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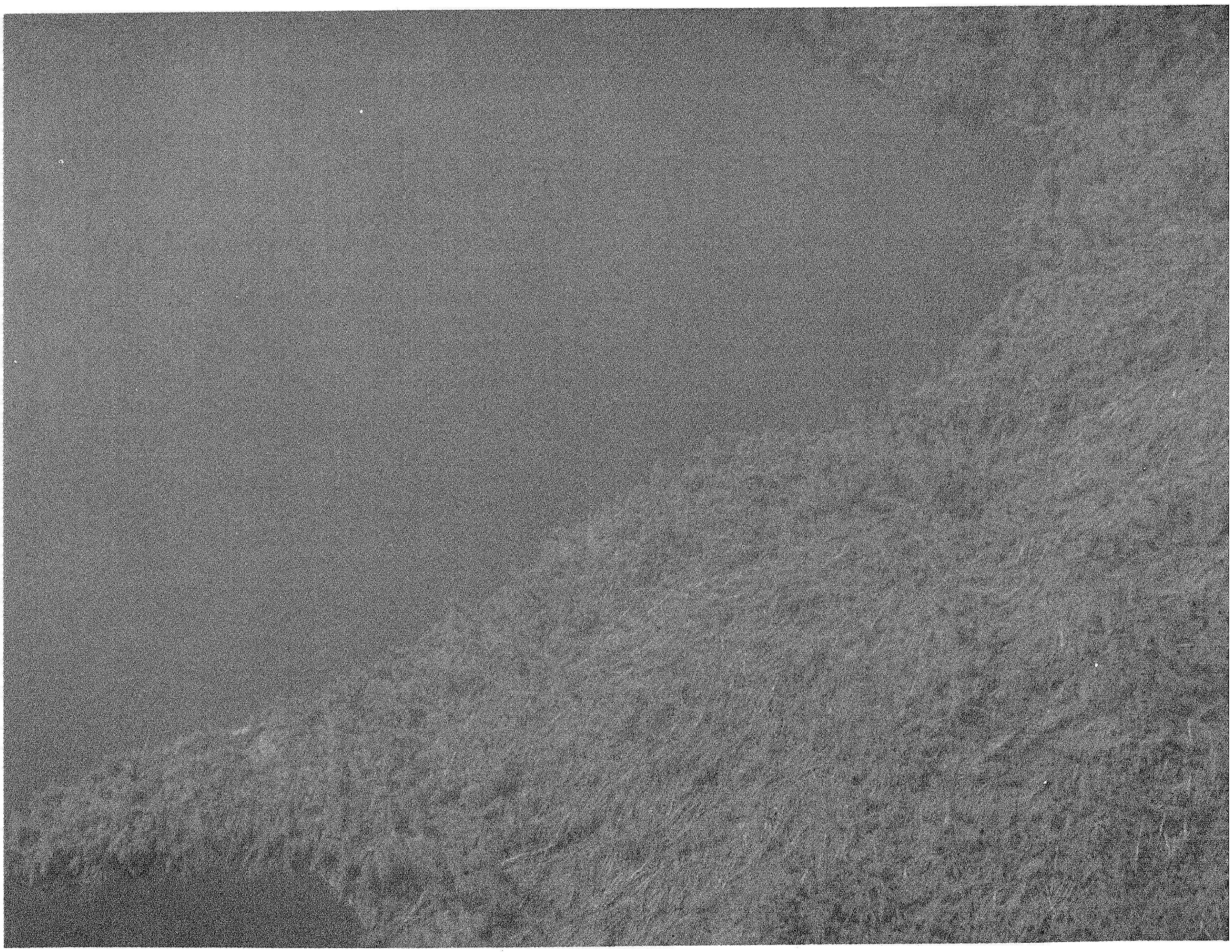

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Structural Legacies of Catastrophic Windstorm in a Mature Great Lakes Aspen Forest

Brian Palik and James Robl

An important concept emerging from forest ecosystem studies is that natural disturbances leave behind a rich legacy of biological structures that provide functional continuity between the old and new forest (Franklin *et al.* 1997). Biological legacies include coarse woody debris, residual live trees, organic soil layers, and plant and animal communities that survive and perhaps flourish after the disturbance.

Even the most catastrophic of disturbances, such as volcanic eruptions, do not eliminate all biological entities from the disturbed ecosystem (Turner *et al.* 1997). It follows that relatively lesser disturbances, such as various types of windstorms, should leave a diverse biological legacy. Documentation of these legacies exists for a handful of ecosystems (e.g., Foster and Boose 1992, Peterson and Pickett 1995), where they are thought to be important for sustaining ecological processes and biological diversity in the new forest.

Studies of biological legacies after natural disturbance have application to forest ecosystem management. Historically, timber-oriented silvicultural disturbances, particularly regeneration harvests, have not provided the full range of biological legacies left behind after natural disturbances. More comprehensive, ecosystem-oriented management approaches stress the importance of mimicking, to varying degrees, the legacies of natural disturbance (Franklin *et al.* 1997). In so doing, ecologists argue, there is greater likelihood of long-term sustainability of all ecosystem components and processes (e.g., avian diversity, Merrill *et al.* 1998).

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The concept of biological legacies, as well as the practice of leaving legacies after silvicultural disturbances, is gaining acceptance in the natural resource management community. One issue facing foresters is how to provide for these legacies while concurrently managing for timber resources. A more fundamental issue is deciding what legacies to leave in a particular ecosystem. This knowledge requires studies of biological legacies in different types of forests and after various types of natural disturbances. Few ecosystem-specific or disturbance-specific data sets on biological legacies exist.

With this need in mind, we examined biological legacies following a catastrophic windstorm in a mature aspen (*Populus grandidentata* and *P. tremuloides*) forest in northern Minnesota. Our overall objective for the project was to quantify the characteristics of biological legacies that result from a catastrophic wind disturbance. Specifically, we quantified legacies of dead trees, coarse woody debris, and residual trees and saplings.

