NATURAL RESTOCKING OF FORESTS FOLLOWING THE 1938 HURRICANE IN CENTRAL NEW ENGLAND[1]

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The New England hurricane of 1938, by destroying many acres of mature and semi-mature forests, initiated new forest associations over a large area. During a decade at the Harvard Forest at Petersham in central Massachusetts, the author was able to participate in a number of studies on the development of these new associations under a variety of conditions. These primarily involve successions following the blowdown of old-field white pine on glacial till soils, although other conditions are also represented.

The available data consists of a series of 14 permanent sample plots, mostly 1/10 acre in size, established in 1940 on various blowdown sites in the Harvard Forest; and a large number of temporary sample plots in the Forest and surrounding townships. These data provide an insight into the development of secondary forest successions following blowdown in central New England with reference to: (1) the relationship of soil types to post-hurricane regeneration, (2) the effect of previous forest association upon the restocking, and (3) the importance of other factors, particularly whether or not the down timber was subsequently logged.

DAMAGE AND SALVAGE

The New England hurricane of September 21, 1938, was one of the most destructive storms in the history of the United States. Considering the damage to the forests alone, nearly 3 billion feet of timber were blown down on more than 600,000 acres of forest land. Damage was severe throughout New England except in Maine and a narrow strip along the New York state line. In the white pine-hardwood region alone, nearly one-half by volume of the total softwood timber stand was destroyed (Baldwin, 1942).

In the Harvard Forest, at least two-thirds of the merchantable sawtimber was uprooted or left as broken snags. According to Rowlands (1939), more than half the timber was blown down on 43 per cent of the area of the Harvard Forest. Of the stands more than 40 years old, 93 per cent of the softwoods were blown down, together with 57 per cent of the mixed-wood stands and 38 per cent of the hardwood stands. On the other hand, few of the younger stands of timber were seriously damaged.

Throughout the region, salvage operations were started immediately following the storm. The New England Timber Salvage Administration was established by the U. S. Government to promote logging and to purchase logs. By the end of 1942, this agency had handled about 700 million board feet. During the same period, some 90 million feet were salvaged on the White Mountain National Forest and nearly 600 million feet were cut by private agencies throughout the region (Baldwin 1942). The war accelerated salvage operations somewhat, but also caused many mill opperators to seek stands more profitable to operate, thus resulting in ever greater forest depletion.

In addition to the salvage operation, considerabe clean-up work was done, principally to reduce the fire hazard. The New England forest emergency project supervised slash disposal, fire lane construction, and other hazard production work on over 200,000 acres, while private owners cleaned up more than 100,000 additional acres.

Relatively little research has been carried out on the effects of the hurricane on the forests. Curtis (1943) published some observations on susceptibility to wind damage . Bess (1944) investigated insect damage following the storm and concluded that practically no standing trees were killed by bark beetles. Cline (1939)and the Committee on Silviculture of the New England section, Society of American Foresters (1941) recommended that reliance be placed on natural reproduction for the restocking of blowdown areas, but the recommendation was made in advance of the appearance of the results of natural restocking surveys.

PREVIOUS RESTOCKING SURVEYS

A small number of surveys have been carried out to obtain information on the rehabilitation of hurricane-damaged forest areas by natural restocking.

Cheston (1940) studied natural regeneration on the Keene (New Hampshire) and Union (Connecticut) forests of the Yale School of Forestry one year after the hurricane. He found that from 24 to 32 per cent of the heavily damaged areas studied were covered by slash, a smaller

[1] Based upon data collected while the author was a member of the staff at the Harvard Forest, 1944-50. The paper is derived from a portion of a doctoral dissertation submitted to Yale University.

percentage of the area being unstocked, and the remainder restocked about equally with desirable and inferior species.

Natural regeneration on white pine lands in the Fox Research Forest at Hillsboro, New Hampshire, was studied by Baldwin (1940), two years after the hurricane. Although he found an average of 16,000 stems per acre on blowdown areas, only one-half consisted of valuable species; and these were highly irregular in their distribution, areas up to one-half acre in size being virtually devoid of valuable stems. Baldwin's 61 mil-acre plots were divided between three soil types, and differences in composition between these soil types were apparent. White pine was found to be much more abundant on the sandy Danby soil than on the heavier Herman and Canaan soils. Red oak, sugar maple, and gray birch, all important on the heavier till soils, were completely lacking on the Danby soil. Paper birch was apparently more abundant on the shallow Canaan soil than on the deep but otherwise similar Hermon type.

