

ORIGINAL ARTICLE

Development and application of boundary-line release criteria

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Abstract

Identifying releases from suppression represents one of the most fundamental dendroecological procedures for quantifying forest disturbance histories. In this study we evaluate boundary-line release criteria, which incorporates the effects of growth history on release response. In eastern hemlock (*Tsuga canadensis* L.) the maximum possible value of a pulse in percent-growth change is dependent on growth decline immediately prior to the pulse. Maximum values of percent-growth-change decline exponentially as prior growth rate increases. This negative exponential rate is quantified as a boundary line, which is used to scale each percent-growth change pulse by the maximum possible value predicted by prior growth rate. The consistency of the relationship between radial growth prior to a release and the magnitude of the release is evaluated in multiple eastern hemlock data sets. Trees from diverse sites show large releases that approach the maximum value predicted by the prior-growth rates. These sites tend to have a history of disturbance, suggesting that disturbance is the most influential variable determining the magnitude of release response. Possible exceptions are sites on the northern and western borders of eastern hemlock's range, which consistently fall short of the boundary line and may be exhibiting unique relationships between prior growth and percent-growth change. Yet overall the relationship between prior growth and percent-growth change appears to be consistent across much of eastern hemlock's range. Furthermore, we demonstrate that similar boundary lines occur in *Pinus ponderosa* (Laws.), *Pinus echinata* (Mill.), *Quercus alba* (L.), and *Quercus macrocarpa* (Michx.). This suggests that prior growth could form the basis of a more unified set of release criteria better able to standardize release responses within and among species. Standardized release criteria would allow more accurate comparisons of disturbance histories among sites, species, and even across landscapes.

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Introduction

One of the most fundamental dendroecological approaches for evaluating the disturbance history of a stand is identification of releases (Lorimer and Frelich, 1989; Frelich, 2002). Calculation of releases is a power-

ful and unique tool that can identify both local and stand-wide disturbances at a high temporal resolution. In general, a release is defined as an event when the percent-growth change in a tree-ring series exceeds a given minimum threshold, such as 25%, 50%, or 100%, which in some criteria must be maintained for a certain length of time such as 5 or 10 years (Lorimer and Frelich, 1989; Payette et al., 1990; Nowacki and Abrams, 1997). Thus, releases depend on the assumption that the magnitude of percent-growth change

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corresponds to the magnitude of a canopy disturbance. However, the relationship between percent-growth change and canopy disturbance is complicated by a number of interrelated and confounding variables. Over the years, release criteria have evolved to account for an increasing number of these variables in an attempt to better relate radial growth patterns to canopy disturbance.

Important examples of variables that affect radial growth response to disturbance include (1) crown size and position, (2) gap proximity, size, and duration, (3) prior growth rate, (4) age and diameter, (5) species, and (6) climate (Nowacki and Abrams, 1997). Crown position is one of the most widely cited of these variables, whereby understory individuals consistently exhibit larger percent-growth increases following a disturbance than their overstory counterparts. A principle explanation for this is that overstory trees generally receive adequate resources and are growing near their optimum. For these trees, relative growth increases become inherently limited, even with the additional light, nutrients, water, and space that follow disturbance. Conversely, understory trees suppressed by low light will often exhibit dramatic increases to their full growth potential in response to the improved conditions following disturbance (Lorimer and Frelich, 1989). Gap characteristics are equally important, with greater responses associated with trees neighboring larger, long-duration gaps than those beside smaller gaps of short duration (Lamson et al., 1990). Moreover, field experiments have demonstrated that slow-growing trees have greater release potential than fast-growing trees, as do young, small-diameter trees compared to old, large-diameter trees (Minckler, 1967a, b; Schlesinger, 1978).

In addition to intraspecies differences in release response, considerable variation exists among species due to physiological differences. For example, shade-tolerant species such as blackgum (*Nyssa sylvatica* Marsh.) and sugar maple (*Acer saccharum* L.) typically release with more vigor than less tolerant species such as red oak (*Quercus rubra* L.) and yellow-poplar (*Liriodendron tulipifera* L.) (Lorimer and Frelich, 1989; Orwig and Abrams, 1994; Nowacki and Abrams, 1997). To account for these differences, threshold levels must vary in accordance with the release characteristics of each species. Finally, climate can affect disturbance-mediated releases in a variety of ways. For instance, climate can affect trees releases by altering the magnitude of the growth response signal; especially when short-term climate shifts align with disturbance events. A disturbance signal could be reduced during unfavorable climatic conditions such as a drought, or enhanced by favorable climatic events such as an extended growing season. Apparently, the effects of climate on tree growth are inversely related with

tree release such that climate influences diminish with greater degrees of release (Rentch et al., 2002). Furthermore, climatic influences on tree growth differ by species, as suggested by the finding that red oak (*Q. prinus*) is more sensitive than chestnut oak (*Q. prinus* L.) (Rentch et al., 2002).

Over time, techniques for deriving disturbance histories from tree-ring data have become increasingly sophisticated and made great progress in accounting for the myriad variables associated with release response. Seminal work by Dr. Craig Lorimer laid the foundation for assessing disturbance using tree rings in a series of dendroecological papers (Lorimer, 1980, 1983, 1985). This culminated in the development of stringent release criteria to determine canopy turnover rates by tracking the canopy accession of trees (Lorimer and Frelich, 1989). Increases in radial growth of 50% and 100% were established to denote moderate and major releases, respectively. Although this work represented a substantial step in reconstructing disturbance histories from tree rings, its application was restricted to solely documenting canopy accession events. Typically, only one canopy accession event is recorded per tree. Recognizing this restriction, Nowacki and Abrams (1997) expanded release criteria to distinguish multiple disturbance events over a tree's lifetime, thereby improving efficiency by maximizing data extraction from each tree-ring time series. Using field-derived release information and estimates of maximal climate influences on tree growth, Nowacki and Abrams (1997) proposed a formal radial-growth averaging equation and a threshold of 25% growth change (%GC) for disturbance detection. This 10-year running comparison technique and threshold value have been subsequently validated by independent testing (Rentch et al., 2002) and successfully applied elsewhere (Schuler and Fajvan, 1999; Winter et al., 2002; Rentch et al., 2003a; Rozas, 2003). Validation testing concluded: (1) the technique provided a fairly accurate estimate of the disturbance year with a precision within approximately 1 year; (2) there was an approximately 1:1 relationship between %GC and percent crown release, and (3) the magnitude of %GC is strongly correlated with disturbance severity (Rentch et al., 2003b).

