United States Department of Agriculture

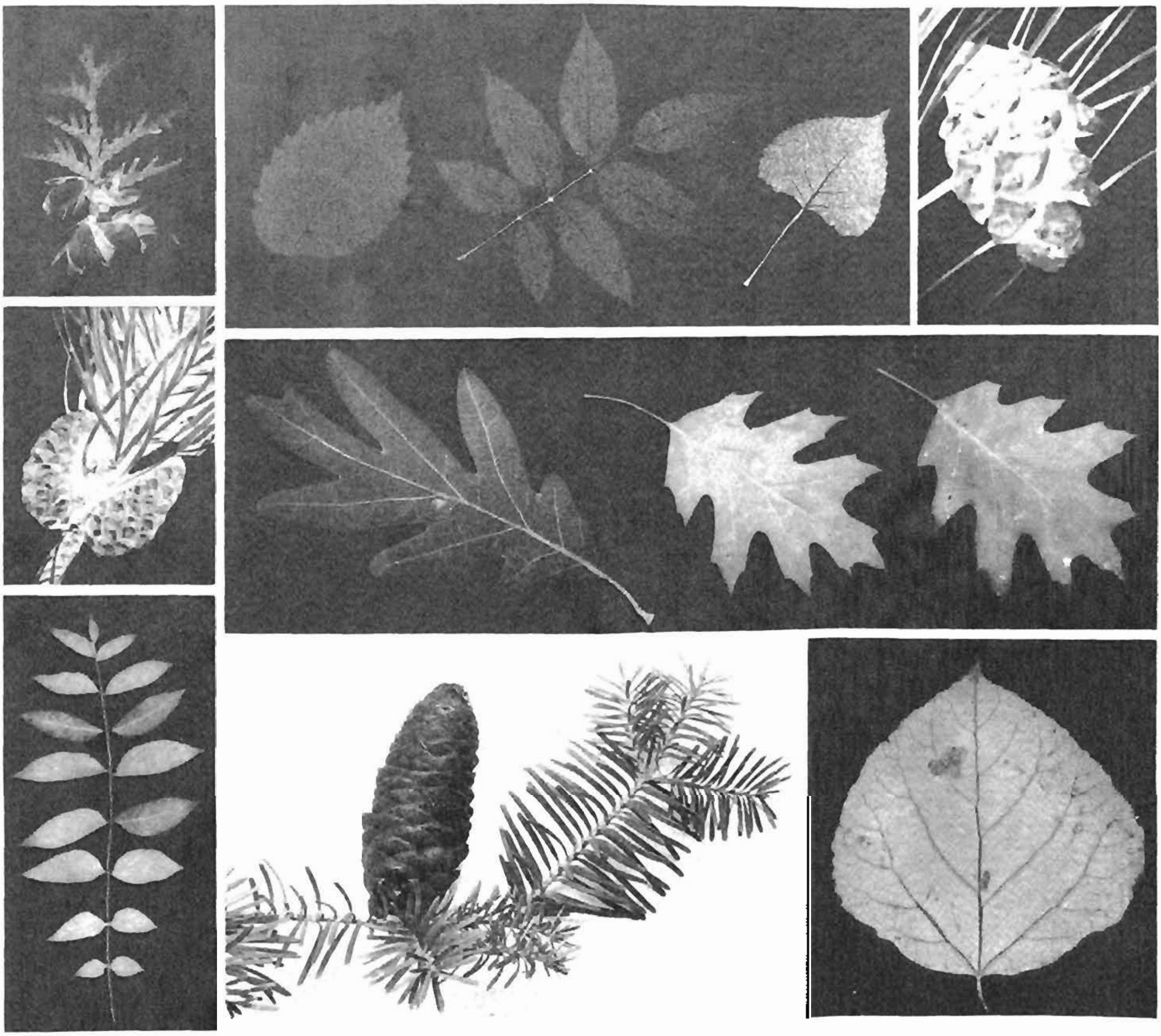
Forest Service

North Central Forest Experiment Station

General Technical Report **NC-111**

Manager's Handbook for Balsam Fir in the North Central States

William F. Johnston



Other Manager's Handbooks are:

Jack pine—GTR-NC-32
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Black spruce—GTR-NC-34
Northern white-cedar—GTR-NC-35
Aspen—GTR-NC-36
Oaks—GTR-NC-37
Black walnut—GTR-NC-38
Northern hardwoods—GTR-NC-39
Elm-ash-cottonwood—GTR-NC-98

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Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
Manuscript approved for publication August 27, 1986
1986

FOREWORD

This is one of a series of manager's handbooks for important forest types in the North Central States. The purpose of this series is to present the resource manager with the latest and best information available on managing these types. Timber production is dealt with more than other forest values because it is usually a major management objective and more is generally known about it. Ways to modify management practices to maintain or enhance other values are included where sound information is available.

The handbooks have a similar format, highlighted by a "Key to Recommendations." Here the manager can find, in logical sequence, the management practices recommended for various stand conditions. These practices are based on research, experience, and a general silvical knowledge of the predominant tree species.

All stand conditions, of course, cannot be included in the handbooks. Therefore, the manager must use technical skill and sound judgment in selecting the appropriate practice to achieve the desired objective. The manager should also apply new research findings as they become available so that the culture of these important types can be continually improved.

The author has, in certain instances, drawn freely on unpublished information provided by scientists and managers outside his specialty. He is also grateful to several resource managers who shared their knowledge about the balsam fir type during field trips and to several technical reviewers who made many helpful comments. In particular, Thomas R. Biebighauser of the Superior National Forest provided information on managing the type for wildlife.

CONTENTS

MANAGER'S HANDBOOK FOR BALSAM FIR IN THE NORTH CENTRAL STATES

William F. Johnston,[1] *Principal Silviculturist, Grand Rapids, Minnesota*

DEFINITION OF TYPE

Balsam fir[2] is pure or comprises a majority of the stocking in the balsam fir type. The type is No. 5 of the Society of American Foresters forest cover types and one of six Lake States types that is combined into the spruce-fir type group by the USDA Forest Service. The balsam fir type occupies 1.9 million acres of commercial forest land in the northern Lake States; 45 percent of this total occurs in Minnesota, 33 percent in Michigan, and 22 percent in Wisconsin.

The balsam fir type often grades into one of the other forest types included in the spruce-fir type group. Also, balsam fir is an important component in a number of other types such as black spruce, aspen, and paper birch.

SILVICAL HIGHLIGHTS

The balsam fir type grows under a wide range of soil and other site conditions, but it is most common on cool, wet-mesic sites where strongly to moderately acid (pH 5.1 to 6.0) Spodosols and Inceptisols are characteristic soils. Although balsam fir grows in pure stands, the balsam fir type more often occurs as mixed stands. On dry-mesic to mesic uplands, balsam fir is commonly mixed with such trees as white spruce, paper birch, and quaking aspen; on wet-mesic to wet lowlands, it is commonly mixed with black spruce, northern white-cedar, and black ash.

Balsam fir seeds prolifically and is able to become established in dense shade. It can survive many years of suppression and still respond to release, but best growth is in about 50 percent or more of full sunlight. An understory of balsam fir seedlings is almost ubiquitous in several upland and lowland forest types. Balsam fir understory trees often succeed overmature stands of quaking aspen and paper birch, and they commonly replace northern white-cedar on cutover swamps. Balsam fir may be a climax type on poorly drained clay soils, but on mesic sites it is gradually replaced by shade-tolerant northern hardwoods such as sugar maple.

The main damaging agents of balsam fir are the spruce budworm, trunk and root rots, and wind. The spruce budworm causes the most damage in overmature stands or dense stands that are pure or have a high proportion of fir. The principal trunk-rot fungus, red heart rot, causes two or three times more cull than root (or butt) rots in balsam fir. Root rots, however, make the tree susceptible to wind damage; on uplands they limit the pathological rotation to about 70 years. Because of rot and shallow rooting, balsam fir is especially vulnerable to wind damage in old, unmanaged stands on wet, shallow soils.

MANAGEMENT OBJECTIVES AND NEEDS

Specific objectives in managing the balsam fir type may differ greatly depending on the forest owner's overall objective and on present or expected stand conditions. Balsam fir has usually had low timber value, and periodically it has been severely damaged by the spruce budworm. A common objective is to convert to another forest type. Conversion alternatives will be discussed later in relation to such factors as site productivity, stand composition, and the spruce budworm.

The timber value of balsam fir could increase substantially in the future because the Lake States has the potential to use much more fir for pulpwood, reconstituted wood panels (such as waferboard), and structural lumber (mainly studs). However, greater utilization of fir is hindered by several factors, including high harvesting costs. Thus, an important

[1] *Present location: Columbia, Missouri.*

[2] *For scientific names of plants and animals, see Appendix, p. 25.*

timber management objective is to grow stands of even-aged balsam fir that are large enough to be harvested efficiently with mechanized equipment but small enough not to be conducive to spruce budworm attack. Medium-sized stands of about 40 acres usually are recommended. To further reduce costs and increase utilization, these stands need to produce at least moderate volumes of fir that are harvested before fungi appreciably decay or stain the wood.

In many parts of the northern Lake States the balsam fir type is important for wildlife habitat, especially for winter cover. Thus, another common objective is to maintain or improve the type for wildlife while still producing a moderate, sustained yield of merchantable timber. Unless special funds are available, habitat management will have to be done through timber management. This will require careful long-range planning and coordinated action by timber *and* wildlife managers.

The balsam fir type is significantly affected by the spruce budworm, rots, and wind. These damaging agents cause substantial timber losses and, through tree mortality, can seriously reduce winter cover or esthetic values. So, whether the primary objective in managing balsam fir is timber production, wildlife habitat, or esthetics, we need to be able to control these agents in present and future stands.

The best way to manage balsam fir stands in terms of age structure and intensity depends on the owner's objective. Even-aged stands are preferred for timber and wildlife management; uneven-aged stands tend to be better where esthetic values are paramount. Because the timber value of balsam fir is usually low, most stands will have to be managed extensively. However, moderately intensive management to shorten pulpwood rotations or to produce small saw logs, for example, may be possible where economic conditions are particularly favorable.

The practices recommended here should lead to improved management of the balsam fir type. Unfortunately, little information exists on the costs and returns of using these practices. General comments about costs are made in several instances, but most economic decisions will have to be based on the particular situation and on the manager's experience and judgment.

KEY TO RECOMMENDATIONS

Recommendations for managing balsam fir stands are given in the following key, which contains a series of alternative statements about various stand conditions or management objectives. The statements include references to the text where these conditions and objectives are discussed. With accurate knowledge of a stand and the owner's overall objective, the resource manager can find the recommended practices.

To use the key, begin with the first pair of like-numbered statements. Select the one statement that better describes the stand in question or owner's objective and obtain a final recommendation, a partial recommendation plus a number, or a number alone. If a number is given, repeat the selection process until a final recommendation is reached. The overall recommendation is the sum of the partial recommendations arrived at while going through the key.

During a spruce budworm outbreak, also consult the key by Flexner *et al.* (1983). Their key illustrates a variety of options available for dealing with vulnerable spruce-fir stands. It stresses minimizing current timber losses and is general enough to be useful throughout the Lake States.

