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Forecasting development of understory American beech after partial cutting in uneven-aged northern hardwood stands

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Abstract

American beech (*Fagus grandifolia* Ehrh.) in the understory of northern hardwood stands can interfere with the development of more desirable species such as sugar maple (*Acer saccharum* Marsh.). Yet, managers have had only limited methods for identifying stands where beech might dominate a new cohort. We examined five uneven-aged stands in New York State to determine the degree of influence that understory beech has on species development after a cutting treatment. No significant differences between stands were found, allowing us to develop a single model for evaluation. Understory beech was assessed using a species index value (SIV), which measures the proportion of stems, weighted by height, for a species on a milacre plot. We used a 5×5 transition matrix to compare pre- and post-cut beech importance levels. Stand-level trends showed an overall increase in the proportion of sample plots with higher levels of understory beech after cutting, with the likelihood of change on individual plots dependent on their pre-cut status. Plots with either no beech or very high levels of beech changed little after cutting, while beech was more likely to reach critical levels of dominance when pre-cut SIV was medium or higher. The transition matrix gives forest managers a means to forecast the probable level of future beech importance following cutting, based upon precursor conditions.

Keywords: *Fagus grandifolia*; American beech; Advance regeneration; Uneven-aged stands; Northern hardwoods

1. Introduction

After beech bark disease spread throughout the northeastern United States, American beech (*Fagus grandifolia* Ehrh.) lost most of its commercial value, since mortality reduced the species' importance as an upper canopy tree in northern hardwood forests. However, it has become a dominant component of the understory in many stands (Twery and Patterson, 1984; Ostrofsky and McCormack, 1986; Houston, 1994). This presents problems for managers since beech interferes with the development of other commercially viable species, such as sugar maple (*Acer saccharum* Marsh.). In fact, at high beech densities, other species may fail altogether or only scattered trees may grow into dominant positions within a new cohort. Site preparation to eliminate understory beech is effective but costly (Kelty and Nyland, 1981; Horsley, 1994). Determining whether pre-cut beech levels will prevent regeneration and growth of other species is critical to evaluating the necessity for these treatments.

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The tendency for beech to dominate an understory is due partly to its physiological traits. It regenerates vegetatively from root suckers, often at great densities. Most suckers form within a 10 m radius of a parent tree, where an injury (e.g. a cut or scrape) occurs on a shallow root (Jones and Raynal, 1986). Freeze-thaw actions of soil and logging activity often induce suckering (Held, 1983; Jones et al., 1989). In addition, American beech has extreme shade tolerance and can survive and grow well for several decades under a closed canopy (Canham, 1988; Tubbs and Houston, 1990). This makes uneven-aged stands particularly susceptible to beech development because the interspersion of small, intermediate, and large trees creates a horizontal and vertical distribution of foliage casting persistent shade to the understory (Kenefic and Nyland, 1996; Nyland, 2002). Such low light levels temper the development of most species except beech, so that it often becomes the primary tree of the understory.

Eventual recruitment of understory trees into the main canopy is influenced by the height and proximity to gaps created by regeneration cuttings (Twery and Patterson, 1984), and by gap size. Smaller gaps, whether overhead or nearby, almost always favor the development of adjacent beech seedlings and saplings since they have a lower light threshold level for improved growth after release (Canham, 1985, 1990). Larger gaps created by the removal or death of large-crowned trees favor sugar maple development. However, maple will become part of the new age class only when not overtopped by beech, and may require an opening directly overhead (Canham, 1985; Poulson and Platt, 1996).

Site preparation, ranging from mechanical cutting to various herbicide treatments, can control advance understory beech (Sage, 1987; Horsley, 1994). Yet, due to the cost and effort, it is important to make the investment only when necessary. To facilitate decisions, managers must have an objective means for determining when the density of understory beech would likely prevent successful regeneration and growth of desired species.

Previous work has evaluated critical thresholds using information on the proportion of plots stocked with undesirable species. In even-aged stands, Marquis (1987) demonstrated that commercially undesirable species like beech would inhibit successful regeneration when more than 30% of 1.8 m radius plots contain eight or more undesirable stems, with stems over 0.3 m in height being weighted twice. Alternatively, Leak (1988) indicated that successful regeneration had not occurred when more than 60% of the regeneration plots were dominated by undesirable species, with dominance determined as the tallest tree on a milacre plot.