One uncertainty associated with the Nowacki and Abrams (1997) approach was extrapolating the 25% GC threshold, which was derived solely from overstory tree response to canopy disturbance, to tree growth while in the understory. To overcome this concern, Ruffner and Abrams (1998) developed a hybrid method in which conservative criteria were applied to the understory segment and less strict criteria to the overstory segment. This hybrid approach attempts to eliminate the effects of canopy position and possibly age, yet the differences in release response between understory and overstory

positions are not quantified. Ideally, these differences would be quantified and integrated into an even more accurate set of release criteria. Furthermore, the criteria would compensate for any other factor beyond canopy class, diameter, and age that affects a tree's potential for rapid growth increases over its lifetime.

Even if the effects of age, size, and climate are quantified, the utility of release criteria would still not be optimized unless a single, standardized method is developed. However, many different release criteria are presently employed in the dendroecology literature, with the nature of each set of criteria dependent on investigator, site, species, and the goals of the analysis. In several cases, different criteria have been used not only among species, but also within species. Thus, direct comparisons among these studies become complicated, thereby diminishing the potential power of dendroecology to quantify disturbance patterns across landscapes and regions. One basic framework of release criteria would ensure that the results of all studies are more comparable. If release criteria were powerful enough to standardize growth patterns within, and even among species, disturbance histories from contrasting sites and forest types could be more readily compared.

To address these standardization issues, Black and Abrams (2003) quantified relationships among tree age, size, canopy class, radial growth rate, and percent-growth-change in eastern Hemlock (*Tsuga canadensis* L.), and developed new release criteria based on the finding that radial growth rate was the most fundamental predictor of percent-growth change pulse. In summary, young, small, and suppressed trees were found to be capable of extremely large pulses in percent-growth change in comparison to their older, larger, dominant counterparts. In addition, smaller, younger, and suppressed trees also showed slower radial growth rates. Radial growth rate appeared to be closely related to the magnitude of percent-growth change pulses. Indeed, when percent-growth change is graphed against average radial growth over the past 10 years, percent-growth-change values extend to a well-defined boundary that declines exponentially across increasing levels of prior growth (Black and Abrams, 2003). An important aspect of this finding is that eastern Hemlock of almost all age, size, and canopy classes demonstrate percent-growth-change pulses that reach this upper boundary. Slow-growing trees, which tend to be small understory individuals, reach the boundary with large pulses in percent-growth change. Fast-growing trees, which tend to be large dominant individuals, can reach the boundary with only modest pulses in percent-growth change. Therefore, release criteria were proposed in which all percent-growth-change pulses are scaled in terms of their maximum possible value, as predicted by level of prior radial growth. This should better compensate for differences among age, size, and canopy

classes and allow for better direct comparisons of release events across all phases of a tree's lifespan. Furthermore, a single prior growth and percent-growth change boundary applies across a wide range of eastern hemlock sites. Scaling all release events to a single boundary (i.e. a standard set of release criteria) would also facilitate direct comparisons of disturbance history across sites.

In this study, we demonstrate how a standard set of boundary-line release criteria can be applied to a variety of eastern hemlock stands. We also show that a single set of release criteria should apply to most stands, and how it would facilitate direct comparisons of disturbance histories among sites. Finally, we show that prior growth strongly influences release response in white oak (*Q. alba* L.), bur oak (*Q. macrocarpa* Michx.), ponderosa pine (*Pinus ponderosa* Laws.) and shortleaf pine (*P. echinata* Mill.). The consistent relationships between prior growth and percent-growth change suggest that similar release criteria may be developed for a wide range of species. Thus, all releases could be better standardized by uniformly expressing them as a percentage of their maximum value as predicted by species and prior growth rate.

Methods

The first step of the boundary-line release criteria was to calculate percent-growth change according to the technique of Nowacki and Abrams (1997). Percent-growth change for a year is equal to $(M_2 - M_1) / M_1$ where M_1 equals average growth over the prior 10 years and M_2 equals average growth over the subsequent 10 years (Fig. 1). Next, average radial growth over the past 10 years (prior growth) was calculated for each ring width in each tree-ring series (Fig. 1). The relationship between prior growth and percent-growth change was plotted for every growth increment of every tree-ring series, with the exception of the first and last 10 years of each series in which percent-growth change could not be calculated. Finally, the upper threshold of the relationship between prior growth and percent-growth change was quantified by calculating a boundary line. For each species, a boundary line was constructed by first dividing the data set into 0.5 mm segments (0–0.49, 0.5–0.99, 1.0–1.49 mm, etc.) of prior growth. Then within each segment, the top 10 percent-growth-change values were averaged. An upper percentile of points or a multiple of standard deviation was not used because of extreme differences in sample size across the levels of prior growth. The top ten points in each section ensured an equal sample size across all prior growth classes, and limited the analysis to the few points that represented true maximal releases. To quantify the boundary line

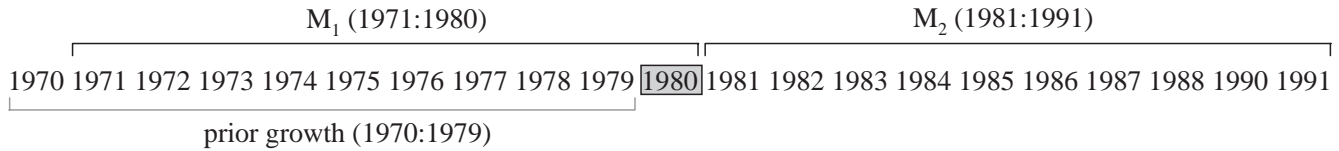


Fig. 1. Graphic of calculations for prior growth and the Nowacki and Abrams (1997) percent-growth change formula. Percent-growth change for a year (1980) is equal to $(M_2 - M_1)/M_1$ where M_1 equals average radial growth over the past 10 years and M_2 equals average radial growth over the subsequent 10 years. Prior growth is equal to average radial growth over the 10 years prior to the year (1980).

linear, power, logarithmic, and exponential curves were fitted to the average of the top 10 percent-growth change values in each segment, and the function that yielded the highest R^2 value was selected (Black and Abrams, 2003).