1. **Balsam fir acceptable type *and* site suitable** .... MAINTAIN OR ALTERNATE FIR 2
   See "Management Objectives and Needs," p. 1;
   "Site Productivity," p. 4; and "Conversion and Alternating Crops," p. 11
1. **Balsam fir unacceptable type; *or* fir acceptable but site unsuitable** 13

   2. **Spruce budworm a minor problem** 3
      See "Spruce Budworm," p. 14
   2. **Spruce budworm a major problem** 10

3. **Stand immature** 4
   See "Rotation," p. 5
3. **Stand mature or uneven-aged** 7

   4. **Balsam fir vigorous, even if suppressed** 5
      See "Intermediate Treatments," p. 6
   4. **Balsam fir weakened by suppression** ...... CLEARCUT WHEN OVERSTORY MATURE .. 12

5. **Stand suitable for intensive management** 6
   See "Rotation," p. 5; "Intermediate Treatments," p. 6; and "Rot and Wind," p. 16
5. **Stand suitable only for extensive management** .... REPRODUCE FIR WHEN MATURE

   6. **Balsam fir suppressed** .... RELEASE
      See "Intermediate Treatments," p. 6
   6. **Balsam fir free to grow** .... THIN WHEN FEASIBLE

7. **Rot and wind a minor problem** 8
   See "Rot and Wind," p. 16
7. **Rot and/or wind a major problem** .... CLEARCUT ... 12
   See "Silvicultural Systems," p. 9

   8. **Even-aged management preferred** 9
      See "Management Objectives and Needs," p. 1
   8. **Uneven-aged management preferred** .... USE SELECTION
      See "Silvicultural Systems," p. 9

9. **Balsam fir advance growth adequate** .... CLEARCUT ... 12
   See "Reproduction Requirements," p. 8; and "Silvicultural Systems," p. 9
9. **Balsam fir advance growth inadequate** .... USE SHELTERWOOD ... 12

(Key continued on next page)

(Key continued)

10. Stand merchantable 11

See "Rotation," p. 5

10. Stand unmerchantable .... RELY ON NATURAL REPRODUCTION

11. Balsam fir advance growth adequate; *or* **top-kill and/or mortality present;** *or* **rot and/or wind a major problem** .... CLEARCUT 12

See "Reproduction Requirements," p. 8; "Silvicultural Systems," p. 9; "Spruce Budworm," p. 14; and "Rot and Wind," p. 16

11. Balsam fir advance growth inadequate; *and* **top-kill and mortality absent;** *and* **rot and wind a minor problem** .... PRESALVAGE 12

12. Slash cover likely to favor fir reproduction .... SPREAD SLASH EVENLY

See "Reproduction Requirements," p. 8; and "Silvicultural Systems," p. 9

12. Slash cover likely to hinder fir reproduction .... SKID FULL TREES

13. Stand merchantable .... HARVEST AND CONVERT

See "Rotation," p. 5; and "Conversion and Alternating Crops," p. 11

13. Stand unmerchantable 14

14. Spruce budworm a minor problem 15

See "Spruce Budworm," p. 14

14. Spruce budworm a major problem .... CONVERT

See "Conversion and Alternating Crops," p. 11

15. Stand likely to be merchantable in 20 years or less .... HARVEST WHEN MERCHANTABLE AND CONVERT

See "Rotation," p. 5; and "Conversion and Alternating Crops," p. 11

15. Stand likely to still be unmerchantable in 20 years .... CONVERT

TIMBER MANAGEMENT CONSIDERATIONS

Controlling Growth

Site Productivity

The balsam fir type grows under a wide range of site conditions in the Lake States; thus, growth rate differs greatly. Site index, or the height of dominant and codominant trees at age 50, ranges from more than 70 feet on the best sites to less than 20 feet on the poorest (see Appendix, fig. 7, for site index curves). A site index of 25 feet is about the minimum for commercial forest land.

Yield tables that use site index are available for spruce-balsam fir stands but not for pure fir stands. The yield per acre of fully stocked, even-aged spruce-fir stands at age 60—the approximate financial rotation for balsam fir—ranges from 2,600 cubic feet of merchantable wood on good sites to 1,300 cubic feet on poor sites. (See Appendix, page 21, on how to estimate the yield and growth of balsam fir stands.)

Balsam fir is found over most of the gradient from wet to dry sites. However, it is most common on wet-mesic sites where adequate soil moisture is available throughout the growing season and standing water may be present during part of the season. Wet-mesic sites often occur along swamp borders or on poorly drained uplands, particularly those with clay soils. Northern white-cedar and black ash are characteristic associates on these sites, whereas white spruce is a characteristic associate on somewhat drier sites.

Balsam fir also commonly grows on mesic sites where adequate soil moisture is available throughout the growing season. Fir may even be the dominant type on these sites after disturbance. The trend on mesic sites, however, is for fir to be gradually replaced by shade-tolerant northern hardwoods such as sugar maple. Balsam fir is sometimes an important associate on wet sites where standing water is present throughout the growing season. But these sites are usually dominated by black spruce and tamarack. To produce timber efficiently, the balsam fir type should be managed mainly on wet-mesic sites where it is well adapted and easy to maintain.

The balsam fir type grows on a wide range of mineral and organic soils that generally fall within the following soil orders: Spodosols, Inceptisols, and Histosols. Formerly called podzols, Spodosols characteristically have a thick layer of raw humus and a well-defined E (formerly A_2) horizon, which is usually gray from leaching. Inceptisols include poorly developed soils such as those formerly called humic gleys. The latter are generally mottled and are periodically waterlogged. Histosols are organic soils (peats) that originate under water-saturated conditions.

Site productivity for balsam fir is usually expressed in terms of site index, which (along with age) is needed to determine yield and growth. Balsam fir site index is most reliable when estimated from a site index equation or from curves based on the total height and total age of dominant and codominant firs growing in even-aged stands (see Appendix, p. 22 and fig. 7). To use the equation or curves properly, trees measured for site index (site trees) should be uninjured dominant and codominant firs that are at least 20 years old and have never been suppressed.

Unfortunately, many even-aged stands do not have suitable site trees for balsam fir. The existing firs often are not free of suppression because they are either overtopped or have developed from the understory. Also, some trees may have been injured in the past; for example, they may have a broken top or be deformed from spruce budworm attack. In these cases the site index of balsam fir can be estimated from the site index of certain associated species, provided that at least one has suitable site trees. Comparative site indexes for balsam fir and some common associates are given in the following generalized tablulation:[3]

Balsam fir	Quaking aspen	Paper birch	Black spruce	Northern white-cedar
(Site index, feet)				
60	70	70	60	40
50	60	55	50	35
40	50	40	40	30
30	35	25	30	25

Site index measurements are unreliable in uneven-aged stands because most trees that appear suitable probably have been suppressed earlier. Measurements are also unreliable in stands less than 20 years old (unless quaking aspen or paper birch is present[4]) and in stands severely disturbed by harvesting or damaging agents. Under these conditions, estimate site index without using site trees.

[3]*Based on equations from Carmean (1982); see Appendix, p. 23.*

[4]*Site index curves beginning at 10 years of age are available for quaking aspen (Perala 1977) and paper birch (Tubbs 1977).*

Soil moisture availability and stand composition indicate general site classes. For example, mesic sites with a northern hardwood component usually have a balsam fir site index from 50 to 60, whereas wet (swamp) sites with a black spruce or northern white-cedar component have a site index of about 35. In addition, general site classes for balsam fir can be determined from soil characteristics as shown in the following tabulation:[5]

Site index	Drainage and textural class
60	Well-drained loams
50	Moderately well-drained silt loams, clay loams, and clays
40	Well- to poorly drained sandy loams and sands; well-decomposed peats (mucks)
30	Excessively drained sands; moderately decomposed peats

Fertilizing probably would increase balsam fir's growth rate on some sites in the Lake States, but no specific guidelines are available. Gross periodic growth increased moderately in dense, unmanaged, 45- to 60-year-old balsam fir stands in eastern Canada after applying 150 to 200 pounds per acre of nitrogen (as urea). Unfortunately, tree mortality was high in these stands, so volume losses often exceeded fertilization gains. Thus, fertilizing of balsam fir is not recommended in dense, unmanaged, 45-year-old or older stands. However, some evidence indicates that nitrogen fertilizer (especially ammonium nitrate) may be beneficial when applied to younger stands where stocking has been reduced by spacing or thinning.

Rotation

Balsam fir stands break up at fairly young ages even though individual trees may live for 200 years. This is because root (or butt) rots begin entering balsam fir at about 25 to 30 years; eventually the trees are weakened, which leads to severe windthrow and windbreakage.

Root rot begins sooner on uplands than in swamps. Balsam fir stands in Michigan's Upper Peninsula break up at about 70 years on uplands, 80 years on transition sites, and 90 years in swamps. These pathological rotations are too long, however, for timber management because wind damage and cull are already substantial by these ages.

For maximum yield and utilization of balsam fir pulpwood, rotations should be shortened enough to

[5]*Adapted from Bowman (1944).*

minimize wind damage and to eliminate decayed or stained wood caused by rot fungi. Shortening rotations also may help reduce spruce budworm losses. Based on Michigan findings (Prielipp 1957), these shorter "quality" or financial rotations are as follows:

Type of site	Rotation
	(Years)
Upland (dry to mesic)	45 to 50
Transition (wet-mesic)	55 to 60
Swamp (wet)	65 to 70

These rotations are for total age. However, balsam fir often has butt rot or has originated from old advance growth, thus making it difficult to determine age. To obtain consistent total ages, see Appendix, page 22.

Mean annual growth of even-aged spruce-balsam fir stands peaks at about 60 years in northern Michigan and northeastern Minnesota. This means the foregoing "quality" rotations, which center around 60 years, should provide maximum or near-maximum yields. However, it is important to recognize the risk of spruce budworm losses when growing balsam fir beyond age 45 (see p. 14).

In Michigan's Upper Peninsula the incidence of root (or butt) rot on uplands increases with the presence of fragipans and with the proportion of northern hardwoods. Thus, the rotations recommended for upland sites (45 to 50 years) probably should be a little shorter where fragipans are present or the proportion of northern hardwoods is high.

If the objective is to produce small saw logs, rotations will probably have to be longer than those recommended for pulpwood. However, by using intermediate treatments such as release and thinning (see next section), it should be possible to grow sawtimber trees on rotations only a little longer than those for pulpwood. Substantially longer rotations should be avoided because they greatly increase the risk of losses from wind, rot, and spruce budworm.

Uneven-aged stands have trees of various ages (or sizes), so the whole stand is not harvested at one time as are even-aged stands. Instead, the older or larger trees are harvested periodically in uneven-aged stands. To minimize wind damage and cull, balsam fir trees should be cut by the time they reach the "quality" rotation and certainly before they exceed the pathological rotation. To make uneven-aged stands less vulnerable to spruce budworm damage, periodically harvest large firs because budworms that spin down from them kill most shorter firs during an outbreak.

Intermediate Treatments

Research and experience are limited on how to manage immature stands of balsam fir. Because it is very shade tolerant, balsam fir is commonly an understory species or forms dense thickets. However, intermediate treatments offer an excellent opportunity to control species composition and speed up development of dense fir stands. Unfortunately, they often produce little or no immediate return and can be justified only on areas suitable for intensive timber management (fig. 1).

