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The Ecology and Distribution of

Taxus canadensis Marshall

in the State of Wisconsin

by

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for the degree of

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ABSTRACT

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I investigated factors affecting the distribution and abundance of the Canada yew (*Taxus canadensis* Marshall) in northern Wisconsin including the past and present effects of fire and herbivory. Herbarium records and the literature suggest that yew was once quite common throughout northern forested communities. Today yew is scarcer occupying a total of 245 sites throughout the state. I could not relocate it in nine historic locations in northern Wisconsin. Highest yew cover (above 25 percent) was found in areas with mixed canopies having less than 30 percent evergreen trees and moist but well drained, acidic, sandy to sandy loam soils. Constantly moist soils were indicated by the presence of jack-in-the-pulpit (*Arisaema atrorubens*). Yew was never found in black spruce-tamarack (*Picea mariana-Larix laricina*) swamps or in upland forests dominated by oaks and/or jack pines (*Pinus banksiana*).

Future management of Canada yew should focus on colonization by seeds and the role that seed dormancy and mycorrhizae play in this. Once the seed dormancy of Canada yew is understood seedlings should be used to establish new populations in the forests of northern Wisconsin and to maintain present populations. Other opportunities for study include determining the effects of different timber harvesting practices on yew abundance, defining the relationships of deer to present populations, and benefits to non-game wildlife.

Keywords- Canada yew, *Taxus canadensis*, Wisconsin, shrub, diversity.

PURPOSE

It is the purpose of this paper to review the ecology of Canada yew, particularly factors controlling its distribution in the northern counties of Wisconsin. Unravelling all that has been suggested and assumed about this plant has proven interesting in its own right. However, the potential pressure all yew species face as potential providers of the anti-cancer drug Taxol (Nature Conservancy 1991, Borman 1991, Whitherup et al. 1990) make it important to address the issues from a new perspective and with fresh data. These data can then be used to locate populations of Canada yew and establish new populations in areas where they are likely to do well.

Information for this project comes from a variety of sources. The first is the current literature and observations gathered from unpublished sources and herbarium records. The second source is phytosociological, chemical and physical data gathered at 49 northern Wisconsin yew sites from 28 May to 26 June 1992. A third information source is anecdotal observations by people who have lived near or owned my research sites for many years, especially where their observations can be reinforced with the data I gathered.

My thesis is presented in two parts: (1) The first part is an overview of the **Ecology of Canada Yew** from published and unpublished work by others. My own data is included as it pertains to plant form, Wisconsin distribution and, to provide examples of points made in the literature. (2) The second part is an investigation of **Present**

Habitat Preferences in Northern Wisconsin, a summary of my work to determine habitat preferences in northern Wisconsin and relationships of yew to biotic and abiotic components of these habitats. The **Methods** section therein provides a detailed description of how this data was collected and analyzed.

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ECOLOGY OF CANADA YEW

Genus History

The genus *Taxus* includes eight mostly allopatric species that are primarily dioecious (Price 1990). It makes its first appearance in the fossil record nearly 180 million years ago during the middle Jurassic period in central Europe (Florin 1960). This appearance is marked by a number of highly developed, now extinct genera suggesting an earlier origin (Florin 1960) though debate is fruitless with present evidence.

Description of *Taxus canadensis*

Canada yew, or ground hemlock as it is often called, is a coniferous evergreen with flat, linear to linear lanceolate entire leaves arranged in a spiral pattern on its branches and a chromosome number of $2n=24$ (Price 1990). Like other yews, it produces seeds that are surrounded by pulpy, red arils. Unlike other yews, *T. canadensis* almost always exists as a shrub and is the only primarily monoecious yew (Allison 1987, Price 1990, Chamberlain 1966).

Natural Range Limits

Canada yew is native to cool, moist areas "from Newfoundland to Manitoba, south to portions of Iowa, Illinois, Indiana, and eastern Kentucky, Virginia, and extreme northern Tennessee and North Carolina" (Price 1990). The southern limits of its present range follow two isoclines. The first delimits the area with total mean annual snowfall greater than 50 centimeters; The second marks the southern extent of 60 or more days per year of

snow cover at least 2 centimeters in depth (Taylor 1991). Northern limits, as defined by Little (1971), are vague but seem to follow the isocline of 40 centimeters of total average precipitation from April to September (Taylor 1991). Florin (1960), Little (1971) and Fassett (1930) have published general maps of this distribution though all are somewhat incomplete for Wisconsin.

Sources of Wisconsin Populations

T. canadensis has likely been in North America at least since the formation of the forests in the Allegheny Plateau region during the late Cretaceous or early Tertiary time (Florin 1960, Braun 1950). In the southernmost portion of its range yew is often restricted to mountain tops or north facing slopes of high ravines thought to have been refugia during the Pleistocene glaciations ending some 10,000 years ago (Braun 1950, Curtis 1959). Paleontological evidence suggests that all populations of *T. canadensis* presently in Wisconsin are most likely post-glacial migrants from such refugia outside of the state (Braun 1950, Curtis 1959).

Wisconsin Distribution

Canada yew's distribution in Wisconsin was determined using herbarium records from all major herbaria in Wisconsin (WIS, MIL, UWS, UWSP, UWL, RIL). Sites were also referred to me by interested individuals (included as verified) and found by searching areas thought to represent appropriate habitats. Figures 1 and 2 summarize this information. Reference is made in Figure 1 to populations not relocated despite four or more hours of

searching.

In total, *T. canadensis* has been found in 44 of the Wisconsin's 72 counties and has likely been extirpated only from Outagamie and Washburn Counties. Ashland, Bayfield, Door, Iron, Forest, Langlade, Lincoln, Marathon, Menominee, Oneida, Price, and Vilas Counties contain scattered large colonies (>300 meters²). Sites in other northern Wisconsin counties consist largely of a few scattered plants. Figure 2 shows only populations currently known in northern Wisconsin. Most southern Wisconsin sites are assumed to still contain yew (Alverson personal communication) but have not been collected from since 1980 and are therefore not included in Figure 2.

Figures 1 and 2 do not include data from the Apostle Islands in Lake Superior, northern Ashland and Bayfield Counties as they will be covered in detail by Judeziewicz (in press). Table 1 summarizes yew's distribution on the Apostles as adapted from Judeziewicz (in press). Yew is absent only on two of the smallest islands. Estimated total area occupied by yew on all other islands is approximately 2430 hectares (Judeziewicz in press); some are occupied at low coverage (less than 10 percent) and others support dense, chest-high colonies (Beals et al. 1960, Judeziewicz in press). These represent the most extensive yew populations in the state for a variety of factors, most likely low deer populations and absence of recent, intense fire.

Table 1. Distribution of *Taxus canadensis* on The Apostle Islands, Lake Superior, Wisconsin. Data adapted from Judziewicz (1993 in press). Presence is based on frequency in surveyed plot, extp.= extirpated in reference to past collection records, and, absent = never collected and not encountered in survey. For exact numbers refer to Judziewicz (1993 in press). Cover is an estimate of the island's surface that is covered by yew. Low cover= 0-1%, Med.Low=2-10%, Med.=11-50%, High=51-90%.

Island	Presence	Cover	Island	Presence	Cover
Basswood	uncommon	low	Michigan	common	med
Bear	moderate	low	North Twin	common	high
Cat	common	high	Oak	uncommon	low
Devils	moderate	med	Otter	common	high
Eagle	common	high	Outer	common	med
Gull	extp.	none	Raspberry	common	high
Hermit	moderate	med low	Rocky	moderate	low
Ironwood	common	high	Sand	common	high
Long	absent	none	South Twin	moderate	low
Madeline	uncommon	low	Stockton	uncommon	low
Manitou	moderate	low	York	common	high

Growth Form

Canada yew often occurs as a clone (genet) of stems (ramets) extending from a common point of origin, represented (at least historically) by an original connected set of underground stems. Single main ramets of these genets can spread above and below the ground for several meters (Allison personal communication). A composite sample of ramets (N=262) from 49 habitat study sites (Figure 3) shows significant linear relationships (R^2 , $p= 0.005$) among ramet diameter at the first root, ramet length from the point of rooting, ramet height from root to tip, and ramet age using a student's T test (Chatterjee and Price 1977). Figure 4 displays the diameter to age relationship; Figure 5- the height to age relationship; Figure 6- the length to age relationship. Mean ramet size across all habitats (N=262) was 9.9 millimeters in diameter, 0.73 meters in height and 14 years old.

These are similar to the relationships reported for Canada yew ramets in Michigan (King 1975) and together imply a strong, genetically fixed component to Canada yew's growth form. Better site and climatic factors appear to produce more side stems rather than altering the growth form of the main stem (King 1975). These measurements also provide evidence contrary to many anecdotal reports of long-lived Canada yew ramets though genets may be much older. The largest and oldest ramet collected was 44 millimeters in diameter, 3.26 meters in height, and 41 years old.

Reproductive Ecology

Layering-- Layering is facilitated by slender ramets being pressed into the moist substrate by their own weight, by the weight of heavy winter snows, and by the weight of debris falling to the forest floor similar to the process described for some individuals of Pacific yew (USDA Forest Service 1992). Layering is common in Wisconsin yew populations. Dirr (1983) notes that Canada yew has been cultivated since 1800, primarily by utilizing this natural layering. Cuttings are taken from October through January. These are then typically treated with hormones and placed in sand or sand:peat under moist conditions and indirect light. Rooting time is between two and three months (Dirr 1983).

Reproduction by Seed-- Allison (1987, 1990, 1991) has discussed the breeding system and reproductive ecology of Canada yew in detail. Seed production was prevalent during the summers of 1991 and 1992 in most natural populations in Wisconsin that were unbrowsed

or existed with deer browse that removed only a portion of each year's new growth. The fruits are dispersed, to some extent, by birds attracted to the fleshy red arils enveloping the seeds (Allison 1990, Price 1990, Florin 1960) and possibly by rodents as documented in *T. brevifolia* (USDA Forest Service 1992, Crawford 1983). However, density of maturing ovules varies even on the same genet. Some ramets may achieve a high density of fruits (>100 per meter² of flattened ramet area) while adjacent ones of the same length and diameter have no fruits at all.

Reproduction of *T. canadensis* by seeds may be limited by strong seed dormancy (Dirr 1983, Allison 1987) that can be broken by periods of stratification. I saw only one new seedling (still emerging from the seed) in the 60 sites I visited during the summer of 1991.

Dirr (1983) notes:

Yew seeds are slow to germinate, natural germination not taking place until the second year. Seeds have a strong but variable dormancy that can be broken by warm plus cold stratification. One recommendation is to hold the seeds for 90 to 120 days of 60 degrees F followed by 60 to 120 days at 36 to 41 degrees F. Another recommendation specifies prechilling the seed for 270 days at 37 to 41 degrees F (Dirr 1983).

Krol and others (1980) suggest endozoochory, seed passage through an animal's digestive tract, is a principal factor in successful regeneration of *Taxus baccata* in the Golenwiowska virgin forest of Poland. This may also be a factor in the regeneration of Canada yew. Further work is needed in this area for all yews including *T. canadensis*.

Pollen Limitations-- Allison (1987) reports that the primary limiting factor in seed

production is pollen availability caused by low plant densities and by the indirect effects of herbivory. *Taxus canadensis* logically has the potential for self-pollination as a primarily monoecious species (single sexed genets are known on Rocky Island, Ashland County, Wisconsin- Allison 1991). This may indeed be a derived condition, providing the species with a "fail-safe" mechanism of reproduction when the species has a low population number or density and thus low pollen density as well (Allison 1987) allowing for a partial compensation for reduction in pollen input from other plants.

Canada yew seed produced by selfing showed no increase in unfilled, lower-weight seeds (Allison 1987). Allison thus concluded that these selfed seeds show little inbreeding depression and will develop into reproductive individuals with the same frequency of seeds formed by out-crossing. These results, as he stated, must be interpreted with caution as they are based on seed weight alone because of the difficulty involved in germinating yew seeds. It may allow for partial compensation of pollen limitations induced by herbivory, though reductions in male strobili numbers by browsing will likely still limit overall seed production (Allison 1987).

HABITAT

Canada yew habitats were grouped into several major categories from a review of the literature and my own sampling of herb, shrub, sapling, tree cover and soil characteristics of 14 meter by 21 meter plots at 49 northern Wisconsin yew sites (Figure 3). Habitats include, boreal forests, hemlock (*Tsuga canadensis*) dominated forests (both within the

common range of hemlock and southerly remnants on steep slopes), white cedar (*Thuja occidentalis*) swamps & bog margins, northern wet-mesic forests, and northern mesic forests dominated by deciduous trees. Canada yew is also found throughout its range in cool moist sites such as seeps on ravine sides, and in small clumps of soil on boulders in riparian areas. These special microsites, often inaccessible to vertebrate herbivores, will not be considered further herein as they are largely uniform across Canada yew's range.

Lake Superior Islands

These islands may be special cases with strong maritime climatic influences allowing for high potential growth of yew. However, I have seen several thriving populations in Forest County, Wisconsin away from the direct maritime influence of Lake Superior or Lake Michigan suggesting that this may not be the only reason the islands contain large yew populations. The marked linear growth relationships of yew, as discussed earlier, across habitats in and out of the lake's climatic influence also suggests this.

Isle Royale, Michigan-- Isle Royale habitats are similar to the balsam fir-white birch (*Abies balsamea* - *Betula papyrifera*) boreal forests on the Wisconsin mainland that formerly held yew (Curtis 1959). Risenhoover and Maas (1987) reported yew to be present in two habitats on Isle Royale. It was most abundant under a mixed canopy of aspen-birch-conifer with an understory dominated by mountain ash (*Sorbus americana*), white birch, white spruce (*Picea glauca*) and balsam fir saplings. Shrubs included Canada yew and honeysuckle (*Lonicera canadensis*). Canada yew increased in this habitat with the

exclusion of moose (*Alces alces*) browse by fencing and increased in an aspen (*Populus* spp.) -white birch stand from which moose were also excluded. This area was inside the "1936 Burn" (Risenhoover and Maas 1980, Krefting 1974) and suggests that yew has the potential to colonize burned areas over time.

