tree regeneration. Forest improvement may include measures to reduce deer damage to regeneration. Such measures may include increased hunting pressure, fencing, tree shelters, or deer repellents.

Figure 11. *Removal of the shade-tolerant midstory at the time of a large crop of acorns helps establish the advance seedlings needed to regenerate oak.*

When regenerating, harvest, kill, or coppice all trees in the area to be regenerated, including the unmarketable ones.

Thinning

Thinning is the removal of selected trees from a stand to reduce competition and favor the growth, health, and development of remaining trees. Thinning is done in stands that have higher densities than optimum for their average tree size (Table 1). Such stands are characterized by high rates of tree mortality; slowing growth of surviving trees; significant reductions in the amount of living crown; and generally, little understory growth or development. These stands can be more vulnerable to insects, disease, drought, and pollution. Timely thinning keeps crop trees healthy and growing to their full potential. Thinning can be done at any stage of stand development following crown closure, or when individual tree crowns begin to interlock and significantly reduce the amount of sunlight reaching the forest floor, and before stands mature (Figure 12).

Sapling stands

Plantations and stands that naturally regenerate from seed or sprouts often need a thinning treatment when they reach sapling size (about 2 to 6 inches dbh). This thinning usually occurs when the stand is between 10 and 20 years old. By this stage, superior trees should begin to express dominance, usually by outgrowing competitors in both height and diameter. Also, at this stage, briars have been largely shaded out and the stand has naturally thinned enough to allow forest workers to walk through it.

Table 1. General tree spacing guide for upland Central Hardwood forests. Individual stand thinning prescriptions should be made with the help of a forester.

Avg. Tree Diameter (inches)	Recommended Tree Spacing (feet)	Tree Stocking (trees/acre)
2	5 – 7	890 – 1740
4	8 – 10	440 – 680
6	10 – 13	220 – 360
8	13 – 17	130 – 220
10	16 – 20	100 – 170
12	18 – 24	70 – 120
14	21 – 27	50 – 90

Figure 12. *Heavily stocked stands at sapling (top), pole (middle), and small sawtimber stages of stand development (bottom). Thinning at each of these stages maintains the vigor and growth of remaining trees while also improving species composition and overall timber quality.*

There are two options for treatments in sapling stands. If crop trees (see sidebar) are not apparent within the stand, wait to thin or concentrate on improving species composition (i.e., the proportion of desirable tree species) while maintaining relatively constant 6 to 12 foot spacing between the trees. Cut trees with a chainsaw or clearing saw (Figure 13), but take care not to damage the remaining trees. Herbicide treatments may also be used to deaden stems. At this stage, also take care not to over-thin. Maintaining the proper tree density will train trees to grow straight and tall, and to shed lower branches more quickly, allowing more potential crop trees to develop.

If crop trees are apparent within the stand, a *crop tree release treatment* should be done. Here thinning is done to release select crop trees, rather than all desir-

Figure 13. *Clearing saws are useful in sapling stands or where there are a large number of small stems to treat. They are much safer and more efficient than chainsaws in these conditions.*

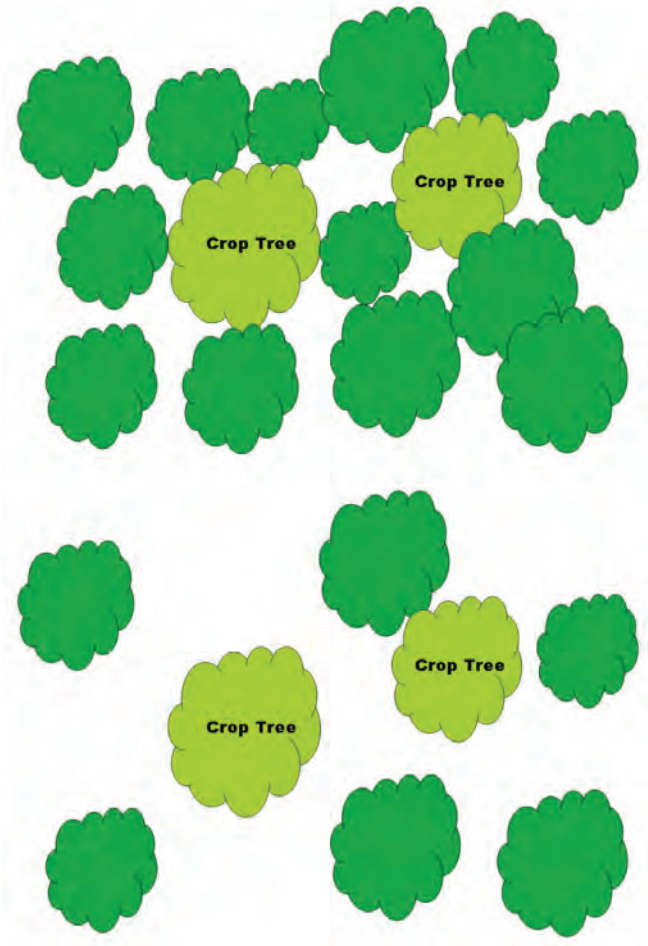

Figure 14. *Example of a crop tree release treatment. The two crop trees were quite crowded and competitors had to be removed to increase their growth (top). A crop tree release (bottom) removed all trees whose crowns were touching the crop tree crowns either on three sides (right crop tree) or all four sides (left crop tree).*