Despite its shade tolerance, balsam fir grows best in about 50 percent or more of full sunlight. This means release from overtopping shrubs or hardwoods is needed to obtain the tree's full growth potential. The degree to which competing vegetation should be controlled, however, depends on the management objective and type of site. Unless balsam fir timber is the only objective, mixed stands—with fir comprising from 50 to 80 percent of the basal area—are probably best for enhancing wildlife habitat and esthetics (see p. 18 and 20). Also, mixed stands will reduce the potential for spruce budworm damage

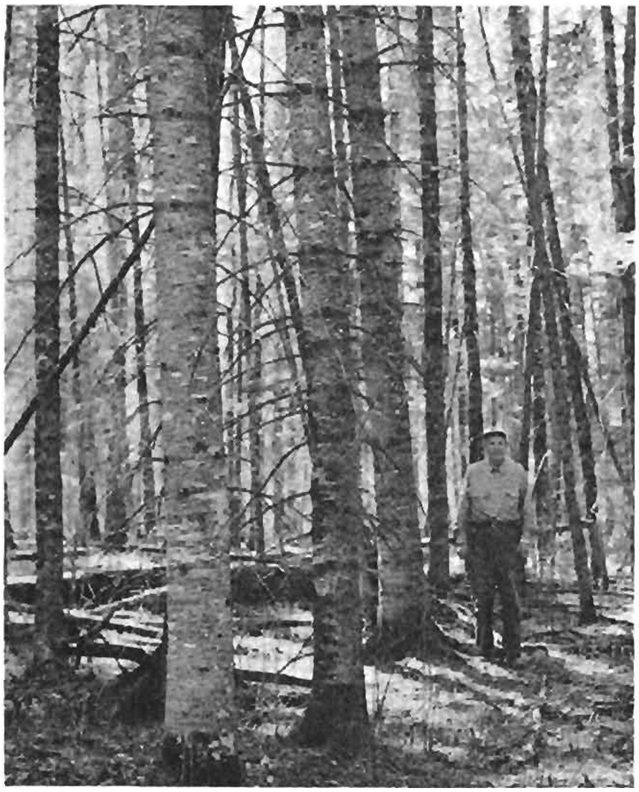

Figure 1.—*These sawtimber-sized balsam firs developed following release of vigorous understory trees more than 20 years ago. Overtopping hardwoods (mainly black ash) were removed carefully in winter.*

(see p. 14). On wet and wet-mesic sites, balsam fir will eventually grow above associated hardwoods; but on mesic sites it may become severely suppressed, especially by northern hardwoods.

Balsam fir generally responds well to release; diameter growth rate at least doubles within a few years after release. For best results the trees should be released while they are still young and vigorous. Indicators of such trees are a current annual height growth of 6 inches or more, a fairly pointed crown, and smooth bark with raised resin blisters. Older, severely suppressed trees—current annual height growth of 1 or 2 inches, flat-topped crowns, and rough bark—should not be released regardless of their size. Even small trees often are old and so respond poorly to release and have a high incidence of rot.

Information from the Northeastern States indicates that a single release or cleaning about 8 years after final harvest or when stand height averages from 6 to 10 feet is usually enough to ensure balsam fir dominance. Aerial herbicide spraying is the most practical way to kill back overtopping shrubs or hardwoods. Selective herbicides for releasing balsam fir include 2,4-D, glyphosate (Roundup[6]), and triclopyr (Garlon); hexazinone (Velpar) also shows promise. The most economical herbicide is 2,4-D, which is effective on quaking aspen, paper birch, black ash, beaked hazel, speckled alder, and willow. Glyphosate is effective on a broad spectrum of woody and herbaceous vegetation (including grasses, some sedges, and bracken fern), whereas triclopyr is effective only on broadleaved species. Glyphosate is especially useful for controlling red raspberry and American beech; triclopyr is better for maples.

At present the two most important herbicides for releasing balsam fir are 2,4-D and glyphosate. A low volatile ester of 2,4-D is generally effective when applied at a total rate of 3 pounds acid equivalent in at least 4 gallons of water per acre. Spray when the new growth of balsam fir has hardened off but shrubs and hardwoods are still susceptible—from late July to early August. Glyphosate is effective when applied at a rate of 1½ pounds active ingredient in at least 5 gallons of water per acre. Spray before foliage turns color or frost occurs—late summer or early fall.

Other herbicides may become available and herbicide labels are constantly revised. Thus, the manager should be alert to more effective or economical herbicides and should always follow specific label instructions. Herbicide spraying should be done carefully, following all pertinent precautions and regulations (see Pesticide Precautionary Statement, p. 27). It is particularly important not to contaminate open water.

Aerial herbicide spraying cannot be used if a mixed stand with some hardwoods is desired. Instead, crop trees needing release are selected and then individual trees within about 3 feet of them are either treated with herbicide or felled. Although it costs more than aerial spraying, injecting herbicide into the stem with a tree injector is more efficient than felling with a power brush saw. Herbicide injection can also be used to kill large, unwanted residual trees on harvest areas and it is a promising alternative to aerial spraying for small stands.

The herbicides commonly used for injection are MSMA and Tordon 101 (a combination of picloram and 2,4-D). These herbicides are usually applied undiluted, using 1 or 2 milliliters per injection at about 2-inch intervals around the stem. Another effective herbicide for injection is glyphosate (Roundup); as a 20 percent solution in water, it should be injected at the rate of 2 milliliters per 2 to 3 inches of d.b.h. For safe and efficient use of these herbicides, always follow specific label instructions.

Desirable stand densities are not known for optimum timber growth of balsam fir in the Lake States. Densities that favor fast diameter growth are recommended because they make it possible to grow pulpwood on shorter rotations or to produce saw logs before decay becomes serious. Stocking guides for even-aged spruce-balsam fir stands in the Northeastern States provide estimates of desirable densities. For unmanaged sapling stands, average number and spacing of potential crop trees required to produce at least the recommended minimum stocking of crop trees (curve B in fig. 2) are given in the following tabulation:[7]

Average stand diameter	Potential crop trees: Number per acre	Potential crop trees: Spacing
(Inches)		(Feet)
1	1,650	5 × 5
2	1,350	5 ½ × 5 ½
3	1,050	6 ½ × 6 ½
4	850	7 × 7

A stocking chart can be used to determine the maximum and minimum stocking levels recom-

[6]*Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.*

[7]*Adapted from Frank and Bjorkbom (1973).*

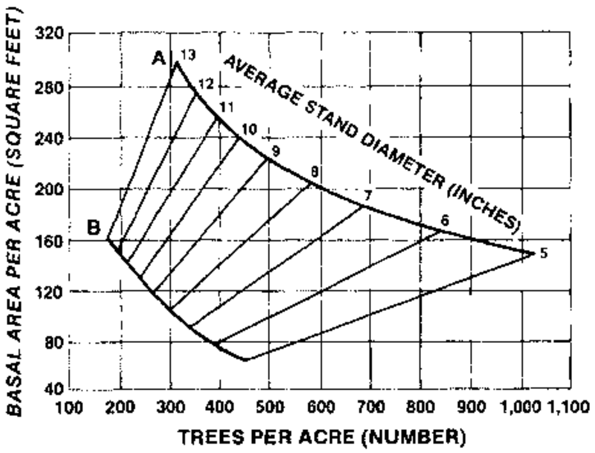

Figure 2.—*Stocking chart for even-aged spruce-balsam fir stands. Adapted from Frank and Bjorkbom (1973) and based on data from the Northeastern States. The maximum and minimum stocking levels recommended for managed stands are represented by curves A and B, respectively.*

mended for managed stands with an average diameter of 5 inches or larger (fig. 2). If the average stand diameter is 6 inches, for example, the maximum stocking is about 830 trees and 170 square feet of basal area per acre; the minimum stocking is about 400 trees and 80 square feet of basal area per acre.

Where intensive management is feasible, spacing or thinning is recommended to reduce stocking in dense balsam fir stands. If done in young stands, these treatments shorten pulpwood rotations to about 45 years, compared to 60 years or more in dense, unmanaged stands. This is because spacing or thinning greatly increases average d.b.h., compared to the small d.b.h.'s in fully stocked (normal) stands (see Appendix, table 1). Shorter rotations should minimize losses to wind, rot, and spruce budworm. Also, by increasing average tree size and making the stand more uniform, spacing or thinning should reduce harvesting costs.

Dense stands between about 10 and 20 years old should have their stocking reduced by spacing or precommercial thinning (see foregoing tabulation). However, neither treatment is needed in young stands that have been hand released or cleaned to favor crop trees. Commercial thinning (at least 5 cords per acre) may be feasible between 25 and 35 years of age (see fig. 2). But heavy thinning must be avoided or substantial wind damage may result. If the average stand diameter is 5 inches or larger, only about one-third of the total basal area should be removed at one time.

A combination of mechanical and manual spacing (or precommercial thinning) probably is the best way to reduce stocking in dense, young stands of balsam fir. Up to half the trees should be eliminated by clearing narrow alternate lanes with mechanized brush cutters or crushers. Then the remaining strips of trees should be thinned by hand. Individual balsam firs can be injected with herbicide or felled as described earlier for hand release.

Unfortunately, little is known about the application or results of the above guidelines to reduce stocking in young fir stands. Effective and economical machines for clearing narrow lanes are not readily available. Care is needed to avoid leaving unwanted trees in exceedingly dense stands. If herbicide injection is used, some nearby crop trees may also be affected because root grafts are common in balsam fir. If trees are felled, no live branches should remain on the stump or they may develop into new trees. Finally, crop trees left exposed after heavy thinning may be damaged by sunscald. Thus, the guidelines in the preceding paragraph should be tested before being used on a large scale.

In commercial thinning well-distributed, high-quality crop trees are left for future growth and less desirable or high risk trees are cut. Harvesting should be done carefully to minimize wounding—and thus subsequent decay—of residual balsam firs (see p. 17).

Controlling Establishment and Composition

Reproduction Requirements

Balsam fir begins to produce seed regularly at about age 30; good seed crops generally occur at 2- to 4-year intervals. In good seed years fir stands yield 5 or more pounds of seed per acre, which is equivalent to 300,000 or more seeds. But cone production may be greatly reduced if the trees have been recently defoliated by the spruce budworm. In some years up to 90 percent of the seed may be destroyed by insects, particularly the balsam fir seed chalcid. Nevertheless, the supply of fir seed is usually ample for natural reproduction.

Balsam fir cones ripen from late August to early September and most of the seed is wind-dispersed in September and October. The effective seeding distance from a mature tree ranges from 80 to 200 feet, depending on such factors as tree height and amount of seed. Many of the seeds, however, stick to the cone scales and fall near the base of the tree.

Most balsam fir seed germinates from late May to early July and practically none remains viable in the forest floor more than 1 year after dispersal. Optimum germination temperatures range from about 64° to 84° F, but temperatures down to at least 54° F are suitable. Within the range of suitable temperatures, moisture is more important than light for germination and initial establishment. If enough moisture is available, seeds will germinate on almost any seedbed and seedlings will survive for the first few years with only 10 percent of full sunlight.

The soil must be disturbed to obtain new balsam fir seedlings promptly after harvesting. The closer seeds lie to mineral soil, the better the initial establishment. Medium-textured mineral soil with some shade is the best seedbed. Unincorporated organic material (duff) with no shade is a poor seedbed, especially if the duff is more than 3 inches thick. Thus, scarification under a shelterwood should produce an excellent seedbed.

Frequent seed crops and balsam fir's ability to become established in dense shade assure a continuous supply of small seedlings in most mature fir stands. But development of this advance growth is determined largely by the amount and character of overhead competition. To obtain the 50 percent or more of full sunlight required for optimum growth of crop trees, openings probably need to be larger than those created by removing individual trees. However, if a stand's basal area is reduced by half or more, competition may become severe from such vegetation as bracken fern, red raspberry, and hardwood sprouts (especially the maples). To develop satisfactorily in heavily cut stands, advance growth should be at least 3 feet tall on sites with average competition and 6 inches tall on sites with little or no competition.

Slash is another factor that can significantly affect balsam fir reproduction. A light slash cover usually favors advance growth survival and new seedling establishment. This is especially true on hot, dry sites where some shade is needed to conserve soil moisture and to moderate surface temperatures. In contrast, a heavy slash cover buries advance growth and creates poor seedbeds; it also hinders scarification and can be a fire hazard. Thus, disposal of some slash should favor fir reproduction in heavily cut stands. Full-tree skidding is recommended to reduce the large amount of slash produced by shelterwood cutting and clearcutting. (See page 18 for control of skidding damage.)

Artificial reproduction of balsam fir is seldom considered because advance growth is almost ubiquitous in many forest types. This no doubt explains why little is known about the requirements for planting or direct seeding balsam fir after harvesting. However, some Christmas tree growers plant balsam fir and so can advise forest owners on planting practices. Recent nursery experience indicates that high-quality fir seedlings can be grown easier in containers than as bare-root stock. Nevertheless, if planting is desired, white spruce is recommended because it has important advantages over balsam fir (see p. 13), including a higher survival rate and little browsing damage by white-tailed deer.