In 1941, after two growing seasons had passed since the hurricane, Brake and Post studied the restocking on 137 former old-field white pine areas in north-central Massachusetts. They concluded that, on the better sites, sufficient volunteer reproduction of the better elements was present in most cases to make possible the development of well-stocked timber stands of good quality. On the poorer sites, reproduction was much less adequate. They found that 98 per cent of the better sites had more than 500 desirable stems per acre, while 88 per cent had more than 1000 stems. On the average sites, 93 per cent had more than 500 stems, and 77 per cent more than 1000 stems. On the poorest sites, however, 84 per cent had more than 500 stems, while only 42 per cent had more than 1000 stems per acre.

An intensive study of the natural restocking on one compartment (Tom Swamp III) of the Harvard Forest was understaken by Larson, Yoder, Gill, and Praher in 1942 under the direction of R. J. Lutz and the writer. Twenty-three stands were included in the study, representing four principal soil types and several former cover types. Adequate restocking was found on all but the wettest areas.

Survey Methods

In the various restocking surveys carried on at the Harvard Forest, methods of surveying the vegetation were modified from time to time.

Permanent sample plots $\frac{1}{10}$ to $\frac{1}{46}$ acre in size were established to follow changes in volunteer stands over a period of years. Although these give a clearly inadequate measure of restocking over a given stand since only one plot was established per stand, they do provide important information on changes from year to year.

In the evaluation of current restocking, reliance was placed upon mil-acre plots or quadrats, 6.6 feet square. In the earlier surveys, these plots were located systematically (*i.e.*, mechanically) in a regular grid, 20 to 50 on each area depending upon its size. Later, a continuous strip of 50 mil-acre plots was run, starting at a point chosen at random, and running at right angles to main topographic features (*i.e.*, up or down the slope). While this single strip technique did not cover the area as well as mechanically-spaced plots, and consequently gave a less accurate picture of a particular area, it did save a great deal of time, and permitted the study of many more tracts.

Measurement of Stocking

The amount and adequacy of natural reproduction can be measured either in terms of abundance (stems per acre), or frequency (per cent of quadrats stocked). In the earlier studies, the numbers of stems per acre was determined for each species and for each type of origin (seedlings, stump sprouts, seedling sprouts, or root suckers). These abundance values give a good record of stand condition, but have two drawbacks. First, every stem on the mil-acre plots must be counted and tallied, often a very arduous task. Then, despite the great amount of work involved, no measure is obtained of the distribution of the reproduction over the area. Abundance values may be quite accurate and yet give no information as to whether the stems are distributed throughout the stand or densely concentrated in a small area.

To overcome these difficulties, frequency rather than abundance has been increasingly used in restocking surveys (Lowdermilk 1927, Haig 1929, 1931). The term *frequency* (also *frequency index* or *frequency per cent*) refers to the number of quadrats that are stocked with a given species or group of species. The unit of restocking, then, is the quadrat rather than the tree, and frequency value will be affected by the size of the quadrat adopted. The mil-acre quadrat was used in most of the present studies because it is conventional, convenient to handle in the field, and simple to compute. Furthermore, a spacing of 6.6 feet approximates that of the normal forest plantation. A stand restocked with a frequency of 100 will have at least 1000 well-spaced stems per acre and would be considered full-stocked by most standards.

In order to compare the results obtained by the two measures of stocking, 540 mil-acre plots were tallied in a total of 20 stands in one compartment (Tom Swamp III) in such a way that the data could be worked up in terms of both frequency and abundance. The two measures yielded similar results although certain differences were apparent. For instance, there were more than twice as many yellow birch seedlings as white ash in the area (abundance), but the ash are more widely distributed (frequency). An examination of the data indicates that the yellow birch seedlings are concentrated in the lower and moister sites.

Similarly, comparisons are afforded by Tables I and II summarizing a study where frequency is based upon the percentage of stands in which the species occurs; and by Tables III and IV summaring a study where frequency is based upon the standard mil-acre plot. In each case, the two measures yielded results comparable in general but differing in detail. In each case, more information could be gleaned from the two analyses than from one alone.