All percent-growth change pulses were then scaled with respect to the boundary line, which represents the maximum possible growth response as predicted by prior growth rate. First, the maximum percent-growth change value must be selected for each growth pulse, which should represent the year and maximum effect of the release event (Nowacki and Abrams, 1997). All other percent-growth change values, which represent the years aggrading to and declining from the maximum percent-growth-change value, were dropped from further analysis. Any remaining percent-growth change values less than 10% were also dropped to ensure that only positive values would be considered as potential releases. Once identified, maximum percent-growth change values greater than 10% were scaled as a fraction of the boundary line by dividing the observed percent-growth change value by the value of the boundary line, given its level of prior growth. Pulses falling within 50–100% of the boundary line were classified as major releases and those falling within 20–49.9% of the boundary line were classified as moderate releases (Black and Abrams, 2003). All pulses below 20% of the boundary line were eliminated to reduce the effects of climate (Black and Abrams, 2003). A disturbance history can be expressed by calculating the proportion of trees showing a release event for each decade of the chronology. SAS programs to automate all aspects of the boundary-line release criteria are available from the authors.

A single boundary line was calculated using data from 25 eastern hemlock stands located throughout the range of the species (Appendix). Growth patterns of several individual stands were evaluated in the context of eastern hemlock's species-wide boundary line with particular attention to stands on the extremes of hemlock's range and stands that fail to reach the boundary line. Furthermore, we plotted percent-growth change and prior growth for bur oak, white oak, ponderosa pine, and shortleaf pine tree-ring measure-

ments to determine whether the boundary line approach is suitable for these diverse species (Appendix).

Results and discussion

Prior growth and percent-growth change were plotted for hemlock in 25 sites, collectively containing 180708 growth increments (Appendix) (Fig. 2). These sites are located throughout the range of eastern hemlock, occurring on a wide variety of edaphic and topographic conditions. In this data set, sample size dropped dramatically after 4.0 mm prior growth. Consequently, 80 percent-growth change values, ten from each of the first eight prior growth segments, were used in the calculation of the eastern hemlock boundary line. On average, 3 percent-growth change values aggrading to or declining from the maximum value of large pulses in percent-growth change were included in the 80 percent-growth change values. Multiple percent-growth change values were included from a single percent-growth change pulse if they represented the highest values in the 0.5 mm prior growth class. This ensured the boundary line would follow the most extreme points observed and provide an estimate of maximum release potential. Twenty-two different trees were represented in the boundary line calculation, and no single tree contributed more than 1 percent-growth change growth pulse. A total of eight points, each comprising the average of the top 10%-growth-change in eight 0.5 mm prior growth segments, was used in the regression. The trend in these points was best described by the negative exponential function $y = 974.54e^{-1.1202x}$ $R^2 = 0.99$ (Fig. 2).

Schall's Gap old-growth hemlock forest is shown as an example of how an individual stand compares to the species-wide hemlock boundary line (Fig. 3A). Several points approach the boundary line, representing disturbance events that elicited the strongest release responses. The number of growth pulses that approach the boundary line depends on the number of disturbance events that occurred over the lifespan of the trees sampled from the stand. Locations of those growth

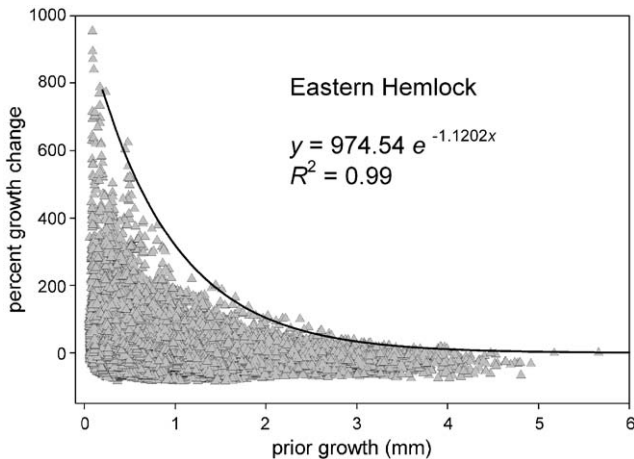


Fig. 2. Plot of percent-growth change with respect to prior growth for 180708 *T. canadensis* growth increments representing 25 different sites. The species-wide boundary line is also shown.

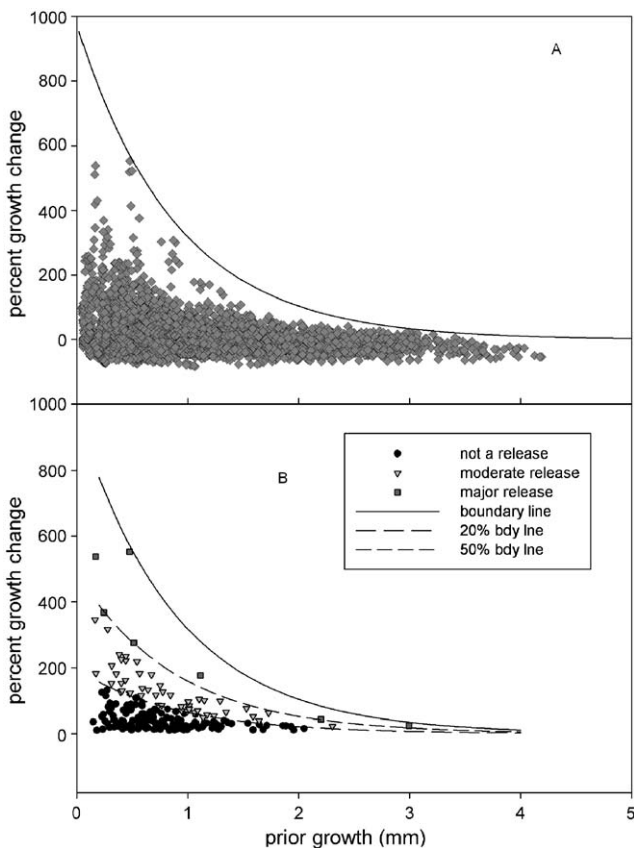


Fig. 3. (A) Prior growth and percent-growth change relationships for eastern hemlock in Schall's Gap. The eastern hemlock boundary line is shown. (B) Maximum percent-growth change values in radial growth pulses that exceed 10% as calculated by the Nowacki and Abrams (1997) formula. Pulses 50% or greater than the value of the boundary line are major releases. Pulses between 20% and 49.9% are moderate releases, while pulses less than 20% of the boundary line are not considered true releases.