Apostle Islands, Wisconsin-- Beals et al. (1960) reported that yew was a common understory element in northern hardwood stands on the Apostle Islands. These are still dominated by sugar maple (*Acer saccharum*), yellow birch (*Betula allegheniensis*) and some white birch with occasionally large portions of cedar and hemlock. Canada yew is also present in these forests where sugar maple and hemlock are fairly rare with a large component of yellow and paper birch taking their place (Swain 1987). Yew was not reported in drier forests dominated by oaks on any of the islands.

Mainland Habitats

Braun (1950) reports others' observations on 5 habitat groups for yew defined largely by the composition of the overstory (Table 2). The first is the hemlock dominated forests of the rocky slopes in western Maryland. In this area northern shrubs such as Canada yew, bush honeysuckle (*Diervilla lonicera*), and elderberry (*Sambucus pubens*) were common (Braun 1950, after Curran 1902).

Yew was also formerly common in the hemlock-dominated forests along the northern slopes of the Porcupine Mountains in Michigan (Braun 1950, after Ruthven 1906). These

populations were assumed to be largely eliminated by deer between 1906 and 1950 (Braun 1950). However, Canada yew is now common in similar habitats along the Black River, Michigan possibly because of low winter deer densities.

Table 2. Representative Yew Habitat Overstory Compositions, after Braun (1950). 1= Forests along north slopes of the Porcupine Mountains in northern Michigan. 2= a mixed hardwoods area on a north slope, circa. Black River, Michigan. 3= hemlock-yellow birch area circa Black River 9mi. south of Lake Superior. 4= hemlock dominated slope forests in western Maryland. 5= Colebrook Virgin Forest. 6= sugar maple dominated stands near Pictured Rocks, Michigan. 7= maple-beech forest adjacent to 6.

Site Number→	1	2	3	4	5	6	7
↓ Species							
<i>Acer saccharum</i>	30.6	9.9	41.0	2.45	12.0	79.8	61.3
<i>Tilia americana</i>	40.1	.8	8.2	1.18	3.5	.6	4.3
<i>Betula allegheniensis</i>	5.4	22.9	21.1	6.60	10.1	6.5	1.4
<i>Tsuga canadensis</i>	18.9	58.9	26.2	86.04	27.5		
<i>Fagus grandifolia</i>				1.58	27.5	1.8	25.2
<i>Quercus rubra</i>	.9			.06	6.0		
<i>Acer rubrum</i>	6.9		.64	1.0			
<i>Pinus strobus</i>			.25	1.0			
<i>Fraxinus americana</i>	.8			3.5			
<i>Thuja occidentalis</i>		1.6					
<i>Ulmus americana</i>			1.6			.6	1.8
<i>Castanea dentata</i>			.12		6.0		
<i>Betula nigra</i>			.19				

A second habitat type is represented by the former hemlock-hardwoods Colebrook Forest of northwestern Connecticut. It was unlogged until 1912 and, when sampled in 1909, its percentage of hemlock and shrub layer was similar to forests where yew is now moderately abundant. Canada yew, hobble bush (*Viburnum alnifolium*), and mountain laurel (*Kalmia latifolia*) were the most abundant shrubs followed by witch hazel (*Hamamelis virginiana*), maple-leaved viburnum (*Viburnum acerifolium*), alternate-leaved dogwood (*Cornus*

alternifolia), and honeysuckle with scattered individuals of elderberry. Herbs formed a sparse cover with one of the most abundant being *Oxalis montana* (Braun 1950, after Hawes 1909).

Post-glacial pockets of northern species on steep slopes represent a third habitat (Pammel 1905, Marks 1942) in the unglaciated Driftless Area of Wisconsin (Figures 1 and 2) similar to Curran (1902). These contain species typical of Hemlock-White pine-Northern Hardwoods Region such as hemlock, white pine (*Pinus strobus*), Canada yew, striped maple (*Acer spicatum*), bush honeysuckle, beaked hazel (*Corylus cornuta*), Canada mayflower (*Maianthemum canadense*), bunchberry (*Cornus canadensis*), blue beadlily (*Clintonia borealis*), and goldthread (*Coptis groenlandica*).

A fourth habitat is the mixed mesophytic, sugar maple dominated stands, such as in the Pictured Rocks area of Michigan's Upper Peninsula. A species-rich herb community scattered among open patches in the shrubs is facilitated here by well drained soil enriched from rapidly decaying deciduous litter. Yew also reaches a very high coverage in the neighboring forests dominated by beech (*Fagus grandifolia*) and sugar maple. Beech and sugar maple saplings are limited to openings between yew clumps. Similar conditions are reported by Westover (1971) and in Wisconsin by Stearns (1951).

A fifth representative habitat is typified by a well-preserved bog remnant at Cedar Swamp in Champaign County, Ohio. Here cedar dominates the edges of the forest and Canada

yew is frequent in the undergrowth. Though no further description is given by Braun, this is possibly similar to the Northern Wet-Mesic Forest community (Table 3) defined in Wisconsin by Curtis (1959).

Rogers (1980) surveyed 71 hemlock-dominated (>75 percent of the overstory) stands greater than 100 years old, from Wisconsin to Nova Scotia. He found *Taxus canadensis* to be present in 14 (20 percent) of those stands. It ranked 16th in commonness among woody plants, but fourth in mean coverage when present (13 percent mean cover). He scored yew with understory plants less than 1 meter in height. Coverage of shrubs, including Canada yew, and small tree species was rarely large under pure hemlock stands presumably because of "a combination of deep evergreen shade, leached coarse-textured soil, and persistent, probably antibiotic litter" (Rogers 1980). This is similar to reports by Christensen (1954) and is perhaps why yew has not been cited as more common in hemlock dominated stands by other authors.

Curtis (1959) stated that there were eight distinct yew-containing plant communities in Wisconsin. Its cover values were highest in Northern wet-Mesic Forest stands. Unfortunately, he failed to name the seven others directly. However, I include the description of this one to provide a context for Curtis' judgement that yew was rare in northern Wisconsin especially since Christensen (1954) noted Canada yew as common in northern Wisconsin. Of the 26 Northern Wet-mesic Forests Curtis surveyed, Canada yew was present in 7 (27 percent) at an average frequency of 3.7, where frequency is the chance

of finding a given species within a distance of one-half of the square root of the quadrat area from any random point in the stand (Curtis 1959). Other authors also report yew in similar habitats (Christensen 1954, Westover 1971). Table 3 lists the other important species that determine this community type.

Table 3. Species which define the Northern wet-Mesic Forest community, after Curtis (1959). Average frequency for the herbs is the chance of finding a given species within a distance of one-half of the square root of the quadrat area from any random point chosen in the stand. Importance values for the trees are the sum of their relative frequency, relative density, and relative dominance. Modal species are those achieving herein their highest cover in any Wisconsin plant community.

Modal Species----->			Dominants----->	
Species	Presence	Freq.	Species	Importance
Carex disperma	39%	12.5	Thuja occidentalis	91
Circea alpina	65%	10.6	Abies balsamea	45
Coptis trifolia	69%	42.5	Tsuga canadensis	40
Dryopteris cristata	58%	4.8	Betula allegheniensis	34
D. austriaca	92%	29.6	Fraxinus nigra	27
Gymnocarpum dryopteris	69%	14.1	Aralia nudicaulis	90
Ilex verticillata	27%	.7	Maianthemum canadense	96
Impatiens biflora	73%	20.2	Dryopteris austriaca	92
Mitella nuda	77%	30.8	Rubus pubescens	92
Osmunda cinnamomea	62%	6.9	Galium triflorum	89
Oxalis acetosella	42%	16.1		
Ribes lacustre	35%	1.1		
Ribes triste	42%	1.9		
Taxus canadensis	27%	3.7		

HERBIVORY AND DECLINE OF CANADA YEW

White-tailed Deer (*Odocoileus virginianus*)

The popular villains-- A general decline of Canada yew abundance from deer browse has been noted by various authors (Leopold 1938, Braun 1950, Curtis 1959, Beals et al. 1960, Lintereur 1969, Alverson et al. 1988). Curtis (1959) stated in his synopsis of the northern mesic forest community:

The evergreen Canadian yew (*Taxus canadensis*) is another characteristic shrub of the northern forests which is now much more rare than formerly, due to heavy browsing pressure of deer... . This plant is ... sought out and utilized by them to the point of virtual extinction in many counties (Curtis 1959).

Leopold (1938) remarked that:

Mobile animals greatly affect plant life, so that a small virgin forest may appear to be natural when actually it has been profoundly affected by forces applied to animals, waters, climate at points far distant. Thus the deer populations determined by laws passed at Lansing by hunters ..., and by lumbering operations ... have apparently exterminated the ground hemlock (yew) from the "virgin" forest of Mountain Lake, Michigan (Leopold 1938).

Braun (1950) also noted yew's decline in northern Michigan under presumably similar forest conditions. She states:

It (*Taxus canadensis*) is severely browsed by deer, which are over-plentiful in many of the northern forests. Maples sprout freely and repeatedly after browsing, while *Taxus* is soon killed (Braun 1950).

These three authors give no data directly supporting these statements and their assumptions of previous yew cover appear to be based on local studies by others. The documented increase in deer populations since the 1930's throughout the Great Lakes region seems to

support these observations (Leopold 1943, Dahlberg and Guettinger 1956, Bersing 1966). However, they do not fully explore the seasonal variability in habitat utilization by deer, a critical consideration.

Canada yew is the preferred fall and winter browse species of deer but is rarely eaten in the summer (Christensen 1954, Dahlberg and Guettinger 1956, Ozonga 1968, Westover 1971, King 1975). Indeed, Christensen (1954) notes yew as common throughout northern Wisconsin but important only in lightly used or non-winter deer range. Christensen (1954) did find yew in deer yards, but only once was it found at a height greater than 30 centimeters in a yarding area. This pattern has also been demonstrated by Westover (1971) in the Huron Mountains of northern Michigan. This suggests that the relationship of deer population to yew cover is more complex than that implied by other observers (Leopold 1938,1943, Braun 1950, Curtis 1959, Beals et al. 1960, Alverson et al. 1988). The problem, I believe, has been one of understanding the limits of sampling by Curtis (1959) and projecting relationships of deer to browse determined on the Apostle Islands, Wisconsin (Beals et al. 1960) to mainland deer populations that have much less restriction in choosing their ideal winter cover.

In the northern portion of their range, deer have moved out of the upland deciduous forest into upland and lowland conifer dominated forests during the winter for as long as historical records are available (Christensen 1954). The trees dominant in these primary wintering areas (yards), are mixtures of *Thuja occidentalis*, *Abies balsamea*, *Picea mariana*

and *Tsuga canadensis*. Deer also utilize areas dominated by *Betula allegheniensis* and *Fraxinus nigra* or saplings of *Populus* spp.. They very rarely use areas dominated by *Acer saccharum* and are not known to use boggy areas dominated by *Picea mariana* and *Larix laricina* as yards (Christensen 1954, Dahlberg and Guettinger 1956).

Deer gather to the same wintering areas year after year largely independent of the available food (Christensen 1954, Dahlberg and Guettinger 1956, Ozonga 1968, Westover 1971, Rongstad 1991 personal communication). Yarding in well-stocked conifer stands has been demonstrated to provide access to microclimatic conditions that offer significant protection from severe winter weather. And, the concentration of deer in their yards is largely controlled by snow depth and population size (Christensen 1954, Dahlberg and Guettinger 1956, Ozonga 1968, Westover 1971).

The stay in the yards may be from a few weeks to several months during which the deer utilize available yew, cedar, hemlock, mountain maple, red maple and black ash browse before less palatable species such as sugar maple and balsam fir. Where yew is present, it is consumed before any other evergreen browse (Christensen 1954, Dahlberg and Guettinger 1956, Beals et al. 1960). Snow depths in the yarding areas are commonly 60 centimeters, though they can be as low as 30 centimeters during low snow years or in local areas where high concentrations of deer have compacted the snow (Christensen 1954). In high snow cover years deer will remain in the yards even if browse is exhausted and starvation results (Christensen 1954, Dahlberg and Guettinger 1956, Westover 1971).

Low food availability and/or low snow cover may move deer from the core of the yarding areas to the adjacent lighter use wintering areas. Yards may be abandoned if destroyed by fire or logging, or if logging is begun on adjacent upland areas before heavy snow cover (Christensen 1954, Dahlberg and Guettinger 1956). Many northern Wisconsin yards were thought to be good yew habitat and occur in counties with many yew populations. Curtis (1959), as mentioned earlier, noted that Canada yew is rare in Wisconsin but reaches its highest importance in Wisconsin plant communities in Northern wet-Mesic Forest; areas that would typically be used for deer yarding as described by others (Christensen 1954, Dahlberg and Guettinger 1956).

Christensen (1954) gives a contrasting picture because of this yarding behavior. He noted that yew was common in northern Wisconsin. His observations were based on a study of winter deer range spanning 258 forest stands in a variety of northern Wisconsin community types. Of these, 79 stands were moderately to heavily used winter deer habitats (yards); 118 of stands were lightly used winter deer habitats; and, 61 stands were not used by deer in the winter. Across all forest types, from lowland conifer swamps to the postulated beech-maple climax forests, Canada yew was found to be an important shrub component in lightly used or non-winter deer range. It achieved much more importance in the areas not used by deer in the winter.