TABLE I. 1941 natural reproduction study soil types and seedling abundance in seedlings per acre

Species	Charlton	Gloucester	Merrimac	Hinckley	All
Gray birch	1830	2200	720	620	1820
Pin cherry	2840	520	740	600	940
Black cherry	800	720	790	400	710
White pine	660	640	1060	850	710
Red maple	510	720	620	230	620
Red oak	250	150	80	60	160
Paper birch	330	60	20	10	90
White ash	40	120	20	20	90
Aspen	100	80	110	20	80
Black brich	40	50	20	10	40
Sugar maple	10	40	..	20	30
Hemlock	130	10	..	10	30
White oak	10	20	20	10	20
Balsam fir	10	10	..	..	10
Yellow birch	40	10	..	..	10
Hickory	10	10	10	..	10
Red spruce	20	10	..	..	10
Beech	10	10	..	..	10
Basswood	10	10	..	..	10
Scrub oak	..	..	20	..	10
All Species	7650	5390	4230	2860	5410
Number of stands	22	82	12	15	131

SOIL TYPES AND RESTOCKING

The young forest stands dating from the 1938 hurricane provide an opportunity to examine the relationship existing between soil types and forest composition. In two studies, variables other than soil type were kept as uniform as possible in field sampling. All of the timber was, of course, destroyed on September 12, 1938, and the ensuing stands were of a single age. The previous cover in all cases was predominantly white pine. Finally, the sampling was undertaken two or three growing seasons after the blowdown so as to provide sufficient time for the new growth to become established, and yet not enough time for competition to greatly reduce the number of seedlings.

The first study consisted of 3,400 mil-acre plots taken in 137 former white pine stands in northern Worcester County by Brake and Post in 1941 and used by them as the basis for their master's theses.

TABLE II. 1941 natural reproduction study soil types and seedling frequency as per cent of stands in which the species occurs

Species	Charlton	Gloucester	Merrimac	Hinckley	All
Red maple	100	99	67	87	95
Pin cherry	100	88	83	87	89
Black cherry	86	93	75	87	89
White pine	86	89	83	100	89
Gray birch	100	82	67	73	82
Red oak	77	77	25	40	68
Aspen	27	38	33	20	34
Paper birch	50	31	17	7	30
White ash	32	23	17	13	23
Sugar maple	14	21	..	7	16
Black birch	14	20	8	7	16
White oak	9	17	17	13	15
Hemlock	27	7	..	13	11
Hickory	5	10	8	..	8
Yellow birch	23	5	..	..	7
Balsam fir	5	5	..	..	4
Beech	5	5	..	..	4
Red spruce	5	1	..	..	2
Basswood	2	1	..	..	2
Scrub oak	..	..	8	..	1
Number of stands	22	82	12	15	131

TABLE III. Seedling abundance in Tom Swamp III, 1942

Species	Gloucester stony phase	Gloucester	Charlton	Sutton	Whitman	All
Red maple	908	2139	1668	558	519	1392
Yellow birch	204	671	508	1692	1046	753
White pine	1029	1030	643	525	106	679
Black cherry	158	994	822	616	125	647
Red oak	662	250	778	616	236	483
Pin cherry	150	1168	116	158	19	420
Gray birch	1054	675	92	300	125	390
White ash	558	539	236	176	206	346
Black birch	404	369	411	100	92	303
Paper birch	129	204	77	41	86	118
Sugar maple	46	16	114	25	25	51
White oak	..	46	39	33	..	29
Hemlock	..	..	72	25	8	26
Aspen	16	41	17	..	..	19
Hickory	46	25	..	..	..	12
Basswood	..	..	..	..	38	8
Total	5364	8167	5593	4865	2631	5676

The second consisted of 600 mil-acre plots in a small area taken by Larson, *et al.* from a single compartment in the Harvard Forest. In each case, the original field notes were reanalyzed by the present worker to determine what differences in forest composition could be attributed to soils type. The results were compiled for seedlings only, leaving out seedling sprouts, stump sprouts, and root suckers, all of which owe their presence to the preceding stand. Results were compiled on both abundancy and frequency bases.