Although practically no balsam fir has been planted for timber management, planting offers better prospects for success than direct seeding. Before direct seeding can be recommended, ways to prepare seedbeds and to protect seeds from seed-eating animals must be developed.

Silvicultural Systems

Balsam fir can be managed in both even- and uneven-aged stands. This is possible because fir reproduction grows best in about 50 percent or more of full sunlight, and yet it commonly becomes established in the understory and is very shade tolerant. Even-aged stands—which include those that originate under aspen or paper birch (see p. 12)—are generally preferred. They are simpler to manage than uneven-aged stands and cost less to harvest. Uneven-aged stands are mainly preferred for special esthetic, wildlife, or other values and will usually make up only a small proportion of managed fir forests. Also, uneven-aged stands should be limited to wet-mesic or similar sites where balsam fir can be maintained with little cultural work and without serious losses from rot or wind.

Depending on stand conditions, either clearcutting or shelterwood cutting is recommended for reproducing balsam fir in even-aged stands. The seed-tree system is not suitable because the residual (seed) trees are too vulnerable to wind damage to be a reliable seed source. The clearcutting and shelterwood systems are usually used in mature, even-aged balsam fir stands. Both systems are also suitable for converting merchantable, uneven-aged fir stands to new, even-aged stands. Clearcutting is necessary, of course, where mortality of overstory firs—mainly from rot, wind, and/or spruce budworm—is expected to be too high to maintain a shelterwood.

Clearcutting is most appropriate for balsam fir stands in which fir advance growth is not only well developed but also well stocked. A milacre[8] stocking

[8] *A milacre is 1/1,000 acre and usually square (6.6 feet on a side).*

from 50 to 60 percent *after* harvesting is considered adequate for seedling-sized firs. Sapling-sized firs should be adequately stocked if the number or spacing of potential crop trees after harvesting approximates the values given in the tabulation on page 7. To achieve adequate stocking after clearcutting, it is usually necessary to harvest the stand carefully; it also may be beneficial to remove some slash (see p. 9 and 18).

The best size, shape, and arrangement for clearcut areas depend on stand conditions and the owner's objective. If well stocked with established fir reproduction, entire stands or large patches (10 acres or more) can be reliably reproduced by a single cutting. Because these areas are large, harvesting and future treatments such as thinning can be mechanized to reduce costs. However, large-scale clearcutting usually has a negative effect on wildlife habitat and esthetic values (see p. 18 and 20). Clearcutting in strips or small patches (from 1 to 5 acres) is recommended where multiple-use management is important. Clearcut strips or small patches are also recommended where fir advance growth is inadequate but where shelterwood cutting is too risky due to damaging agents such as rot and wind. Balsam fir is reproduced on these small areas by natural seeding from the bordering uncut stand.

Clearcut strips are well suited for fir stands with uniform structure and stocking, whereas small patches are better suited for nonuniform stands. Strips may be arranged either as alternate strips or as progressive strips in sets of three. On cool, moist sites where maximum shading is not necessary to establish fir seedlings, fairly wide strips are recommended to reduce harvesting costs. Strips that are perpendicular to, and progress toward, the prevailing wind direction—generally from the western quadrant (NW-SW) in the Lake States—should maximize seed dispersal and minimize wind damage. Based on balsam fir's seeding distance (see p. 8), strips can be up to 3 chains (1 chain = 66 feet) wide with seeding from both sides or 2 chains wide with seeding only from the windward side. These distances can also be used to determine the width of small patches or of subsequent enlargements.

On hot, dry sites where shelter is necessary for seedling establishment, strips should be: (1) no wider than half the stand height and (2) oriented east-west, with subsequent strips progressing southward. Narrow strips are also recommended for the last set of either alternate or progressive strips. This set tends to reproduce poorly because removing it usually eliminates all (or most) of the nearby seed source. To minimize the area receiving limited seeding, strips in the last set should be as narrow as possible and yet wide enough for the trees to be windfirm; strips about 1 chain wide are suggested.

Figure 3.—*This balsam fir understory developed following partial cutting of a mixed stand about 15 years ago. Such advance growth is typical in stands partially opened by harvesting or other disturbance.*

Balsam fir seedlings generally are well developed and well stocked where mature stands have been partially opened (fig. 3). Hence shelterwood cutting is most appropriate where fir advance growth is inadequate. Unfortunately, mature balsam fir often is vulnerable to serious wind damage after a stand is partially cut. Thus, the shelterwood system should be used only on areas or sites where fir is known to be windfirm.

When using the shelterwood system, a two-stage cutting is suggested in which trees are removed either in strips or uniformly throughout the stand. The first stage—either a preparatory or seed cutting—should leave a crown cover of about 60 percent and not remove more than 40 percent of the basal area. This opens the stand enough to favor fir reproduction without risking major problems from wind and competing vegetation. The least desirable trees should be removed, leaving uniformly spaced dominant and codominant trees of balsam fir and other desirable species. Residual trees should be selected for good seed production, windfirmness, and timber quality. In some stands thick duff or a heavy slash cover hinders seedling establishment following the first cutting, so scarification or slash disposal may be needed to improve seedbeds.

The second stage or final cutting should be made as soon as both the stocking and development of fir reproduction are adequate (see p. 9 and 10). Harvesting and other operations must be done carefully, of course, to avoid damaging either residual trees or reproduction (see p. 18).

The selection system should be used to manage balsam fir in uneven-aged stands. However, as indicated earlier, uneven-aged stands are appropriate mainly for special purposes and on certain sites. The information in the next paragraph should be considered carefully before deciding whether to make selection cuttings in a particular stand.

Under the selection system it is necessary to develop and maintain a balanced distribution of size (or age) classes with decreasing numbers of trees as the d.b.h. classes increase. This requires periodic cuttings to remove trees in a variety of size classes. Each operation is a combined harvest of the largest trees and a thinning or other intermediate treatment of the smaller trees. The selection system should be limited to good-quality stands that are windfirm and have mixed age and size classes, whereas the clearcutting or shelterwood system is recommended to rehabilitate highgraded or otherwise degenerate stands. The selection system is especially appropriate on wet-mesic sites because uneven-aged fir stands are easy to maintain on these sites. However, with frequent cuttings, the selection system can probably succeed on a variety of sites.

When using the selection system, different cutting intervals (years between cuttings) and residual basal areas are recommended depending on the management intensity that can be practiced. Although the cutting interval may vary as stand or other conditions change, guidelines from the Northeastern States for spruce-balsam fir stands are as follows (Frank and Blum 1978):

Management intensity	Cutting interval	Residual basal area
	(Years)	(Square feet/acre)
Intensive	5	115
	10	100
Extensive	20	80

Three or more cuttings are usually needed to convert an unmanaged forest to a selection forest because it takes time to develop a balanced distribution of size classes, especially when each cutting must be fairly light to control wind damage. Remove no more than 30 percent of the basal area at one time. For satisfactory development of balsam fir reproduction, make openings larger than those created by removing a single mature tree. However, to control less tolerant species, the diameter of openings should not exceed the stand height. Some old trees may have to be kept in the beginning, but eventually none should be grown more than about 10 years beyond the "quality" rotations given on page 6. Also, because repeated cuttings are required, it is critical to minimize logging damage (see p. 18).

Windfirmness of the residual trees should be given top priority when marking a balsam fir stand for selection cutting. To make optimum use of growing space, leave crop trees or potential crop trees as evenly distributed as possible. In previously unmanaged stands high-risk and low-quality trees usually comprise the bulk of the material removed initially, but the percentage of such trees diminishes with succeeding harvests. Generally, the marking priority is: (1) high-risk trees likely to die before next harvest, (2) low-quality trees, (3) slow-growing trees, (4) trees of less desirable species, (5) trees whose removal will improve spacing, and (6) mature trees with desirable characteristics.

Conversion and Alternating Crops

The main purpose of this handbook is to present information on how to manage the balsam fir type. Often, however, balsam fir will not fulfill the owner's objective as well as some other forest type. Also, fir commonly occupies sites better suited for other types, and it is sometimes severely damaged by the spruce budworm. In such cases the manager may need to consider converting balsam fir to, or alternating it with, another forest type or tree species.

What type to convert to or alternate with—as well as when and how—usually depends on several interrelated factors: management objective, soil-site conditions, species composition, spruce budworm hazard, successional stage, and merchantability. Of course, the management objective should be realistic both biologically and economically. Depending on site and stand conditions, balsam fir can be converted to or alternated with one or more other types or species. Aspen, paper birch, red pine, eastern white pine, and white spruce can be grown on a fairly wide range of sites. Of other associated types, jack pine is best suited to dry sites, northern hardwoods to mesic sites, and black spruce and northern white-cedar to wet sites.

Depending on the factors mentioned above, conversion can be either natural or artificial, prompt or gradual. Clearcutting a balsam fir stand that contains some aspen, for example, often results in prompt conversion to aspen by suckering. Or the manager can quickly convert to other conifers by planting after clearcutting. In contrast, selection cuttings in a fir stand that contains northern hardwoods may lead to gradual conversion to sugar maple and other tolerant hardwoods. The various options for converting to or alternating with other types or species should be considered in relation to both short- and long-term objectives. For example, prompt harvesting after a budworm outbreak to salvage fir pulpwood can be followed by planting a long-lived conifer to produce sawtimber.

The opportunities to convert balsam fir to, or alternate it with, other types are many and varied because fir grows under a wide range of conditions and its seedlings form an almost ubiquitous understory in many Lake States types. Only general guidelines on conversion and alternating crops are presented here. More detailed information on associated types is available in the following references:

Type name	Reference[9]
Hardwood types	
Aspen	Perala 1977
Paper birch	Safford 1983
Northern hardwoods	Tubbs 1977
Pine types	
Jack pine	Benzie 1977a
Red pine	Benzie 1977b
	Schone *et al.* 1984
Eastern white pine[10]	Lancaster and Leak 1978
Spruce-fir types	
Spruce-fir[11]	Flexner *et al.* 1983
	Frank and Bjorkbom 1973
White spruce[11]	Stiell 1976
Black spruce	Johnston 1977a
Northern white-cedar	Johnston 1977b
All types	Burns 1983[12]

Balsam fir and aspen often exist together and where they do it is difficult to manage one to the exclusion of the other. Balsam fir and paper birch are also commonly associated. Even if the main objective is to grow balsam fir timber, an aspen or birch component probably should be maintained for multiple-use purposes such as wildlife habitat and esthetics. In addition, aspen and birch are important in dealing with the spruce budworm. Some aspen should be present for easy conversion by suckering in case of an outbreak, and a birch overstory can significantly reduce fir mortality. However, if birch does not form an overstory, fir mortality may be severe and suddenly expose the birch, causing dieback and death.

On most sites balsam fir and aspen should be managed as alternating crops (fig. 4), whereas balsam fir and paper birch should be managed together. However, if high-quality logs of northern hardwoods, red pine, or white spruce can be grown on a site (aspen and paper birch site indexes 60 or more), the manager should consider conversion even though it may be costly.

In a mature stand of fir with some aspen (at least 18 square feet of basal area per acre), clearcut to produce a fully stocked stand of aspen suckers (fig. 4, left). If fir advance growth is sparse, harvest areas should be within 2 to 3 chains of seed-bearing firs (see p. 10). Once the aspen is mature and fir forms an understory (fig. 4, right), harvest the aspen to release the fir. Well-distributed openings in the fir stand will allow enough aspen suckers to develop so the cycle can be repeated when the fir matures.

Balsam fir also commonly forms an understory in paper birch stands. When the birch is mature, it can be harvested to release the fir, just as in aspen stands. To reduce spruce budworm losses, maintain some overstory birch (or aspen) by clearcutting progressive strips or small patches rather than large areas. Harvesting must be done carefully to leave an adequate stocking of fir (see p. 10 and 18). To ensure a birch component in the new stand, scarify the soil in scattered openings and leave seed-bearing birches within 3 chains. Once the fir matures, treat the stand as described below.