Christensen (1954) did find yew in deer yards (habitats where Curtis marked it as achieving its highest coverage in Wisconsin). However, only once was it found at a height greater

than 30 centimeters in these yards. This pattern of yew distribution in non-yards vs. yards has also been demonstrated by Westover (1971) in the Huron Mountains of northern Michigan. Yew was not important in areas dominated by heavy cover of hemlock independent of deer usage (Christensen 1954). This is similar to the negative relationship of yew and hemlock cover found by Rogers (1980). Thus, yew's absence in hemlock dominated stands may be due to shade and/or unfavorable litter conditions produced by the hemlock.

These findings suggest that the reported decline in yew cover in the upland communities not strongly dominated by hemlock or lowland communities dominated by cedar cannot be fully explained by deer browse. Even at low population densities deer will be limiting to yew in yarding areas (Christensen 1954, Dahlberg and Guettinger 1956). At high population densities, after food in normal yards is critically depleted, and during low snow years they may range out of the primary yarding areas and consume yew in winter range that is less favorable under normal winter conditions. They may also occasionally range into uplands and consume exposed yew and downed tree tops in areas logged before heavy snow cover. But, these will be episodic outbreaks rather than continuous stresses. During normal conditions in upland forests dominated by deciduous trees deer will consume yew only in the fall before yarding and when it is exposed in early winter clear-cuts. Work is currently underway by Dr. Waller and associates to elucidate the nature of this relationship.

Other evidence of deer limiting yew comes from Judeziewicz (1992 personal communication) and his survey of the Apostle Islands. In the 1950's and early 1960's there was a deer population irruption on several of the islands. The State of Wisconsin responded by opening very liberal hunting seasons on these islands. Judeziewicz found a strong negative relationship of yew cover in 1991-1992 with the average number of deer harvested per mi² of each island from 1953-1964. General reduction in yew cover with increased deer browse was also noted for the Apostle Islands by Beals et al. (1960), though both of these relationships are not directly applicable to upland deciduous forests on the mainland because the deer remain on the islands year round. Beals et al. (1960) cite several studies on the seasonal importance of yew browse but do not clearly suggest the limitations of their findings as applied to mainland environments where summer and winter deer habitats can be very different.

Moose (*Alces alces*)

Moose browse has been implicated in yew's demise in boreal habitats on Isle Royale (Brandner and others 1990, Risenhoover and Maas 1987, Krefting 1974, Brown 1935, Murie 1934) and its limitation in New Foundland (Bergerud and Manuel 1968). Moose browse may once have been a factor in limiting yew in the swampy areas along the Boise-Brule River in Douglas County, Wisconsin and the north-central counties of Wisconsin where moose were moderately abundant in the past (Jackson 1961). However, moose have been extirpated since 1921 except for a trickle of unsuccessful colonists from Minnesota or northern Michigan (Jackson 1961).

ALTERNATE EXPLANATIONS FOR DECLINE OF CANADA YEW

Fire

Hot humus-consuming fires were extremely common in the Great Lakes Region in the early portion of the 20th century. They often started in logging slash and then spread into standing mature timber under draughty conditions (Lorimer and Gough 1988). Such mature stands of sugar maple and hemlock are normally resistant to intense fires even under draughty conditions (Frelich and Lorimer 1991, Lorimer and Gough 1988). Thus, the increased frequency of intense fires with large scale logging was atypical of Canada yew's Wisconsin habitats. This type of fire appears to strongly affect *T. brevifolia*, especially in shrub form (USDA Forest Service 1992) and thus is predicted to strongly affect Canada yew. Some yew may have escaped this period of burning along water courses, in deep ravines and in towns such as Mellen, Wisconsin as suggested to me by various observers (Vandevoorde 1991, personal communication; Wiita 1991; Hanson 1991, personal communication; Jensen 1991, personal communication; Bonitz 1992, personal communication) confounding any general interpretation of fire effects on yew.

Records for the frequent and widespread fires near the turn of the 20th century over large areas of Canada yew's range are non-existent or anecdotal at best (Plummer 1912, Holbrook 1943, Mitchell and LeMay 1952, Davis 1959, Pyne 1982), limiting direct inferences of fire's effect on Canada yew. Wildfires have been largely suppressed in Wisconsin since the late 1930's (Mitchell and LeMay 1952) and are not currently

extirpating populations. However, some of the decrease in yew cover reported by various authors may be attributable to fire rather than deer, especially where the noted decrease was in upland deciduous areas not typically frequented by deer in the winter.

For example, Judeziewicz (in press) observed very little yew on the southern half of Outer Island, Apostle Islands, Lake Superior, Wisconsin. Yew concentrations on the northern half were much higher yet both halves had similar low deer populations. He examined aerial photos of Outer Island and observed that a fire had decimated the vegetation on the southern half of the island in the mid-1930's leaving the northern half of the island untouched. Swain (1987, 1989) observed a similar pattern for decreased yew coverage on York, Sand, and Outer Islands.

Figures 1 and 2 herein also suggest Canada yew has been limited by fire. Canada yew has been collected around but never inside the boundaries of the Peshtigo fire of 8 October 1871 (Figures 1 and 2). This fire burned over 518,000 hectares and killed 1200 people (Lorimer and Gough 1988, Wells and Davenport 1983). The lack of yew in the burned area and its presence in surrounding areas that were similar habitats pre-fire (Curtis 1959) suggest that there was yew inside the fire boundary and that it has been unable to recolonize the burned area even though more than 120 years have passed.

Agricultural development of the burned area may have also played a role in this. However, another mechanism may also be operating as well. Canada yew can re-invade burned areas (Risenhoover and Maas 1987) though it may be limited not only by seed germination (Krol,

Cichoki and Mizera 1980, Dirr 1983), but also by the pyro-reduction of mycorrhizae in extremely hot soil consuming fires. Mycorrhizae have not yet been documented to occur with Canada yew, but they exist in association with *Taxus baccata* (Strullu 1978; Strullu, Gorret and Garrec 1982) and *T. brevifolia* (Wang et al. in press, Griffiths and Robatzek in press). Lack of these in burned soil may have contributed to the failure of yew to recolonize the area of the Peshtigo Fire. I am currently investigating this phenomena.

Rodents

Ramets observed during the summers of 1991 and 1992 were damaged at only three sites by snowshoe hares (*Lepus americanus*) and five sites by unidentified rodents out of 60 sites examined. Snowshoe hare browse is easily distinguished from the tearing browse of deer who lack upper incisors and cannot browse Canada yew twigs greater than 3.0 millimeters in diameter (King 1975, Allison personal communication). The three hare-damaged populations were in low, swampy areas and had species compositions similar to the "northern wet-mesic forest" described in Table 2. Rodent damage, though occasionally locally excessive, does not appear important regionally at this time.

Insects and Disease

Dirr (1983) states that yews, in general, are susceptible to needle blight, twig blight, root rot, other fungus diseases, twig browning, black vine weevil, strawberry root weevil, taxus mealybug, grape mealybug, scales, ants, termites and nematodes but that these are not serious problems for Canada yew.

English (1976) states that the genus *Taxus* faces several potential pests particularly in cultivation and in nursery settings. The black vine weevil, *Brachyrhinus sulcatus*, larvae eat the bark and cambium from the roots causing rapid dying of the plant similar to transplant shock. Termites, *Reticulitermes* spp., may attack yew and occasionally girdle a branch or kill an entire plant. Taxus mealybug, *Dsymiccocus cuspidatae*, is a small waxy looking sucking insect that occasionally infests yews. I have seen none of these on natural yew populations in northern Wisconsin.

Hansen (in press) reports that *Phytophthora* spp. have been found in some *T. brevifolia* in the western United States. *Phytophthora cinnamomi* is known to be a problem in nursery stocks (Lambe and Willis 1979) and should be investigated further as a potential pathogen of natural populations of Canada yew.

Fletcher scale-- *Lecanium fletcheri*, is a soft scale insect with a pale yellow to brown shell two to three millimeters in length that occasionally infests yews and can cause damage at high densities (English 1976). Each scale can contain as many as 800 eggs that hatch in June and feed on new growth (English 1976, Moore 1980). This insect occurred in 14 of 49 northern Wisconsin's populations of Canada yew observed in the summer of 1992 (Figure 3) at one to ten scales per ramet. However, several populations showed heavy infestations of >100 scales per ramet in 1991 but had no apparent loss of vigor though still lightly infected when re-visited in 1992. This suggests that Fletcher's scale may not be a serious problem in Wisconsin yew populations, though it is present and should be

monitored.

Unknown Needle Necrotic Factor-- I have also observed some type of "needle drop" preceded by intense yellowing affecting several populations. This possibly correlates with one of the blights named by Dirr (1983) or with the activation of endophytic needle fungi similar to those now known to exist in Pacific yew (Stone in press). Other observers concur with my observations and note that populations seem to recover in a few years (Allison 1991, personal communication; Vandevoorde 1991, personal communication). Further work needs to be done in surveying natural populations for all of these pests.

Winter Desiccation-- This is a problem in some populations normally buried by snow. Typical winter conditions were demonstrated by a site just outside Mellen, Ashland County, Wisconsin. On 8 November 1991, 15 centimeters of snow bent half of all yew ramets over until parallel to the ground; average ramet height was 1.3 meters for the population. On 6 January 1992, 30 centimeters of accumulated snow bent all ramets to the ground and completely covered them. In contrast, snowcover was low during the winter of 1990-1991 (<10 centimeters all winter) and several populations in sunny locations near this area suffered extensive desiccation. Dirr (1983) also noted that *T. canadensis* prefers moist sandy loam and is susceptible to desiccation, especially during the winter months.

AGRICULTURAL CONVERSION

Drainage

Agricultural drainage has lowered the water tables over much of the eastern third of northern Wisconsin allowing mesic forest species to replace cedar swamps. This process is similar to that documented for other drained northern Wisconsin swamps (Christensen 1954) and compounds "edge effects" of landscape pattern conversion (Alverson et al. 1988). Yew was collected at such an Outagamie County cedar swamp in 1949. By 1991, only 2 hectares of cedar cover remained in the formerly 260 hectare swamp and the water table had been lowered one meter by drainage ditches. Large remnant white cedars (45-56 centimeters DBH) were interspersed with box elder (*Acer negundo*) and other species atypical of cedar swamps. Neither yew nor cedar reproduction was present in 1991. In areas where agriculture conversion of cedar swamps and surrounding areas continues, it is likely that yew will be completely extirpated as deer increasingly rely on the few remaining woodlots therein for year-round cover.

Damage From Livestock

Browse by domestic livestock, especially cattle and horses, may have been an important factor in yew's ecology. The wave of homesteading that pushed into the northern forests following the logging operations of the late 1800's also brought a wave of livestock. Horses, unlike deer, have incisors on both the upper and lower jaws. They can thus browse

yews of greater diameter than the native deer. Cattle lack upper incisors but can directly damage larger yews by pulling them from the ground. The documented toxicity of yews to domestic animals, especially *Taxus cuspidata* (Casteel and Cook 1985, Thompson and Barker 1978, Wise and Swereck 1973), may have limited the direct impact of domestic stock on yew.

This threat has been virtually eliminated in areas where farming collapsed with the close of primary forest logging in the 1920's and 1930's. Yew is now recolonizing some of these areas. Populations in the Chequamegon National Forest, Ashland County, Wisconsin show this well. Yew plants <30 centimeters in height are often found along abandoned fences surrounding even aged hardwood stands less than 60 years old that were formerly homestead pastures (Foster 1991, field observations; Hanson 1991, personal communication; Jensen 1991, personal communication; Anon. 1898; Rockford Map Publishers 1958). There are no yew plants interior to these fencelines. Yews along the fence row are likely the result of bird dispersal (Foster, 1991 Field Data).

The Suggested Role of Edge

Yew's decline has also been noted in a study of edge effects in Wisconsin and the Upper Peninsula of Michigan (Alverson et al. 1988). This is based on the process of increasing edge in the forest as a whole from harvesting numerous small blocks on a short rotation (<40 years for pulp). This edge is favored by species, like deer, whose populations increase dramatically with the percentage of the forest in edge as modeled by McCaffery

(1986). The few remaining "islands" of the original forest cover are strongly affected by penetration of these edge species.

Specifically, Alverson et al. (1988) state that the record high deer populations in Wisconsin are causing the widespread decline of formerly common woody species such as eastern hemlock (*Tsuga canadensis*), white cedar (*Thuja occidentalis*), and Canada yew as well as associated herb species. Exclosure evidence suggests that this occurs at densities as low as 4 deer/km² (Alverson et al. 1988). This is also confirmed in deer yarding situations by Christensen (1954). Experiments are currently underway to test the contribution of increased edge to deer populations and the subsequent reduction of reproduction in these formerly common woody plants. If the effect is most pronounced in deer yarding areas, as previously discussed, then their results should confirm this. However, the seasonal relationship of coniferous browse utilization to deer population may be masked by heavy browse in upland areas cut in the early winter before the deer yard up. This would make the timing of cuts increasingly important in maintaining yew populations in upland areas as edge effects increase the deer populations beyond the generally accepted carrying capacity of the winter range.

PRESENT HABITAT PREFERENCES IN NORTHERN WISCONSIN

Rationale for Study

The noted decline of yew and the role of edge effects/deer in that decline originally interested me in *Taxus canadensis*. The distributional and habitat data in Wisconsin had not been thoroughly reviewed since authors such as Leopold, Braun and Curtis made their pronouncements of yew's demise. The mentioned accounts of yew's decline suggested additional research was warranted for several reasons.

Habitat preferences for yew were defined largely on the basis of dominant tree species and not specifically for Wisconsin. Further management of yew for taxol production and/or restoration will benefit from defining Canada yew's habitat and soil preferences.