TABLE IV. Seedling frequency in Tom Swamp III, 1942

Species	Gloucester stony phase	Gloucester	Charlton	Sutton	Whitman	All
Red maple	49	53	52	29	20	43
Black cherry	14	38	40	26	14	30
Red oak	46	20	41	24	19	29
White pine	41	32	32	24	8	27
White ash	44	27	16	11	16	19
Yellow birch	9	17	18	25	18	18
Pin cherry	8	32	11	12	2	15
Black birch	28	16	14	9	8	14
Gray birch	14	23	3	24	8	13
Paper birch	6	11	6	4	3	7
Sugar maple	4	2	9	2	3	5
White oak	..	6	3	..	..	3
Hemlock	..	..	6	5	1	2
Aspen	2	4	..	..	..	2
Hickory	8	2	..	..	..	1
Basswood	..	..	..	..	2	1

Of the stands sampled by Brake and Post, 131 were found to be on Charlton, Gloucester, Merrimac, or Hinckley soils on the basis of the soils map published by Latimer, *et al.* (1927). All are well-drained upland soils. Charlton and Gloucester soils are derived from late Wisconsin glacial till, the Charlton parent material being predominantly Brimfield Schist while the Gloucester parent material is predominantly granite. Merrimac and Hinckley soils are derived from glacial outwash, Merrimac occurring in sand plains laid down by aggrading glacial meltwater streams, while Hinckley occurs in kame deposits formed by meltwater coming directly off the ice. Theoretically, the till soils, being loams, should support a richer flora than the outwash soils which are sands. Of the tills, the Charlton is derived from the richer and more easily decomposed parent material and should be the more fertile. Of the outwash sands, Merrimac has the higher water table and should provide the better site.

Tables I and II give the abundance and frequency respectively of seedlings of various species on these soil types. That the till soils were better stocked than the outwash soils, and contained a better representation of the mesophytic species can readily be seen. There is little significant difference in stocking between the Charlton and Gloucester soils, however. The Charlton soil had more seedlings per acre, but the difference is entirely attributable to the great number of pin cherry seedlings. On the frequency basis, the restocking was comparable. Likewise, there is little if any significant difference in composition of restocking between the Merrimac and Hinckley soils. Although several species are more abundant on the Merrimac soils, the same species are more frequent on the Hinckley soils.

Of the light-seeded pioneer species, gray birch (*Betula populifolia* Marsh.), pin cherry (*Prunus pensylvanica* L.), and black cherry (*P. serotina* Ehrh.) had seeded in profusely on all sites, but with somewhat better success on the till soils. Paper birch (*B. papyrifera* Marsh.) and aspen (*Populus tremuloides* Michx. and *P. grandidentata* Michx.), being south of their optimum range, were less well represented. None of these species, however, could be expected to maintain dominance in the stand after forty or so years in central New England.

Three longer-lived species, white pine (*Pinus strobus* L.), red maple (*Acer rubrum* L.), and red oak (*Quercus rubra* L. and including in these studies, black oak, *Q. velutina* Lam.), had also become established in substantial numbers. White pine was more abundant upon the outwash sands where it is the characteristic species in older stands, while red maple and red oak were more common on the till soils where they are the characteristic species in older stands (Spurr 1950). These three would seem to be the dominant species in the new stands.

On the till soils, a number of mesophytes were found. These included white ash (*Fraxinus americana* L.), black birch (*B. lenta* L.), yellow birch (*B. lutea* Michx.), sugar maple (*A. saccharum* Marsh.), hemlock (*Tsuga canadensis* (L.) Carr.), and occasional beech (*Fagus grandifolia* Ehrh.), balsam fir (*Abies balsmea* (L.) Mill.), red spruce (*Picea rubens* Sarg.), and basswood (*Tilia americana* L.). There is some evidence that the yellow birch and hemlock were more successful on the Charlton soils than on the Gloucester. Some of these trees also occur infrequently on the outwash sands.

Finally, three xerophytes were found scattered on the outwash and occasionally on the tills. These include white oak (*Q. alba* L.), scrub oak (*Q. ilicifolia* Wang.), and hickory (*Carya* spp.).

The 1942 study of Tom Swamp III gives much information about a small tract. All the blowdown areas in a small compartment were heavily sampled. Five soil types were included: Gloucester stony fine sandy loam, shallow phases, on the top of a low ridge; Gloucester stony fine sandy loam, a little lower on the ridge; Charlton stony fine sandy loam; Sutton stony silt loam; and Whitman stony silt loam. Sutton is the imperfectly drained and Whitman is the poorly drained member of both the Gloucester and Charlton soil catenas. The Charlton soils occupy somewhat lower and moister sites than the Gloucester soils so that differences in composition attributable to these two series may be as much due to moisture differences as to fertility differences.

