The Effects of *Dennstaedtia punctilobula* on Tree Seedling Regeneration Post Forest Harvesting

FRST 497 Graduating Essay

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Abstract

Dennstaedtia punctilobula (Hayscented fern) is a native invasive fern found in eastern North America. It hinders the growth of many tree species, significantly *Acer saccharum* (Sugar Maple). This fern regenerates quickly on disturbed sites that range in light levels. This makes deforested sites an ideal growing habitat. *D. punctilobula* is able to hinder the growth of tree seedlings by intercepting sunlight with their thick frond canopy. The thick fronds also make an ideal living habitat for insects and rodents which are known to feed on germinating tree seedlings. As well, its thick root system is proven to possess allelopathic attributes which result in a physical and chemical barrier to germinating tree seedlings. Nutrients found in the mineral soil are necessary for tree seedlings to grow; however, growth is impeded by the fern's roots. Although *D. punctilobula* is a difficult species to remove from a site once established, its further growth and expansion can be hindered through different tree harvesting designs and alternative silvicultural practices of scalping, mowing and herbicide treatments.

Key Words:

Dennstaedtia punctilobula, Hayscented fern , *Acer saccharum*, Sugar Maple, growth, frond, canopy, regeneration, deer, herbicide, mowing, scalping, scarification

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Introduction

The Northern Hardwood forest is located in eastern North America and is known for its tree species diversity. *Acer saccharum* (Sugar Maple) is found in this region and is known on a global scale for making maple syrup. As a result, eastern North America is the top producer in the world of maple syrup. Furthermore, it is also seen as a strong cultural identifier for many Canadians. *Dennstaedtia punctilobula* (Hayscented fern) is threatening this multimillion dollar industry because it impedes the germination of not only Sugar Maple, but also the majority of other deciduous tree species located in the region. This paper will discuss the effects of *D. punctilobula* on the germination of many tree species, but with a focus on *A. saccharum*. This literature review will discuss in detail the fern's range of distribution, ecology, and effects on *A. saccharum* and other tree species. Current mitigation methods to control the fern will also be discussed, followed by silvicultural advice that promotes the reestablishment of healthy and diverse forest stands. Lastly, the future outlook for eastern North America's forests will be reviewed based on a 'no-action' approach to mitigating *D. punctilobula*.

Background, History and Range of Habitat

D. punctilobula is a native invasive fern located in eastern Canada and United States (Hill & Silander, 2001; Cody *et al*, 1977). Figure 1 exhibits the distribution of *D. punctilobula* in Canada. It is homosporous and a member of the leptosporangiate fern group, which means that the sporangia arise from a single epidermal cell (Cody *et al*, 1977). The fern responds aggressively to disturbed sites by its ability to spread vegetatively through rhizomes, as well as sexually through spore dispersal (Penrod & McCormick, 1996; Hughes & Fahey, 1991).