Crop Tree Selection Criteria

Thinning is a complex task requiring the skills of a forester. The forester will take several items into consideration during crop tree selection including:

- Crown above or in the main canopy of the forest
- Full, healthy crowns
- Straight trunk free of damage, decay, forks, epicormic branches (bole sprouts that emerge from the trunk when stimulated by increased sunlight following thinning), and other defects
- Species adapted to the site
- Species selected to meet management objectives

Figure 15. *A crop tree release treatment in a larger sapling-sized oak stand. Competing trees were removed mechanically with clearing saws (left) and the crop tree was released on all four sides using the crown-touching method (right). Notice that the area between crop trees was largely left uncut (left background).*

able trees in the stand. Generally at this stage, no more than 75 to 100 crop trees per acre, well-distributed over the stand (approx. 20 to 25 feet spacing), need this treatment. Trees should be released with the "crown-touching" method, where all competitors with crowns that touch the crop tree are cut or deadened (Figures 14 and 15). This allows the crop tree to develop a full, well-balanced crown and achieve its full growth potential. In areas between the crop trees, you may do additional thinning as described above, but again be careful not to thin further around the crop trees. This would give crop trees too much space and cause low branching, short trunks, more defects, and lower timber value.

For both of the above options, you often must manage stump sprouts. Some saplings in young stands may be stump sprouts of desirable species, but often occur as multiple sprouts growing from one stump. Weaker sprouts in these clumps eventually may die, but by the sapling stage, two to four still usually remain,

Figure 16. *During the sapling stage of stand development, clusters of stump sprouts (left) should be thinned to the single best-formed stem (right).*

competing with each other for sunlight and space. Left alone, these sprouts tend to grow away from each other, resulting in leaning trees with trunk sweep, which later in their development may degrade timber value to some degree. Further, untreated sprouts often develop decay over time. This usually occurs when decay enters the cut stump and travels into the base of the sprouts, particularly those that originate closer to the top of the stump. Therefore, during these initial thinning treatments, select the single best sprout that originates low on the stump and cut off the rest (Figure 16). Herbicides should not be used in this treatment, because they may damage or kill the remaining sprout.

Pole stands

Pole size stands have average tree diameters of 6 to 12 inches dbh and typically are 20 to 50 years old. Thinning treatments at this stage will vary tremendously depending on stand composition, previous thinning activity (if any), and landowner goals. Potential treatments include:

- **low thinning**—removes the smallest trees from the stand,
- **crown thinning**—similar to crop tree selection and removes larger trees from the stand, or
- **free thinning**—includes aspects of both (Figure 17).

These can be complicated treatments; therefore, we suggest the use of a forester in developing the prescription. Regardless of which treatment is selected, only about 60 crop trees per acre need be selected at this stage of stand development. Crop trees should be spaced about 25 to 30 feet apart with an overall spacing between all trees of 12 to 20 feet. As with the sapling stage, you must take care to not over-release crop trees at the pole stage.

Sawtimber stands

Stands at later stages of development may need thinning. Sawtimber size stands (12 inches dbh and larger) may be thinned through the sale and harvest of timber followed by cull tree removal. This may be done in an improvement harvest, as previously described. White oak veneer stands require special care when thinning. Veneer texture or grain pattern may be negatively affected by variable growth rates caused by infrequent, heavy thinning, especially in previously unmanaged stands. Maintaining smaller trees that shade the boles of crop trees helps prevent epicormic branches (bole sprouts that emerge from the trunk when stimulated