Natural restocking after the hurricane by seedlings of all species did not differ appreciably between the three upland soils (Tables III and IV), but total restocking was somewhat poorer on the imperfectly drained Sutton soil, and markedly poorer on the poorly-drained Whitman soil.

Very little difference is apparent for the individual species between the restocking on the three upland soils. Perhaps the most obvious correlations between composition and soil are provided by white pine and yellow birch. The former is most common on the driest soils and decreases with increasing soil moisture, while the latter is most common on the Sutton soil and decreases with decreasing soil moisture. White ash is actually both more frequent and abundant on the Gloucester soil than on the Charlton, thus seeming to indicate that it has little preference for the supposedly richer Charlton. Several of the light-seeded species, especially the birches, had apparently become established in greater numbers on the drier soils. Eliminating these, an eventual red oak-red maple-white pine-white ash association could be predicated with yellow birch, black birch, and perhaps including paper birch as being locally abundant.

The first study clearly demonstrates that the till soils (Charlton and Gloucester) support a richer tree flora than the outwash soils (Merrimac and Hinckley). The second study suggests that the restocking is most successful on the well-drained tills (Gloucester and Charlton) rather than on the excessively drained Gloucester stony phase, or the more poorly drained Sutton and Whitman soils. In neither study, however, is there any clear evidence of differences between two soil types of the same drainage and same particle size (*i.e.,* between Gloucester and Charlton, or between Merrimac and Hinckley). We may conclude, therefore, that the differences in restocking are largely attributable to differences is soil texture and moisture, and not to parent material differences where texture nad moisture are the same.

Previous Stand and Restocking

The 14 permanent sample plots in the Harvard Forest provide an opportunity to study the changes in restocking with time on various combinations of previous stand and soil type. Eight of the plots were located on glacial till and 6 on outwash. Of the till plots, 6 followed old field white pine, one followed an immature white pine plantation on an old field, and one followed hardwoods. Of the outwash plots, one followed selectively cut white pine and 5 followed old-growth white pine and hemlock.

The changes in abundance from 1940 to 1948 are presented for the 6 plots following old-field white pine on glacial till in Table V. All are on well-drained sites. Although short-lived species such as black cherry (largely eradicated in early years by tent caterpillar defoliation and suppression), pin cherry, gray birch, and aspen make up ⅓ of the 1948 stand, considerable numbers of longer-lived species also occur. Perhaps the most notable feature is that, except for the seedling white pine, paper birch, and gray birch which largely became established in 1941, there has been little change in the restocking since the plots were established. In other words, the restocking 10 years after the hurricane is very largely made up

Table V. Natural restocking on permanent sample plots. Six plots following old-field white pine on glacial till

Species	Abundance (stems per acre)				
	1940	1941	1942	1944	1948
Long-lived trees					
Red maple	1470	2000	1590	2160	1280
White ash	790	890	770	980	890
White pine	...	260	240	470	390
Red & black oak	320	520	400	370	320
Paper birch	...	290	260	220	200
Black & yellow birch	130	40	120	160	200
White oak	70	60	110	80	90
Sugar maple	30	10	10	10	20
Others (Hem., Hick., Basswd.)	..	..	10	10	10
Total	2810	4070	3510	4460	3400
Short-lived trees					
Black cherry	3300	2500	1100	1800	980
Gray birch	100	590	400	320	490
Aspen	250	290	190	270	240
Total	3650	3380	1690	2390	1710
Total	6460	7450	5200	6850	5110

Plots A (P.H.IV.), F (T.S.V.), G (T.S.VI.), H (T.S.I.), I (T.S.I.), J (S.C.II).

of the plants present in the understory at the time of the hurricane plus pioneer species that became established shortly after the hurricane.

Of the long-lived species present today, there is every reason to believe that red maple and red oak will continue to make up the dominant stand. The white pine is largely suppressed by the hardwood growth and may be expected to largely disappear. The white ash, paper birch, black birch, and yellow birch cannot compete overly well with the aggressive oak and maple and should become less important as the years go by. In other words, the post-hurricane stands followed old field pine will evolve into a red oak and red maple association with lesser quantities of white ash and the birches; this is the same association that is known to follow the clearcutting of old field pine and that is described as the transitional type on well-drained soils.