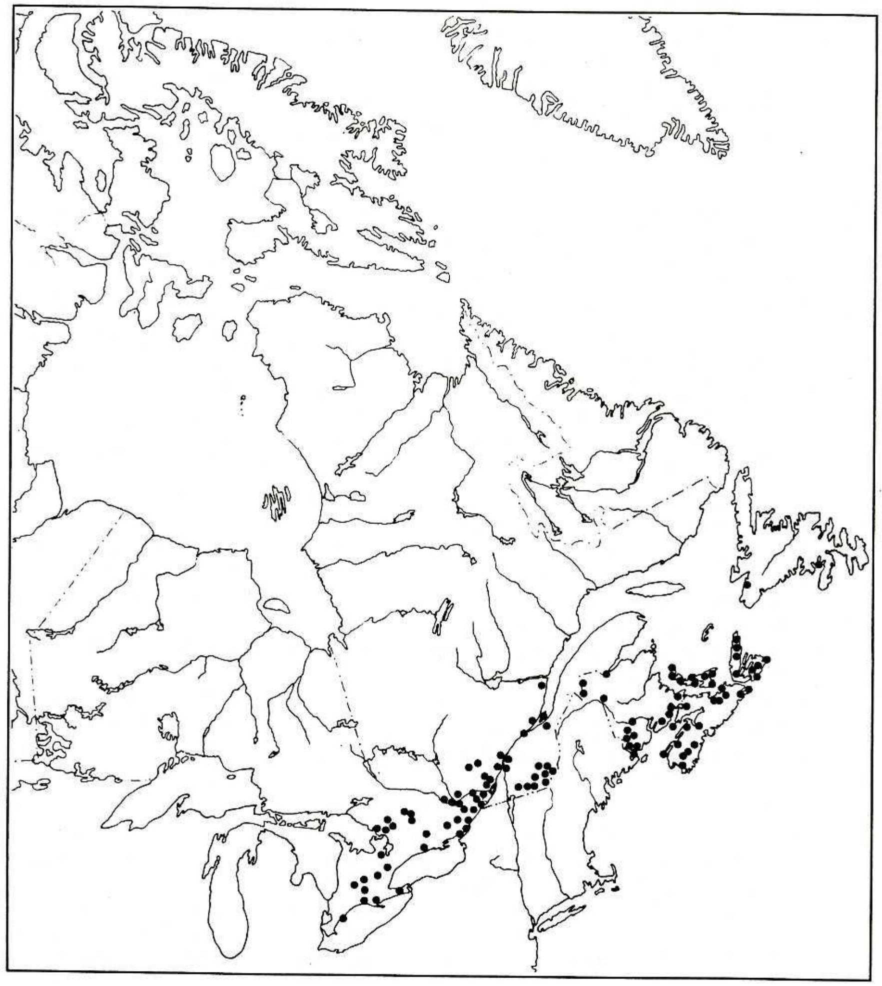

Figure 1: Distribution of *Dennstaedtia punctilobula* in Canada (Cody *et al*, 1977).

D. punctilobula's distribution is not limited by isotherms, annual precipitation, length of growing season or average number of frost free days in the Northern Hardwood forest (Cody *et al*, 1977). As a result, this makes the fern quite adaptable to it choice of growing sites. Cody *et al* (1977) support this finding by noting that the fern grows on sites where site precipitation varies; site temperature ranges between -29C and 38C; frost-free period ranges between 120-180 days; and the growing season ranges between 160-220 days.

D. punctilobula can easily be found in abandoned pastures and along roadsides in eastern Canada (Cody *et al*, 1977). The upturned mineral soil makes ideal microsites for *D. punctilobula*. This is also why the fern is being found in greater abundance in forest understories. The disturbed forest floor and increased light availability support the fern's natural growing habitat. In these areas with exposed mineral soil, *D. punctilobula* can form dense colonies which deter the growth of other shrubs and seedlings. This aggressive behaviour is detrimental in many habitats with high species diversity because it delays, or in some cases, prevents the regeneration of many tree seedlings. However, this fern can be beneficial following a large natural disturbance where the humus layer has been removed, such as with a fire. In these cases, the attributes which are typically viewed as being negative become adventitious to a site's regeneration. Due to its ability to form a dense ground cover, it prevents soil erosion with its matted-root system and the dead fronds protect the soil from eroding. Furthermore, it maintains soil nutrients by preventing rain runoff.

Reproduction and Growing Habitat

The full reproduction process is described in detail by Cody *et al* (1977):

"The reproduction of D. punctilobula *occurs by means of spores that are produced in sporangia clustered under the cup-shaped indusium of the small round sorus situated on the upper margin of the under sides of the lobes of the pinnules. A spore germinated to form a small green prothallus. The male prothallus is always only one cell thick. Antheridia may arise at any point on the shaded side and the prothallus may continue to grow for 5 mo or more and produce great numbers of antheridia. The female prothallus is always chordate in shape and about three cells in thickness. The archegonia are borne on the underside of a central thickening or swelling. Only rarely are prothalli hermaphroditic. A motile spermatozoid from the antheridium (one from each of the 32 sperm mother cells) fertilizes the egg or oosphere. The resultant zygote then germinates and produces a sporeling which grows into the familiar fern plant. Archegonia will continue to be produced on a prothallus until one is fertilized, but only one sporeling per prothallus will grow to maturity."*