Though useful, such methods only help managers to identify stands requiring understory treatment based upon a single success criterion—whether desirable species will dominate the new cohort after cutting. Yet, in some circumstances managers would accept a mixture of beech and other species, as long as some minimum number of desirable trees became a principal member of each new cohort. To explore this opportunity, we used the concept of species importance to evaluate the potential for beech development on plots in uneven-aged stands. We used the comparative heights and density of advance beech relative to that of other species as an indicator of the future composition following partial cutting. This paper proposes a method for determining the likely increase in beech importance after partial cutting when varying degrees of initial conditions are present.

2. Methods

2.1. General approach

A contingency table provides a tool for estimating the probability of beech development on an individual plot, and for evaluating the shift in beech importance of all plots across a stand. We quantified the levels of American beech seedlings and saplings from pre-cut to post-cut periods to determine if there was any relationship. Both numbers and heights of stems were used in the analysis since taller stems oppress smaller, younger trees and will more likely succeed underneath canopy gaps. We created a species index value (SIV) using height as a weighting factor for evaluating the importance of trees on a plot. Then we accounted for the proportion of plots shifting to a different level of beech SIV after treatment to forecast the probability that beech would likely dominate on a plot with a particular pre-cut status. Stand level-changes were assessed by evaluating the marginal totals of the contingency table.

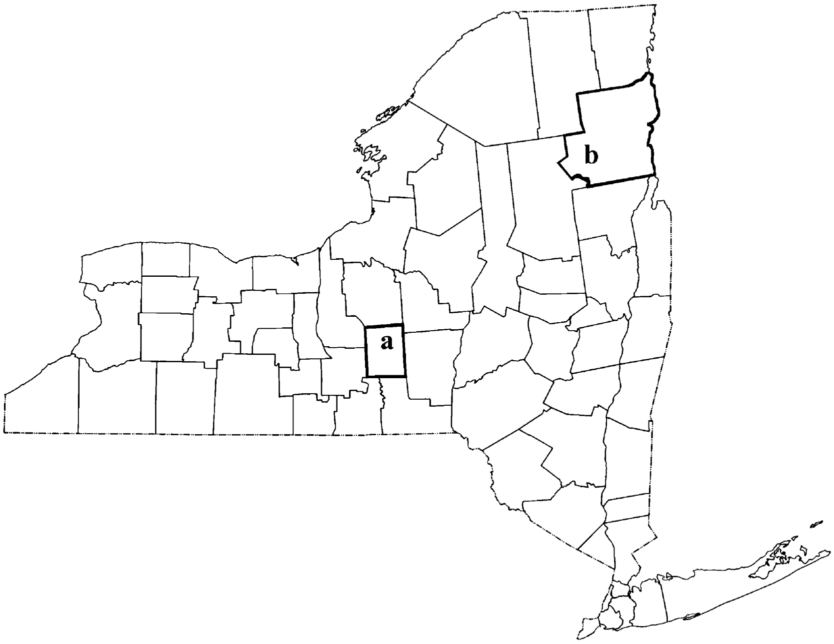

Fig. 1. Location of study sites at the Cuyler Hill State Forest in Cortland County (a) and the Huntington Wildlife Forest in Essex County (b) in New York state.

2.2. Study area

We selected five stands in two areas of New York State (Fig. 1). Two were located in the Adirondack region, on the Archer and Anna Huntington Wildlife Forest at Newcomb, NY in Essex County. The others were located on the Allegheny Plateau in central New York, at the Cuyler Hill State Forest near Cuyler, NY in Cortland County.

Soils in both areas are derived from glacial till. Those on the Adirondacks site belong to the Becket series. They have a granitic parent material, a sandy loam texture, and a low pH. Most contain a spodic horizon, consisting of a mixture of organic material and aluminum and iron deposits (USDA SCS, 1975). Soils at the central New York sites belong to the Lordstown, Mardin, and Volusia series. These soils have shale and sandstone parent material, are classified as medium textured loams to silt loams, and have a pH ranging from 5 to 6.