Confirmatory information on a frequency basis is provided by data from 6 small blowdown areas in the southeast corner of the Tom Swamp Block, considered by some as representing the best sites in the forest (Table VI). Again it may be seen that a red oak-red maple association is the result of the blowdown of old field white pine on well-drained glacial till. In this case, white ash and black birch will apparently be the chief secondary species since the gray birch is short-lived and the black cherry and white pine cannot be expected to survive in any number.

In contrast to the above cases, where the hardwood advance growth under the previous pine stand accounts in large measure for the post-hurricane stand, are cases where immature pine stands were blown down at a time when their density was still great enough to prevent the establishment of an understory. The example of plot B (P. H. I.), a 28-year-old dense white pine plantation in 1938, is typical. In 1940, there were 9840 pin cherry seedlings per acre and only 120 others of which 80 were red maple and 40 red oak. Eight years later, the only changes were a slight increase in the pioneer species marked by the addition of 520 white pine seedlings, 280 gray birch seedlings, and 160 additional red maple seedlings. With no advance growth from the previous stand, the restocking is inadequate even after 10 years. This is true not only for the case cited, but for all similar instances of the blowdown of dense pine plantations and other stands where no advance growth was present.

Hardwood stands were generally more resistant to hurricane damage than softwood or mixed-wood stands, and only one permanent plot was established in hardwood blowdowns (Plot D, T.S. IV). Total restocking increased slowly from 3000 stems per acre in 1940 to 4460 in 1948. Red maple (580), white pine (760) and the birches (1940) were the most abundant species in 1948. Again, however, the pine was largely suppressed

TABLE VI. Frequency of restocking under favorable conditions Tom Swamp I. and II., 1942

Species	Seedlings	Seedling sprouts	Stump sprouts	All elements
Red oak	31	11	..	41
Red maple	27	13	5	38
White ash	11	13	1	24
Gray birch	21	..	x	21
Black cherry	18	2	..	19
Black birch	12	1	1	14
White pine	12	..	..	12
White oak	6	3	x	8
Yellow birch	5	3	..	7
Sugar maple	3	2	x	6
Paper birch	5	..	..	5
Aspen	3	..	..	3
Basswood	1	1	..	2

Based upon 300 mil-acre plots in 6 small blowdown areas.
x Indicates species present but at frequency less than 0.5 percent.
Species not listed but occurring at low frequency include beech, hickory, black oak, hemlock, red spruce, and large-toothed aspen.

TABLE VII. Natural restocking on permanent sample plots. Five plots following old growth white pine and hemlock on glacial stratified drift

Species	ABUNDANCE (stems per acre)				
	1940	1941	1942	1944	1948
Long-lived species					
White pine	580	670	650	860	570
Red maple	260	290	160	200	170
Paper birch	..	20	150	20	100
Red oak	70	80	140	170	90
White ash	50	110	60	50	50
Hickory	..	20	40	20	40
White oak	10	20	30	40	30
Hemlock	20	20	..	10	10
Basswood	20	20	10	20	10
Sugar maple	20	10	..	..	10
Black birch	30	..	10	..	x
Yellow birch	..	x	10	10	x
Beech	30	20	10	10	x
Elm	..	x	10	..	x
Total	1090	1280	1280	1410	1080
Short-lived species					
Pin cherry	610	840	860	900	420
Gray birch	40	310	300	340	310
Black cherry	50	120	100	210	90
Aspen	10	90	80	70	40
Total	710	1360	1340	1520	860
Total	1800	2640	2620	2930	1940

x Indicates species is present with frequency less than 5 percent.
Plots C (T.S.IX.), E (T.S.IV.), K (S.C.IV.), L (S.C.IV.), M (T.S.IX.).

even 10 years after the storm. Red oak (100) and hemlock (90), though not as abundant, were represented by large vigorous stems, and the eventual emergence of a hemlock-red oak-red maple association can be postulated.

A better sample is available for hurricane blowdown areas following old-growth white pine and hemlock stands on glacio-fluvial outwash sands (Table VII). Of the 5 plots, one is at the Boulder Site in Tom Swamp IV, two are located in the old Barre Woods along the Swift River in the Slab City Block, and one is located in Tom Swamp IX. On the latter plot, which represents the driest site, little restocking of any kind had become established in 10 years, but the average of the 5 shows a good restocking of white pine together with a scattering of various hardwoods. Obviously, the restocking on the excessively-drained sands is much less adequate than on the glacial tills, a fact previously indicated by the mil-acre temporary plot surveys. Equally important, however, is the apparent fact that the white pine is successfully reestablishing itself on these "natural white pine soils," while the hardwoods are few in number and are not particularly vigorous.