pulses along the boundary line are a function of the prior growth rate the trees were experiencing immediately prior to the disturbance event. Thus, every stand will have a unique pattern of percent-growth change values that should reflect the unique disturbance history of the trees included in the sample. To identify the disturbance history in Schall's Gap, the year of maximum percent-growth change was identified for each growth pulse. Of the 6300 growth rings measured in Schall's Gap (Fig. 3A), a subset of 198 growth change-values qualified as pulse maxima (Fig. 3B). Of these pulse maxima, a total of 57 releases were identified: 50 moderate (between 20% and 50% of the value of the boundary line) and seven major (above 50% of the value of the boundary line) (Fig. 3B). All pulse maxima below 20% of the value of the boundary line were not considered true releases and are dropped from further analysis. Disturbance history of the stand can then be evaluated by summarizing the frequency of releases by decade. When releases are summarized by decade, widespread release corresponds with historically documented disturbance events (Black and Abrams, 2003). For example, a stand-wide release event in Schall's Gap corresponds with two well-known windstorms, the Great Hurricane of 1846 and July Storm of 1850 (Ludlum, 1963; Nowacki and Abrams, 1997).

To more clearly illustrate variability in the growth patterns among stands, the relationship between prior growth and percent-growth change is shown for four other sites in Pennsylvania (Fig. 4). Along with Schall's Gap, Hemlocks Natural Area and Bear Meadows experienced large growth pulses that approach the boundary line, despite tremendous differences in site characteristics (Figs. 3 and 4A,B). Schall's Gap and Hemlocks Natural Area occur in narrow ravines with soil underlain by sandstone and shale colluvium, while Bear Meadows is a high-elevation bog forest where the Hemlocks grow on a floating sphagnum mat (Abrams et al., 2000) (Fig. 4). However, a commonality among Schall's Gap, Bear Meadows, and Hemlocks Natural Area is that all three have experienced major disturbances. Substantial logging events occurred in Bear Meadows in the 1880s, and in the vicinity of Hemlocks Natural Area around 1910 (Cook and Kairiukstis, 1989; Abrams et al., 2000). Detailed dendroecological studies have been conducted in Bear Meadows and Schall's Gap, and reveal that massive disturbances initiated synchronous releases, which was immediately followed by a major pulse in regeneration (Abrams et al., 2001; Black and Abrams, 2003). Thus, disturbance appears to be a very influential factor determining whether growth pulses approach the boundary line.

In contrast to Schall's Gap and Bear Meadows, Tionesta Scenic Area and Alan Seeger Natural Area do not show release events that approach the boundary line (Fig. 4C,D). Tionesta Scenic Area is located on the