After a summer of field observations in 1991 Canada yew appeared more common than was previously assumed. Several populations referred to me by individuals concerned with yew's decline were highly browsed but appeared to be indicative of only local conditions. I wanted to know if yew did well in these habitats even with minimal browse pressure. I also hypothesized that Canada yew in Wisconsin had a negative relationship to hemlock cover as suggested by Rogers (1980).

METHODS

Site Selection Criteria

The 49 northern Wisconsin yew sites surveyed in this study (Figure 3) were chosen using

the following subjective criteria:

1. Preference was given to sites visited by me during the summer of 1991 and to those used by Alverson et al. (1988). This minimized time spent solely in searching for yew populations. Preference was also given to sites in Wisconsin for access to collection records and because the various habitat types known to contain yew were well represented here.
2. Sites on public property were given preference for accessibility and future management opportunities.
3. Apostle Island National Lakeshore sites were not included as they were being sampled by Dr. Judeziewicz who had agreed to share his findings.
4. Sites presumably containing yew by virtue of microclimatic phenomena alone (cliff sides, boulder tops etc.) were not considered even though they comprise a substantial proportion of the remaining yew sites in Wisconsin. These have almost no other vascular flora in conjunction with the yew, are largely uniform throughout Wisconsin, and are not likely candidates for intensive future management of forests or yew.
5. A range of sites meeting previous criteria were then selected so that some had high yew cover, implying low deer browse; some had low yew cover with high browse, and some had both low cover and low browse.
6. Distribution of sites across the northern part of the state was also considered as I wanted to include sites that were presumably physically and ecologically dissimilar. All sites were placed in the field so that they were entirely within an area of subjective ecological homogeneity having similar soils, slope, aspect, and yew cover representative of the stand as a whole.

Sampling Regime

My sampling was modeled after Kotar et al. (1988); exact site locations are available upon request. His typing system was used rather than that of Curtis (1959) as it is based on a more recent sampling; Curtis only published a description of one plant community of the eight he said contained yew; and, Kotar et al. (1988) provide keys readily used to determine the habitat type in the field. A sample data form is included in Appendix A.

Six contiguous square plots of 7 meters by 7 meters were laid out to form a 14 meter by 21 meter rectangle at each site. Percent cover by species was sampled for seven categories of plant cover: herbs and fern allies, shrubs, saplings <1ft., saplings 1-4.5ft., Saplings <4in DBH and >4.5ft, pole trees 4-10in. DBH, and large trees >10in. DBH. in each 7m*7m subplot. Plant coverages were measured using six cover classes of 0-1%, 2-5%, 6-25%, 36-50%, and 76-100% (Kotar et al. 1988). In subsequent analyses the median of each class was used to average data from subplots so average cover of species could be compared by site and so that total coverage of all species could exceed 100% for the site as the layers of vegetation cause site coverage to exceed 100% on a regular basis.

Environmental parameters sampled each include: site aspect, topography, configuration and slope. Representative samples of the upper 30 centimeters of soil at each site were air-dried in the field and taken to the State of Wisconsin Soil and Plant Analysis Lab in Madison, Wisconsin for determination % clay, %sand, %silt, %organic material, soil pH, P lbs./acre, exchangeable K, Ca, Mg lbs./acre and total N% content. Munsell chroma and color, % mottling, and Munsell color of drainage mottles was described in the field under ambient sunlight to determine if soils were hydric.

I later calculated estimated cation exchange capacity (CEC) for all soil samples using formulae provided by the state lab. In these calculations the atomic symbol is used and the units of measurement for the elements are pounds per acre.

For soils greater than 50% sand: $CEC = 0.75 (Ca/400 + Mg/243 + K/780)$.

For soils with <5% organic material (OM): $CEC = (Ca/400 + Mg/243 + K/780)$.

Soils with >6% OM: $CEC = (Ca/400 + Mg/243 + K/780) * (2 - 0.05 OM) + 0.00056 OM^2$.

Data Analysis-- Data from field reports (Appendix 2) was used to determine the habitat type for each site (Kotar et al. 1988) as well as to ordinate stands in species space using Principal Components Analysis (PCA) on the PC-ORD program for the IBM PC (McCune 1991).

PCA is a basic descriptive statistical technique. It uses eigen analysis where the eigen values of species and their corresponding vectors are used to place a stand in space defined by orthogonal species' axes (Greig-Smith 1983, Ludwig and Reynolds 1988). The principal component of variation of all stands' placement in the resulting multi-dimensional space can then be correlated to the eigen vectors for various species, soil measurements, and environmental measures. The process is repeated for 10 subsequent axes of variation orthogonal to the first until a reasonable amount of the variation in site grouping has been "explained" (Table 4). PC ORD only utilizes the first three iterations for graphic analysis of patterns in the data. The output from this technique is especially useful in separating sites into ecologically similar groups and comparing the different environmental conditions determining these groupings by overlaying environmental parameters over any particular species cover value in all plots (for example see Figure 8).

Table 4. Variance of site ordinations in species space extracted by subsequent iterations of PCA on untransformed species percent cover data for 49 northern Wisconsin Canada yew sites.

Axis	Eigen Value	% of Variance	Cum. % of Variance
1	57264	27	27
2	42242	20	47
3	21949	10	57
4	20570	10	67
5	12961	6	73
6	10920	5	78
7	8583	4	82
8	6291	3	85
9	4937	2	87
10	4044	2	89

I used a species centered approach for my PCA analyses. This results in all stands being compared to a hypothetical stand composed of all species included in the study at their average cover determined from all stands. This is necessary because otherwise the first axis of variation extends from the origin to this hypothetical stand's position in species space (Ludwig and Reynolds 1989). I ran two PCA analyses. The first used untransformed species percent cover data. The second employed species percent cover data that was arcsine squareroot transformed (McCune 1991), a more conservative approach with percentage data (McCune 1991, Snedecor and Cochran 1988).

Qualitative environmental variables cannot be correlated to the principal components of variation in the PCA analyses. However, they were graphically overlain on the sites as grouped by the principal components of variation. The pattern of this overlay suggests reasons for the grouping of apparently similar sites- i.e. low browse overlaying high yew

cover etc. (Greig-Smith 1983).

RESULTS

Present Habitat Preferences

Table 5 is a summary of plant habitat types as described by Kotar et al. (1988) in which Canada yew was located across northern Wisconsin.

Table 5. Habitat types found to contain Canada yew in the summer of 1992.

Designations were determined in the field using measurements of dominant tree and understory coverage and the author's interpretation of keys provided in Kotar et al. (1988).

Name	Dominant Tree Species	Dominant Herb Species	Number of Sites
ACaCi	<i>Acer saccharum</i>	<i>Calophyllum thalactroides</i> <i>Circea quadrisulcata</i>	1
AH	<i>Acer saccharum</i>	<i>Hydrophyllum virginianum</i>	1
ATD	<i>Acer saccharum</i>	<i>Dryopteris spinulosa</i>	8
ATM	<i>Acer saccharum</i>	<i>Maianthemum canadense</i>	14
AViO	<i>Tsuga canadensis</i> <i>Acer saccharum</i>	<i>Viola pennsylvanica</i> <i>Viola pubescens</i> <i>Osmorhiza claytoni</i>	9
PMV	<i>Pinus strobus</i>	<i>Maianthemum canadense</i> <i>Vaccinium angustifolium</i>	5
TMC	<i>Tsuga canadensis</i>	<i>Maianthemum canadense</i> <i>Coptis groenlandica</i>	11
			Total= 49

Present Canada yew Habitat Types

The following habitat types were found to contain Canada yew in northern Wisconsin during the summer 1992. The types were determined in the field using Kotar's (Kotar et

al. 1988) habitat type field guide and associated keys for northern Wisconsin. The types are based on groups of indicator species including the dominant overstory trees, dominant understory plants, and species that are found with higher frequency in the habitat type than elsewhere.

ACaCi (Acer/ Calophyllum - Circea)- has a canopy dominated by sugar maple with an herb understory dominated by blue cohosh (*Calophyllum thalactroides*) and enchanter's nightshade (*Circea quadrisulcata*). Grasses and sedges, big-leaved aster (*Aster macrophyllus*), hog peanut (*Amphicarpa bracteata*), northern maiden hair fern (*Adiantum pedatum*), and interrupted fern (*Osmunda claytoniana*) are also occasionally dominant.

At least some of the following diagnostic group of herbs and shrubs will also be present: jack-in-the-pulpit (*Arisaema atrorubens*), bloodroot (*Sanguinaria canadensis*), false nettles (*Boehmeria cylindrica*), wood nettles (*Laportea canadensis*), elderberry (*Sambucus pubens*), sharp-lobed hepatica (*Hepatica acutiloba*), early meadow rue (*Thalictrum dioicum*), wild geranium (*Geranium maculatum*), tick trefoil (*Desmodium glutinosum*), and greenbriers (*Smilax* spp.). This habitat type often occupies lower slope areas where surface drainage is poor. Shrub cover is generally poor but herb diversity can be high (Kotar et al. 1988).

AH (Acer/ Hydrophyllum)- has a canopy dominated by sugar maple and an herb understory dominated by Virginia waterleaf (*Hydrophyllum virginianum*). Other dominant understory vegetation usually includes grasses and sedges, sugar maple seedlings, sweet

cicely, violets (*Viola pennsylvanica* and *V. pubescens*), Trilliums (*Trillium grandiflorum* and *T. cernuum*), bloodroot, lady-fern (*Athyrium filix-femina*), spinulose wood fern, and nettles (*Boehmeria cylindrica*, *Laportea canadensis*, and *Urtica* spp.). The canopy may often contain yellow birch, hemlock, and basswood (*Tilia americana*). These types are mesic to wet-mesic and presumed to be nutrient rich (Kotar et al. 1988).

ATD (Acer-Tsuga/ Dryopteris)- has a canopy dominated by sugar maple and hemlock with an understory of the spinulose shield fern (*Dryopteris spinulosa*). The understory is often sparse and lacking a well developed shrub layer. Grasses and sedges, sugar maple seedlings, spinulose shield fern, and northern maidenhair ferns are the common dominant understory plants. They commonly lack or are only sparsely covered by the following species associated with dryer and/or more nutrient deficient sites: witch hazel (*Hamamelis virginiana*), maple-leaved viburnum (*Viburnum acerifolium*), tick trefoil, goldthread, oxalis (*Oxalis montana*), and bracken fern (*Pteridium aquilinum*). They also have low coverage of species associated with richer sites: sweet cicely, blue cohosh, bloodroot, nettles, waterleaf, and sharp-leaved hepatica. This type is differentiated from the similar ATM habitat by ATD's domination by ferns and lack of a well developed shrub layer (Kotar et al. 1988). The significant finding using these habitat types was that I found no Canada yew in characteristically drier habitats. These areas are typically dominated by mixtures of oaks (*Quercus* spp.), white pines (on the more mesic dry sites), and jack pine (*Pinus banksiana*). Yew was found in stands where these occurred in the canopy but not where

they were dominant, especially jack pine. Yew was also never found in boggy areas with saturated soils dominated by black spruce (*Picea mariana*) and tamarack (*Larix laricina*).

ATM (Acer-Tsuga/ Maianthemum)- has a canopy of sugar maple and hemlock with an understory dominated by Canada mayflower (*Maianthemum canadense*) and ferns while generally lacking in shrubs. Coverage of all understory plants is typically low. These stands lack or are only sparsely covered by the following species associated with dryer and/or more nutrient deficient sites: witch hazel, maple-leaved viburnum, tick trefoil, goldthread, oxalis, and bracken fern. They also have low coverage of species associated with richer sites: sweet cicely, blue cohosh, bloodroot, nettles, waterleaf, and sharp-leaved hepatica. Basswood, yellow birch, and ash (*Tilia* spp.) may also be present in the canopy (Kotar et al. 1988).

AViO (Acer/ Viola - Osmorhiza)- has a canopy of sugar maple with understory dominated by *Viola pennsylvanica* and *V. pubescens* with sweet cicely (*Osmorhiza claytoni*). The shrub layer is usually poorly developed. The dominant understory species are grasses and sedges, sugar maple seedlings, sweet cicely, spinulose wood fern, northern maidenhair fern, violets, false solomon's seal (*Smilicina racemosa*), hairy solomon's seal (*Polygonatum pubescens*), Belworts (*Uvularia grandiflora*, *Uvularia sessilifolia*), and trilliums. The presence of the herb group containing sweet cicely, blue cohosh, bloodroot, elderberry, wood nettle (*Laportea canadensis*), wild leeks (*Allium tricoccum*), cut-leaved grape fern (*Boytrichium virginianum*), hepatica (*Hepatica americana*), and wild sarsaparilla (*Aralia*

nudicaulis). Soils under this type are typically mesic and nutrient rich (Kotar et al. 1988).

TMC (Tsuga/ Maianthemum - Coptis)- has a canopy dominated by hemlock with an understory of Canada mayflower and goldthread (*Coptis groenlandica*). Typically dominant understory plants also include grasses and sedges, spinulose wood fern, blue beadlilly (*Clintonia borealis*), sugar maple seedlings, red maple seedlings (*Acer rubrum*), hazel bush (*Corylus* spp.), bunchberry (*Cornus canadensis*), and lycopodium (*Lycopodium* spp.). The following species are diagnostic of this community type when occurring in a mixture with the previous dominant species: twinflower (*Linnaea borealis*), blueberries (*Vaccinium* spp.), and barreground strawberry (*Waldenstenia fragaroides*). This habitat type is often found in lower slopes on strongly podzolized loamy sands and sandy loams and lacks a well developed shrub layer in undisturbed stands (Kotar et al. 1988).