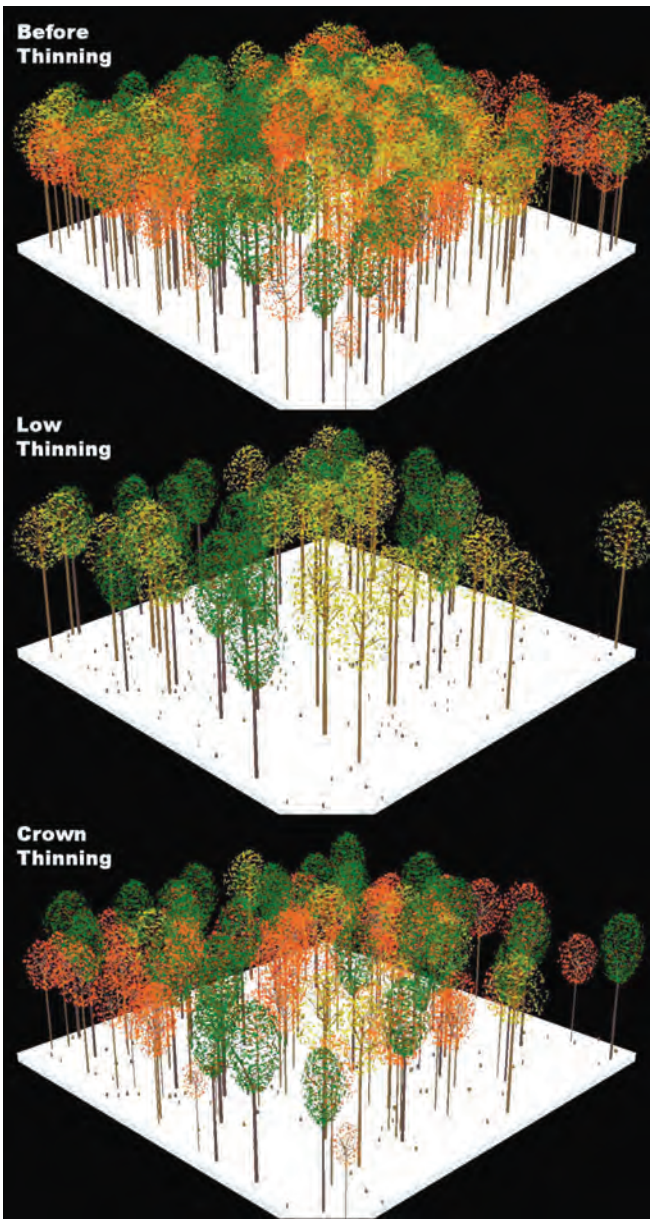

Figure 17. *Example of low thinning and crown thinning in a mixed yellow-poplar (yellow-green), red oak (dark green) and sugar maple (red-orange) stand. Low thinning removes most small maples that prevent epicormic sprouting on the remaining oak stems, but may also aid in the establishment of new oak seedlings. Crown thinning maintains many of these slower-growing and often shade-tolerant species and also trainers that shade residual stems.*

by increased sunlight following thinning (Figure 18) that would reduce sawtimber and veneer quality. To maintain optimum tree vigor and growth and to maintain high quality timber, thin more frequently, but harvest fewer trees each time. This is better than infrequently thinning a large proportion of the trees each time. Thinning prescriptions should be uniquely designed by a forester for each forest stand.

Figure 18. *Epicormic branching degrades timber grade and value. Trees that are stressed or have small, unhealthy crowns are prone to develop epicormic sprouts following a timber harvest or thinning.*

At this stage of forest stand development, mistakes in marking and harvest can have dramatic impacts on future forest health and productivity. For this reason, we **highly recommend** that you use a forester for marking these treatments. Further, the landowner and/or the forester should supervise logging crews very closely to prevent damage to remaining crop trees (Figure 19).

Forest Improvement Mechanics

Foresters use five basic methods for killing or removing trees for forest improvement: cutting, girdling, frilling, injection, or basal bark spraying. Pruning, which is also discussed here, can be applied early in

Thin when tree crowns start touching to maintain their growth rates. Do not over-thin! Employ a forester to mark and/or carry out a forest thinning.

Figure 19. *Logging damage caused by the skidding operation during a commercial thinning severely reduced the potential value of what should have been a veneer-quality white oak.*

stand development to improve quality and quantity of potential crop trees.

Cutting

If enough merchantable timber volume exists, have a forester mark the saleable trees for an improvement cut and harvest them in a timber sale. If there are not enough merchantable trees to sell, you can cut the small sawtimber and large pole-sized trees for firewood or some other use with a chainsaw (Figure 20). All other trees requiring removal in the forest improvement operation can be felled using either a chainsaw or a clearing saw. For larger nonmerchantable trees, like wolf and cull trees, girdling or frilling is a safer option; these trees may be dangerous to fell and may damage neighboring crop trees when they fall.

Stumps of felled trees may be treated with herbicide to prevent sprouting. This treatment is called **cut stump treatment** (Figure 20). This is particularly important in stands to be regenerated in the near future (< 10 years) where there are a significant number of undesirable and/or invasive species. Herbicide is not usually necessary after thinning or crop tree release in stands at earlier stages of forest development, such as the sapling and pole stages, because shade from the rapidly expanding crowns of the remaining trees suppresses

Chainsaw Safety

Chainsaws are useful tools but inherently dangerous in the hands of untrained, inexperienced operators. If you lack experience, consider hiring a forester, logger, or other trained labor to do your chainsaw work. Chainsaw safety training may be offered from the Indiana Department of Natural Resources Division of Forestry, Purdue Extension foresters or your local chainsaw dealer.

Figure 20. *Trees may be thinned using chainsaws or clearing saws. Stumps of felled trees may be sprayed with herbicide to prevent sprouting.*

the growth of sprouts from the cut stems. An exception to this is grape vine control in sapling stands, where tree tops are still within easy reach of sprouting vines.

Table B-3 in Appendix B lists the herbicides commonly used for cut stump treatment. Herbicide is applied to the outer 1 to 2 inches of the stump to include the cambium layer next to the bark (Figure 21). Apply herbicide immediately following cutting. Cut stump treatments may be applied using a squeeze bottle, squirt bottle, or backpack sprayer. However, in late winter and early spring, increased sap flow can flush herbicide from the stump surface in some species, including sugar and red maple, and grape vines. If possible, delay cutting for these species or consider using another technique such as basal bark spraying. Do not treat the stumps of desirable species with herbicide. These stump sprouts may develop into saplings that will help to regenerate the stand in the future.

CAUTION!