STUDY AREA AND STORM CHARACTERISTICS

We conducted our study in the Trout Lake natural area on the Chippewa National Forest. The Trout Lake area, located in north-central Minnesota, is approximately 2,740 ha in size. It is forested predominantly by aspen, with lesser amounts of other northern hardwood species, including sugar maple (*Acer saccharum*), northern red oak (*Quercus rubra*), paper birch (*Betula papyrifera*), and eastern white pine (*Pinus strobus*). The majority of the forest is 65 to 70 years in age, having developed after logging and wildfires early in the 20th century. Upland soils throughout most of the study area are loamy sands and sandy loams derived from glacial outwash.

On July 13, 1995, a severe summer storm, accompanied by strong downbursts, swept across northern Minnesota in an easterly direction. In the north-central portion of the State, the storm damaged at least 4,000 ha of forest; approximately 152 ha were affected in the Trout Lake area. Storm damage to the Trout Lake forest was concentrated in a large number of discrete blowdown patches (fig. 1). Within these patches, we conducted our sampling for this study.

METHODS

GIS Assessment

After the storm, the Chippewa National Forest created a *GIS* coverage of the study area that included blowdown polygons, as digitized from aerial photography. We used this coverage to determine blowdown patch locations and sizes. We also used the coverage to examine relationships between residual tree densities and amounts and types of mortality, and selected physical traits of the patches, including patch size, distance to large lakes, aspect, and soil types. We found no strong relationships in these analyses and will not report on them further.

Vegetation Sampling

We used point-quarter sampling to assess tree mortality and damage within blowdown patches. In each patch, we located an initial sampling point by selecting a random distance and compass bearing while standing at the approximate center of the patch. Additional points were located along the long axis of a patch by pacing randomly selected distances of at least 50 m from each subsequent point. The number of sample points ranged from 8 to 28 depending on patch size. We divided the area around each point into four quarters along cardinal compass directions. In each quarter, we recorded the distance (m) from the point to the nearest tree (diameter at breast height (d.b.h.) $\geq$ 10 cm) damaged by the storm. We also recorded species, d.b.h., and damage class for each sampled individual. Tree damage classes included: windthrown (uprooted at the soil line), snapped (broken bole), leaning (at least partially uprooted, often supported by another tree), and crushed (hit by another tree).

We used variable-radius (prism) plots to sample live, residual trees (d.b.h. $\geq$ 10 cm) and saplings (2.5-cm $\geq$ d.b.h. < 10 cm) within each patch. We took prism samples at every other (one-half) of the dead-tree sample points using a 10-factor (English unit) prism for trees and a five-factor prism for saplings. At each point, we recorded the species and diameter of all live trees and saplings in the sample.

We determined amount of coarse woody debris on the ground through estimates of cover in 1-m^2 quadrats. Four quadrats were sampled at each live-vegetation sample point, one quadrat in each cardinal compass direction, at a distance of 3 m from the central sample point. We separated storm-recruited coarse woody debris into two classes that included logs in contact with the ground and logs held above the ground by branches or root systems. We defined debris as woody stems or branches $\geq$ 10 cm diameter (portion within the quadrat). We recorded cover in the following classes: 0-1 percent, 1-10 percent, 10-30 percent, 30-60 percent, and 60-100 percent.

RESULTS

Blowdown Patch Characteristics

There were 30 discrete blowdown patches identified within the study area (fig. 1). Patch size ranged from less than 2 ha up to 18 ha. Nearly 70 percent of the patches were less than 4 ha in size, while less than 20 percent of the patches were greater than 12 ha in size. We sampled storm-caused tree mortality and residual vegetation in 22 of the patches (numbered in fig. 1).

Tree Mortality

Amount of tree mortality was highly variable among blowdown patches. Density of trees killed by the storm ranged from about 180 stems/ha to nearly 800 stems/ha (fig. 2). Storm mortality in the majority of patches fell between 300 to 600 stems/ha (fig. 2).

In all patches, the composition of trees killed by the storm largely reflected relative abundance of different taxa in the pre-disturbance forest. Most damaged trees were aspen, followed by paper birch, and maple (*A. rubrum* and *A. saccharum*) (fig. 2).

Damaged trees were predominantly windthrown (52 percent of all trees pooled among patches), while about 30 percent were snapped along their boles, 8 percent were uprooted but