Where mature balsam fir has at least three to five paper birch seed trees per acre, clearcut the stand in progressive strips or small patches or use shelterwood cutting. Strips should be from 1 to 2 chains wide and patches 1 acre or less in size. Scarify about 50 percent of the harvest area to prepare favorable seedbeds for both fir and birch. Full-tree skidding with branches and tops intact prepares favorable seedbeds when the soil is not frozen or covered by snow. Seedling reproduction may be supplemented by vigorous stump sprouts if the birch is younger than 60 years. However, sprouts usually contribute no more than about 10 percent to birch stocking because many are eliminated by repeated deer browsing.

The future composition of the new stand can be controlled by releasing potential crop trees about 8 years after final harvest or when stand height averages from 6 to 10 feet. To obtain a mixed stand in

[9] *For full citations, see Appendix, p. 25.*

[10] *Includes eastern hemlock in Burns (1983).*

[11] *See eastern spruce-fir in Burns (1983).*

[12] *Provides up-to-date summaries.*

Figure 4.—*These views show the key steps in managing balsam fir and aspen as alternating crops: clearcut mature fir and associated aspen to produce aspen suckers (left); harvest mature aspen to release fir understory (right), preferably earlier than shown.*

which balsam fir is the dominant species, use the guidelines in the tabulation on page 7, except include the release of about 150 paper birch per acre.

Balsam fir is also commonly associated with northern hardwoods and may even be dominant for a while after disturbance. However, on fertile mesic sites (well-drained loams), fir does not compete well with long-lived shade-tolerant hardwoods such as sugar maple. On sites with a sugar maple site index of 55 or more, control fir advance growth in order to favor hardwood reproduction and clearcut mature fir if hardwood advance growth is adequately stocked. The minimum number per acre of well-spaced hardwoods should be 5,000 seedlings 3 to 4 feet tall or 1,000 saplings 2 to 4 inches in d.b.h. If such stocking is lacking, remove the fir in two or more stages—by shelterwood cutting, for example—so the hardwoods can become established or better stocked.

On less well-drained hardwood sites (sugar maple site index less than 55), balsam fir should be managed along with its associated hardwoods. These include yellow birch—plus eastern hemlock in Michigan and Wisconsin—on somewhat poorly drained sites and black ash and red maple on poorly drained sites. To grow only pulpwood, reproduce all species when the fir is mature (about age 50); use clearcutting where fir advance growth is adequately stocked and shelterwood cutting where it is not. To grow both pulpwood and hardwood saw logs, clean or thin young stands to obtain the desired proportions of fir and hardwoods. Then harvest the fir at about age 50 and leave the hardwoods until they mature (roughly age 100). Depending on how much the stand is opened, fir may produce a second crop of pulpwood while the hardwoods develop into sawtimber. When the hardwoods are mature, reproduce all species as described above and repeat the process. Because of balsam fir's shade tolerance, selection cutting is suitable where a high proportion of fir is desired.

Converting balsam fir to other conifers should be considered where aspen and paper birch site indexes are less than 60 and northern hardwoods are not aggressive. Balsam fir sometimes grows on dry to dry-mesic sites, especially as an understory of jack or red pine. However, these sites (usually sandy soils) are better suited for pine, with red pine outproducing jack pine except on extremely dry sites. In most cases the manager should eliminate fir when harvesting pine and convert jack pine to red pine.

Balsam fir is a common associate of eastern white pine on mesic to wet-mesic sites. Fir—either pure or mixed with eastern hemlock—often forms an understory in mature white pine stands. This understory may improve wildlife habitat or esthetics, but usually it should be removed so white pine or another preferred conifer can be established. White pine can be reproduced naturally by shelterwood cutting or artificially by clearcutting and planting. Blister rust-resistant stock is now available for areas where white pine blister rust is a major problem. To convert to another conifer, red pine should be planted on the drier, less fertile sites and white spruce on the moister, more fertile sites.

White spruce is generally a minor associate in balsam fir stands on mesic to wet-mesic sites. However, because of its higher value, longer life, and greater tolerance of budworm defoliation, white spruce is usually preferred over balsam fir. Common objectives are to increase the stocking of white spruce and to manage for spruce sawtimber. If a mature fir stand has more than 500 well-distributed white spruce 3 feet or taller per acre, clearcut the stand to release them but use care to minimize logging damage (see p. 18). If white spruce advance growth is inadequate, either use shelterwood cutting and scarification to obtain natural reproduction or clearcut the stand and plant white spruce.

As the new stand develops, intermediate treatments will be needed to favor white spruce over balsam fir or other species. To produce a stand of spruce sawtimber, release—by cleaning, for example—200 to 300 white spruce crop trees per acre during the sapling stage. Then, in the pole stage thin the surrounding trees one or more times to keep the spruce crop trees dominant. Because white spruce sawtimber requires a rotation of 80 to 100 years, most or all of the shorter-lived fir and other species should be removed before the final harvest.

As indicated earlier, balsam fir often grows on wet-mesic to wet sites, especially in mixed swamp conifer stands that contain northern white-cedar and black spruce. Although the pulpwood produced by balsam fir sometimes makes these stands more attractive economically, fir is not well adapted to wet sites (mainly organic soils). In addition, balsam fir usually is not as valuable for wildlife habitat (particularly deeryards) as northern white-cedar. Unfortunately, balsam fir often dominates the advance growth in mixed swamp conifer stands, so it commonly succeeds northern white-cedar and black spruce after harvesting or other disturbance.

In most cases the manager should minimize the balsam fir component on wet sites and favor associated swamp conifers. On harvest areas broadcast burning of slash simultaneously eliminates fir advance growth and improves seedbeds for associated conifers. Usually northern white-cedar or tamarack should be reproduced on the more productive sites and black spruce on the less productive sites.

Controlling Damaging Agents

Spruce Budworm

The spruce budworm is the most serious pest of balsam fir in the Lake States. Recurring outbreaks have caused much growth loss and mortality. In addition, severe defoliation by the budworm often leads to attack by other insects and rot fungi. Thus, the spruce budworm is the most damaging agent of balsam fir in the Lake States.

High mortality of balsam fir from the spruce budworm is most likely in fir stands with the following characteristics:[13]

1. high basal area or percentage of stand (50 percent or more) in balsam fir and/or white spruce;
2. mature stands (50 or more years old), especially if extensive;
3. open stands with tops of balsam fir and/or white spruce protruding above canopy;
4. stands on poorly drained soils that are extremely wet or dry; and
5. stands downwind of a budworm outbreak.

Hazard-rating systems are available for assessing the vulnerability of balsam fir to budworm-caused mortality. These systems help the manager make either short-term decisions during a budworm outbreak to minimize present losses or long-term decisions between outbreaks to reduce future losses. Short-term rating systems can help the manager decide which stands to harvest or spray during the next few years. These systems require technical procedures and so are used mainly by pest management specialists. For detailed information on short-term rating systems, consult Agriculture Handbook 636 (Witter and Lynch 1985).

Long-term rating systems help the manager set priorities and schedules for harvesting or other treatments to reduce the vulnerability of fir stands. These systems are based on stand vulnerability, which has been related to different stand characteristics in different geographic regions of the Lake States. Separate, region-specific systems must be used to reliably estimate the potential loss of balsam fir from a budworm outbreak. Long-term rating systems have been developed for Minnesota and Michigan's Upper Peninsula but not for Wisconsin.

Both the Minnesota and Michigan systems are easy to use because they utilize readily available (or easily obtainable) stand data and simple computations. Routine compartment examinations or inventories usually provide the necessary data. To use the Minnesota system, for example, the manager only has to determine the preoutbreak basal area of balsam fir and the percent of stand basal area in nonhost species (those other than fir or spruce). Agriculture Handbook 636 (Witter and Lynch 1985) should be consulted for the procedures and tables needed to use the Minnesota and Michigan systems. Unfortunately, these systems are region-specific and thus probably are not applicable elsewhere; for example,

[13]*Adapted from Witter and Lynch (1985).*

tests indicate the Minnesota system is unreliable in Wisconsin. Another precaution is that the Michigan system is not applicable on wet sites with organic soils.

How to handle the spruce budworm problem—especially over large areas and long time periods—is a complex and somewhat controversial subject. However, a few principles regarding the budworm and its control apply to most situations. The manager should consider the following principles carefully before undertaking specific practices:

1. A strong interdependence has apparently evolved between the spruce budworm and balsam fir forests. Thus, budworm control and fir management are practically inseparable.
2. The continuing underutilization of balsam fir ensures a buildup of mature and overmature fir stands, which are highly vulnerable to budworm damage. Therefore, increased utilization that diversifies the age class distribution of future fir stands is needed to obtain long-term budworm control.
3. Both major types of budworm control—insecticidal and silvicultural—have limitations. A combination usually provides a better overall control program than either type alone.
4. Specific practices to control the budworm depend not only on stand characteristics but also on the management intensity that is feasible. Intensive management offers a good opportunity to reduce the probability of an outbreak and to minimize economic loss if an outbreak occurs.

During a spruce budworm outbreak the manager should consider three alternatives for handling high-hazard stands: (1) harvest as much fir as possible before serious losses occur; (2) if harvesting cannot keep pace, spray high-value stands with insecticides until they can be harvested; and (3) abandon low-value stands. When stands have a similar hazard rating, various stand characteristics can be used to further rank harvesting or spraying priorities. Stands on extremely wet or dry sites usually are more vulnerable to budworm damage than those on good sites. However, it is economically better to give higher priority to stands on good sites. If sites are similar, stands with more balsam fir should be harvested first because they have more potential for mortality. Also, stands 50 years or older should be harvested before those younger than 50 years, especially if top-kill or mortality is already present. To obtain the greatest economic return, harvest stands with the highest volume of undecayed wood. The amount of fir actually harvested or sprayed will depend on the management intensity that is economically feasible.

Once a budworm outbreak has developed, balsam fir trees begin to die after 3 to 5 consecutive years of severe defoliation. Dead fir usually remains usable for 1 to 3 years, depending on local differences in decay rates. Generally, merchantable fir stands should be harvested as rapidly as possible to salvage damaged, dying, and dead trees. Even if fir advance growth is inadequate, the stand should be clearcut if either budworm-caused top-kill and/or mortality is present or rot and/or wind is a major problem (see next section). Where fir advance growth is adequate (see p. 9), a new fir stand likely will develop after clearcutting; otherwise consider converting to or alternating with another forest type or tree species (see p. 11). Presalvage cutting is appropriate if the owner wants to maintain fir and inadequate advance growth is the only unfavorable stand condition. Such cutting removes highly vulnerable trees in anticipation of damage but leaves some balsam fir for a seed source.

Even young fir stands that develop after harvesting may be damaged by the spruce budworm. To control the budworm in these stands, fell all overstory host trees—white spruce, black spruce, and balsam fir—as soon as adequate fir reproduction is established. This is necessary because these residual trees commonly support budworm populations and can serve as infestation centers for future outbreaks.

Insecticide spraying is used mainly in mature or nearly mature, high-value stands to keep balsam fir alive until it can be harvested. Spraying is recommended in mature stands that have been severely defoliated for 2 consecutive years and cannot be harvested within 5 years. Spraying may also be used to suppress budworm populations before defoliation becomes severe. Conditions are suitable for spraying when fir and spruce buds have broken, needles are beginning to spread out and elongate, and most budworm larvae are in their fourth instar. These conditions usually occur by late May or early June in the Lake States.

Various chemical and microbial insecticides are currently registered for spruce budworm control. Carbaryl (Sevin 4-Oil) is the most commonly applied insecticide; other common ones include acephate (Orthene), *Bacillus thuringiensis* (Dipel and Thuricide), and trichlorfon (Dylox). Some of these insecticides differ substantially in their characteristics; also, the list of registered insecticides and their labels are subject to change. Therefore, consult a pest management specialist to find out the latest recommended treatment for the situation. Insecticide spraying should be done carefully, following all pertinent precautions and regulations (see Pesticide Precautionary Statement, p. 27).