In some species, herbicide can be **translocated** or moved between trees through naturally occurring grafts in their root systems. The damage caused by herbicide movement between treated and untreated trees through these grafts is commonly called flashback. Tulip poplar is particularly sensitive to herbicide flashback with Tordon or Pathway herbicides, which are commonly used in cut stump, girdling, frilling, and injection treatments.

Girdling

Killing a tree and leaving it standing allows the tree to deteriorate slowly, therefore doing little or no damage to surrounding trees. Trees killed or "deadened" in forest improvement work are often called snags. Snags are

Figure 21. *For stumps larger than 2 to 3 inches in diameter, herbicide need only be applied around the outer 1 to 2 inches to include the cambium layer.*

important habitat for many species of wildlife including squirrels, woodpeckers, song birds, owls, and bats.

Girdling is one method of killing trees in place and creating snags. Girdling severs the bark and cambium layers in a continuous ring around the full circumference of the tree trunk. Girdling is done using either a chainsaw or an axe. Axe girdles are made by removing at least a 4-inch wide ring of bark and cambium (Figure 22). This is most easily accomplished in spring when the bark on many tree species is naturally loose. Single chainsaw girdles are sometimes bridged by the growth of new cambium from below and above the cut. A double girdle using a chainsaw with cuts spaced approximately 6 inches apart and ½ to 1 inch deep into the wood is usually effective (Figure 23). Care must be taken to ensure that axe or saw cuts are continuous

Figure 22. *An ax girdle should remove at least a 4-inch wide band of bark and cambium.*

Figure 23. *A proper double girdle with cuts spaced about 6 inches apart and ½ to 1 inch deep. Herbicide is not usually required for a double saw girdle.*

around the full circumference of the trunk, otherwise sugars still move from the crown to the roots and the tree survives (Figure 24). However, some trees may still survive a double chainsaw girdle, particularly those with ingrown bark seams or healing wounds. Where

Figure 24. *An improper girdle (left) does not make a continuous break in the full circumference of the phloem and cambium, allowing sugars to move from the crown to the roots. This allows the tree to eventually heal the girdle (center). This is remedied by making a diagonal cut to connect the two girdle ends (right).*

practicable, girdles should be cut above wounds that are at the base of the trunk. "Plunging" the saw blade into the trunk where a bark seam occurs may sever these connections, but this should only be attempted by experienced saw operators because of the extreme risk of "kickback" from the chainsaw.

Herbicides can also be used with girdling on hard-to-kill trees or to eliminate the need for a second chainsaw cut in double girdling (Figure 25). Herbicides eliminate unwanted sprouting that often occurs after girdling. In a regeneration opening, this sprouting might interfere with desirable regeneration. Herbicide should be sprayed around the full circumference of the girdle cut using a squirt bottle, spray bottle, or backpack sprayer. Table B-3 lists herbicides appropriate for this method.

Figure 25. *Single chainsaw girdle (left) followed by application of herbicide to the cut (right).*

Chainsaw girdles work best for larger diameter (>8 inches dbh), structurally sound trees. Girdle cuts only need to be deep enough to sever the cambium and a few rings of sapwood. A common mistake made by inexperienced forest workers is to make the girdle cuts much deeper than is necessary to kill a tree. When girdled, small diameter trees have less supporting strength and are thus vulnerable to breaking and falling over. Although this may not occur while actually girdling it, it could make the stand unsafe to venture into for several years. Likewise, hollow or decayed trees may have little solid wood supporting the weight of the tree's trunk and crown. Cutting into that slim margin of strength with a chainsaw increases the risk of complete trunk failure and extreme danger to the forest worker. Therefore, for trees less than 8 inches dbh or trees that are hollow or decayed, use one of the other methods described in this handbook.

Frilling

Frilling, also referred to as "hack-and-squirt," is a combination of manual and herbicide treatments where a hand axe is first used to make a "frill" type girdle with downward cutting strokes around the entire circumference of the tree trunk (Figure 26). These "frill" cuts penetrate the cambium, leaving cups or pockets into which herbicide is applied. Use a squeeze bottle, squirt bottle, or backpack sprayer with wandless hand gun or "gunjet" to apply the herbicide. If the tree has wounds or seams with ingrown bark, make the frill above the defect, if possible. Frilling is recommended for trees larger than 4 inches dbh where chainsaw girdling is not safe. Frilling can be done any time of the year except

Figure 26. *A frill girdle is done using a hand ax (top) with herbicide applied to the wound (bottom).*

Figure 27. *An example of an herbicide injection system for killing standing trees (left). Approximately one cut is made per inch of tree diameter, or with approximately 1½ inches of space between cuts, edge to edge, using a hand ax blade ground down to 1½ to 2 inches wide (top right). Herbicide is then applied to the cuts (bottom right).*

during the periods of high sap flow in early spring. As with girdling, flashback can occur with frilling.

Injection

Injection of a lethal dose of herbicide into the tree through cuts into the stem is another common method of control. Specialized tools, like the Hypo-Hatchet™, are available from forestry suppliers for this method, but you also can use more conventional cutting tools and a squirt bottle. For example, a hand ax or hatchet blade can be ground down to a 1½ to 2 inch width and sharpened to a fine edge to make an effective injection wound. A shingler hammer also provides the ideal width and only requires sharpening the blade to make it useful for herbicide injection (Figure 27).