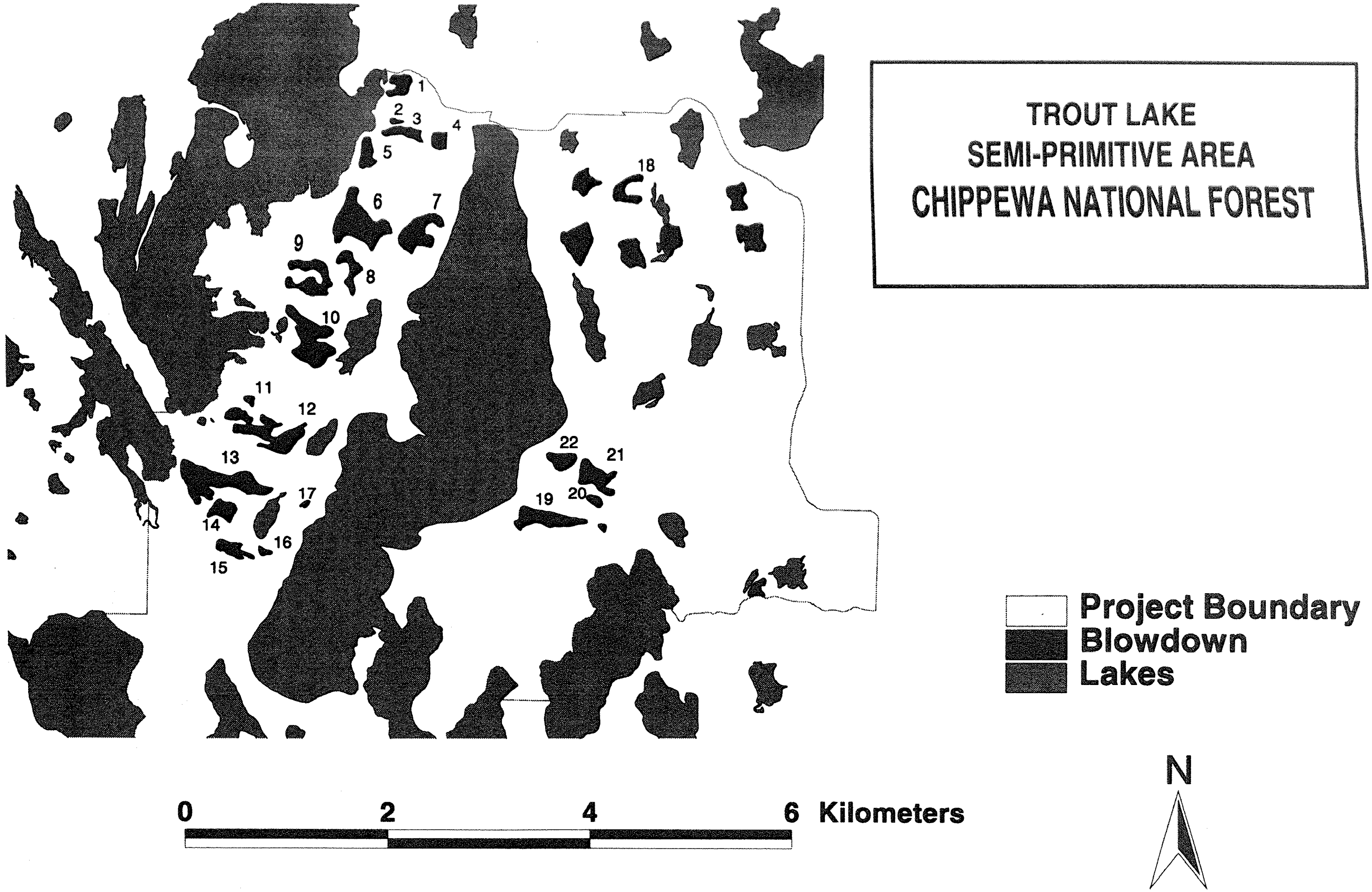

Figure 1.—*Study area showing locations and sizes of the 22 sampled blowdown patches.*

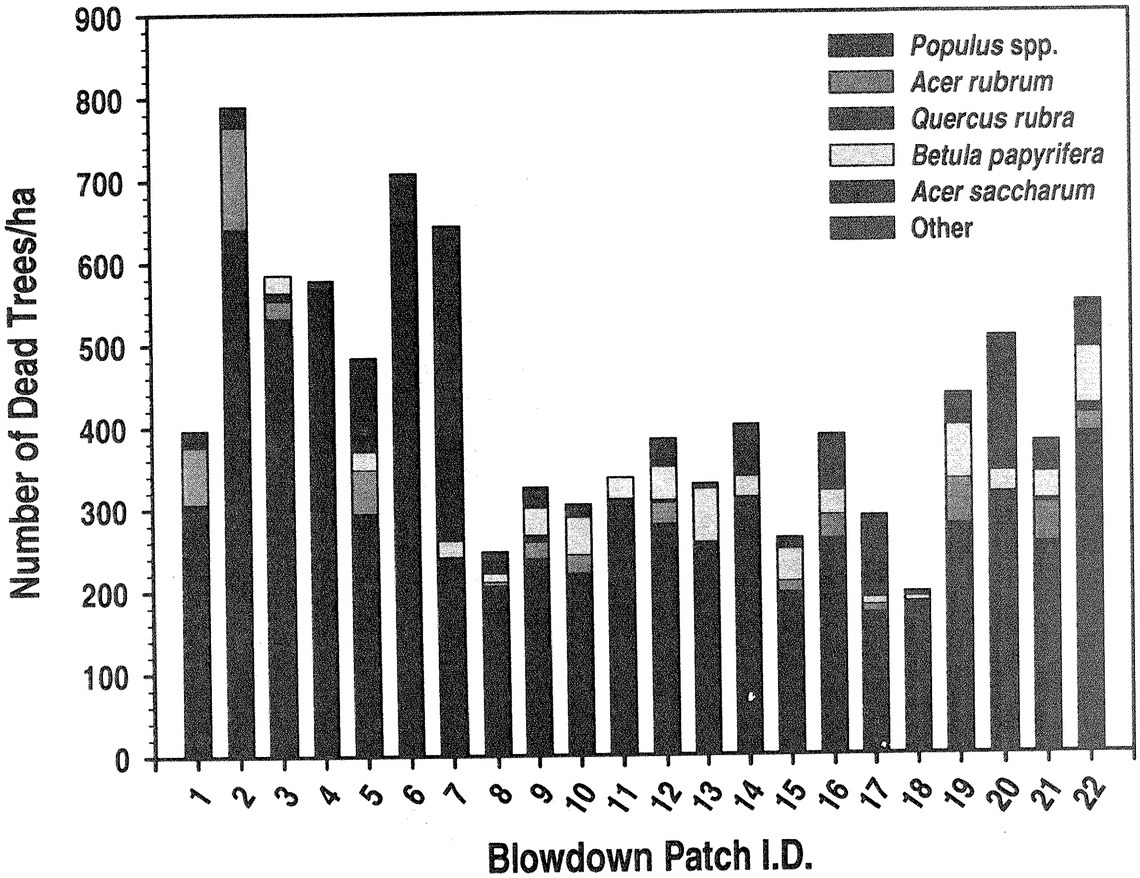

Figure 2.—*Dead tree (diameter ≥ 10 cm at 1.4-m height) densities by species for each blowdown patch.* Populus *spp. includes* P. grandidentata *and* P. tremuloides. *Other species include* Pinus strobus, P. resinosa, Ostrya virginiana, Tilia americana, Abies balsamea, Picea glauca, Fraxinus nigra, *and* Quercus macrocarpa.

leaning on another tree, and 10 percent were crushed by another falling tree. The proportion of trees in the damage classes varied somewhat among taxa. For instance, 60 percent of aspen were windthrown while 30 percent were snapped; few were crushed or leaning. In contrast, larger percentages (35 to 65) of maple and paper birch were crushed or leaning.