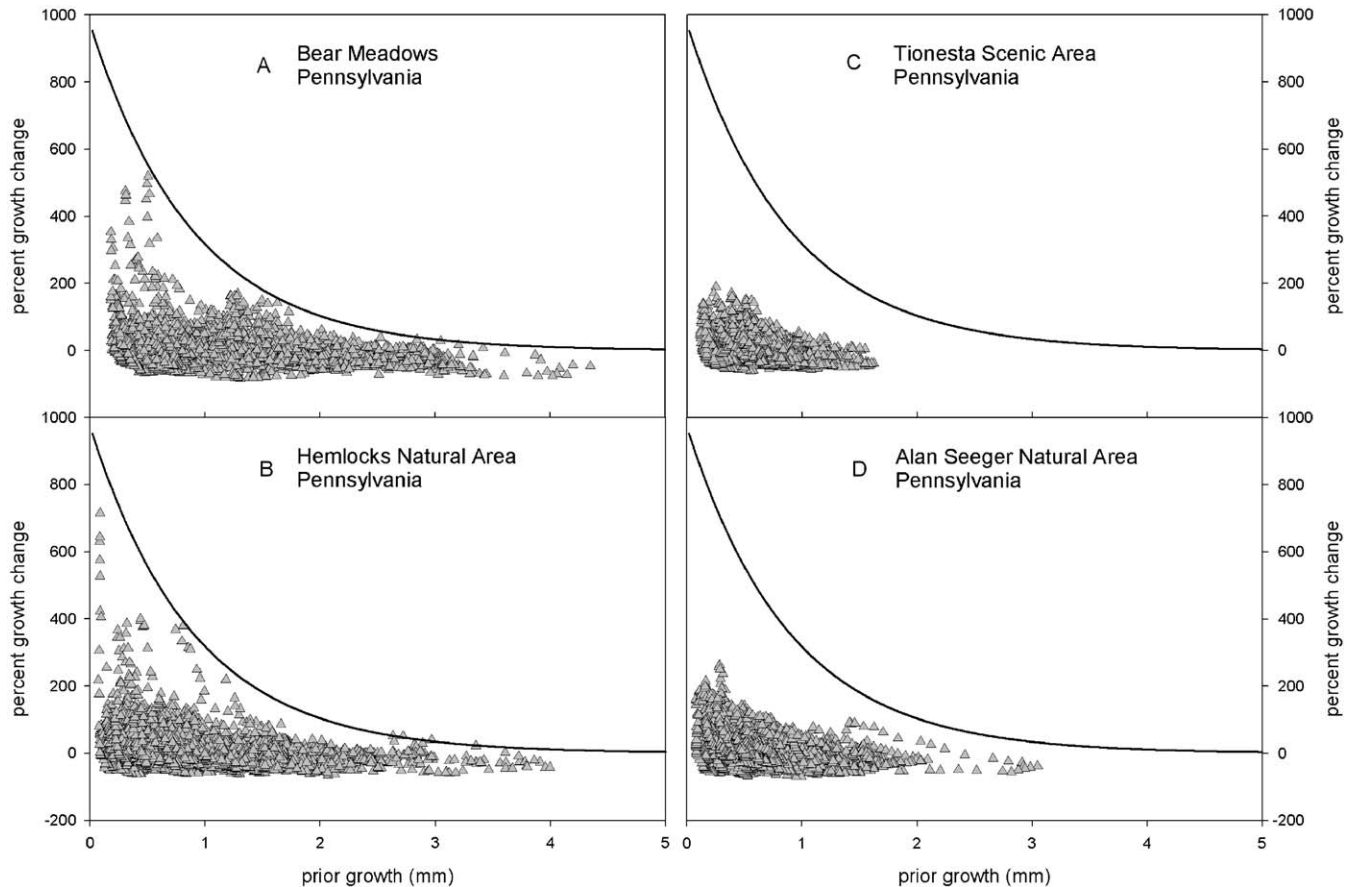


Fig. 4. Prior growth and percent-growth change relationships for four eastern hemlock stands in Pennsylvania.

Allegheny High Plateau of northwestern Pennsylvania while Alan Seeger Natural Area is within 20 miles of Schall's Gap, and like Schall's Gap, contains Hemlock growing in a protected stream valley at the base of a sandstone ridge. One possible scenario is that the trees sampled from Tionesta Scenic Area and Alan Seeger Natural Area experienced smaller canopy disturbances that did not elicit large percent-growth change pulses. A potential complication is that a previous study does indicate a disturbance event in 1846 in the Alan Seeger Natural Area (Nowacki and Abrams, 1994), and Ruffner and Abrams (1998) report disturbance in a nearby chestnut oak old-growth talus slope forest. However, the trees used in this present analysis were not necessarily chosen for the purpose of reconstructing disturbance. Indeed, percent-growth change values are consistently lower for Tionesta Scenic Area and Alan Seeger Natural Area such that any release criteria would reveal a history of relatively infrequent disturbance. Thus, these Tionesta Scenic Area and Alan Seeger Natural Area samples most likely illustrate growth patterns of trees that experienced infrequent canopy disturbance.

Beyond Pennsylvania, sites that do approach the boundary line are scattered throughout the range of eastern hemlock. However, sites located in the northernmost and westernmost regions of hemlock's range consistently fail to produce percent-growth change pulses that approach the boundary line (Fig. 5). Two examples from the north include a site from Maine and a site from Quebec (Fig. 5A,B). In both northern stands, growth pulses do approach the boundary line at very low levels of prior growth, yet consistently fall short of the boundary line at higher levels of prior growth. Both western stands consistently fall short of the boundary line across all levels of prior growth (Fig. 5C,D). For these sites near the borders of hemlock's range, stressful conditions may be limiting release response. If additional western and northern hemlock stands are found to consistently fail to reach the boundary line, modified boundary lines should be considered for extreme sites.

The effects of prior growth on release response are also very pronounced in the four additional species included in this study (Fig. 6). The relationship between prior growth and percent-growth change for shortleaf pine tree-ring series (22 different sites, $N = 74925$ growth increments) reveals a very strong decline in release