Make the injection with an angled, downward stroke of the blade, forming a cup or pocket into which you dispense about 1 milliliter of concentrated herbicide. You can dispense the herbicide from a squeeze bottle, squirt bottle, or backpack sprayer with a wandless hand gun or "gunjet." The injection cut should penetrate the cambium and go a little way into the sapwood. The horizontal axis of the cut should be level so it holds the herbicide, preventing it from running out and down the side of the trunk. Space injections evenly around the full circumference of the trunk, one injection for each inch in trunk diameter or approximately 1½ inches between injections, edge to edge. Keep injections on the same horizontal level as you work around the tree's trunk.

Injection is recommended for trees under 10 inches dbh. As diameter increases, more injections can be made at a closer spacing to ensure more uniform kill. At some point, injection will merge into frilling. As with girdling and frilling, injection should not be done during periods of high sap flow nor with species subject to flashback.

Basal bark spraying

This technique involves spraying an herbicide diluted in an oil carrier to the bark at the base of vine, shrub, or tree stems. The oil in the mixture allows the herbicide to penetrate the bark. Once inside the bark, the herbicide enters the plant's vascular system and gets distributed throughout the plant, eventually killing it. Commercially available oils designed for basal bark applications include mineral-, paraffin-, aliphatic-, and vegetable oil-based products. Diesel oil or kerosene can be used in a pinch, but these are not as safe to the user nor are they as environmentally friendly as the more benign commercial grade oils. Ready-to-use herbicide-oil mixtures are also commercially available. Consult with a forester or your herbicide dealer for the appropriate herbicide and oil diluents for your particular application (Table B-3).

Basal bark treatments are most commonly applied using a backpack sprayer with a straight wand and an adjustable cone nozzle (Figure 28). Apply the spray at the base of the stem or from the ground line, up 12 to 15 inches, and around the full circumference of the stem, thoroughly wetting the stem to the point of runoff for more dilute mixtures or not to the point of runoff for more concentrated mixtures. Species that are difficult to kill, have thick bark, or have stems that

Figure 28. *Basal bark spraying using a triclopyr and bark oil mixture to selectively remove a red maple and black gum that are competing with a red oak crop tree (left). The herbicide and oil mixture should be applied from the ground line up the stem 12 to 15 inches and around the full stem circumference (right).*

are larger will require more herbicide applied both higher up the stem and more heavily at the root collar where bark may be thinner. However, be careful to avoid significant runoff from the stem or overspraying on surrounding ground. Herbicides commonly used for basal bark spraying have some soil activity and can be absorbed by the roots of surrounding non-target vegetation.

Basal bark spraying is recommended for trees, vines, and shrubs under 6 inches in diameter. Stems larger than 6 inches should be treated with one of the other methods. You can effectively treat larger stems of thin-barked species (e.g., beech) with this method. However, because of the larger volume of herbicide concentrate used in basal bark treatments and the cost of the oil carrier, other methods are usually more cost-effective for larger trees. You can use basal bark spraying during many parts of the year; however, better control may be achieved on some hard-to-kill species with late summer through fall applications. Do not do basal bark spraying when the bark is wet or frozen, when snow is on the ground, nor when the air temperature exceeds 85° to 90° F. At high temperatures, the ester formulation of herbicides commonly used in basal bark applications volatilizes, potentially reducing effectiveness on target stems and damaging non-target vegetation. Although herbicide costs are usually higher, the labor costs are generally lower than with other methods. Further, when all safety measures are considered, basal bark spraying is safer than methods using chainsaws or other sharp tools.

Pruning

Pruning is usually done with hand saws or saws on long poles designed especially for that purpose (Figure 29). Hand saws may be used for pruning younger trees where all unwanted branches are within reach from the ground. Pole saws allow for additional sections of pole to be added or are telescoping, ranging in sawing height from 12 to 40 feet. Depending on model and features, these saws can cost from $100 to over $1000.

Ideally, branches should be pruned before they die or reach 2 inches in diameter. The larger the branch stub left, the longer it takes for the wound to heal, increasing the opportunity for harmful insects or decay to attack the tree. Remove no more than one-third of the live crown in a single pruning. Remove all dead branches within reach. For younger trees less than 40 feet tall, maintain half the tree height in live crown. For improved timber quality, pruning should provide for clear, knot-free wood in at least the first 12 to 16 feet of trunk length (Figure 30).

Two methods of pruning have arisen from two different schools of thought (Figure 31).

- Method one calls for cutting the branch off just outside the branch collar in a cut angling down and away from the trunk (Figure 31, center). The branch collar is the swollen tissue at the base of the branch where it connects to the trunk. Open-grown landscape trees usually have large limbs, and thus should be pruned using method one.