Vegetation at both study areas is classified as a northern hardwood type, Society of American Foresters (SAF) type #25 (Eyre, 1980). The central New York sites also share similarities with the black cherry—maple subset (SAF type #28) of northern hardwoods. The overstory is dominated by sugar maple, along with yellow birch (*Betula alleghaniensis* Britton) in the Adirondacks, and white ash (*Fraxinus americana* L.) and black cherry (*Prunus serotina* Ehrh.) in central New York. Minor associates include eastern hemlock (*Tsuga canadensis* (L.) Carr), red maple (*Acer rubrum* L.), and American basswood (*Tilia americana* L.). While American beech has typically been a major component of these communities, its presence in the overstory has diminished due to death from beech bark disease and the cutting of diseased trees from the stands. Primary understory trees include American beech, sugar maple, striped maple (*Acer pennsylvanicum* L.), yellow birch, and eastern hophornbeam (*Ostrya virginiana* (Mill.) K. Koch).

2.3. Stand descriptions

All five stands are uneven-aged and have undergone at least two selection cutting treatments (Table 1). Cutting treatments resulted in residual basal areas ranging from 13 to 20 m^2/ha (57 to 87 ft^2/ac). Pre-cut data

Table 1
Characteristics of stands used in the study, including location, size, cutting treatment and year of measurement

Stand	Location	Size of stand (ha)	Number of plots	Residual BA after cut (m^2/ha)	Year of cut	Years to post-cut measurement
1	Adirondacks	9.2	56	13.3	1987	9
2	Adirondacks	3.6	22	20.2	1989	11
3	Central NY	6.5	66	19.7	1991	8
4	Central NY	6.2	62	14.7	1991	8
5	Central NY	6.1	40	16.1	1981	16

were collected at each site during the growing season before the latest cutting treatment, and post-cut data were collected from 8 to 16 growing seasons afterward. Differences in stand area affected the number of sample plots at a site.

2.4. Sampling

Plots were installed along systematic grids. In the Adirondack stands, gridlines run in both N–S and E–W at distances of 40 m (132 ft) apart. Stands in Central New York have gridlines 30 m (100 ft) apart in one direction and either 30 m (100 ft) or 15 m (50 ft) apart in the other direction. Data were collected from 0.0004 ha (0.001 ac) plots, located at the intersection of gridlines (Table 1). Plots that fell on skidtrails were excluded from the study. For all tallies, stems were categorized by tree species and grouped into four size classes: 0.3–0.9 m (1–3 ft), 0.9–1.8 m (3–6 ft), 1.8 m to 2.5 cm dbh (6 ft to 1 in. dbh), and 2.5–10.2 cm dbh (1–4 in. dbh).

2.5. Development of an SIV

We developed an SIV to describe the importance of each species on a plot, as measured by the number of stems weighted by height class:

$$\text{SIV} = \frac{\Sigma[H \times N]_{\text{species}}}{\Sigma[H \times N]_{\text{plot}}}$$

where H is the height in ft at the midpoint of a size class, N the number of stems in a size class.

Since the two largest size classes from the tallies used diameters as cut-off points, we converted those measures to heights using height–diameter regressions developed by Kenefic (1995) and Kenefic and Nyland (1999). We estimated the class heights by averaging the calculated heights for American beech, sugar maple, striped maple, yellow birch, and eastern hophornbeam. We could then redefine the largest classes as 1.8–4.6 m (6–15 ft), and 4.6–11.9 m (15–39 ft).

2.6. Data analysis

We used a contingency table to evaluate the changes in SIV of American beech. Class widths were based on inspection of the frequency distribution of beech SIV's present in the data set and are defined as: absent (SIV = 0), low (0.01–0.25), medium (0.26–0.50), high (0.51–0.75), and very high (0.76–1). The table contains a 5×5 matrix accounting for the transitions of all sample plots established in a stand. Individual cells of the contingency table show what number of plots with a given pre-cut SIV for beech (the rows) end up in each post-cut class (the columns). Totals along the bottom and right side show the total number of plots having a particular beech SIV for each time period.

Even though we created separate contingency tables for each stand, we recognized that pooling the data into one table would strengthen the analyses by increasing sample size. So we tested whether beech development was similar among stands by applying the heterogeneity G-test (Sokal and Rohlf, 1995) to the five tables. Results indicated a similarity in the proportions of plots in corresponding cells across all tables, at a P-value of 0.70. Consequently, we integrated the 246 plots from the five stands into a single contingency table for further analysis (Table 2).