Coarse Woody Debris

In addition to leaving standing dead trees, the windstorm recruited coarse woody debris directly to the forest floor. Coverage of logs in contact with the ground varied among blowdown patches (fig. 3), ranging from < 0.5 to 9 percent. In general, coverage was higher for logs slightly elevated above the ground by their crowns or root systems (fig. 3). This coverage was also variable among patches, ranging from about 3 to > 20 percent. For all patches combined, cumulative coverage of logs on the ground plus those above the ground averaged about 19 percent. However, this coverage was highly variable within each patch (fig. 3); coefficients of variation ranged from 30 to nearly 200 percent.

Newly recruited coarse woody debris tended to be larger diameter logs. This is because most dead trees were aspen (fig. 2) and the diameter distribution for dead aspen had a modal diameter class of 30 cm (fig. 4). In contrast, the diameter distributions for dead maple and paper birch were right-skewed with modal diameter classes of 10 or 15 cm (fig. 4).

Residual Trees and Saplings

Residual tree (d.b.h. ≥ 10 cm) density varied widely among blowdown patches, ranging from 50 stems/ha to nearly 300 stems/ha (fig. 5). Residual sapling (2.5 ≥ d.b.h. < 10 cm) density showed the same degree of variation, ranging from 0 to more than 400 stems/ha (data not shown). Residual tree and sapling densities

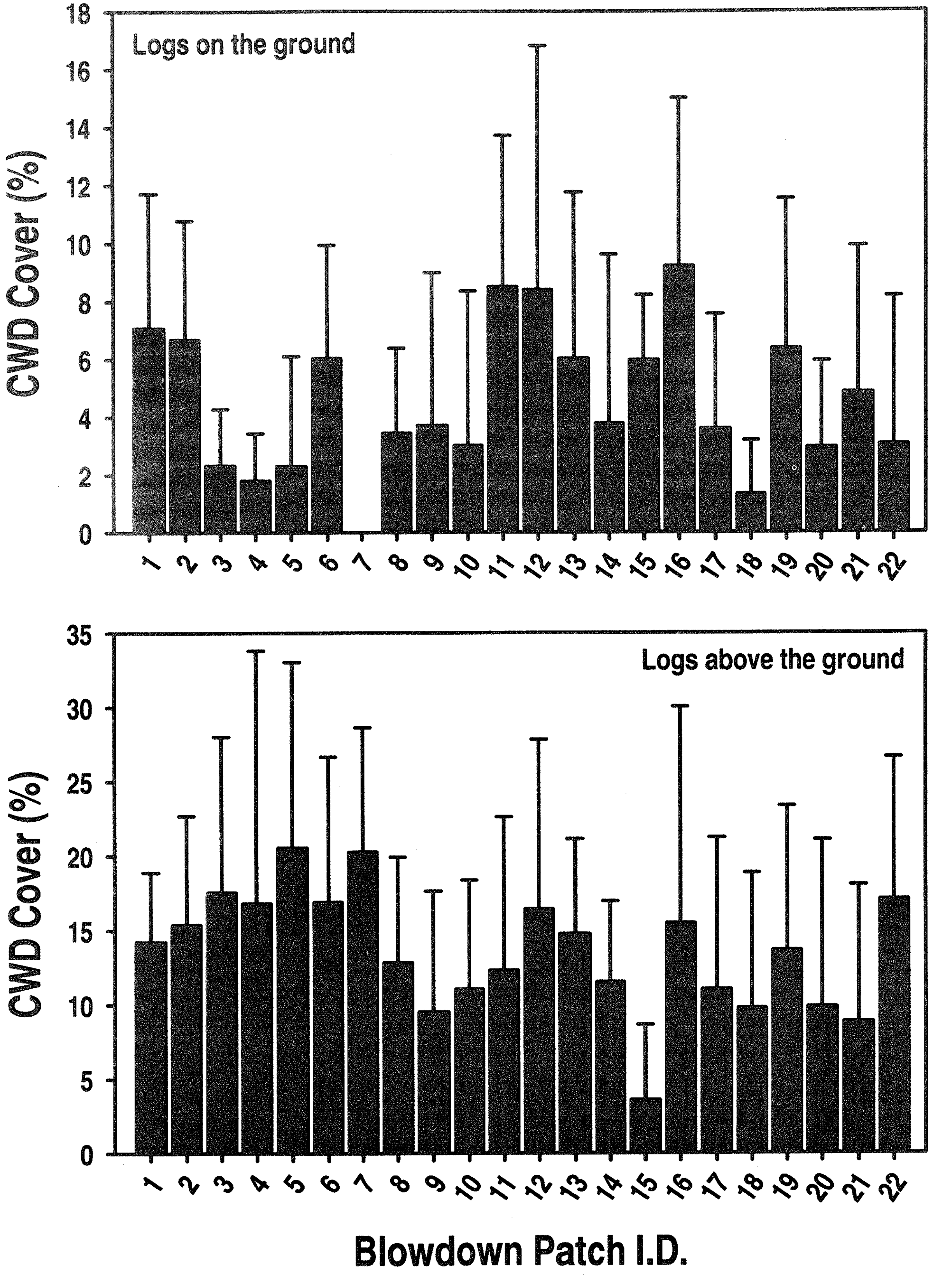

Figure 3.—*Mean (± 1 sd) coarse woody debris (downed tree) coverage for each blowdown patch. The top figure shows coverage of stems in contact with the forest floor. The bottom figure shows coverage of stems elevated above the forest floor by branches or roots.*