A final case deals with natural reproduction in a selectively cut white pine stand on sandy soil after the residual stand was blown down by the hurricane (Plot N, T.S. IX). Here the composition is similar to that for the uncut old-growth in Table VII, except that the restocking is more abundant. Total restocking increased from 3440 in 1940 to 3980 in 1948, with white pine (1320-1650), red maple (1040-1130), and red oak (560-500) being the most abundant species. Short-lived pioneer species (gray birch, cherries, aspen) were few in number (160-460) compared to the better sites. The year by year tally indicates that the present stand was established prior to the hurricane, that it was released from the understory by the blowdown of the overstory, and that it had changed little in composition from 1938 to 1948.

In general, it would appear that the young stands following the logging of hurricane blowdown stands are generally similar to the hardwood stands that normally follow logging in the same area. On glacial tills, red oak-red maple association seems to be the rule together with such minor components as are characteristic to the soil drainage and the locality. On stratified outwash sands, a white pine-red oak-red maple stand seems to be emerging on most sites.

Effect of Logging and Miscellaneous Factors on Restocking

Both the temporary and the permanent sample plot data indicate the great importance of residual trees and advance growth in forming the new stand. Much of the present stand on blowdown areas is derived from advance growth under the old stand. Where there was no such growth, present restocking is inadequate, and the areas could well have been planted. In other words, it appears that the blowdown areas did not provide sites favorable to the establishment of new growth. Only pioneer species such as pin cherry and gray birch were able to invade these areas in any number. Even white pine could not establish itself in any great number in blowdown sites on sandy soils, and has come in on the glacial till soils only after hardwoods have developed.

Since the new stand is largely evolved from advance growth and residuals, the size of the blowdown and the propinquity of seed supply does not appear to be particularly important in determining the character of the restocking. Actually, most of the blowdown areas are confined to a few acres in size since the pre-existing stands were comparably small and since the hurricane frequently tended to blow down patches of trees rather than everything. Even where large timber occupied large areas, however, and was completely blown down, the character of the new growth does not appear to be different from that in the typical small opening.

All the tracts considered in the above survey were logged after the hurricane. They may therefore be considered as cutover areas as well as blowdown areas, and it is not therefore surprising that the restocking on them is similar to that found on areas of standing timber cutover before and since the hurricane. A restocking survey of the Pisgah tract is thus of considerable interest in that it throws light upon post-hurricane regeneration in the absence of log salvage.

The Pisgah tract is a 20-acre stand of primeval forest in Winchester, New Hampshire, owned by Harvard University. It is one of a number of stands in that locality which have been studied intensively (Cline and Spurr 1942), and was completely blown down in 1938. No logging was done, however, on the argument that the windthrow was a natural disturbance and that the prostrate stand was in every sense as much a virgin forest as the pre-existing old growth white pine and hemlock.

In the summer of 1942, four growing seasons after the hurricane, a transect was run from the top of the ridge dominating the east portion of the tract southwest across the topography to the end of the blowdown timber. Seventy mil-acre plots were tallied by the stocked quadrat method.

Conditions following blowdown on this virgin timber tract differed very greatly from those on second-growth areas. The tangled blowdown of heavy timber (largely hemlock and white pine) was 4 to 10 feet thick over most of the area. Under this criss-cross of logs, the soil was moist and relatively undisturbed except around the uprooted stumps. The boles of the fallen trees covered over 30 per cent of the area, and inasmuch as most of these were suspended several feet from the ground, they affected practically all of the surface. Mineral soil was exposed in stump pits on about 8 per cent of the area. Rock outcrops, either naked or covered by a thin organic layer, were prominent on another 15 per cent of the transect. Wet Whitman soil covered somewhat less than 5 per cent of the area, the remainder being a shallow phase of Hermon (the podzol equivalent of Gloucester).

The tree reproduction differed between high slopes and low slopes (Table VIII). On the high slopes (26 plots), seedlings of paper birch, red maple, black cherry and black birch predominated. Little advance growth of any kind had persisted. The stand on the low slopes (44 plots), however, was dominated by hemlock and beech advance growth. Seedlings of other species were present but most seemed likely to be soon overtopped. Yellow birch occurred instead of the black birch of the high slopes.