We calculated transitional probabilities for each row of the combined table by dividing cell values by row totals. These values provide an estimate for the likely change in beech importance on a plot after

Table 2
Contingency table showing total number of plots in each SIV class for pre-cut and post-cut periods among the five stands combined[a]

Pre-cut beech SIV class	Post-cut beech SIV class					
	Absent	Low	Medium	High	Very high	Total
Absent	85	17	5	5	8	120
Low	5	13	9	4	3	34
Medium	2	3	7	9	3	24
High	2	2	5	3	8	20
Very high	4	2	1	3	38	48
Total	98	37	37	24	60	246

[a] SIV classes are defined as: absent (SIV = 0), low (0.01–0.25), medium (0.26–0.50), high (0.51–0.75), and very high (0.76–1).

treatment. Since the transition probabilities are calculated from a single table of observed data, it is not directly possible to calculate confidence intervals around the values in each cell. However, we can more generally test whether the sets of probabilities between rows are significantly different.

To test this, we used the *G*-test of independence (Sokal and Rohlf, 1995), commonly known as an $R \times C$ test of independence. The null hypothesis, tested at an α of 0.05, states that the proportion of plots with a given post-cut SIV is independent of the pre-cut SIV class from which they started. We applied the William's correction factor (Sokal and Rohlf, 1995) in cases where the calculated *G*-statistic was close to the critical value of the χ^2 distribution.

The fact that several cells of our contingency table contain small frequencies is often a cause for concern with this test. However, Cochran (1954) noted that the test statistic can be adequately compared to the χ^2 distribution if the contingency table has less than 30 degrees of freedom and the expected values are all 2 or greater. The degrees of freedom for our table were 16, and no expected values were less than 2.0.

We also performed a more detailed study for plots falling within the three middle pre-cut SIV classes. Plots in each class were sorted according to species categories for the tallest stem on each plot. Categories included: beech, commercial, non-commercial, or multiple species (a combination of species from at least two of the other categories). Sugar maple accounted for 75% of the tallest commercial stems, with the others consisting of white ash and black cherry. Eastern hophornbeam and striped maple accounted for equal proportions of the non-commercial species. We compared shifts in beech SIV to the number of plots falling in each category. Cause for changes in beech SIV for plots in each class were also classified as due to: (1) growth of existing stems of a particular species category; (2) in-growth of new stems on a plot; (3) loss of stems from a plot; or (4) a combination of these factors.

We assessed stand-level differences between pre- and post-cut beech SIV using the McNemar test of significant changes (Zar, 1984). The null hypothesis, tested at an α of 0.05, states that the row totals (pre-cut period) are not significantly different from column totals (post-cut period). A χ^2 statistic was computed by ignoring values along the main diagonal of the contingency table and comparing all the oppositely paired cells in the off-diagonal positions (i.e., $\text{cell}_{1,2}$ vs. $\text{cell}_{2,1}$).

3. Results

3.1. Plot-level beech development

The analysis indicated that beech development was most predictable for plots with either absent or very high pre-cut beech levels (Fig. 2). Approximately 70 and 80% of the plots within those classes did not change status after the cutting. When beech was present in conjunction with other species (pre-cut SIV was low, medium or high), beech development varied. Although we did not find a strong correlation between pre- and post-cut beech SIV in these classes, beech SIV was more likely to increase after treatment when pre-cut beech SIV was medium or high than when low. The proportions of plots moving into the