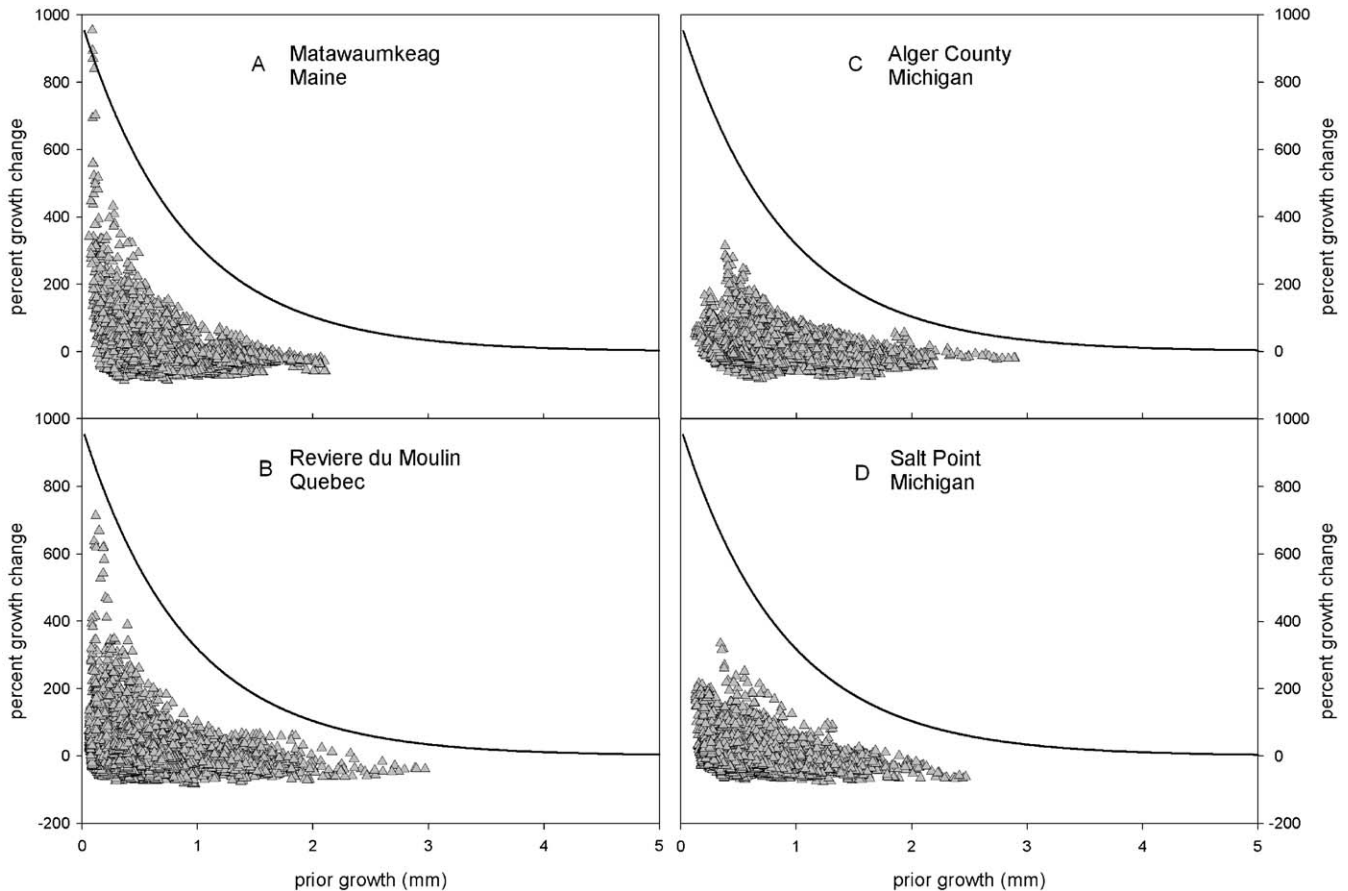


Fig. 5. Prior growth and percent-growth change relationships for four eastern hemlock stands located near the boundaries of the species' range.

response with increasing growth rates (Fig. 6). This species is capable of tremendous percent-growth change increases when growing slowly, but this ability diminishes very rapidly as prior growth increases. Similar to eastern hemlock, the relationship between prior growth and percent-growth-change can be summarized by a negative exponential function ($y = 998.65e^{-1.0337x}$) with an R^2 of 0.96. The decline in percent-growth change is less pronounced for ponderosa pine, yet is still very significant. The negative exponential function ($y = 655.97e^{-0.9354x}$ $R^2 = 0.93$) describes the relationship estimated using a total of 1,57,243 growth increments from 24 sites (Fig. 6). For bur oak, the function is ($y = 511.27e^{-0.7018x}$ $R^2 = 0.99$) as estimated using 92092 growth increments from 37 sites. The function ($y = 527.22e^{-0.787x}$ $R^2 = 0.97$) best describes release response for white oak, as estimated from 164,867 growth increments located across 24 sites (Fig. 6).

Eastern hemlock, white oak, bur oak, ponderosa pine, and shortleaf pine represent a wide variety of forest types, life histories, and geographic locations. Eastern hemlock is a late-successional, shade-tolerant species

with a range from southern Canada through the southern Appalachians (Burns and Honkala, 1990). White oak is another eastern species that typically occurs in closed forests, yet is much less shade tolerant than eastern hemlock. In contrast, shortleaf and ponderosa pine are intolerant of shade and at least historically have occurred in more open forest types with relatively little competition and a high frequency of disturbance (Burns and Honkala, 1990). The fact that tolerant and intolerant species, coniferous and deciduous species, and eastern and western species all exhibit a distinct negative exponential boundary line indicates that prior growth strongly influences release response in a diversity of species and forest types. Therefore, we believe that boundary line release criteria as we have demonstrated for eastern hemlock can be derived for a variety of additional species. For these other species, the species-specific boundary line function would simply be substituted in place of the eastern hemlock function when calculating releases. This would help account for species-specific differences in release response and avoid problems such as more heavily weighting shade-tolerant