The beech recorded was all advance growth except for one seedling. About sixty per cent of the hemlock consisted of advance growth, most of this occurring on low slopes. The advance growth ranged up to 10 and 15 feet in height and much of it had persisted for many years under the old stand. Hemlock seedlings were equally as common on high as on low slopes. The other trees present consisted almost entirely of seedlings which had germinated since the hurricane. Paper birch dominated areas of exposed mineral soil although black birch and black cherry also occurred there. Noticeable was the absence of pin cherry, aspen, and gray birch.

TABLE VIII. Frequency of restocking on the Pisgah Tract, 1942

Species	High slopes	Low slopes	Total
Species most frequent on high slopes			
Paper birch	69	48	56
Red maple	42	23	30
Black cherry	42	16	26
Black birch	46	7	21
Species most frequent on low slopes			
Hemlock	35	55	47
Beech	12	27	21
Yellow birch	4	16	11
Infrequent species			
Red oak	..	..	3
White pine	..	..	3
Red spruce	..	..	1
Gray birch	..	..	1
Total	94	94	94

In this case where no logging followed the blowdown of old growth pine and hemlock, the following stand represents essentially a later successional stage than the preceding one, being characterized by hemlock and beech. In other words, the blowdown accelerated rather than set back successional development by felling the overstory and releasing the tolerant understory.

SUMMARY

Studies of natural restocking in and around the Harvard Forest, Petersham, Massachusetts, during the 10-year period following the hurricane of September 21, 1938, have yielded information on successional trends on hurricane blowdown areas. Four surveys of restocking were made in 1941-42 involving a total of 4,370 mil-acre quadrats. In addition, 14 permanent sample plots, mostly 0.1 acre in size, were tallied at intervals from 1940 through 1948.

Many factors apparently affect the composition of the new stand on a given area, prominent among them being: (1) soil type, (2) composition of the former stand, (3) advance growth present at the time of blowdown, and (4) whether the down timber was logged or not.

Where ample advance growth was present and no logging was carried out, the new stand is essentially a late-successional association composed of the released understory trees. Where advance growth is present but where the timber has been logged, the released understory trees are intermingled with pioneer species that have seeded in on the disturbed areas. Where little or no advance growth is present, pioneer associations exist.

Red oak and red maple are the characteristic dominant species on all sites although they are often outnumbered by pioneer species. White pine is characteristic of the sandy outwash soils, and is found in a suppressed state on the till soils. White ash and other mesophytes are found on the till soils, particularly on the imperfectly drained and the more fertile sites. The principal pioneer species are gray birch, pin cherry, and black cherry, but these are short-lived and will eventually disappear from the association. Pioneer species also include paper, black, and yellow birches which

are relatively long-lived and which will form part of the mature associations.

In practically every case, the character of the new stand was apparent within only two growing seasons of the hurricane. The absence of later successful invasion of seedlings is attributable in part to competition from growth already established, and in part to unfavorable environment in the blowdown areas.

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THE USE OF DISTANCE MEASURES IN PHYTOSOCIOLOGICAL SAMPLING[1]

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Introduction

A number of methods have been described in recent years which utilize spacing distances instead of fixed-area plots for the sampling of plant communities in compositional studies. All of these methods possess certain obvious advantages when compared to the standard plot techniques, since they all are more efficient in terms of results obtained per man-hour expended. They are faster, require less equipment and fewer workers, and are much more flexible, in that there is no need to adjust the sample size for the particular density of the vegetation type under study. The advantage in speed is particularly great, with savings of 90% or more commonly obtained. Currently, the main disadvantage of these distance methods lies in their unfamiliarity, which raises doubts as to their precision and limitations. The purpose of the present paper is to compare some of the methods, as used on three natural forests and an artificial random population, with respect to their relative accuracy and other characteristics.

In a stand of any plant community, the component individuls exist in a certain number, distributed over a certain area. This characteristic, called density, may be determined for each species separately, or for each life form (*e.g.*, trees) independently of species. In fixed-area plot sampling, a relatively small portion of the total area is examined, usually by means of a number of separate subsamples. In each of these subsamples, the density is determined directly by counting and the result expanded to total density per stand (or per acre) by use of the ratio between sample size and stand size. Instead of this idea of the number of plants per unit area, a more useful concept is the amount of area per plant, the *mean area* (M), which is the reciprocal of the density. When plant abundance is given as mean area, the way is immediately opened for the use of distance between plants as a measure of that

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