Overstory Characteristics of Yew Sites

PCA analysis (McCune 1991, Ludwig and Reynolds 1988) grouped yew habitats into three main sets using data on coverage for all vascular plants. Groupings were similar for using transformed vs. untransformed data and are thus reported herein using untransformed data as the groups are easier to interpret. The first grouping is a forest with mixed canopies of evergreen and deciduous trees and hemlock cover below 30 percent wherein yew achieves its highest cover (Figures 7 and 8). This is consistent with previously discussed habitat observations across Canada yew's range by Braun (1950) as listed in Table 1; and, with

those of Beals (1960), Curtis (1959), Stearns (1951) and Christensen (1954) for Wisconsin.

The second group consists of hemlock dominated stands (>30 percent cover) wherein yew only achieves a cover greater than 30 percent but never exceeds 40 percent. This is consistent with trends described across yew's range in Rogers (1980); and in Wisconsin as discussed in Christensen (1954).

The third habitat group consists of cedar dominated stands (Figure 9) wherein yew never achieves cover above 30 percent (even in Menominee Reservation cedar swamps where present deer browse was nonexistent). This type is consistent with Braun (1950). Large striped maple (*Acer spicatum*) cover and low Canada yew cover are consistent with deer yarding areas (Figure 10) (Christensen 1954). However, yew may also have trouble finding adequate rooting areas in the saturated soils of these areas even without the pressure of deer browse. The predominance of yew in upland sites and general lack in lowland sites along the Gogebic/ Penoque Range in Iron County, Wisconsin also suggests yew may have a hard time persisting in saturated soils. Deer populations have always been historically low in this part of Iron County (Mladenoff and Howell 1980).

Highest yew cover was consistently associated with mixed canopies having less than 30 percent evergreen trees and moist but well drained soils indicated commonly by the presence of jack-in-the-pulpit (*Arisaema atrorubens*). Yew was never found in black spruce-tamarack (*Picea mariana-Larix laricina*) swamps or in upland forests dominated by

oaks and/or jack pines (*Pinus banksiana*). In all other habitats in northern Wisconsin it was found on slopes of all aspects and in any place on the slope that had well-drained but mesic soil.

Soil Characteristics of Yew Sites

Canada yew achieves high cover (above 25 percent) across all habitat types (as discussed previously) in sandy to sandy loam acidic soils with pH 4.0 to 5.1 (Figure 11). These soils have concentrations of organic material (OM) from 0 to 10 percent (Figure 12) and low estimated cation exchange capacities (CEC) of 0 to 10 (Figure 13). These soil characters are common across much of northern Wisconsin (Wisconsin State Board of Soil and Water Conservation Districts 1980, Hole 1976).

High CEC and high OM are often associated with sub-optimal yew habitat, especially with cedar swamps and with other lowland forests having seasonally waterlogged soil. These types of habitats clearly stand out as a separate group in the PCA analysis figure presented herein. Harvesting yew from this type of site may rapidly decimate these already stressed populations and restoration of yew to these areas would likely be a lot of work for limited results.

CONCLUSION

Summary

Canada yew was once more common in Wisconsin. It has been known to inhabit boreal forests, hemlock-dominated forests both within hemlock's main northern range and post-glacial southerly remnants on steep slopes also dominated by hemlock; cedar swamps & bog margins; northern wet-mesic forests; and northern mesic forests dominated by deciduous trees with some conifers in the canopy. It achieves its highest cover on the latter type where hemlock or cedar remain at low coverages. This is most likely because deer do not regularly use this habitat in the winter and partially because the light limitations evergreen shade places on the yew shrubs.

Yew is also found throughout its range in cool moist sites with little to no tree cover- i.e. seeps on ravine sides and small clumps of soil on boulders in riparian areas. The number of collections since 1980 in Wisconsin (Figure 2) indicate that yew is not universally disappearing from its former Wisconsin range. Deer browse is especially limiting Canada yew in northern Wisconsin conifer-dominated stands normally associated with deer yards and where early season logging causes deer to yard in upland habitats out of their normal wintering areas. Low snow years allowing deer to wander outside their normal wintering areas will continue to occasionally impact upland yew populations.

Agricultural conversion has caused a large amount of damage in the eastern one third of

northern Wisconsin through drainage and concentration of deer into the remaining woodlots. Other factors, such as rodent damage, may become important on a local level or, like fire, have been very important in the past but are limited in regional importance now. Yew will likely continue to decrease in counties where it is already facing pressures of increased human development and deer populations (eastern one-third of northern Wisconsin). Canada yew genets may increase slowly in Wisconsin counties where they are presently doing well (central one-third of northern Wisconsin) especially where heavy winter snows protect the upland populations in most years. As discussed previously, avoiding late fall and early winter harvesting operations in upland areas with yew colonies will help maintain present genets by keeping deer from yarding in and consuming the yew.

Harvesting Canada yew for industrial pharmaceutical processing is not a viable alternative for most northern Wisconsin populations. Though complete synthesis of Taxol in the near future remains unlikely, several companies have made very recent strides in partial synthesis of taxol and in large scale propagation of *Taxus brevifolia* (Piesch and Wyant in press) that make large scale harvesting of *T. canadensis* unlikely in the near future. However, we now have a much more complete understanding of the distribution of Canada yew in Wisconsin and its ecological preferences. This has already opened the door to utilization of the genetic resources of Wisconsin Canada yew populations.

What Managers Can Do For Yew

Production, dispersal, and colonization by new genetic individuals via seeds is less certain

than present genet persistence and bears on the long-term status of Canada yew in the state. Re-colonization of suitable habitats could be greatly enhanced by restoration plantings. Opportunities for success in this endeavor abound because of modern fire suppression methods; knowledge of yew's phytosociological and soil preferences herein; and, the comparative ease of propagating yew from cuttings as previously discussed. Determining the nature of Canada yew's seed dormancy (as previously discussed) will also be helpful in understanding the natural spread of Canada yew; in forming new genetic individuals; and for development of an inexpensive method of direct sowing plants in restoration plantings.

Such a restoration system could include replicate plantings within Canada yew's known habitat preferences shrubs generally have an adverse impact on local herb diversity when occurring in high density (Whitaker 1956, Ford and Newbould 1977). Within each type the effects of various levels of canopy harvesting (e.g. light thinning, heavy thinning, shelterwood, clearcut) on yew growth could be determined. This would allow assessment of light level impacts on growth by measuring of changes in light levels with each treatment. This type of replicated planting could also be used to study the impact of harvest timing on yew survival. Canada yew also likely forms mycorrhizal associations (as stated earlier). If such associations are found then replicate plantings could be established both with and without mycorrhizae to determine their impact on Canada yew growth. If such a relationship exists, lack of it may be a principal factor in limiting new genet establishment. I am also currently working with Dr. Waller and associates to measure the impact of deer browse on yew growth by comparing exclosed and freely

browsed yew populations.

Further study on such replicated plantings would also allow determination of Canada yew's impact on bird populations through provision its fleshy arils for food and its provision of brushy nesting cover for ground nesting birds such as wrens and grouse. It is possible that this useful shrub has several wildlife benefits previously unseen because of its limited distribution. Thus, increasing the abundance of this formerly common plant by establishing new colonies may provide multiple benefits and has a good chance of success because of the previously discussed characteristics of Canada yew. It is definitely worthy of further consideration.

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Figure 2- Collections of *Taxus canadensis* in Wisconsin made after 1980.

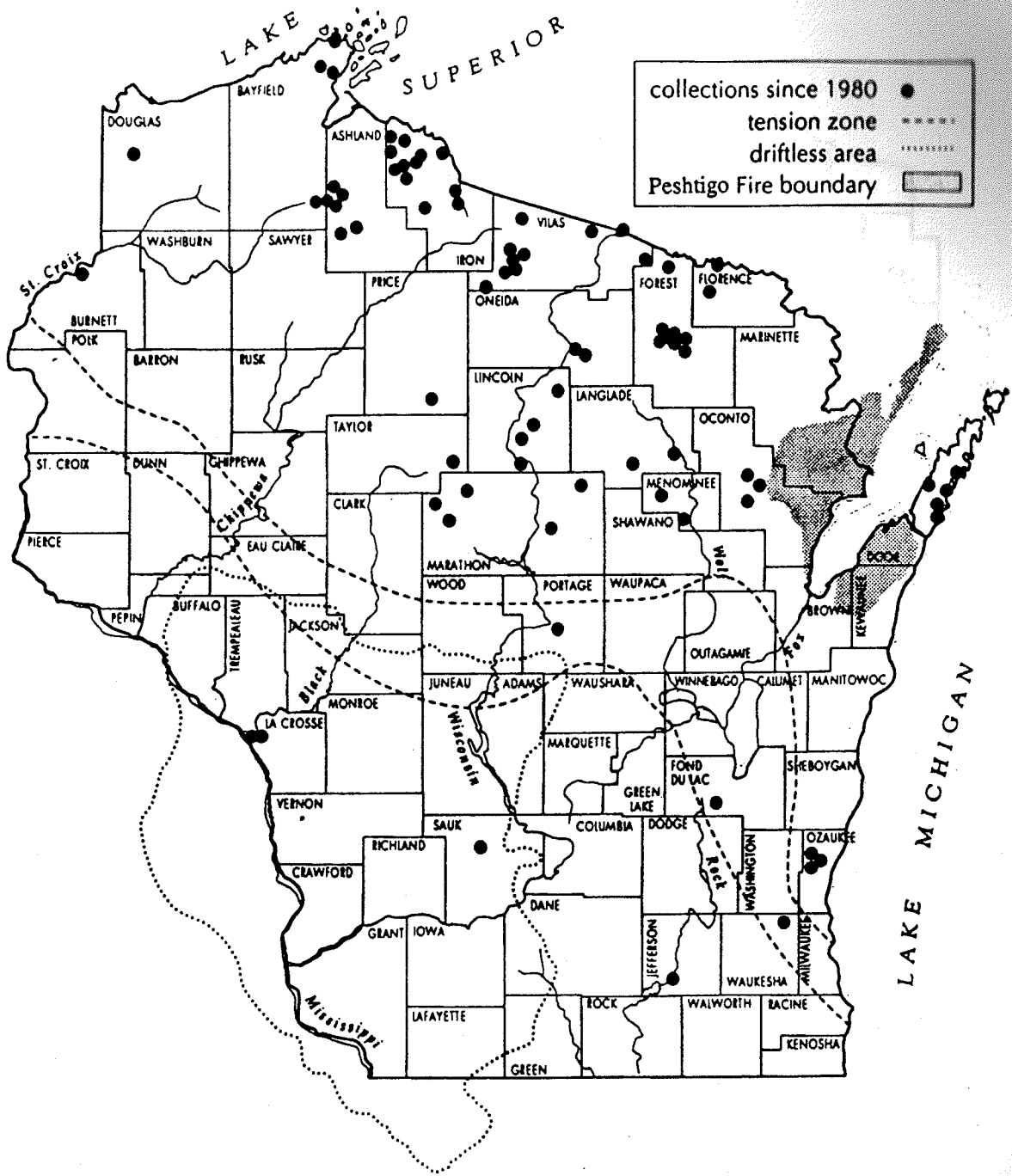


Figure 3- Habitat sampling sites in northern Wisconsin, 1992. Grey areas define boundaries of Tribal, State and National Forests.

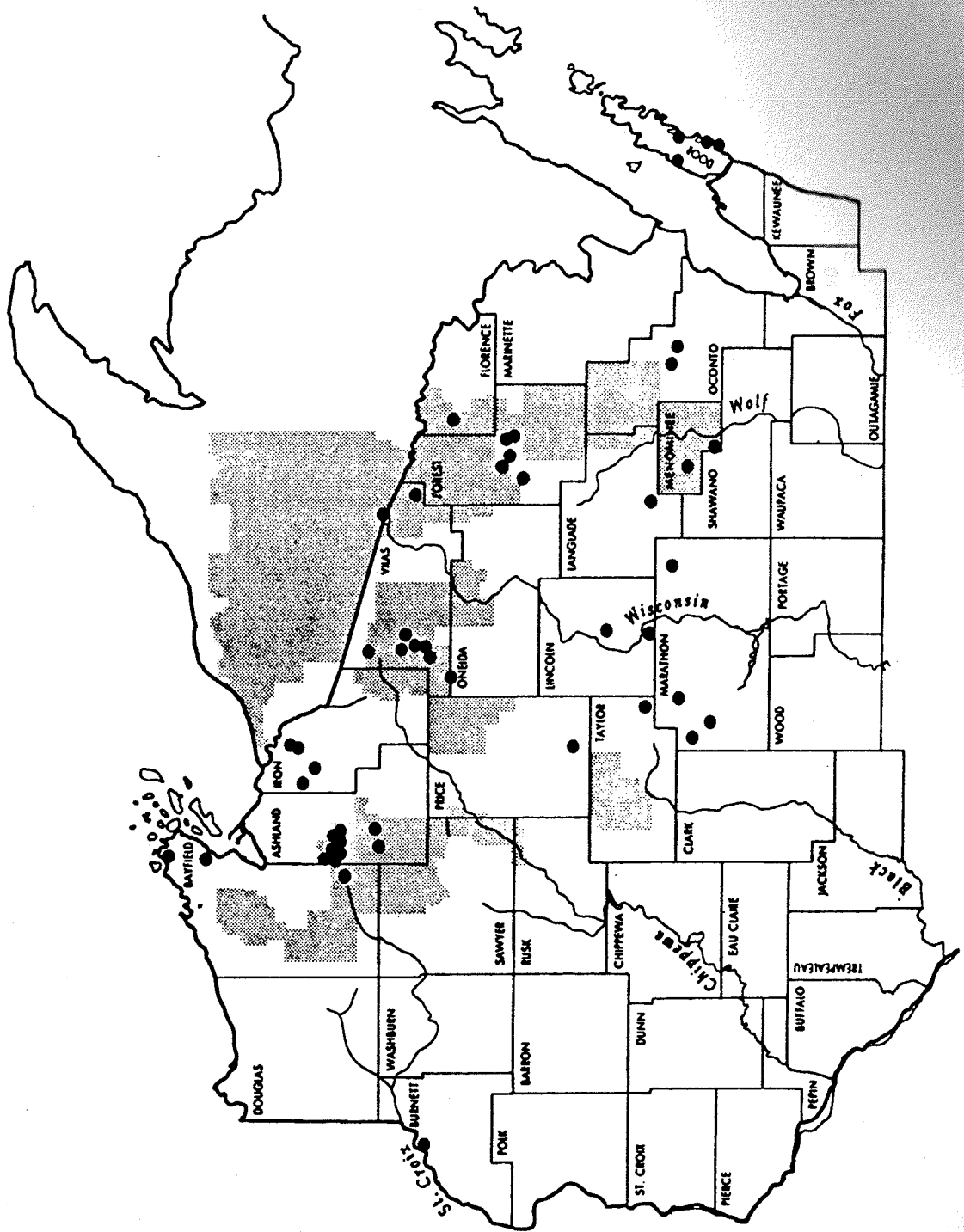


Figure 4- Diameter at first root vs. Age for 262 Canada yew ramets collected at 49 northern Wisconsin sites.