The future management of low-value fir stands abandoned during a spruce budworm outbreak depends on such factors as species composition, soil-site conditions, and the owner's objective. Death of the overstory fir commonly releases fir advance growth, allowing it to develop into a new stand. Death of the fir may also offer a good opportunity to change to another forest type as discussed under "Conversion and Alternating Crops" (p. 11) (fig. 5).

Between outbreaks the manager should undertake long-term measures or strategies to reduce future budworm losses. Probably the best measure is to increase the amount of nonhost species. Harvesting often offers a good opportunity to change a predominantly fir stand to a mixed stand or another type (see p. 11). When economically feasible, intermediate treatments such as release or cleaning can be used to produce mixed stands of fir and hardwoods or fir and other conifers (see p. 6). For maximum effectiveness in reducing future budworm losses, these various operations should be spatially arranged so as to break up large areas dominated by fir.

Although mixed stands may reduce future budworm losses, they also reduce the yield of balsam fir—at least in the short run. This is especially true where fir is overtopped by other species such as hardwoods. The manager should weigh the benefits of increased fir growth after release, for example, against the potential losses from a budworm outbreak. If harvesting or insecticide spraying can be prompt after an outbreak begins, release or other intermediate treatments will increase fir yield. If prompt action is doubtful, it is safer to manage fir in mixed stands.

Other long-term measures that should help reduce future budworm losses are to diversify the age class distribution of balsam fir stands and to shorten the rotation. Utilization that equals, or temporarily exceeds, annual growth will often be needed to eliminate the buildup of mature and overmature fir that exists in many areas. Unless the objective is to produce small saw logs, harvest fir stands as soon as possible where they exceed the "quality" rotations given on page 6. When economically feasible, thin dense young stands; this not only shortens their rotation (see p. 8) but also keeps them vigorous and probably less vulnerable to budworm damage.

Figure 5.—*Typical stand of balsam fir killed by the spruce budworm and now dominated by red raspberry. The lack of reproduction offers a good opportunity to convert—by planting—to another conifer.*

Rot and Wind

Trunk rot and root (or butt) rot are the two major types of decay found in living balsam fir trees. The principal trunk-rot fungus is red heart rot, which causes two or three times more cull than root-rot fungi. The economically important root-rot fungi include four white (or yellow) stringy rots and two brown cubical rots (see Appendix, p. 25, for scientific names). Shoestring root rot, a white stringy rot, is probably the most prevalent species. Root rots damage fir mainly by making the tree susceptible to windthrow or windbreakage; they also kill the tree directly (especially shoestring root rot), cause cull by extending into the trunk, and reduce growth.

Red heart rot enters balsam fir trees through fresh wounds such as broken tops or branches and trunk injuries. These wounds are commonly caused by harvesting and snow or ice storms; black bears sometimes wound trunks by stripping the bark. Root (or butt) rots enter balsam fir through root or basal wounds caused by harvesting and various natural phenomena. Shoestring root rot invades fir especially during droughts and following severe defoliation by the spruce budworm.

Except for woodpecker holes, few reliable external indicators of trunk and root rot exist for balsam fir. Old wounds probably indicate the presence of rot, but the causal fungi rarely produce fruiting bodies on living trees; in addition, the important shoestring root rot mainly develops below ground. However, as discussed under "Rotation" (p. 5), stand age and site conditions strongly influence the presence of rot. Therefore, in most cases, the "quality" rotations given there will minimize losses from rot; they may also help reduce future budworm losses. Even shorter rotations should be considered for stands vulnerable to rot because of severe budworm defoliation or other significant damage.

Other ways to control losses from rot include growing balsam fir on suitable sites, releasing fir advance growth, minimizing damage from mechanized operations, and monitoring budworm or other damage. In general, manage fir on wet-mesic sites where it grows well and has less rot than on dry sandy sites or on highly productive (mesic) hardwood sites. Release not only increases the growth rate but also apparently can reduce the incidence of rot. However, if fir advance growth is severely suppressed (especially by northern hardwoods), do not release or otherwise manage it for timber. Mechanized equipment must be used carefully to minimize wounding of residual firs (see next section). This is particularly important if the rotation is lengthened in order to produce saw logs. Fir stands that have suffered from budworm defoliation, drought, or storm damage should be checked periodically. If losses from rot begin or appear imminent, reproduce the stand by using an appropriate silvicultural system (see p. 9).

As already indicated, wind commonly uproots or breaks off balsam fir trees weakened by root (or butt) rot. Wind also uproots balsam fir because of its shallow root system. This often occurs where the rooting zone is shallow, such as on sites with a high water table or a fragipan. Moderate windstorms blow down some trees—such as those weakened by rot—and leave them lying crisscrossed, whereas severe windstorms generally blow down all trees in an area and leave them lying parallel to each other. Wind damage is usually increased by partial cutting—especially in stands not previously managed, in stands with considerable root (or butt) rot, and on sites with a shallow rooting zone.

Wind damage to balsam fir can be controlled by good management. To minimize losses from wind and rot combined, use the "quality" rotations given on page 6. Do partial cutting such as thinning and shelterwood cutting only on areas or sites where fir is known to be windfirm. If wind is a major problem, manage fir extensively—for example, do nothing except clearcut when mature—or do not manage for fir at all.

When setting up a fir stand for partial cutting, make sure the windward side is protected by a zone of uncut timber at least 1 chain wide. Also, make the cutting boundary smooth and reasonably straight to avoid wind damage resulting from sharp angles such as corners. In mixed stands of fir and hardwoods, leave a well-distributed hardwood component. For other ways to control wind damage when doing partial cutting, see "Intermediate Treatments" (p. 6) and "Silvicultural Systems" (p. 9). If damage—which occurs especially during the first 3 to 5 years after cutting—becomes severe, consider a salvage operation to minimize the timber loss.

Other Agents

Although the spruce budworm is the predominant insect damaging balsam fir (including cone crops) in the Lake States, a few other insects can become important pests. Outbreaks of two defoliators, the hemlock looper and the eastern blackheaded budworm, have seriously damaged mature and overmature stands dominated by fir. Two secondary insects, the balsam fir bark beetle and the balsam fir sawyer, often attack fir weakened by the spruce budworm or drought. The fir coneworm commonly attacks fir cones and may cause significant seed loss. Diversifying the age class distribution of balsam fir stands and shortening the rotation—as discussed under "Spruce Budworm" (p. 14)—should reduce damage by the defoliators; control of the spruce budworm should reduce damage by the secondary insects. No silvicultural measures are known for controlling the coneworm.

Balsam fir is host to many rusts, cankers, and other diseases, including a conspicuous yellow witches' broom. But none except rots (see p. 16) is economically important, so control measures are not needed.

Wildlife sometimes damages balsam fir by feeding or other activities. For example, moose, white-tailed deer, and snowshoe hares browse reproduction; mice and voles feed on bark of reproduction; black bears strip bark of mature trees; birds (such as spruce grouse) and red squirrels nip buds; and mice, voles, and birds consume seed. It is fortunate these activities usually do not severely damage fir because no practical control measures are known. Actually, as long as balsam fir stands can be established or maintained, these activities should be considered beneficial to wildlife rather than damaging to fir.

Because of its thin bark and shallow root system, balsam fir is susceptible to damage from harvesting and other mechanized operations. Residual trees often develop rot from wounds to their base or roots (see p. 16), and advance growth commonly is crushed by equipment or buried by slash. Hence treatments that involve keeping residual trees or advance growth—for example, thinning or shelterwood cutting—should be done carefully by skilled operators using small, maneuverable equipment. Ideally, such treatments should be done in winter when the base and roots of trees, and the stems of small advance growth, are protected by a snow pack. Full-tree skidding is recommended if a heavy slash cover is likely; however, skidding damage needs to be controlled by following the above precautions.

To release balsam fir from large cull hardwoods, use herbicide injection rather than felling to kill the hardwoods (see p. 7). This not only minimizes damage to the fir but also provides standing dead trees for cavity-nesting wildlife.

Balsam fir trees of all sizes are easily killed by fire because of their thin resinous bark, shallow root system, and flammable needles, which often are close to the ground. However, good fire protection now results in little loss, and much of the fir type grows on wet-mesic to wet sites where wildfire risk is normally low. Heavy cutting, of course, produces large amounts of balsam fir slash, which can be a fire hazard for several years. Therefore, use full-tree skidding if a heavy slash cover is likely, such as after shelterwood cutting or clearcutting.

OTHER RESOURCE CONSIDERATIONS

Boughs and Christmas Trees

Compared to timber production, balsam fir boughs and Christmas trees are minor products of natural stands. However, large quantities of boughs (for making wreaths) and many Christmas trees are harvested in certain areas of the northern Lake States. Prolonged needle retention, color, and pleasant fragrance are characteristics that make balsam fir attractive for these uses.

Boughs are cut from the lower branches of open-grown trees or from trees felled for pulpwood. Christmas trees include large ones (20 to 60 feet tall) for community use as well as small ones for home use. The large trees must be open-grown, as occurs when sparse fir reproduction develops after heavy cutting. Some small firs are harvested from natural reproduction, but shearing is needed to make them competitive with sheared, plantation-grown trees.

The potential for producing more balsam fir Christmas trees by shearing natural reproduction appears good on small, privately owned areas and on power line rights-of-way. However, little is known about the spacing and other cultural requirements to grow marketable trees. Forest managers probably can obtain some advice from Christmas tree growers experienced with balsam fir. A potentially serious pest is the balsam gall midge, which forms galls on the needles of young, open-grown firs. The infested needles drop prematurely and make the trees unmarketable. If this insect becomes a problem, consult a pest management specialist for the most appropriate treatment.

Wildlife Habitat

The balsam fir type is important to many wildlife species in the northern Lake States. The timber wolf, an endangered species (threatened in Minnesota), and four species with sensitive habitat needs—pine marten, fisher, Canada lynx, and bobcat—are all associated with this type. Other species that use the balsam fir type for part or all of their habitat needs include: common mammals such as white-tailed deer, moose, black bear, snowshoe hare, and small rodents (for example, red-backed vole, deer mouse, and red squirrel); various birds, especially spruce grouse, warblers, and three-toed woodpeckers; and a few reptiles and amphibians, particularly salamanders and frogs.

Balsam fir stands are beneficial for both "edge" and "interior" wildlife species. Although edge species (such as deer and hare) are associated mainly with forest openings and young stands, they often use middle-aged or mature fir stands for protection from weather or predators (fig. 6). Interior species (such as marten and warblers) use mature fir stands for most or all of their habitat needs. The best way to manage balsam fir stands for wildlife depends on the species the forest owner wants to favor. If a diversity of species is desired, various stand conditions must be maintained. This is most feasible on large (especially public) forests.