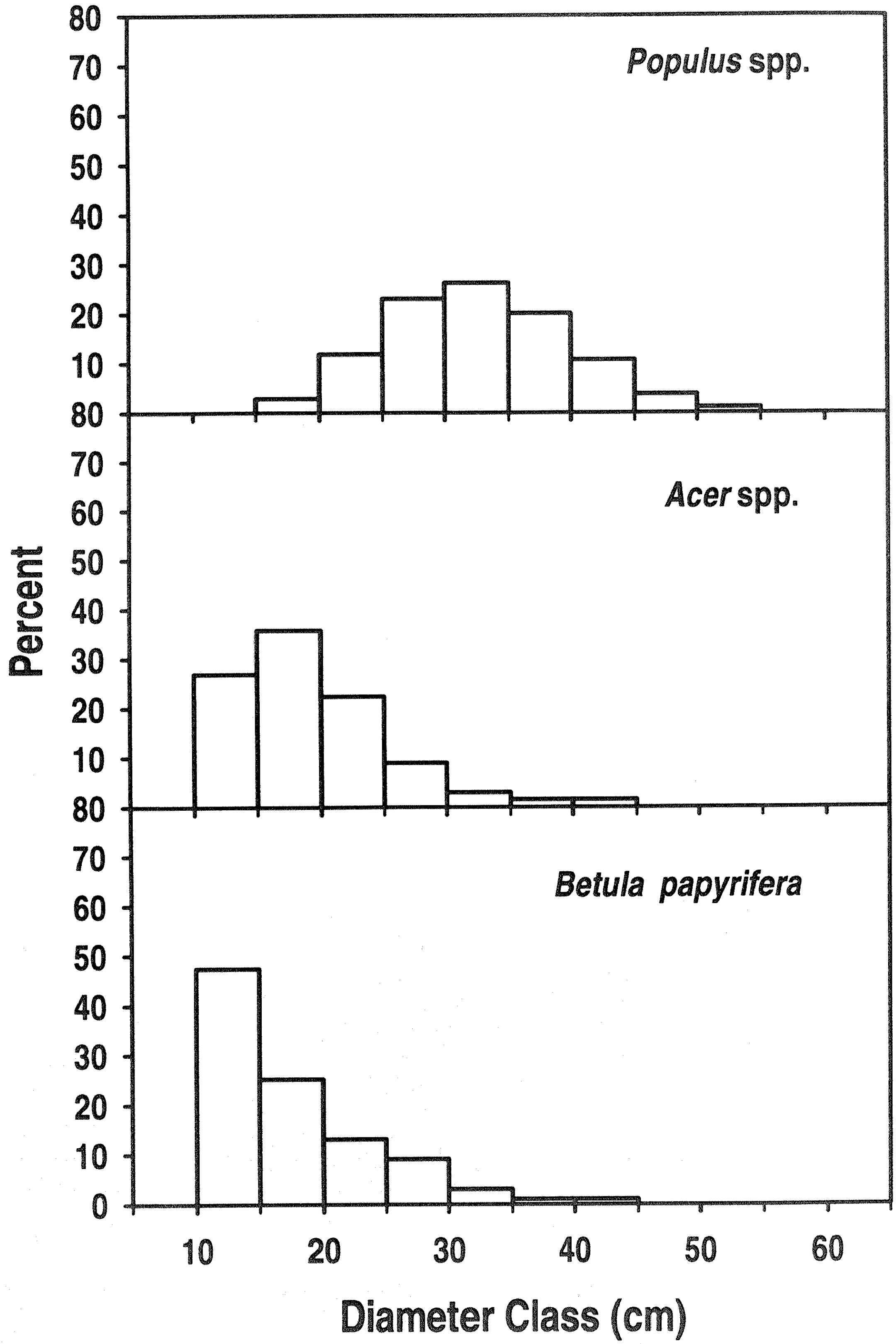

Figure 4.—*Diameter distributions for important taxa of dead trees. Each distribution includes all individuals of a taxon pooled among blowdown patches.* Populus *spp. includes* P. grandidentata *and* P. tremuloides. Acer *spp. includes* A. saccharum *and* A. rubrum.