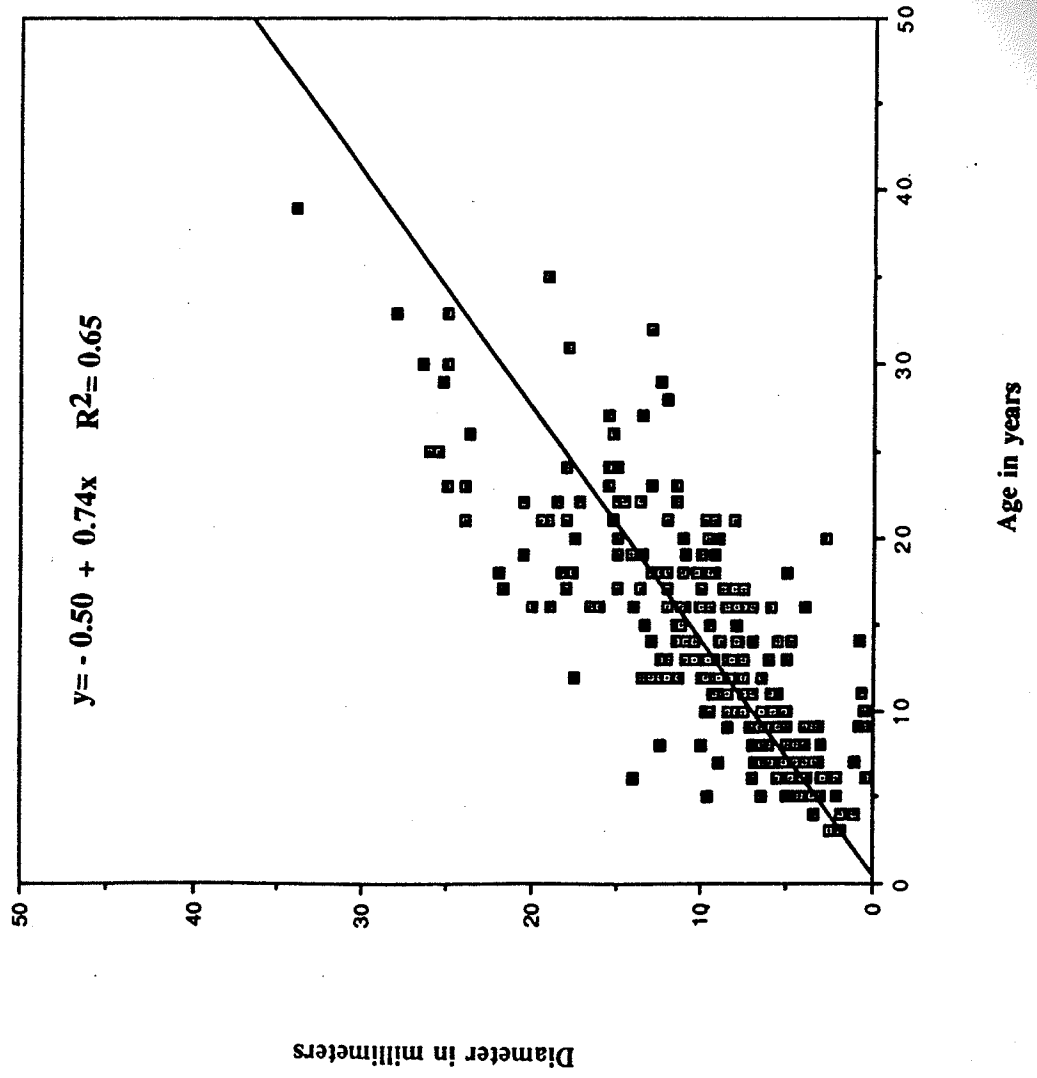


Figure 5- Height vs. age for 262 Canada yew ramets collected at 49 northern Wisconsin sites.

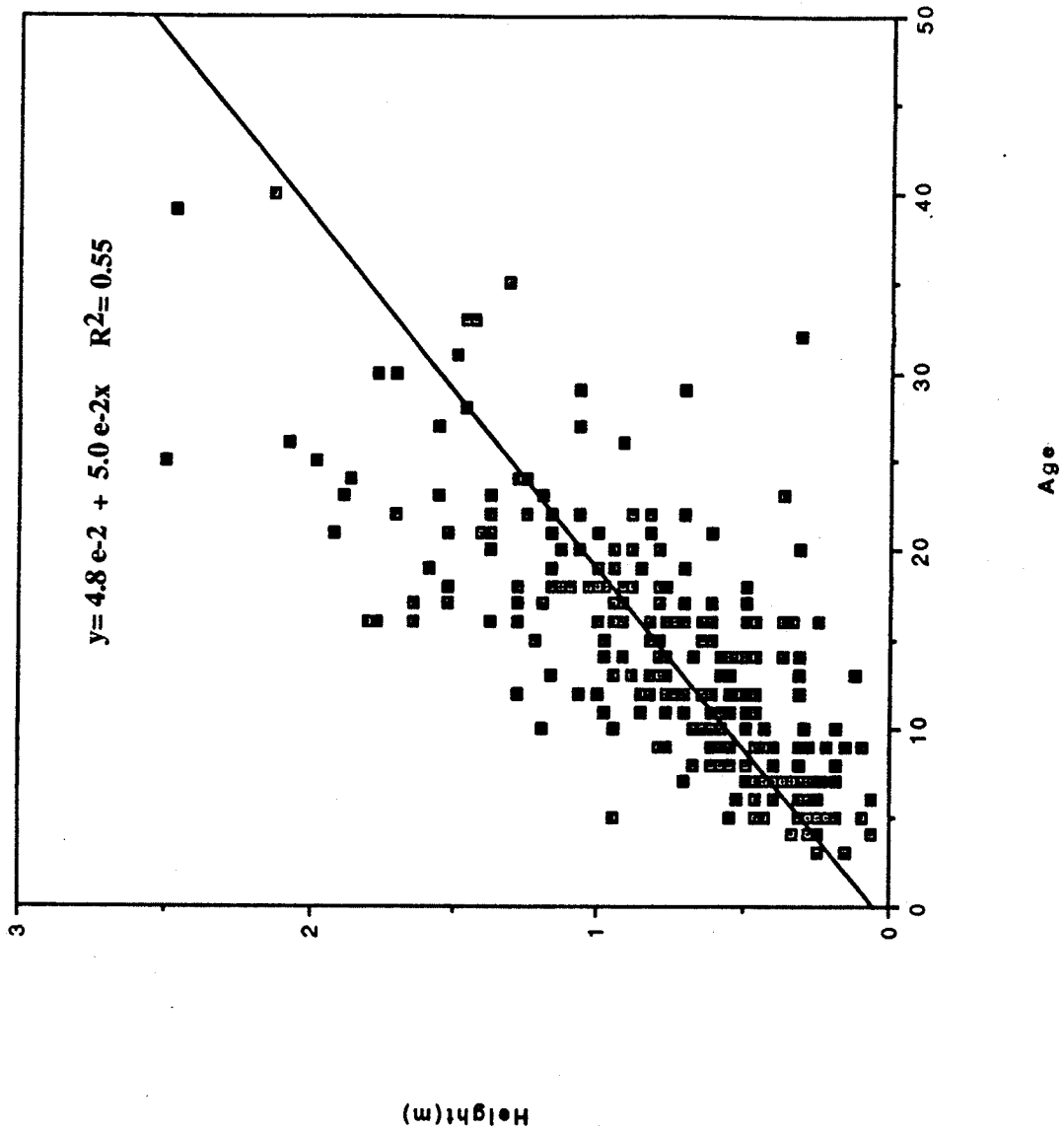
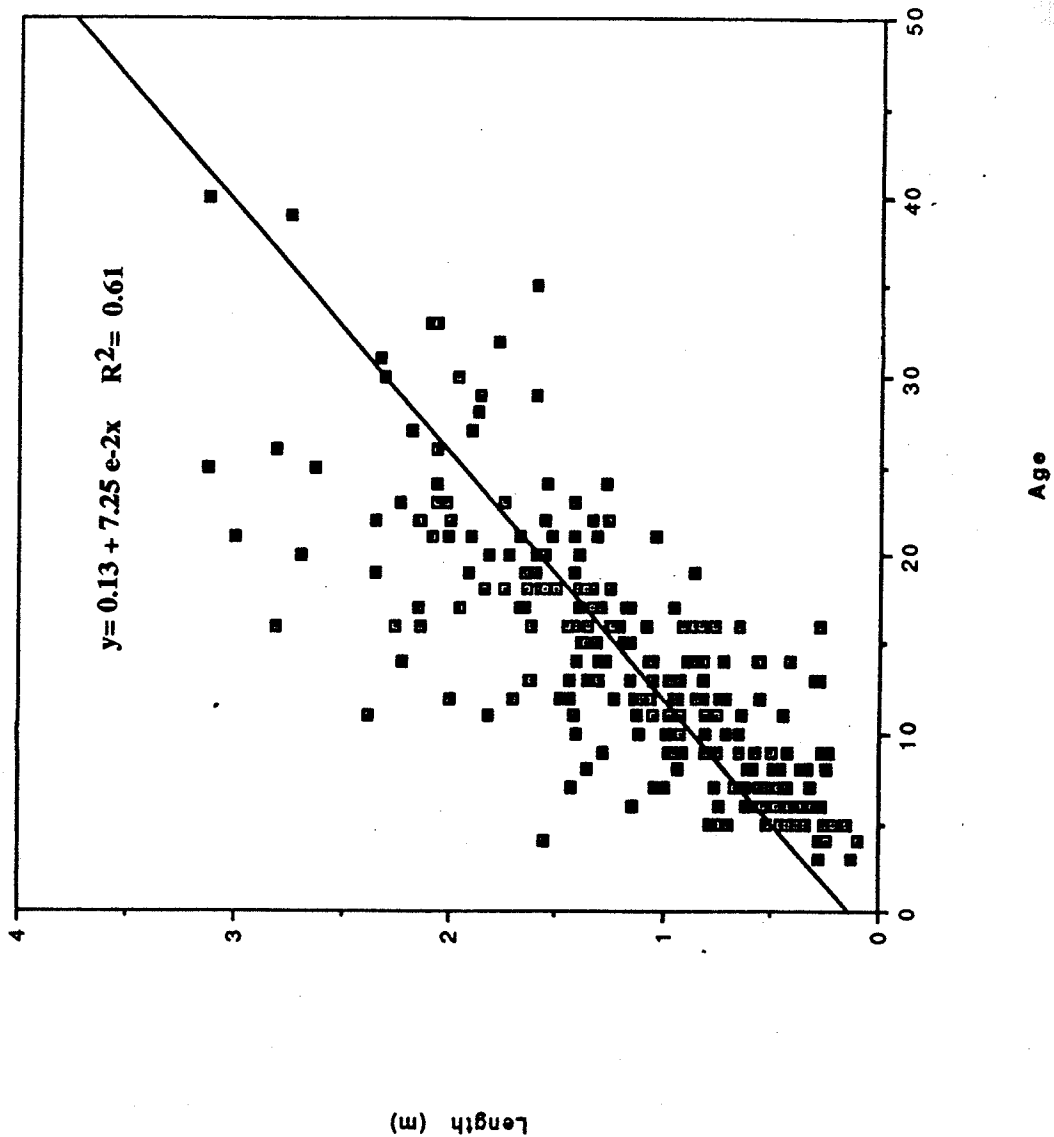
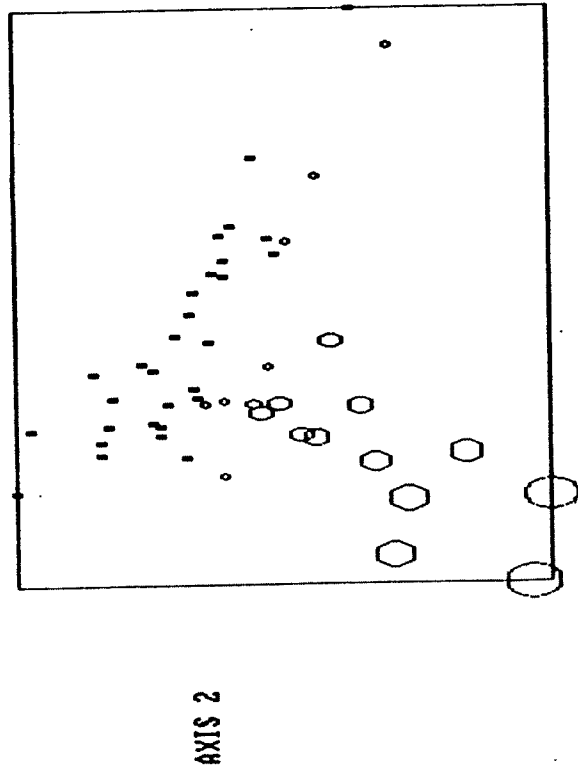


Figure 6- Length vs. age for 262 Canada yew ramets collected at 49 northern Wisconsin sites.