The balsam fir type protects several wildlife species from winter temperatures and snow. Although not as beneficial as northern white-cedar or eastern hemlock for deeryards, balsam fir is important because it is more widespread and easier to establish than white-cedar or hemlock. Compared to white spruce, balsam fir generally has few branches near the ground; thus, deer can bed down closer to a fir tree and be less exposed to heat loss. Fir stands

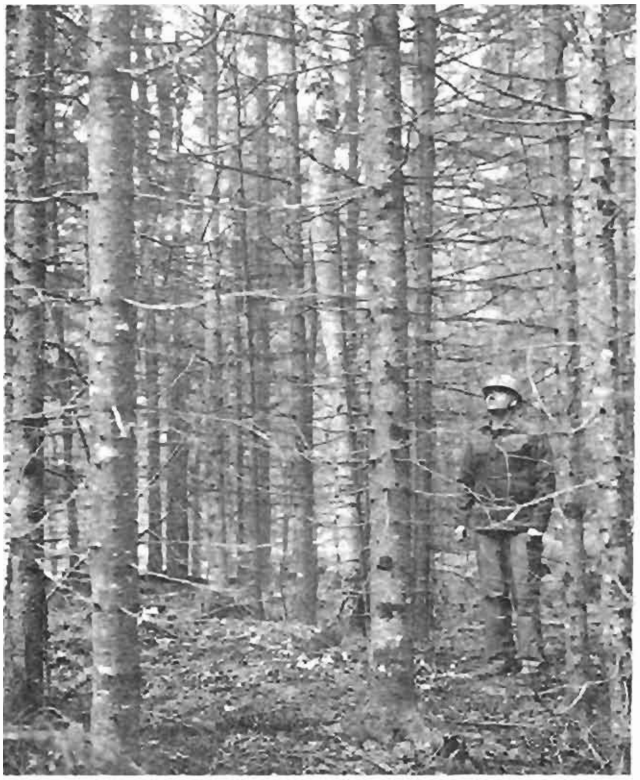

Figure 6.—*This closed stand of pole-sized balsam fir provides important habitat for several wildlife species. Such stands often are used for protection from weather, both in winter and summer.*

more than 20 years old with a basal area of at least 70 square feet per acre moderate temperatures. Also, snow is not as deep in balsam fir stands as it is in aspen and paper birch stands. Consequently, fir stands often are heavily used by deer and by moose with calves during the severe winter months. For similar reasons, deer and furbearers (such as fisher, lynx, and marten) use fir stands for travel lanes.

Edge wildlife species benefit most from balsam fir when stands suitable for winter cover occur adjacent to young (especially hardwood) stands, which produce browse or other food. For good deer and moose cover, manage fir in even-aged stands and maintain a closed canopy. If cover is critical, avoid heavy partial cutting and try to prevent severe budworm defoliation. A well-developed fir understory beneath mature aspen or paper birch also provides winter cover, especially in areas without adequate white-cedar or hemlock stands.

Other habitat important to deer and moose—and also used by hare—is poorly to moderately stocked or patchy pole- and sawtimber-sized fir stands. These lower density stands (with a basal area of less than 70 square feet per acre) support a well-developed shrub layer that provides food in close proximity to conifer cover. Converting such stands to spruce or pine plantations—especially using herbicides to control shrubs and hardwoods—greatly reduces the use of these areas not only by deer, moose, and hare but also by their predators such as the wolf, lynx, and fisher. Extensive areas of fir mixed with hardwoods are utilized especially by the bobcat and fisher.

During the warm summer months balsam fir stands provide shade that helps cool deer, moose, and bear after feeding in open areas. Moose commonly rest in fir stands near wetlands where they feed. To provide cooling sites for these and other wildlife species, leave from 2- to 5-acre patches of well-stocked balsam fir distributed throughout large harvest areas. Unfortunately, these patches can sustain spruce budworm infestations and should not be left where budworm control is a more important consideration. Also during summer various birds use fir stands for nesting; warblers such as the Cape May, blackpoll, and blackburnian especially prefer this habitat.

Another value of balsam fir for several wildlife species is protection from predators. Species such as marten, hare, songbirds, and even deer will use well-stocked fir stands for protection. Balsam fir also benefits certain predators; for example, single fir trees left on harvest areas provide perches for hunting and roosting hawks and owls. However, residual firs (or spruces) should not be left because they are too vulnerable to wind damage and can serve as infestation centers for budworm outbreaks (see p.15).

Many wildlife species feed on balsam fir (see p. 17), but only a few use it to much extent. Fir needles and buds make up a major portion of the spruce grouse's diet. Fir browse may form up to 30 percent of the moose's fall and winter diet; however, the average is much lower. In addition, fir stands attacked by the spruce budworm attract many insect-eating birds, especially Cape May, black-throated green, and blackburnian warblers, and woodpeckers such as the rare black-backed three-toed and northern three-toed. Woodpeckers, in turn, produce tree cavities that are used by various wildlife species, thus enhancing the value of the balsam fir type. On harvest areas slash supports insects eaten by birds such as the dark-eyed junco and winter wren. However, some slash should be removed in heavily cut stands to favor fir reproduction and reduce the fire hazard (see p. 9).

To benefit a diversity of wildlife species in the northern Lake States, maintain from 10 to 20 percent of each management area (such as a compartment) in balsam fir stands. If conifer cover is lacking, promote succession to fir on enough of the area to achieve the recommended range. If fir stands occupy much more than 20 percent of an area, convert some of the area to other types, especially hardwoods (see p. 11). Converting excessive fir acreage to aspen would most benefit edge species, which include major game species such as white-tailed deer and ruffed grouse. Maintaining a moderate—rather than large—proportion of fir should not only enhance wildlife habitat (and esthetics) but also reduce vulnerability to budworm damage.

To manage balsam fir stands for a diversity of wildlife species, maintain a range of age (or size) classes from young seedlings to mature trees. Although this range can be obtained in uneven-aged stands, even-aged stands are preferred for wildlife (as well as timber) management in the Lake States. Depending on the food and cover needs in an area, fir stands should range from poorly to well stocked and from pure fir to half hardwoods. When harvesting fir stands, use small patches (from 1 to 5 acres) to favor edge species and large patches (from 10 to 40 acres) to favor moose and interior species. On larger harvest areas it is important to leave patches of well-stocked balsam fir for cover. These patches should be well distributed, from 2 to 5 acres in size, and total about 5 percent of each harvest area. However, as mentioned earlier, such patches should not be left where budworm control is a more important consideration.

Esthetics

Large stands of balsam fir—especially when pure and dense—have little esthetic appeal. But smaller stands (less than 100 acres) diversify the landscape, particularly when they are interspersed in extensive hardwood forests. Balsam fir stands mixed with hardwoods such as quaking aspen, paper birch, and red maple provide an attractive variety of tree forms and foliage colors. In addition, fir stands have a distinctive fragrance that recreationists enjoy and understory firs sometimes form a screen along roads.

To improve the esthetic appeal of large, mature fir stands, make small- or medium-sized openings (less than 40 acres) by clearcutting or shelterwood cutting; for best results, locate these openings so they create scenic vistas. To enhance the esthetic appeal of small fir stands, thin those that are densely stocked to produce larger trees or use selection cutting to develop a variety of tree sizes. To make both large and small stands more attractive, develop mixtures of fir and hardwoods during intermediate treatments or when the stands are reproduced. If present, favor hardwoods—particularly the maples and paper birch—on exposed locations such as ridges and hilltops.

To minimize the impact of harvesting on the esthetic appeal of the balsam fir type, the manager should: (1) have harvest boundaries follow natural site or forest type lines and (2) remove heavy slash cover or other debris to leave harvest areas neat. In heavily cut stands easily visible to the public, remove slash by full-tree skidding and burn it at the landing. Keep landings from becoming eyesores by locating them in inconspicuous places and by burning all slash piles.

Water

Balsam fir stands have higher evapotranspiration rates than hardwood stands, and dense fir stands intercept more precipitation than pine stands. This means water yield for streamflow is less from fir stands than from hardwood stands and slightly less from dense fir stands than from pine stands. Thus, the manager should consider converting fir to hardwoods—or even to pines—if higher water production is a major objective. Water yield from the fir type can be increased somewhat, of course, by any type of cutting or other treatment that opens dense stands.

Clearcut areas up to at least 40 acres should have no detrimental effect on water quality provided they are well distributed and have skid and haul roads laid out carefully to protect against soil erosion. Also, aerial spraying of pesticides should cause no serious hazard to water quality if all pertinent precautions and regulations are followed (see Pesticide Precautionary Statement, p. 27). It is particularly important not to contaminate open water with pesticide, so do not spray vegetation bordering ponds, lakes, and watercourses.

Balsam fir is desired along trout streams because its shade keeps the water cool and few trees are felled by beaver for dam building. Where fir predominates, not only is shade maintained but also beaver dams—which reduce the quality of trout streams—are infrequent.

APPENDIX

Yield and Growth

Tables are limited for determining the present yield and future growth of balsam fir stands in the Lake States. The only ones available that give yield and growth by site index are for mixed stands of spruce and fir (tables 1 and 2). However, these tables can be used to obtain quick, rough estimates for pure fir stands. One table gives the yield and growth of fully stocked (normal), even-aged stands (table 1); and the other gives the yield of variously stocked, uneven-aged stands (table 2).

A microcomputer program called TWIGS is recommended for obtaining more detailed information on the yield and growth of balsam fir stands. The program not only can be used for fir stands of any age structure or species combination, but also it provides additional information on management and economics. TWIGS is briefly described later in this section.

Table 1.—*Yield and growth per acre of fully stocked, even-aged spruce-balsam fir stands by site index and total age*[1]

Total age	Heights of dominants	Trees 1 inch d.b.h. and larger: Average d.b.h.	Number	Basal area	Volume[2]	Growth[2]	Trees 4 inches d.b.h. and larger: Volume[2]	Growth[2]
Years	Feet	Inches		Square feet	Cubic feet	Cubic feet	Cords	Cords
SITE INDEX 60								
30	36	3.3	1,550	110	—	—	—	0.9
40	48	4.7	1,020	135	1,020	106	13	1.1
50	60	5.5	820	145	2,040	74	22	.8
60	66	5.8	780	150	2,580	41	28	.4
70	70	6.0	750	155	2,920	30	32	.3
80	73	6.2	740	160	3,200	22	34	.2
SITE INDEX 50								
30	30	2.8	2,050	110	—	—	—	—
40	41	4.1	1,350	130	920	95	12	1.0
50	50	4.8	1,100	145	1,860	70	21	.7
60	55	5.1	1,020	150	2,400	39	27	.4
70	58	5.3	990	155	2,700	28	30	.2
80	60	5.4	980	155	2,930	21	32	.2
SITE INDEX 40								
30	24	2.5	2,650	110	—	—	—	—
40	33	3.5	1,750	130	780	72	11	0.9
50	40	4.1	1,420	140	1,580	60	19	.7
60	44	4.3	1,320	150	2,000	33	24	.4
70	46	4.5	1,270	150	2,270	34	26	.2
80	48	4.6	1,260	155	2,490	19	28	.1
SITE INDEX 30								
30	18	2.1	3,450	100	—	—	—	—
40	24	2.9	2,250	120	500	48	7	0.6
50	30	3.4	1,800	135	1,010	38	12	.4
60	33	3.6	1,700	140	1,290	22	16	.2
70	35	3.7	1,650	145	1,460	16	18	.1
80	36	3.8	1,620	145	1,590	12	19	.1

[1] *Values adapted from Bowman (1944) and based on data from northern Michigan and northeastern Minnesota.*
[2] *Merchantable volume and periodic annual growth of peeled wood.*

Table 2.—*Yield per acre 10 years after measurement for uneven-aged spruce-balsam fir stands by site index and basal area*[1]

Basal area per acre	Site index[2] 30	40	50	60	Site index[2] 30	40	50	60
Square feet	------ *Cubic feet*[3] ------				----- *Cords*[3] -----			
40	290	540	670	780	3	6	8	9
60	530	900	1,150	1,280	6	11	14	15
80	870	1,400	1,730	1,840	10	16	20	22
100	1,280	1,990	2,420	2,700	15	23	28	32
120	1,640	2,400	2,840	3,180	19	28	34	38
140	—	2,660	3,080	3,420	—	31	36	40

[1]*Values adapted from Bowman (1944) and based on data from northern Michigan and northeastern Minnesota.*

[2]*See section below for precautions and guidelines on estimating site index in uneven-aged stands.*

[3]*Merchantable volume of peeled wood.*

Site Index

An estimate of balsam fir site index is needed to use either the tables or TWIGS. The best estimate is obtained using the total height and total age of uninjured dominant and codominant firs that are at least 20 years old and have never been suppressed. Site index curves (fig. 7) are convenient for making estimates from a few trees. But with many trees, faster and more precise estimates can be obtained using the following equation:[14]

$$SI = 0.2198H^{1.1644}(1-e^{-0.0110A})^{-2.0364H^{-0.1775}}$$

where SI = site index (feet at 50 years),
H = total height of dominants and codominants (feet),
A = total age (years), and
e = base of natural logarithms.