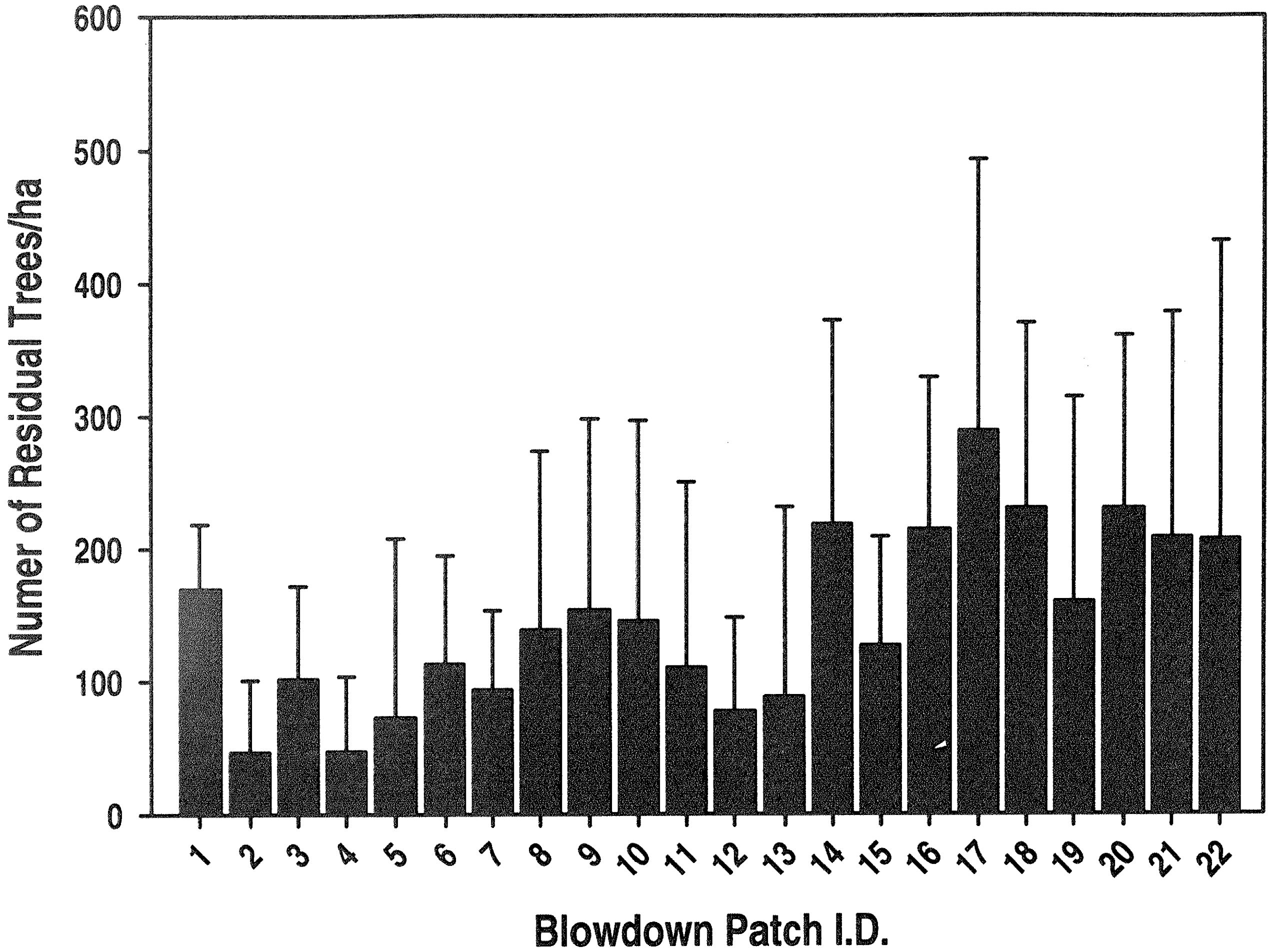

Figure 5.—*Mean (± 1 sd) live residual tree (diameter ≥ 10 cm at 1.4-m height) densities (all species combined) for each blowdown patch.*

were variable within patches as well (fig. 5). Coefficients of variation averaged 91 percent for trees and 157 percent for saplings. This reflects varying spatial patterns of residuals within patches, ranging from dispersed individual trees to small clumps of residuals.

Compared to trees killed by the storm, residual trees were divided among more taxa (fig. 6). In addition to aspen, paper birch, and maple, many patches contained residual red oak, eastern white pine, or red pine (*Pinus resinosa*) (fig. 6). Residual saplings were largely sugar maple, paper birch, and ironwood (*Ostrya virginiana*) (data not shown).

Diameters of residual trees were variable, ranging from 10 cm to greater than 55 cm (fig. 7). As with trees killed by the storm, there were differences among taxa in diameter distributions of live residual trees. Aspen and pine had near normal, unimodal distributions centered around to 30- to 35-cm diameter classes (fig. 7). Most other taxa had distributions approaching a reverse J-shape, with most individuals in the smaller diameter classes.

DISCUSSION

We pursued our research with the primary objective of learning how a major windstorm affected the structure of the study forest. However, we also wanted to provide data sets to foresters interested in biological legacy management in aspen ecosystems. With these dual objectives in mind, our research points to several interesting results.

One important result is that the impact of the storm, in terms of tree mortality and structural legacies, was highly variable among patches (e.g., density of dead trees, fig. 2; coverage of