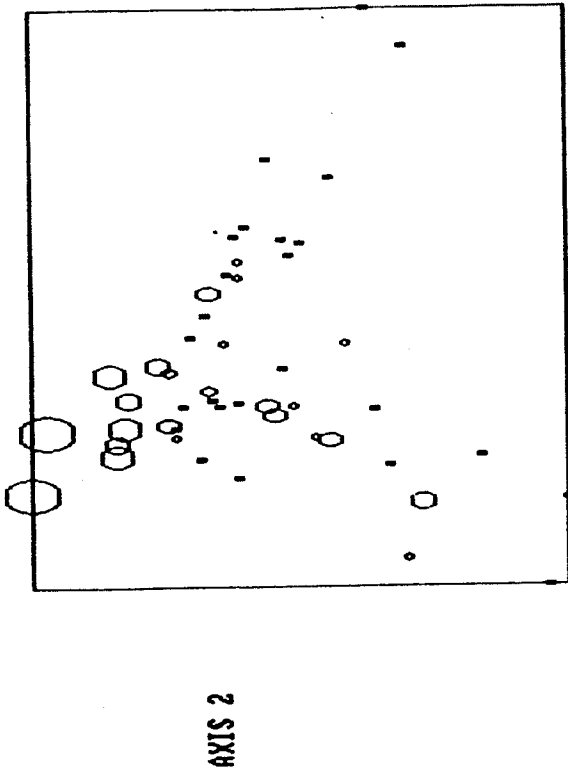


PCA ANALYSIS 49 YEW SITES ALL SPECIES, CENTERED ONLY



Overlay=TSUGAN AXIS 1 *Tsuga canadensis*

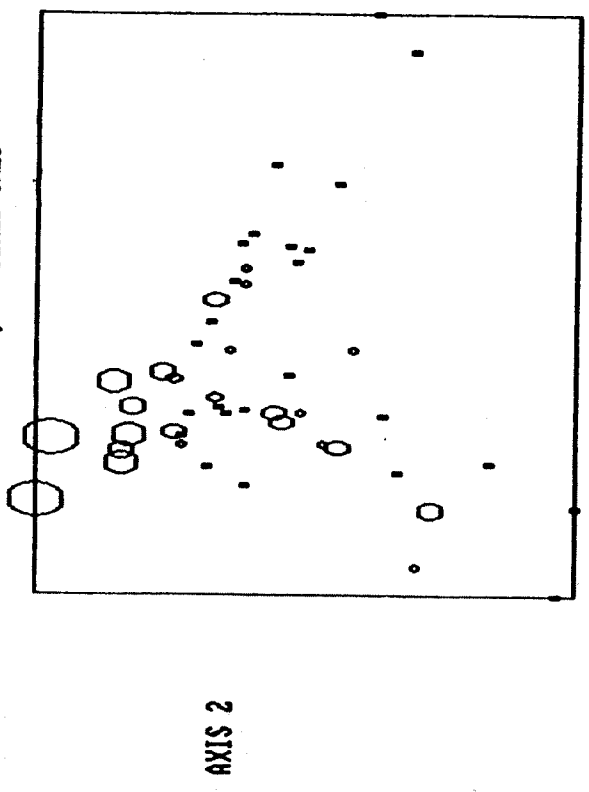
PCA ANALYSIS 49 YEW SITES ALL SPECIES, CENTERED ONLY



Overlay=TAXCAN AXIS 1 *Taxus canadensis*

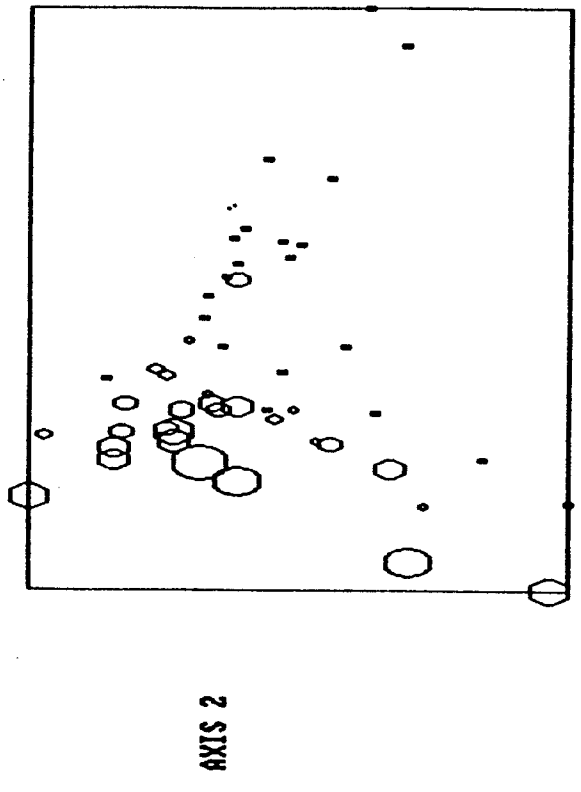
Figure 7. Comparison of Canada yew cover and hemlock cover. Circles are sized proportionally to plant cover and are centered over stands as ordinated in species' space by species centered PCA (McCune 1991). Axes 1 and 2 are the two orthogonal axes that explain the majority of variance in the placement of stands in the species' space.

PCA ANALYSIS 49 YEW SITES ALL SPECIES, CENTERED ONLY



Overlay=TAXCAN AXIS 1 *Taxus canadensis*

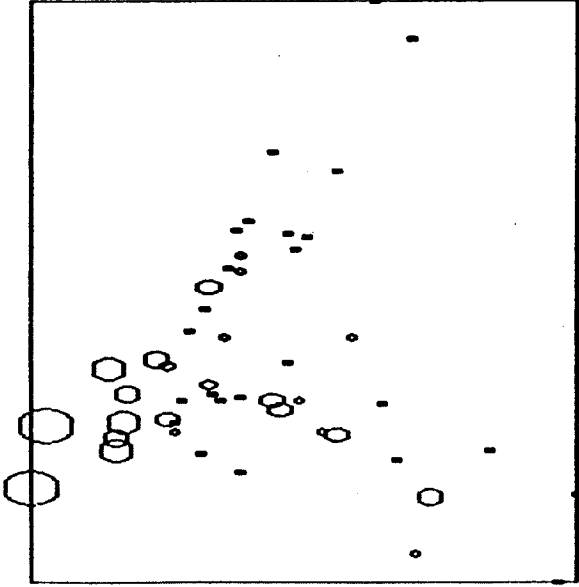
PCA ANALYSIS 49 YEW SITES ALL SPECIES, CENTERED ONLY



Overlay=ACESAC AXIS 1 *Acer saccharum*

Figure 8- Comparison of Canada yew cover and sugar maple cover. Circles are sized proportionally to plant cover and are centered over stands as ordinated in species' space by species centered PCA (McCune 1991). Axes 1 and 2 are the two orthogonal axes that explain the majority of variance in the placement of stands in the species' space.

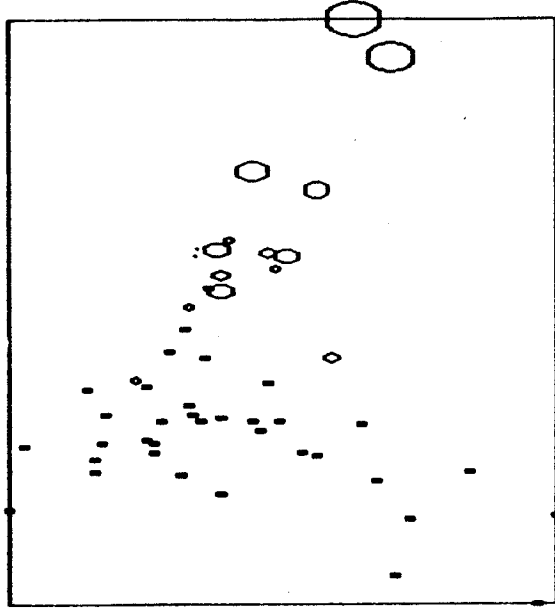
PCA ANALYSIS 49 YEW SITES ALL SPECIES, CENTERED ONLY



Overlay=TAXCAN

AXIS 1 *Taxus canadensis*

PCA ANALYSIS 49 YEW SITES ALL SPECIES, CENTERED ONLY

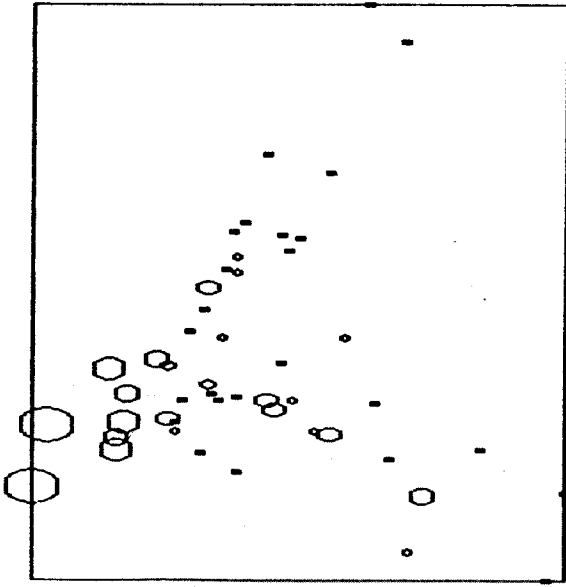


Overlay=THIOCC

AXIS 1 *Thuja occidentalis*

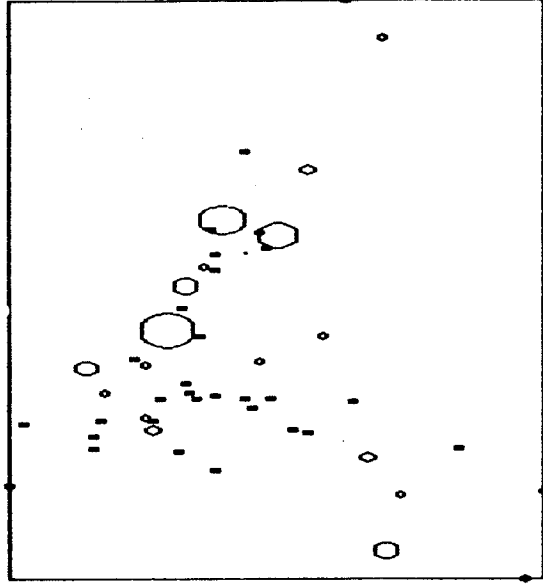
Figure 9. Comparison of Canada yew and cedar cover. Circles are sized proportionally to plant cover and are centered over stands as ordinated in species' space by species centered PCA (McCune 1991). Axes 1 and 2 are the two orthogonal axes that explain the majority of variance in the placement of stands in the species' space.

PCA ANALYSIS 49 YEW SITES ALL SPECIES, CENTERED ONLY



Overlay=TAXCAN AXIS 1 *Taxus canadensis*

PCA ANALYSIS 49 YEW SITES ALL SPECIES, CENTERED ONLY



Overlay=ACESPI AXIS 1 *Acer spicatum*

Figure 10- Comparison of Canada yew and striped maple (*Acer spicatum*) cover. Circles are sized proportionally to plant cover and are centered over stands as ordinated in species' space by species centered PCA (McCune 1991). Axes 1 and 2 are the two orthogonal axes that explain the majority of variance in the placement of stands in the species' space.

Figure 11- Canada yew cover vs. pH at 49 northern Wisconsin sites. Yew cover data are conservatively arcsine square root transformed (McCune 1991).

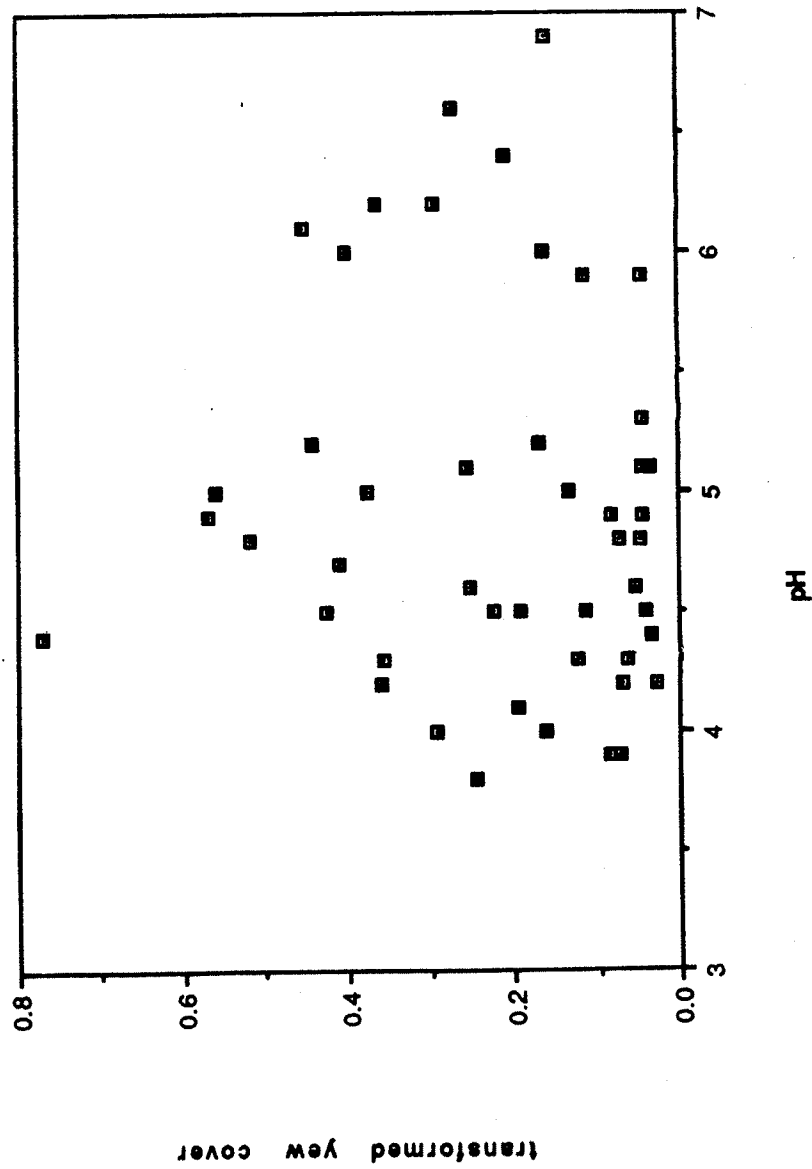


Figure 12- Canada yew cover vs. percentage of soil that is organic material at 49 northern Wisconsin sites. Yew cover data are conservatively arcsine square root transformed (McCune 1991).