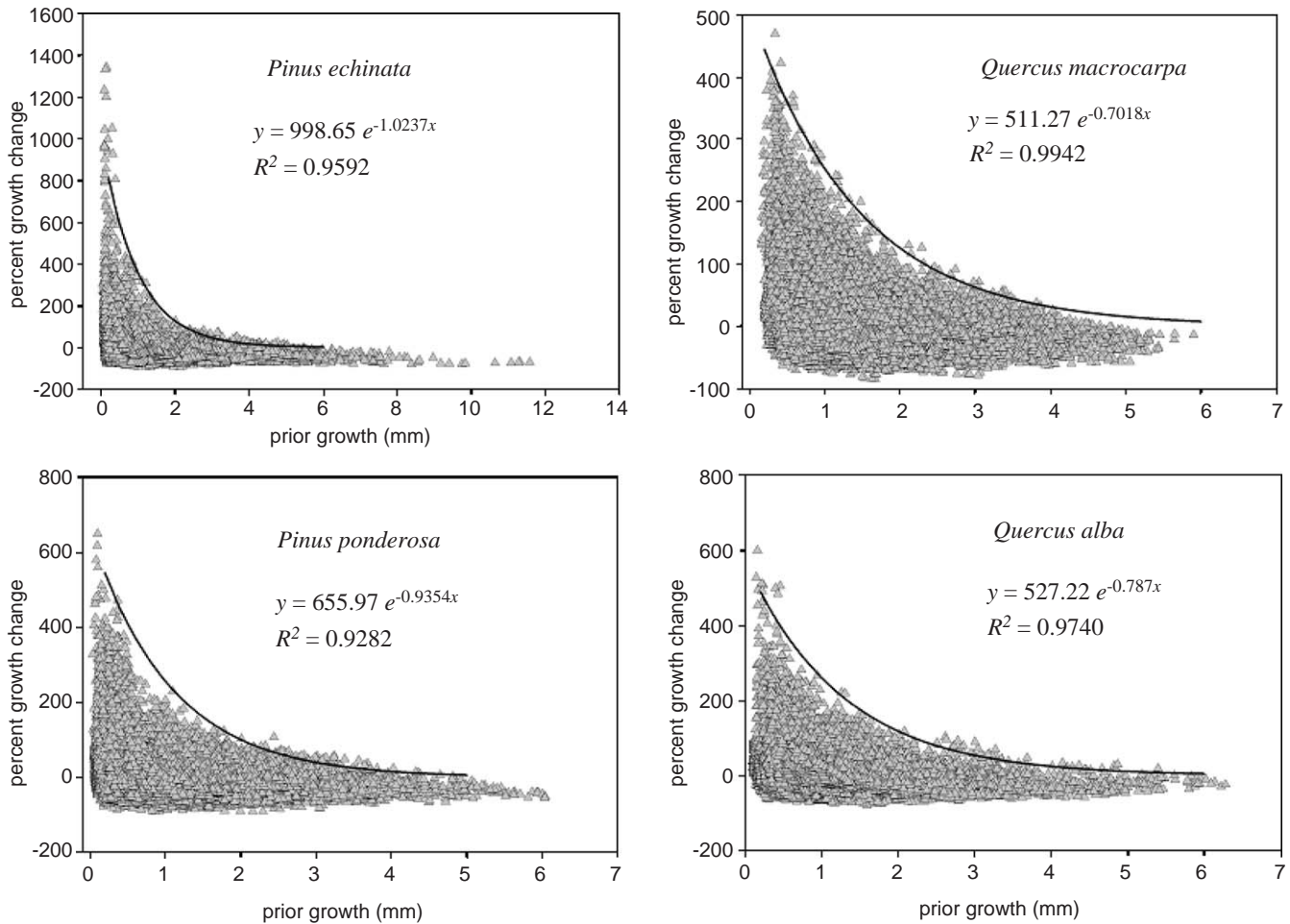


Fig. 6. Relationship between percent-growth change and prior growth for four tree species. The boundary line calculated for each species is also shown. Regression lines are fitted by $n = 10$ points for *P. echinata* (Mill); $n = 11$ points for *Q. macrocarpa* (Michx.), $n = 10$ points for *P. ponderosa* (Laws.), and $n = 12$ points for *Q. alba* (L.). See text for details on boundary line calculation.

species relative to less responsive intolerant species. Our species-specific prior-growth boundary-line technique may better standardize comparisons within and among species, helping to overcome this problem.

Overall, the inclusion of prior growth helps to standardize release responses of trees in various size, age, and canopy classes. In addition, combining data across multiple sites provides a species-wide estimate of release response so that a single boundary line can be generated. Individually, each site may only have a few extremely large release responses, and the location of those large pulses along the boundary line depends on the level of prior growth immediately prior to release. Yet by combining many sites, maximum release responses are encountered across a wide variety of prior growth rates to reveal the species-wide boundary line. A single boundary line provides a consistent metric by which to scale release events and thereby should allow for more direct comparisons of disturbance histories among sites.

As tree-ring data sets continue to accumulate and are made available for public use, boundary lines may be developed for more species, allowing direct comparisons of release events within or among diverse stands. More validation research from stands with a known disturbance history is necessary. Likewise, the effects of extreme site conditions on release response should be more rigorously investigated, and will be pertinent not only to these release criteria, but also to other criteria that have been previously proposed. Furthermore, thresholds for excluding the effects of climate will have to be established for each species, and may be much higher in species that occupy sites where climate is more limiting. Yet the fact remains that prior growth clearly affects release response and should be incorporated into future release criteria. We believe that these prior-growth boundary lines could be used to establish more consistent release criteria that will allow for more direct comparisons of disturbance histories across a diversity of sites.

Appendix

Tree-ring data sources used in the development of prior-growth boundary lines (NOAA, 2003) are listed below.

Site	Source	Contributor
<i>T. Canadensis</i>		
Adirondack Mountain Reserve	ITRDB	E.R. Cook
Alan Seeger	ITRDB	E.R. Cook
Alger County	ITRDB	E.R. Cook
Bear Meadows	Abrams et al. (2000)	M.D. Abrams
Dingman's Falls State Park	ITRDB	E.R. Cook
Hemlock Cove—Sunset Field	ITRDB	E.R. Cook
Hemlocks Natural Area	ITRDB	E.R. Cook
Ice Glen	Abrams et al. (2001)	M.D. Abrams
Kelsey Tract	ITRDB	E.R. Cook
Matawaumkeag	ITRDB	E.R. Cook
Mohawk Trail	ITRDB	E.R. Cook
Mount Rogers	ITRDB	E.R. Cook
Pack Forest	ITRDB	E.R. Cook
Pot Lake—Northwest Lake	ITRDB	E.R. Cook
Presque Isle River	ITRDB	E.R. Cook
Ramseys Draft	ITRDB	L.J. Puckett, R.L. Phipps
Reviere du Moulin	ITRDB	E.R. Cook
Rickett's Glen State Park	ITRDB	E.R. Cook
Salt Point	ITRDB	E.R. Cook
Salt Springs State Park	ITRDB	E.R. Cook
Savage Gulf	ITRDB	E.R. Cook
Shenandoah National Park	ITRDB	E.R. Cook
Sweetroot Natural Area	ITRDB	E.R. Cook
Tionesta Natural Area	ITRDB	E.R. Cook
<i>P. echinata</i>		
Athens	ITRDB	H.D. Grissino-Mayer
Clemson Forest	ITRDB	M.K. Cleaveland
Clifty Canyon	ITRDB	D.W. Stahle
Drury House	ITRDB	D.W. Stahle
Ellen Cockran Hollow	ITRDB	D.W. Stahle
Horton House	ITRDB	D.W. Stahle
Hot Springs	ITRDB	S. Schoenholtz, G.C. Jacoby, E.R. Cook, D.W. Stahle
Jacob Wolf House	ITRDB	D.H. Journey, D. Wolfman, D.W. Stahle.
Lake Winona	ITRDB	D.W. Stahle
Lead Mine Hampton Hills	ITRDB	A.C. Barefoot
Levi Wilcoxon	ITRDB	G.G. Hawks, D.W. Stahle
Roaring Branch	ITRDB	S. Schoenholtz, G.C. Jacoby, E.R. Cook, D.W. Stahle
Lower Rock Creek	ITRDB	D.N. Duvick
Lynn Hollow and Look Rock Trail	ITRDB	W. Blozan, M.D. Therrell, D.W. Stahle
Magazine Mountain 2	ITRDB	E.T. Estes
McCurtain County	ITRDB	S. Schoenholtz, G.C. Jacoby, E.R. Cook, D.W. Stahle
New Hill Beaver Tree Farm	ITRDB	A.C. Barefoot
Ozark	ITRDB	E.T. Estes
Pine Hills 4	ITRDB	E.T. Estes
Piney Creek	ITRDB	E.T. Estes