Figure 29. *Pole saws allow pruning to extended heights. Trees should be pruned to at least a 12- to 16-foot height.*

Figure 30. *Young black walnut pole in need of pruning (left). Same tree after pruning (right) up to 12 feet high.*

Figure 31. *Forest researchers disagree on how close to the trunk trees should be pruned. One method recommends cutting just outside the branch collar, as shown in the center picture. The other method advocates cutting inside the branch collar, flush, or nearly flush, with the trunk (left).*

Figure 32. *Pruning is a three-step process. First, make an undercut 1 to 2 inches from the trunk, approximately ½ inch deep (A). Second, at ½ to 1 inch further out on the limb from the undercut, cut from above until the limb is completely severed (B, C, D). Third, a final cut removes the branch stub (E, F). This cut should be made either just outside the branch collar or nearly flush with the trunk, depending on species, objectives, and other factors described in this handbook.*

- In method two, the limb is cut parallel and close to the trunk, actually cutting into the branch collar (Figure 31) (O'Hara 2007). In forest stands managed intensively for timber, use method two to maximize the amount of clear, knot-free wood growing in the tree. One exception is when a branch exceeds 1 to 2 inches in diameter at its base, thus leaving a large wound when cut. Excessively large pruning wounds take longer to heal and encourage insect infestation and decay. Another exception is where branches grow in a whorl at the same height on the trunk, as they do on some species of pine and spruce. Pruning a whorl of branches too close to the trunk can almost girdle the tree.

Regardless of the method used, the three-cut process described in Figure 32 should be used. Using this method prevents the weight of the falling branch from tearing the bark off the trunk below the branch as the cut nears completion. Pruning may be done any time of the year except spring, when the bark is most easily torn or otherwise damaged.

Forest Improvement Assistance

For further information on improving your forest or to obtain forestry assistance, contact any of the following:

The Indiana Division of Forestry provides professional forest management assistance through District Foresters located throughout the state.

Indiana Division of Forestry
402 West Washington Street, Room 296W
Indianapolis, IN 46204
(317) 232-4105

Consultant Foresters provide a full range of services for forestland owners. The Indiana Forestry and Woodland Owners Association publishes a directory of private consultant and timber industry foresters.

Directory of Professional Foresters
Indiana Forestry & Woodland Owners Assoc.
1007 N 725 W
West Lafayette, IN 47906
(765) 583-3501

Purdue University's Department of Forestry and Natural Resources conducts research in forest improvement methods and provides continuing education programs and forestry and wildlife literature for forest landowners:

Purdue Forestry and Natural Resource Extension
(765) 494-3583

The Indiana Division of Fish and Wildlife provides wildlife management assistance through District Biologists located throughout the state.

Indiana Division of Fish and Wildlife Private Lands Program
402 West Washington Street
Indianapolis, IN 46204
(812) 334-1137

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Appendix A: Is Forest Improvement Worth the Cost?

Timber stand improvement (TSI), one form of forest improvement, is an investment that can pay handsome returns. Forest stands growing on productive sites that are well managed and well stocked with higher-value species will produce the largest rate of return for TSI dollars invested. The following example is provided by Dr. William L. Hoover, Professor of Forest Economics at Purdue University:

> The TSI of a 60-acre mixed hardwood forest stand is being considered. The stand is well stocked with veneer species (oak, walnut, maple) with the potential to make veneer logs and prime sawlogs. A commercial harvest is planned in 15 years. Without TSI the unit value of the timber in 15 years is estimated to be $310 per thousand board feet (MBF). TSI will thin out lower value trees to provide more growing space for the high value crop trees, resulting in a substantial increase in the volume of timber that will be in veneer species. The resulting estimated value of the standing timber 15 years after TSI is $494 per MBF. The volume in 15 years is expected to be 4.5 MBF per acre and would be essentially the same with or without the TSI. TSI costs vary according to forest stand conditions and the type and amount of work needed. For this example, let's assume that TSI costs $100 per acre in year 0 (i.e., I_0 = $100 per acre). The value of the timber at the end of the 15 year investment period (i.e., n = 15 years) if we did not do TSI is:
>
> $$V_{NONE} = 4.5 \text{ MBF per acre} \times \$310 \text{ per MBF} = \$1{,}395 \text{ per acre}$$
>
> If we do TSI, the value is:
>
> $$V_{TSI} = 4.5 \text{ MBF per acre} \times \$494 \text{ per MBF} = \$2{,}223 \text{ per acre}$$
>
> Our annual rate of return on the TSI investment (i) is calculated as:
>
> $$i = \left[\left(\frac{V_{TSI} - V_{NONE}}{I_0}\right)^{\frac{1}{n}} - 1\right] \times 100$$
>
> $$= \left[\left(\frac{\$2{,}223 - \$1{,}395}{100}\right)^{\frac{1}{15}} - 1\right] \times 100$$
>
> $$= 15.1\%$$
>
> This is only one example of a wide array of possible investment returns from TSI. If the same scenario were imposed on a stand that had a much higher black walnut composition, the annual rate of return could be as high as 20% over the same investment horizon. Lower-quality stands growing on poorer sites will yield lower rates of return.