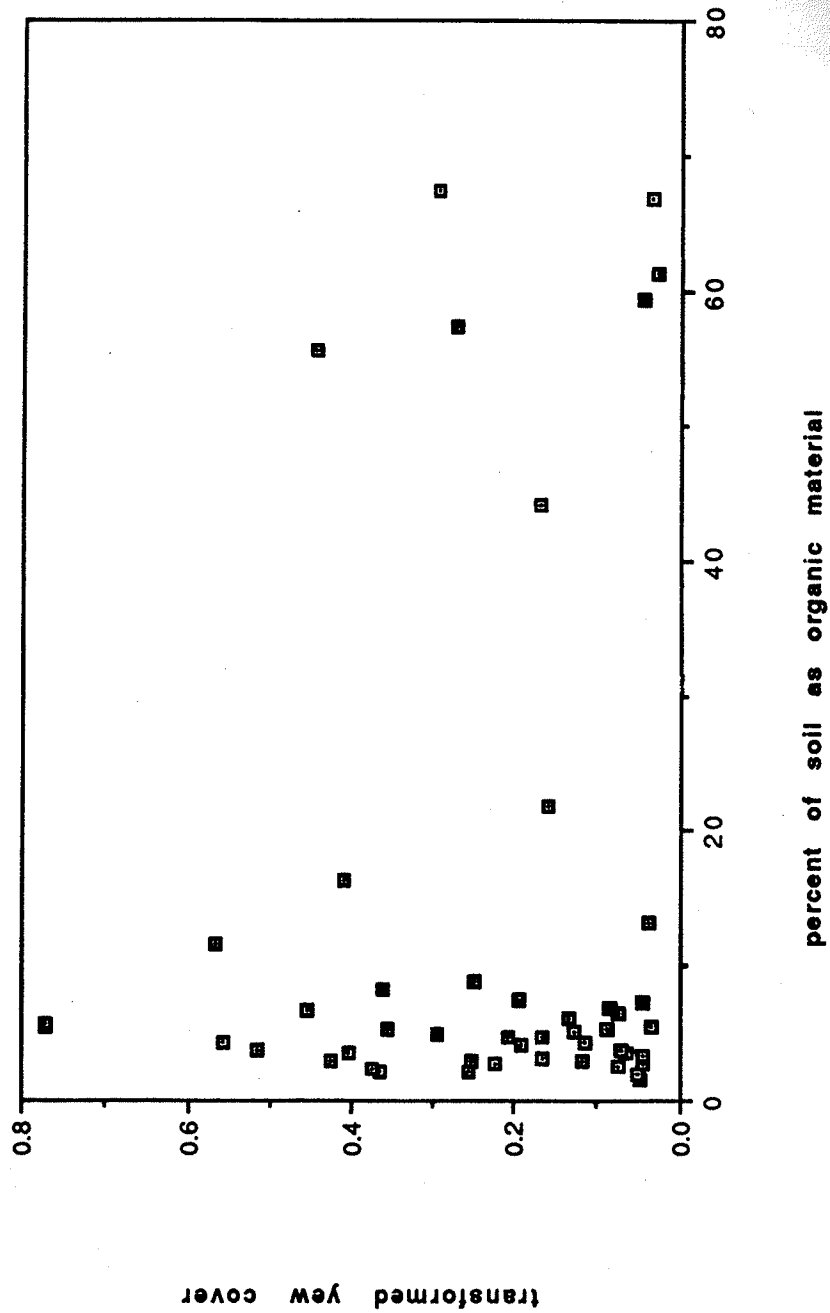
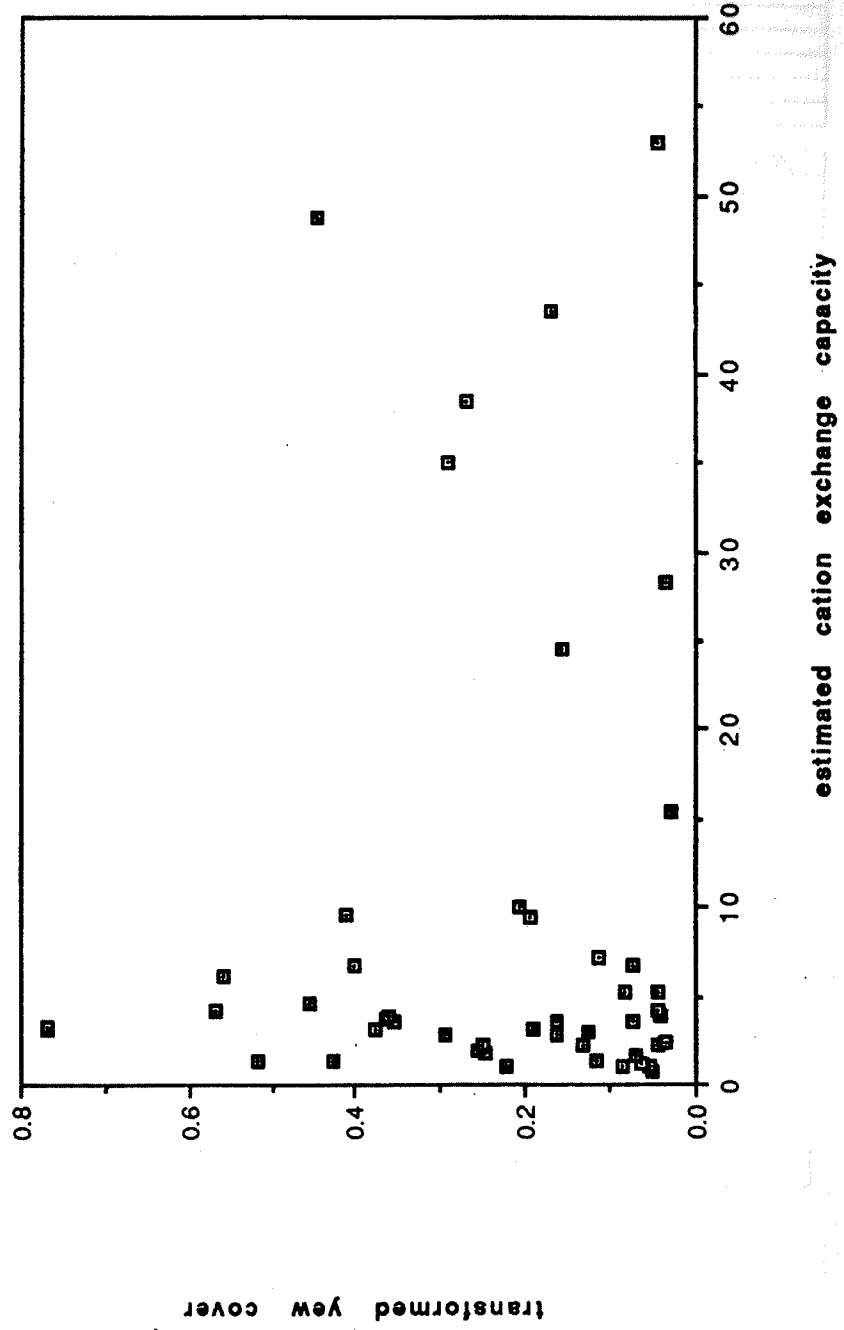


Figure 13- Canada yew cover vs. estimated cation exchange capacity at 49 northern Wisconsin sites. Yew cover data are conservatively arcsine square root transformed (McCune 1991).



Site:
Date:

Investigator/s:

APPENDIX II: Sample Data Sheets

Cover classes: 1=<5%, 2= 5-10%, 3=11-25%, 4=26-50%, 5=51-75%, 6=76-100%
Sub Plot (7m*7m): A -> F, see site map.

A	B	C	D	E	F	Ground Flora
						Allium tricoccum
						Anemone quinquefolia
						Anemone thalictroides
						Aralia nudicaulis
						Arisaema atrorubens
						Asarum canadense
						Caulophyllum thalictroides
						Clintonia borealis
						Coptis trifolia
						Cornus canadensis
						Cypripedium acaule
						Cypripedium calceolus
						Dentaria diphylla
						Dentaria laciniata
						Galium triflorum
						Gaultheria procumbens
						Hepatica acutiloba
						Maianthemum canadense
						Mitchella repens
						Mitella diphylla
						Polygonatum pubescens
						Smilacina racemosa
						Sphagnum spp.
						Streptopus roseus
						Thalictrum dioicum
						Trientalis borealis
						Trillium cernuum
						Trillium grandiflorum
						Viola canadensis
						Viola cucullata
						Viola incognita
						Viola pallens

A	B	C	D	E	F	Ferns & Allies
						Adiantum pedatum
						Athyrium filix-femina
						Osmunda claytoniana
						Dryopteris spinulosa
						Onoclea sensibilis

A	B	C	D	E	F	Seedlings <1 ft.

A	B	C	D	E	F	Shrubs
						Taxus canadensis
						Dirca palustris
						Hamamelis virginiana
						Lonicera canadensis
						Vaccinium angustifolium

A	B	C	D	E	F	Seedlings 1-4.5ft.

A	B	C	D	E	F	Large Trees >10" DBH
						Abies balsamea
						Acer rubrum
						Acer saccharum
						Acer spicatum
						Betula allegheniensis
						Betula papyrifera
						Fraxinus americana
						Fraxinus nigra
						Pinus strobus
						Populus grandidentata
						Populus tremuloides
						Quercus rubra
						Thuja occidentalis
						Tilia americana
						Tsuga canadensis

A	B	C	D	E	F	Sap <4" DBH, >4.5'

A	B	C	D	E	F	Med. Trees 4-10" D

Browse on Reverse

Yew Ramet Data

Diam.	Ht.	Lngh.	Age.	Reprod.

cm m m YRS per Upper 1m²

Diam.	Ht.	Lngh.	Age.	Reprod.

Diam.	Ht.	Lngh.	Age.	Reprod.

Site:
Date:

Investigator/s:

Topography: 1 2 3 4 5 6

Overall Vegetation Coverage:

Configuration: 1 2 3 4

Aspect: 1 2 3 4

Slope:

Original Cover:

Overstory Dominants:

Soil Samples Collected:

Landform:

Habitat Type:

Soil Notes:

MUST INCLUDE COLOR, CHROMA, MOTTLING % by LAYER, +Litter description

Species	4	6	8	10	12	14	16	18	20										
<i>Abies balsamea</i>																			
<i>Acer rubrum</i>																			
<i>Acer saccharum</i>																			
<i>Acer spicatum</i>																			
<i>Betula allegheniensis</i>																			
<i>Betula papyrifera</i>																			
<i>Fraxinus americana</i>																			
<i>Fraxinus nigra</i>																			
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<i>Populus grandidentata</i>																			
<i>Populus tremuloides</i>																			
<i>Quercus rubra</i>																			
<i>Thuja occidentalis</i>																			
<i>Tilia americana</i>																			
<i>Tsuga canadensis</i>																			

Site Map:

TOPOGRAPHY:

- 1 - RIDGE
- 2 - UPPER SLOPE
- 3 - MID SLOPE
- 4 - LOWER SLOPE
- 5 - BENCH OR FLAT
- 6 - STREAM BOTTOM

CONFIGURATION:

- 1 - CONVEX (DRY)
- 2 - STRAIGHT
- 3 - CONCAVE (WET)
- 4 - UNDULATING

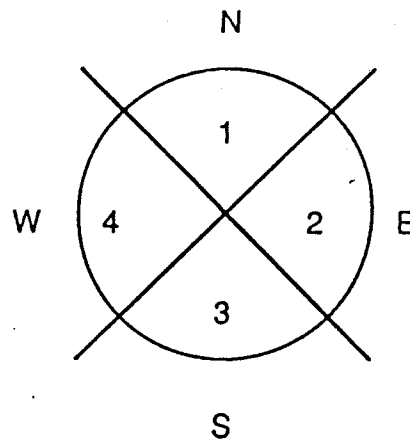
SLOPE:

- 1 - 0-10%
- 2 - 11-25%
- 3 - 36-50%
- 4 - > 50%

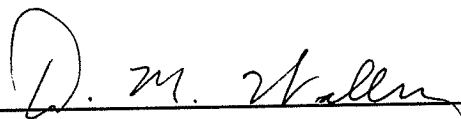
VEGETATION COVERAGE:

- 1 - 0-1%
- 2 - 2-5%
- 3 - 6-25%
- 4 - 26-50%
- 5 - 51-75%
- 6 - >75%

ASPECT: (1-4)



Approved by:

A handwritten signature in black ink, appearing to read "D. M. Waller", is written over a horizontal line.

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