Total age is needed to use the site index curves or equation, but breast height age is usually determined because balsam fir often has butt rot. To obtain total age, compare breast height age and total height values with the site index curves and estimate the general site class. Then use the following tabulation (Carmean and Hahn 1981) and add the number of years given for this site class to breast height age:

Site index	20	30	40	50	60	70
Years	15	13	11	10	9	8

[14]*Adapted from Carmean and Hahn (1981).*

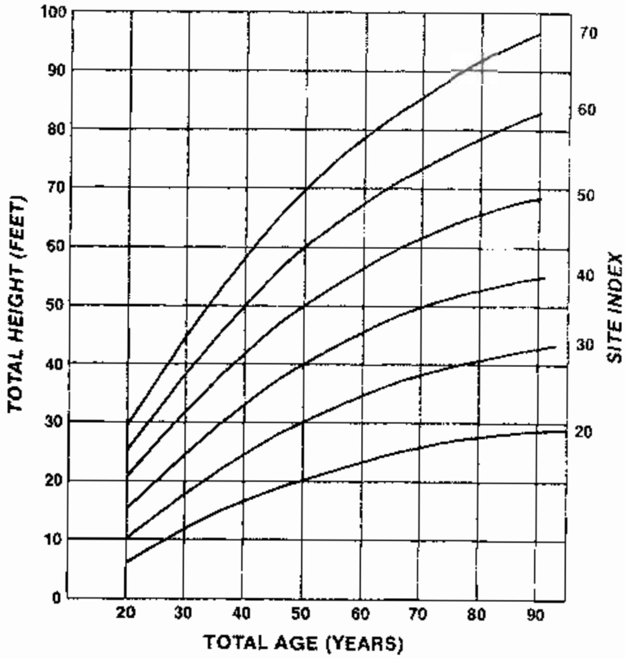

Figure 7.—*Site index curves for balsam fir stands in the Lake States. Adapted from Carmean and Hahn (1981).*

The foregoing procedure is good for obtaining consistent total ages, but it is important to remember that the years added are based on assumptions whose accuracy is unknown. Large errors can occur in estimating both total age and site index if the site trees initially grew faster or slower in height than assumed.

Unfortunately, many dominant and codominant firs are not suitable for site index measurement because they became established under other trees and have suffered from early suppression. This is particularly true in uneven-aged stands of balsam fir, but it applies also to even-aged fir stands that originated under associated species such as quaking aspen. In either case, if dominant and codominant trees of quaking aspen, paper birch, black spruce, or northern white-cedar are present and have not been suppressed, their site index values can be measured and then used to estimate balsam fir site index. The tabulation of comparative site indexes on page 5 is convenient for roughly estimating site index from a few trees. But if many trees are measured, the following equations (Carmean 1982) can be used to make faster, more precise estimates:

Species used to estimate balsam fir site index (SI_{BF})	Equation
Quaking aspen (QA)	$SI_{BF} = -1.366 + 0.851(SI_{QA})$
Paper birch (PB)	$SI_{BF} = 12.096 + 0.707(SI_{PB})$
Black spruce (BS)	$SI_{BF} = -7.212 + 1.168(SI_{BS})$
Northern white-cedar (NWC)	$SI_{BF} = -15.196 + 1.852(SI_{NWC})$

These equations should be applicable to most sites because they are based on a wide range of site indexes. The manager should use the equations cautiously, however, because they are derived from other equations that are based on few plots and/or have large standard errors.

Sometimes no suitable trees are available for estimating balsam fir site index. For example, overstory trees of fir or associates may be uneven-aged, indicating early suppression; the stand may have been clearcut recently; or it may be too young (generally less than 20 years old) for reliable site index measurements. In such instances general site classes for balsam fir can be determined from soil characteristics and stand composition as discussed under page 5.

TWIGS

The North Central Forest Experiment Station developed The Woodsman's Ideal Growth projection System (TWIGS) as a microcomputer version of the Station's Stand and Tree Evaluation and Modeling System (STEMS). Unlike STEMS, which can evaluate many stands at a time, TWIGS is a microcomputer program designed to intensively examine one stand at a time. The program simulates the growth, mortality, and management of trees in stands, using biologically based, individual-tree models developed for the Lake States. TWIGS can be used to estimate the present yield of any balsam fir stand and to project its growth and development as a result of various management (cutting) options, including no cutting. The program can also be used to evaluate the aeconomics of these options.

TWIGS is written in the Pascal language for use on microcomputers such as the APPLE II and IBM Personal Computer. It is also available in FORTRAN for use on the Data General computer system. However, the program is continually being modified and refined, so anyone desiring to use TWIGS should obtain the latest appropriate version from the North Central Forest Experiment Station, 1992 Folwell Avenue, St. Paul, Minnesota 55108. For a detailed description and sample run of TWIGS, consult Belcher (1982).

To obtain accurate results (output) from TWIGS, you must enter information (input) into the program that validly represents the stand being examined. The input needed includes: year and age of stand when measured, site index for balsam fir, and a "tree list." This list may consist of individual tree data from one sample plot or aggregated data from more than one plot. Either variable- or fixed-radius plots can be used. The data needed to prepare a tree list include: species, d.b.h., crown ratio (optional), expansion factor (number of trees per acre represented by each tree list entry), and tree class (acceptable, undesirable, or cull). If detailed tree data are not available, TREEGEN—a program separate from TWIGS but on the same diskette—can generate a hypothetical tree list from less detailed stand data.

An important feature of TWIGS is that it can "grow" a balsam fir stand following various simulated management (cutting) options; thus, you can see which one best fulfills the management objective. Output displayed or printed by the program includes stand summaries of: (1) initial conditions, showing present yield; (2) conditions after cutting, showing values for cut trees and the residual stand; and (3) conditions after projection, showing the effect of growth and mortality on future yield. These summaries include the number and basal area per acre of live, cut, and dead trees by species (or species group), plus a stand volume table showing board feet of sawtimber, cubic feet and cords of pulpwood, and tons and cords of fuelwood (residue). TWIGS also presents economic evaluations to further help you select a satisfactory management option.

Metric Conversion Factors

To convert	to	Multiply by
Acres	Hectares	0.405
Board feet[1]	Cubic meters	0.005
Board feet/acre[1]	Cubic meters/hectare	0.012
Chains	Meters	20.117
Cords[1]	Cubic meters	2.605
Cords/acre[1]	Cubic meters/hectare	6.437
Cubic feet	Cubic meters	0.028
Cubic feet/acre	Cubic meters/hectare	0.070
Degrees Fahrenheit	Degrees Celsius	([2])
Feet	Meters	0.305
Gallons	Liters	3.785
Gallons/acre	Liters/hectare	9.353
Inches	Centimeters	2.540
Number/acre	Number/hectare	2.471
Pounds	Kilograms	0.454
Pounds/acre	Kilograms/hectare	1.121
Square feet	Square meters	0.093
Square feet/acre	Square meters/hectare	0.230
Tons	Metric tons	0.907
Tons/acre	Metric tons/hectare	2.242

[1] *The conversion of board feet and cords to cubic meters can only be approximate; the factors are based on an assumed 5.663 board feet (log scale) per cubic foot and a cord with 92 cubic feet of solid material.*

[2] *To convert °F to °C, use the formula* $5/9(°F - 32)$ *or* $\frac{°F - 32}{1.8}$.

Common and Scientific Names of Plants and Animals

PLANTS

Alder, speckled ... *Alnus rugosa*
Ash, black ... *Fraxinus nigra*
Aspen, quaking ... *Populus tremuloides*
Beech, American ... *Fagus grandifolia*
Birch
  Paper ... *Betula papyrifera*
  Yellow ... *Betula alleghaniensis*
Fern, bracken ... *Pteridium aquilinum*
Fir, balsam ... *Abies balsamea*
Hazel, beaked ... *Corylus cornuta*
Hemlock, eastern ... *Tsuga canadensis*
Maple
  Red ... *Acer rubrum*
  Sugar ... *Acer saccharum*
Pine
  Eastern white ... *Pinus strobus*
  Jack ... *Pinus banksiana*
  Red ... *Pinus resinosa*
Raspberry, red ... *Rubus idaeus*
Rot, root (or butt)
  Brown cubical ... Main fungi are:
    Balsam butt rot ... *Tyromyces balsameus*
    [None] ... *Coniophora puteana*
  White stringy ... Main fungi are:
    Shoestring root rot ... *Armillaria mellea*
    [None] ... *Perenniporia subacida*
    [None] ... *Resinicium bicolor*
    [None] ... *Scytinostroma galactinum*
Rot, trunk ... Main fungus is:
  Red heart rot .. *Haematostereum sanguinolentum*
Rust, white pine blister ... *Cronartium ribicola*
Spruce
  Black ... *Picea mariana*
  White ... *Picea glauca*
Tamarack ... *Larix laricina*
White-cedar, northern ... *Thuja occidentalis*
Willow ... *Salix* spp.

ANIMALS

Bear, black ... *Ursus americanus*
Beaver ... *Castor canadensis*
Beetle, balsam fir bark ... *Pityokteines sparsus*
Bobcat ... *Lynx rufus*
Budworm
  Eastern blackheaded ... *Acleris variana*
  Spruce ... *Choristoneura fumiferana*
Chalcid, balsam fir seed . *Megastigmus specularis*
Coneworm, fir ... *Dioryctria abietivorella*
Deer, white-tailed ... *Odocoileus virginianus*
Fisher ... *Martes pennanti*
Grouse
  Ruffed ... *Bonasa umbellus*
  Spruce ... *Canachites canadensis*
Hare, snowshoe ... *Lepus americanus*
Junco, dark-eyed ... *Junco hyemalis*
Looper, hemlock ... *Lambdina fiscellaria*
Lynx, Canada ... *Lynx canadensis*
Marten, pine ... *Martes americana*
Midge, balsam gall ... *Paradiplosis tumifex*
Moose ... *Alces alces*
Mouse, deer ... *Peromyscus maniculatus*
Sawyer, balsam fir ... *Monochamus marmorator*
Squirrel, red ... *Tamiasciurus hudsonicus*
Vole, red-backed ... *Clethrionomys gapperi*
Warbler
  Blackburnian ... *Dendroica fusca*
  Blackpoll ... *Dendroica striata*
  Black-throated green ... *Dendroica virens*
  Cape May ... *Dendroica tigrina*
Wolf, timber ... *Canis lupus*
Woodpecker
  Black-backed three-toed ... *Picoides arcticus*
  Northern three-toed ... *Picoides tridactylus*
Wren, winter ... *Troglodytes troglodytes*

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PESTICIDE PRECAUTIONARY STATEMENT

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key—out of the reach of children and animals—and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first-aid treatment given on the label and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill dump, or crush and bury them in a level, isolated place.

Note: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the Federal Environmental Protection Agency, consult your county agricultural agent or State extension specialist to be sure the intended use is still registered.

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☆ U.S. Government Printing Office: 1987—755-904/40144

Johnston, William F.

Manager's handbook for balsam fir in the North Central States. Gen. Tech. Rep. NC-111. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1986. 27 p.

Presents the resource manager with a key to the recommended practices for managing balsam fir stands, especially for timber. Discusses control of growth, establishment, composition, and damaging agents; also discusses managing for boughs and Christmas trees, wildlife habitat, esthetics, and water. Includes information on estimating yield and growth.

KEY WORDS: *Abies balsamea*, Lake States, timber management, silviculture, spruce budworm control, wildlife management.