Appendix B: Prescription Tables

Table B-1. General forest improvement prescriptions appropriate for various stages of forest stand development and forest conditions.[1]

Stand Development Stage	Approx. Age (years)	Forest Improvement Practices	Wildlife Considerations	Other Considerations
Mature stand with impending timber harvest (within 0 – 10 years)	65 – 100+	• Control grape vines and invasive plants, preferably at least 3 years prior to harvest. • Control midstory canopy trees at least 5 years prior to harvest to recruit advance oak regeneration. • In single tree selection harvesting, leave adequate numbers of healthy trees of desirable species to provide seed sources for future stand regeneration.	• Maintain grape vines on edges. • Identify and mark den trees to save. • Leave adequate numbers of mast-producing trees like oaks. • Make regeneration openings large enough (minimum of 1 acre) to benefit early succession habitat wildlife.	Avoid diameter limit cut and "high-grade" type timber harvests that degrade stand health and long-term productivity. Even small numbers of invasive plants present at the time of timber harvest may quickly spread and become a serious pest following the harvest.
Recently harvested stand	0 – 3	• Control grape vines. • Complete regeneration openings. • Control cull trees. • Control invasive plants.	• Retain or create 4 to 7 snags per acre and/or 4 to 6 cull/den trees per acre.	Complete forest improvement work within one year after a harvest to avoid dense briars and brush. **However, watch out for hazards left over from the logging!**
Sapling stand (< 6" dbh)	5 – 20	• Thin to ~ 6' – 10' spacing (430 to 900 trees/acre), favoring desirable species. • Thin stump sprout clusters to the single best stem. • Prune selected high-value species if time and funds allow. • Control grape vines. • Control invasive plants.	• Release some mast producing trees and shrubs, such as dogwoods, serviceberry, and hazelnut, along stand edges.	
Pole stand (6" – 12" dbh)	15 – 50	• Thin to ~ 14' to 20' spacing (70 to 120 trees/acre) with ~ 25' to 30' between selected crop trees. • Crop tree release. • Control grape vines. • Control invasive plants.	• Release some mast producing trees and shrubs, such as dogwoods, serviceberry, and hazelnut, along stand edges.	
Small sawtimber stand (12" – 18" dbh).	30 – 70	• Improvement harvest/commercial thinning. • Crop tree release. • Control invasive plants.	• Retain or create 4-7 snags per acre and/or 4-6 cull/den trees per acre.	Tree species and markets determine feasibility of commercial thinning in small sawtimber stands.
Previously unmanaged, maturing stand	50 – 90	• Improvement harvest. • Control cull trees. • Control grape vines. • Control invasive plants.	• Retain or create 4 to 7 snags per acre and/or 4 to 6 cull/den trees per acre.	
Diameter limit cut or "high-graded" stand	Anytime	• Improvement harvest or clearcut harvest. • Complete regeneration openings or control all residual standing trees if a clearcut harvest. • Control cull trees. • Control invasive plants.	• Retain or create 4 to 7 snags per acre and/or 4 to 6 cull/den trees per acre. • Make regeneration openings large enough to benefit early succession habitat wildlife. • Maintain grape vines on edges.	The decision to do an improvement harvest or a clearcut harvest depends on the condition of the stand.

[1]Specific forest improvement prescriptions should be developed for each forest stand with the assistance of a forester.

Table B-2. Forest improvement mechanics – most common methods for controlling target trees, shrubs, and vines.

Control Method	Forest Improvement Practice	Herbicide	Timing	Caution	Notes
Cutting alone	• Thinning sapling and pole stands. • Crop tree release. • Stump sprout thinning. • Grape vine control in heavy shade and at least 3 years prior to timber harvest.	none	Anytime	Larger trees (> 10 inches dbh), particularly wolf trees, hollow trees, or trees with significant amounts of decay are hazardous to fell. Use other control methods for these types of trees.	Use herbicide for grape vines in sapling stands, recently harvested stands, or where significant amounts of sunlight reach the forest floor.
Girdle, ax or double chain saw	• Thinning pole stands. • Crop tree release. • Cull tree removal.	none	Anytime, although ax girdling easier in spring when bark is loose.	Hollow or decayed trees may be dangerous to chain saw girdle. Use other control methods for these types of trees.	Some hard-to-kill species may survive double chain saw girdle. Girdling alone may stimulate strong stump sprouting or root suckering on certain species. Herbicide would improve kill rate and reduce sprouting and root suckering.
Cut stump	• Completing regeneration openings – stems < 4 to 6 inches dbh. • Cull tree removal. • Midstory canopy removal. • Grape vine control in sun, imminent or completed timber harvest.	Yes – See Table B-3	Anytime but during winter or spring sap flow for species like sugar maple and grape vine.	Larger trees (> 10 inches dbh), particularly wolf trees, hollow trees, or trees with significant amounts of decay are hazardous to fell. Use other control methods for these types of trees.	Stumps of desirable species should not be treated with herbicide in regeneration openings.
Girdle, chain saw single or double	• Completing regeneration openings – stems > 4 to 6 inches dbh. • Thinning pole stands. • Crop tree release. • Cull tree removal. • Midstory canopy removal.			Hollow or decayed trees may be dangerous to chain saw girdle. Use other control methods for these types of trees.	Use double girdle with herbicide on hard-to-kill species like black gum.
Frill	• Completing regeneration openings. • Thinning sapling and pole stands. • Crop tree release. • Cull tree removal. • Midstory canopy removal.				Create small overlapping cups or pockets around the tree's circumference to hold the herbicide.
Injection	• Completing regeneration openings. • Thinning sapling and pole stands. • Crop tree release. • Cull tree removal. • Midstory canopy removal.				One injection for each inch in dbh or approx. 1.5 inches between cuts, edge to edge. Evenly space injections around the tree trunk circumference and make them horizontally aligned on the same level.
Low volume basal bark	• Thinning sapling stands. • Midstory canopy removal. • Grape vine control.		Anytime except when bark is wet or frozen or when snow prevents spraying to the ground line. Method is particularly useful during late winter and spring sap flow.		It's important to spray on all sides of stems over 1 inch in diameter and to spray to ground line or root collar.