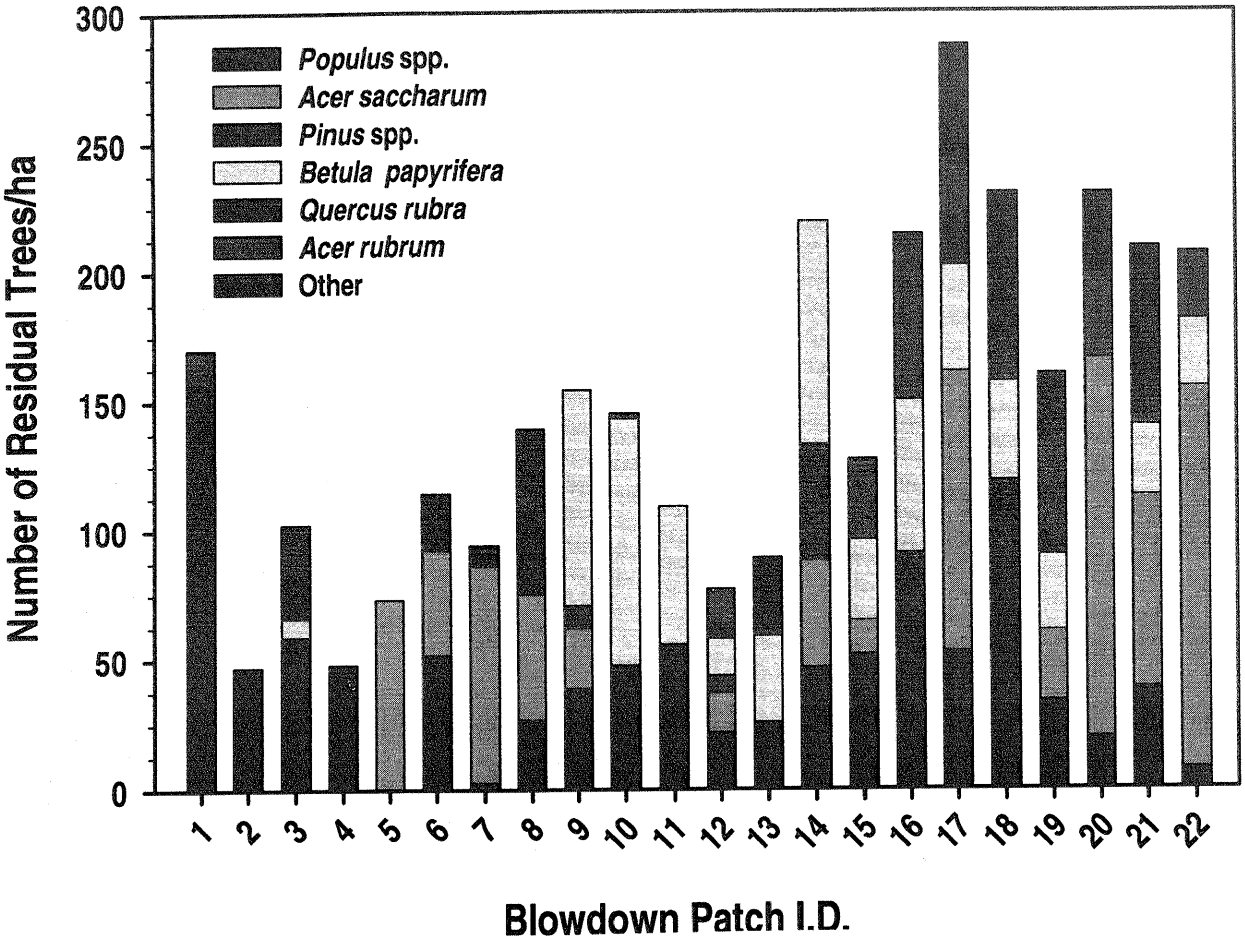

Figure 6.—*Live residual tree (diameter ≥ 10 cm at 1.4-m height) densities by species for each blowdown patch.* Populus *spp. includes* P. grandidentata *and* P. tremuloides. Pinus *spp. includes* P. strobus *and* P. resinosa. *Other includes* Ostrya virginiana, Tilia americana, Ulmus americana, Picea glauca, Fraxinus nigra, *and* Quercus macrocarpa.

logs on the ground, fig. 3). The among-patch variation suggests that silvicultural recommendations for residual trees, snags, and similar materials, that are based on fixed values used in every situation, do not reflect the true, highly variable nature of legacies resulting from natural disturbance. This natural variation suggests that a forester should consider a range of densities and coverages for various legacies when incorporating them into a silvicultural plan. In other words, varying the number of residual trees, or logs on the ground, or snags, among cutting units emulates natural disturbances better than adhering to some fixed number per unit area in all cases.

A second important result of our study is that spatial variability in legacy characteristics is evident within patches, as, for example, with residual tree density (fig. 5). High within-patch variation suggests that impacts of disturbance, and the legacies left behind, range from being clumped in space to dispersed as individual features across a stand.

Spatial pattern of retention is an important issue in natural resource management. Historically, within-stand retention is approached in a dichotomous sense, as either dispersed or clumped (Acker *et al.* 1998). A host of potential advantages and disadvantages are associated with each approach (Franklin *et al.* 1997, Palik *et al.* 1997). For instance, microclimate modification is greater with clumped residuals than with dispersed trees, but the impact of altered microclimate is concentrated over a lesser stand area with clumping. Recent conceptual treatments emphasize variable retention as