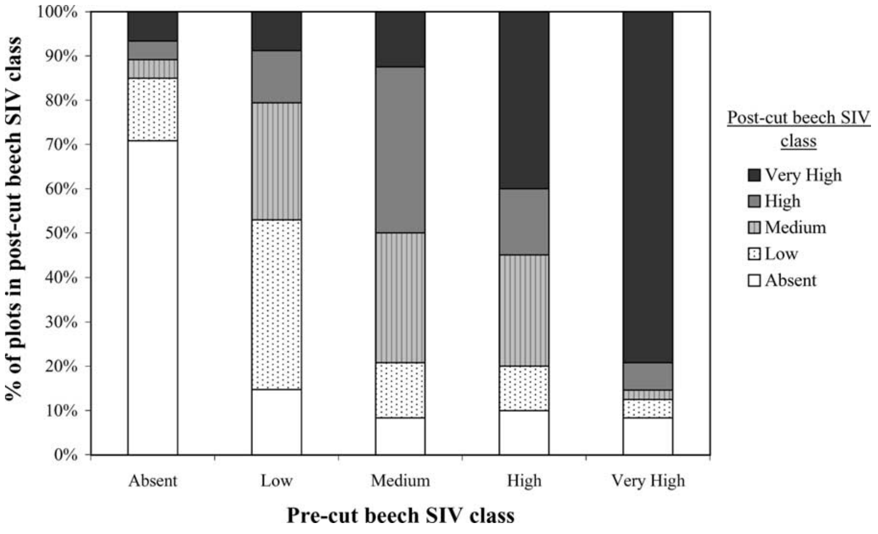

Fig. 2. Transition probabilities of plots from pre-cut to post-cut beech SIV classes, where classes are defined as: absent (SIV = 0), low (0.01–0.25), medium (0.26–0.50), high (0.51–0.75), and very high (0.76–1.0).

next highest SIV class were 38 and 40% for the medium and high classes, vs. 26% for the low class.

3.2. Evaluating transition probabilities

The probability of post-cut beech development differed significantly between pre-cut classes ($P < 0.0001$). The low P-value in this test reflected the markedly different transition probabilities between the absent and very high classes compared to the intermediate classes. When we developed a 3 × 5 version of the contingency table, by excluding the absent and very high pre-cut classes, differences in the transition probabilities of low, medium, and high pre-cut beech were less distinct, but still statistically different ($P = 0.04$).

3.3. Comparison of plots within mid-range SIV classes

In the low and medium classes, there was a relationship between the change in beech SIV and species of tallest stem, except for cases where stems of multiple species were among the tallest of a plot (Table 3). Beech SIV increased after cutting in 100% (only one plot) in the low class and 78% of plots in the medium class when beech was the tallest stem, and on 70 and 67% of the plots in those classes when a non-commercial species was tallest. When a commercial species was tallest, beech only increased on 17% of the plots in the low category and on none in the medium category.

Table 3
The total number of plots with the tallest stem per species category in each of the mid-range SIV classes, and the number of plots per species category that increased in beech SIV after treatment

Species category	Pre-cut beech SIV class					
	Low		Medium		High	
	Total no. of plots	No. of plots increase	Total no. of plots	No. of plots increase	Total no. of plots	No. of plots increase
Beech	1	1	9	7	11	4
Commercial	11	2	2	0	0	0
Non-commercial	13	9	3	2	0	0
Multiple species	9	4	10	3	9	4

Because beech, either solely or in conjunction with other species, was among the tallest stems in all 20 plots in the high SIV class, it was not possible to make a correlation between changes in SIV and species of tallest stem. Beech SIV decreased in all of the plots where beech was among the tallest with a commercial species and increased on all plots where beech and a non-commercial species were tallest.

Reasons for change in SIV differed between pre-cut classes. For all plots in the low class, increases in beech SIV were due to growth of beech stems into greater height classes rather than a loss of other species. Decreases in beech SIV were due to loss of beech stems. For both the medium and high classes, increases in beech SIV were due to a combination of growth of beech stems and loss of other stems. Decreases in the medium class were due to growth of existing commercial stems, while decreases in the high class were due to in-growth of new commercial stems.

3.4. *Stand-level beech development*

A comparison of row and column totals in Table 2 indicated that there was a modest, but significant, increase in stand-level beech SIV after partial cutting ($P = 0.04$). Major shifts occurred where beech was absent or very high. The proportion of total plots in the absent class dropped from 49 to 38% after cutting, while the very high class increased by 5%. The low, medium, and high SIV classes each increased by only 1–2%.

4. Discussion

4.1. *Plant dynamics reflected in transition probabilities*

Many plant species, especially those reproducing vegetatively, often exhibit spatial distributions that are more clumped than uniform (Whitford, 1949). Regeneration develops largely around established parents, so stem tallies of sample plots tend to be either zero or very high for these species. Furthermore, dispersion into new areas occurs slowly through time, unless viable seed is introduced from adjacent areas. So, spatial distributions captured by stem tallies on sample plots will also not change appreciably over short periods.