Table B-3. Herbicides commonly used in forest improvement work.

Control Method	Herbicide[1,2,3,4]	Rate	Dilute With	Timing	Caution[5]	Notes
Cut stump Girdle, chain saw (single or double) Frill Injection	*glyphosate* Accord, Glypro, Razor, Rodeo, Roundup, or others	50 – 100%	Water	Anytime but during winter or spring sap flow for species like sugar maple and grape vine. Best control achieved during periods of active growth and full leaf expansion (summer)	Least consistent performance of all listed herbicides for cut surface treatment of woody vegetation.	Injection – 1 ml undiluted per cut with cuts spaced at 2 inches, edge to edge. This is particularly effective on beech.
	dicamba Banvel, Clarity, Vanquish, or others	25 – 50%		Anytime but during winter or spring sap flow for species like sugar maple and grape vine.	Potential non-target damage through root absorption from soil. High volatility may also cause non-target damage.	Apply at higher concentrations for hard-to-kill species. May add *2,4-D amine* to speed control in girdle and frill applications.
	imazapyr Arsenal, Stalker, Chopper Gen2, Arsenal AC	6 – 9% 3 – 5%			Potential non-target damage through root absorption from soil or root grafts with treated trees.	Injection – 1 ml solution per cut with cuts spaced at 1 inch, edge to edge. **Effective at low concentrations!**
	triclopyr amine/ choline Garlon 3A, Vastlan, Tahoe 3A, or others	50 – 100%				Injection – 1 ml diluted or ½ ml undiluted per cut with cuts spaced at 1 to 2 inches, edge to edge.
	picloram + 2,4-D Pathway or Tordon RTU	100%	Ready to use. Do not dilute.		Non-target trees, especially tulip poplar, sensitive to picloram products through root absorption from soil or root grafts with treated trees.	Injection – 1 ml undiluted per cut with cuts spaced at 2 inches, edge to edge.
	aminopyralid + triclopyr Capstone	100%				Injection – 1 ml per cut spaced 3 to 4 inches from cut center to cut center.
Injection	*2,4-D amine or ester* 2,4-D amine, Weedestroy AM-40 Amine Salt, 2,4-D L. V. 4 Ester or others	100%	Ready to use. Do not dilute.	Best control achieved from mid-May to mid-October.	Ester formulations of 2,4-D volatilize above 70°F and thus may cause non-target damage during summer months.	Injection – 1 ml undiluted per cut with cuts spaced at 1½ to 2 inches, edge to edge. Use the closer spacing for hard-to-kill species like hickory, dogwood, red maple, and blue beech.
Cut stump	*imazapyr* Chopper or Stalker	6% – 12%	Basal Oil (Commercial-grade aliphatic, mineral, paraffinic, and vegetable-based basal oils available from herbicide dealers. Diesel and kerosene were historically used, but are no longer recommended.)	Anytime except when bark is wet or frozen or when snow prevents spraying to the ground line. Method is particularly useful during late winter and spring sap flow.	Potential non-target damage through root absorption from soil or root grafts with treated trees.	Spray full circumference of stump bark from ground up and outer 1 inch on stump cut surface. Spray enough to evenly wet bark surface but not to the point of runoff.
	triclopyr ester GGarlon 4, Garlon 4 Ultra, Tahoe 4E, or others	15 – 20%			The ester formulation of triclopyr may volatilize at air temperatures exceeding ~85-90°F, possibly reducing control and causing damage to non-target vegetation.	
Low volume basal bark	*imazapyr* Chopper or Stalker	6 – 9%			Potential non-target damage through root absorption from soil or root grafts with treated trees.	Spray full circumference of stem to evenly wet bark from ground line up 12-18 inches (higher end of range for larger diameter or hard-to-kill species.)
	triclopyr ester Garlon 4, Garlon 4 Ultra, Tahoe 4E, or others	15% – 25% (20% commonly used, but lower rates may effective on many species)			The ester formulation of triclopyr may volatilize at air temperatures exceeding ~85-90°F, possibly reducing control and causing damage to non-target vegetation.	Spray full circumference of stem to evenly wet bark from ground line up 12-15 inches (higher end of range for larger diameter or hard-to-kill species.)
	triclopyr ester Pathfinder II RTU	100%	Ready to use. Do not dilute.			

[1]The listing of specific herbicides does not constitute an endorsement by Purdue University or the Indiana Department of Natural Resources.
[2]Herbicide *common name italicized*
[3]Herbicide trade name(s)
[4]RTU means "ready to use"
[5]Caution refers to potential non-target damage or performance limitations. For applicator safety information, refer to herbicide label. Always read and follow manufacturer's label.

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