Shannon County	ITRDB	R.P. Guyette
Sylamore	ITRDB	E.T. Estes
<i>P. ponderosa</i>		
Abouselman Spring	ITRDB	A.M. Lynch, A.C. Caprio, T.W. Swetnam
Alcova Reservoir Site A	ITRDB	T.P. Harlan, M.A. Stokes
Antelope Lake	ITRDB	R.K. Adams, R.L. Holmes
Baca	ITRDB	A.M. Lynch, A.C. Caprio, T.W. Swetnam
Beaver Creek	ITRDB	D.A. Graybill
Big Elk Meadows	ITRDB	B.J. Raimo, A.M. Lynch, T.W. Swetnam
Black Forest East	ITRDB	P.M. Brown, C.A. Woodhouse
Defiance East (Fort Defiance)	ITRDB	M.A. Stokes
Buckhorn Mountain	ITRDB	C.H. Sieg, D. Meko
Cabresto Canyon	ITRDB	A.M. Lynch, A.C. Caprio, T.W. Swetnam
Capulin Volcano	ITRDB	P.M. Brown, C.A. Woodhouse
Cat Mesa	ITRDB	A.M. Lynch, A.C. Caprio, T.W. Swetnam
Crater Lake	ITRDB	T.W. Swetnam, J.H. Speer
Cross Canyon Arizona	ITRDB	W.J. Robinson, J.S. Dean
Crystal Cave Sequoia National Park	ITRDB	L.J. Graumlich, J.C. King
Dalton Reservoir	ITRDB	R.K. Adams, R.L. Holmes
Devil's Gulch	ITRDB	B.J. Raimo, A.M. Lynch, T.W. Swetnam
Drumhill Ridge	ITRDB	C.H. Baisan, T.W. Swetnam, B.E. Wickman
Elephant Rock	ITRDB	A.M. Lynch, A.C. Caprio, T.W. Swetnam
El Valle	ITRDB	W.J. Robinson, J.S. Dean
Emigrant Springs	ITRDB	C.H. Baisan, T.W. Swetnam, B.E. Wickman
Fish Lake	ITRDB	C.H. Baisan, T.W. Swetnam, B.E. Wickman
Gila Cliff Dwellings	ITRDB	D.A. Graybill
Granite Mountain (NW of Prescott)	ITRDB	T.P. Harlan, M.A. Stokes
<i>Q. alba</i>		
Backbone State Park	ITRDB	D.N. Duvick
Buffalo Beats North Ridgetop Forest	ITRDB	D.B. Houston, J.R. McClenahan
Cass Lake B	ITRDB	L.J. Graumlich
Current River Natural Area	ITRDB	D.N. Duvick
Dolliver Memorial State Park	ITRDB	D.N. Duvick
Dysart Woods	ITRDB	B.C. McCarthy, D.L. Rubino
Fire Tower Road Creek Forest	ITRDB	E.R. Cook
Fox Ridge State Park	ITRDB	D.N. Duvick
Greasy Creek	ITRDB	D.N. Duvick
Hutchenson Forest	ITRDB	E.R. Cook
Joyce Kilmer Wilderness	ITRDB	E.R. Cook
Lacey-Keosauqua State Park	ITRDB	D.N. Duvick
Lilley Cornett Tract	ITRDB	E.R. Cook
Lincoln's New Salem State Park	ITRDB	D.N. Duvick
Lower Rock Creek	ITRDB	D.N. Duvick
Mammoth Cave	ITRDB	E.T. Estes
Mountain Lake Virginia	ITRDB	E.R. Cook
Patty's Oaks Blue Ridge Parkway	ITRDB	E.R. Cook
Pinnacle Point/ Hawksville Gap	ITRDB	E.R. Cook
Pulaski Woods	ITRDB	E.R. Cook
Roaring River	ITRDB	D.W. Stahle
Sipsey Wilderness	ITRDB	E.R. Cook
Wegener Woods	ITRDB	D.W. Stahle
Yellow River State Forest	ITRDB	D.N. Duvick
<i>Quercus macrocarpa</i>		
Assiniboine River Alluvial Logs	ITRDB	S. St. George

Blair	ITRDB	C.H. Sieg, D. Meko
Bruce Park	ITRDB	S. St. George
Cedar Cliff Farm	ITRDB	D.N. Duvick, R. Landers
Cross Ranch Sanger Unit	ITRDB	C.H. Sieg, D. Meko
Crystal Cave	ITRDB	C.H. Sieg, D. Meko
Custer State Park	ITRDB	C.H. Sieg, D. Meko
Fort Dufferin	ITRDB	S. St. George
Frawley	ITRDB	C.H. Sieg, D. Meko
Frawley Dairy Farm	ITRDB	C.H. Sieg, D. Meko
Grace Coolidge	ITRDB	C.H. Sieg, D. Meko
Hankins Group	ITRDB	C.H. Sieg, D. Meko
Horseshoe Lake	ITRDB	S. St. George
Hyland Park	ITRDB	S. St. George
Icelandic State Park Pembina Hills	ITRDB	C.H. Sieg, D. Meko
Kildonan Park	ITRDB	S. St. George
Killdeer-Dvirnak	ITRDB	C.H. Sieg, D. Meko
LaBarriere Park	ITRDB	S. St. George
Lake Herman State Park	ITRDB	C.H. Sieg, D. Meko
Manitoba Historical Timbers	ITRDB	S. St. George
Marais River	ITRDB	S. St. George
Masonic Island/ Bear Island	ITRDB	C.H. Sieg, D. Meko
Mud River	ITRDB	C.W. Stockton
Munsen Park	ITRDB	S. St. George
Orland Hutterite Colony	ITRDB	C.H. Sieg, D. Meko
Parker Farm	ITRDB	S. St. George
Preparation Canyon State Park	ITRDB	D.N. Duvick, R. Landers
Red River Alluvial Logs	ITRDB	S. St. George
Remus Farm	ITRDB	S. St. George
Rockerville	ITRDB	C.H. Sieg, D. Meko
Sandwich	ITRDB	D.N. Duvick
Shay	ITRDB	S. St. George
St. Jean Baptiste	ITRDB	S. St. George
St. Norbert	ITRDB	S. St. George
St. Vital Park	ITRDB	S. St. George
Ste. Agathe	ITRDB	S. St. George
Stone State Park	ITRDB	C.H. Sieg, D. Meko
Thompson	ITRDB	C.H. Sieg, D. Meko
Winnipeg	ITRDB	S. St. George

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