These factors typify the regeneration dynamics of American beech where root suckers are a common mode of reproduction. Multiple suckers can arise in close proximity to each other off a single root, clustered around a parent tree. Plots with very high levels of advance beech regeneration will most likely be near existing trees and would also be prone to further sucker development after treatment. A lateral spread of beech to unoccupied areas is unlikely except by germination of imported beech nuts, or by the gradual extension of beech roots from adjacent areas. These dynamics help to explain why beech regeneration in our sample stands did not increase appreciably where it had been previously absent and why suckers became more dense or taller than other species around existing beech advance regeneration.

The presence of understory beech did not completely inhibit regeneration and development of other species on some plots. When pre-cut beech SIV was moderate, species development was often related to its height status on the plot. This is consistent with conclusions by Leak and Wilson (1958). They found that development of a particular species depended on its distribution, height, and abundance as advance regeneration. Sugar maple was much more likely to become the dominant (tallest) species when already present as tall advance regeneration, and beech would more likely dominate areas with tall advance beech. In our study, beech importance increased on approximately 75% of the plots where beech was tallest (in the low and medium categories) but was oppressed by growth of commercial species on about 80% of plots where a commercial species had been tallest. However, advance regeneration of non-commercial species did not prevent the development of beech.

4.2. *Use of the contingency table as a management tool*

Other available guidelines (e.g. those by Marquis (1987) or Leak (1988)) have typically compared stand-wide beech levels to some pre-set density threshold. However, most stands will contain plots with a wide distribution of beech importance values. The degree that beech importance varies from plot to plot can be accounted for by using a contingency table.

We used the probabilities reported in the table to determine the likelihood that beech importance will increase on a plot, given a particular condition. To determine the likely development of all plots in a stand, we simply multiply the number of plots in each pre-cut SIV class by the appropriate probabilities. Then to assess the stand-level changes, we sum up the number of plots in each post-cut column. Thus, we can forecast what proportion of the stand area would likely support no, moderate, or very high levels of beech after a partial cutting.

Determinations like these can give managers an indication of the need for site preparation to reduce the abundance of understory beech. Such decisions have financial as well as ecological importance. For instance, conditions are not likely to change when all plots fall within the absent or very high classes. When the majority of plots have very high levels of beech and a landowner wants other species in the new cohort, site preparation should precede any partial cutting of the overstory. If the stand has only scattered pockets of dense beech interspersed with areas supporting no or only limited beech, some landowners might elect to skip site preparation given that the proportion of area having non-beech species satisfied the management objectives. For plots with mid-range beech SIV, the need for site preparation becomes greater with increasing SIV, particularly when beech SIV levels are medium to high. For these cases, landowners can use the ratio of low:medium:high plots to estimate the proportion of total area that will increase in beech importance.

Note that the transition probabilities pertain to changes after only one time period into the future. They do not describe changes that might occur after several entries. We did find a similar pattern of post-cut beech development in the two regions of New York State; however the probabilities may not prove reliable in stands with appreciably different site conditions than found in our study areas. Factors like important differences in species composition or high pressure from deer browsing may alter the stand outcome.

Unlike traditional methods, the contingency table does not provide just yes or no answers about the need for site preparation. It allows users to forecast likely shifts in the distribution of beech importance across a stand receiving no site preparation. Given the management objectives, users can determine if the projected increase in beech is sufficient to warrant site preparation. Our contingency table approach should prove most useful in making these judgments for stands where understory beech occurs at intermediate levels of abundance or in a clumped fashion across part of the stand area.

5. Conclusions

The relationship of understory beech development to pre-cursor conditions was examined in five uneven-aged stands in New York State. Shifts in the importance of understory beech were measured using an SIV that accounted for both numbers and heights of stems on sample plots. The five stands showed similar beech development patterns, allowing us to combine the data into a single contingency table applicable to uneven-aged northern hardwood stands.

Our data indicate that little change occurred after a cutting on plots where pre-cut beech SIV was either absent or very high. This reflects the fact that beech regeneration will more likely develop near a parent tree and not spread quickly into new parts of a stand. Plots with abundant and/or tall advance beech will continue to have it after a cutting. When beech SIV is low, beech development will be minimal and advance regeneration of other species will most likely persist and develop adequately. Beech will most likely become the dominant species on plots ranging in pre-cut SIV from medium to very high.

The transition probabilities of the contingency table allow forest managers to estimate the change in the distribution of SIV across a stand by multiplying the number of plots in each class by the corresponding probabilities. Based on this information, managers can decide whether any shifts into the higher SIV classes are great enough to warrant site preparation.

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