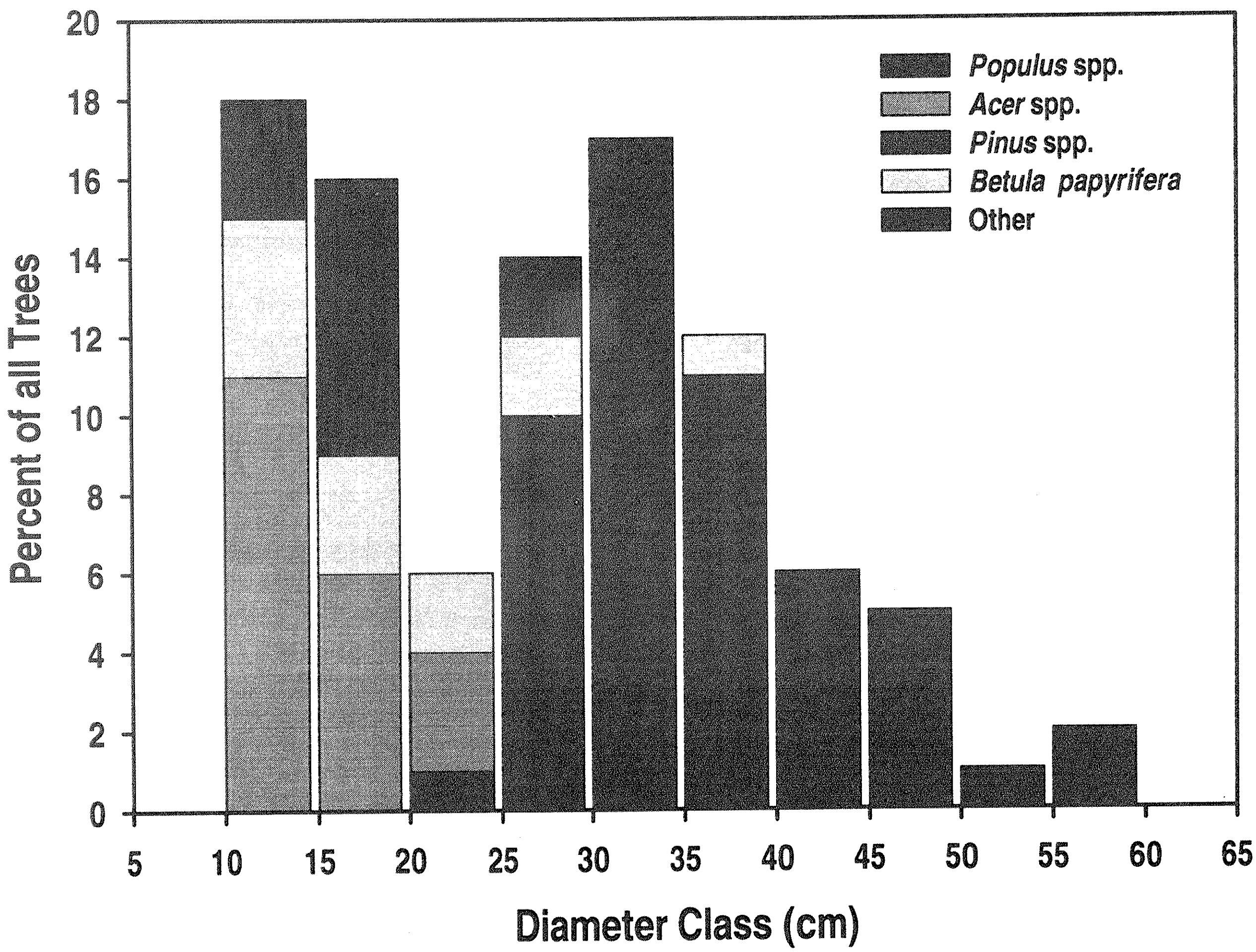

Figure 7.—*Diameter distributions for major taxa of live residual trees (diameter ≥ 10 cm at 1.4-m height). Each distribution includes all individuals of a taxon pooled among blowdown patches.* Populus *spp. includes* P. grandidentata *and* P. tremuloides. Acer *spp. includes* A. saccharum *and* A. rubrum. Pinus *spp. includes* P. strobus *and* P. resinosa. *Other includes* Ostrya virginiana, Tilia americana, Ulmus americana, Picea glauca, Fraxinus nigra, Quercus macrocarpa, *and* Quercus rubra.

more emulative of the legacies of natural disturbance (Franklin *et al.* 1997). With variable retention, a forester varies the spatial pattern of residual material from dispersed to clumped within a harvest unit.

A third important result is that residual tree composition includes a range of taxa. Although the majority of residuals were aspen, with lesser amounts of paper birch and maple, individuals from a number of other taxa also survived the storm. The relative abundance of residual aspen, paper birch, and maple was proportional to their dead tree abundance, in both cases reflecting their numbers in the pre-disturbance forest. In contrast, the relative abundance of other residual taxa, e.g., pine, usually exceeded dead tree abundance. In fact, pine was largely unaffected by the storm, reflecting the wind firmness of the taxa (Seymour and Hunter 1992). This indicates that to emulate wind disturbance, harvesting should leave residual trees from a variety of taxa. A forester should determine residual composition based on pre-disturbance abundance and by windfirmness. Abundant taxa, such as aspen in our study, in the pre-disturbance forest should occur in the residual pool because the odds favor many individuals of these taxa surviving the disturbance. Less abundant taxa may be included in the residual pool if they are naturally windfirm, such as eastern white pine.

Finally, our results show how new coarse woody debris and live residual trees span a range of sizes, including large individuals. Most of the largest dead trees and residual live trees were aspen, because this taxon dominated the upper canopy layer. However, even taxa that were abundant lower in the canopy, such as maple and paper birch, or were rare in the forest, such as pine, had some larger individuals in both the dead and residual tree pools. Small residual trees and saplings were also common. Most residual saplings were sugar maple and red maple, species that are not commercially valuable in Minnesota aspen forests.

In Great Lakes aspen forests, deliberate falling of some large individuals of commercial species to add to the coarse woody debris pool on the ground is not common. Similarly, when harvesting these forests, it is uncommon to retain large live individuals of commercially desirable species. Moreover, foresters do not generally protect saplings of non-commercial species. Rather, the newly recruited dead wood pool consists largely of small-diameter logging slash; residual live trees usually are poorly formed, small-diameter stems; and saplings of non-commercial species are destroyed by equipment traffic. Legacy management requires tradeoffs on all of these practices, if harvesting is to emulate the effects of large-scale, natural canopy disturbances.

CONCLUSION

Obviously, one cannot harvest timber from a forest and still leave the quantities of residual trees, deadwood, and saplings that result from catastrophic wind disturbance. We do not suggest doing so. Rather, we present quantitative data that can guide legacy management in commercial aspen forests. Managers can use these data as baselines to judge the degree to which their management moves legacy characteristics away from patterns resulting from natural disturbance (Palik and Engstrom 1999). An important consideration to keep in mind is that nature provides managers with a flexible model for legacy management. High spatial variation in the impacts of natural disturbance gives foresters some creative license to adjust legacy characteristics to meet various objectives in different places and at different times. To guide these decisions, we suggest the following as a basic framework for legacy management:

1. Vary the amount of live residual trees and dead wood among cutting units, rather than using fixed amounts for every harvest situation.

2. Vary the spatial distribution of live residual trees, snags, and downed logs within cutting units. The distribution should vary from clumped to dispersed.

3. Include a range of taxa as components of the live residual and dead tree pools, including commercial trees.

4. Include a range of tree sizes in the live residual and dead tree pools, including merchantable stems.

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We report on biological legacies resulting from a major windstorm in a Minnesota aspen forest and suggest guidelines for managing legacies with silvicultural disturbance.

KEY WORDS: Aspen, biological legacy, natural disturbance, silvicultural disturbance.

Our job at the North Central Forest Experiment Station is discovering and creating new knowledge and technology in the field of natural resources and conveying this information to the people who can use it. As a new generation of forests emerges in our region, managers are confronted with two unique challenges: (1) Dealing with the great diversity in composition, quality, and ownership of the forests, and (2) Reconciling the conflicting demands of the people who use them. Helping the forest manager meet these challenges while protecting the environment is what research at North Central is all about.

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