The spores found in the sporangium weigh very little and when launched, typically fall within 5-10 m of the mature plant (Cody *et al*, 1977); however, they have been found as far away as 3-4 km from the closest mature fern colony (Penrod & McCormick, 1996). In addition, *D. punctilobula* spores have been found to germinate up to 10 years after production (Hammen, 1993; Cody *et al*, 1977). Even if the spores land a great distance from the original fern colony, it is very difficult for them to germinate if they do not land on an appropriate microsite. The fertilization process is quite fragile and the conditions need to be appropriate for a spore to find an ideal germination location which also happens to be in close proximity to a prothallus of the other sex (Cody *et al*, 1977). For example, a dry season will restrict the ability of fertilization because water is needed to maintain the prothallus which is also very sensitive to environmental conditions.

When a spore does land on an appropriate microsite, it will germinate in approximately 16 days (Cody *et al*, 1977). Throughout the growing season, D. *punctilobula* decreases in abundance (Hill & Silander, 2001) due to a diminishing supply of nutrients. The majority of *D. punctilobula*'s development occurs between May and June; however, new fronds may arise between May and September or until the first sharp frost (Cody *et al*, 1977). The first frost kills the existing fronds and prevents further growth until the next growing season. *D. punctilobula* matures within three years (Roberts & Laurence, 1935).

D. punctilobula rhizomes have a forking structure and are found 5-15 cm below the ground's surface (Cody *et al*, 1977). The fern's roots also have a symbiotic relationship with mycorrihizal fungi which may assist in nutrient gathering (Conard, 1908). *D. punctilobula* can vegetatively reproduce which permits rapid colonization of an area through root expansion. Furthermore, since it has the ability to vegetatively and sexually reproduce this makes it difficult to completely remove from a site once established (Hill & Silander, 2001). Hill and Silander (2001) noted that *D. punctilobula* rhizomes can grow at a rate of roughly 9 cm/yr while Cody *et al* (1977) noted that an individual rhizome may exceed 11 cm/yr due to its forking structure and changing direction.

As noted above, *D. punctilobula* has the ability to withstand and reproduce quickly after natural disturbances that expose the mineral soil, such as with fire and logging. If the fern is already present on a site prior to the disturbance, the next growing season will result in a boom in the population due to the rhizomes being undamaged and the increase in available light (Engelman & Nyland, 2006). Many natural disturbances release nutrients back into the soil, which also contributes to the fern's ability to populate rapidly. *D. punctilobula* can be useful in many severely disturbed sites because it has the ability to grow on rocky or sterile fields (Cody *et al*, 1977).

D. punctilobula spores need to land on the appropriate substratum to germinate. It grows best on exposed, moist mineral soil. As a result, logging operations provide an ideal habitat for spore landing, prothallus development, fertilization and a new adult fern to grow (Groninger & McCormick, 1992). Furthermore, although it has the ability to grow rapidly on mineral soil, it can naturally be found in open woods, clearings and the banks of roads where sunlight is abundant (Hill & Silander, 2001; Hughes & Fahey, 1991; Flaccus, 1959; Conard, 1908). It has no specific soil richness or moisture content specifications; therefore, *D. punctilobula* is a very dynamic and persistent species. Due to *D. punctilobula's* ability to grow on a variety of surfaces, it has been found in swampy areas all the way to limestone ledges (Engelman & Nyland, 2006; Cody *et al*, 1977).

D. punctilobula is not restricted by soil acidity and can grow in a multitude of pH levels (Cody *et al*, 1977). Hou (1950) noted that the fern dominated and thrived in stands with lower pH levels, around 3.4 to 4.8. It was further noted that as the soil pH decreased**,** the availability of manganese increased. Maganese is a critical nutrient needed for fern growth. Therefore, this newly avaialble nutrient could be an aiding factor to a population boom in *D. punctilobula* in lower pH soils. When acid rain began to alter the soil bonding capabilities in the 1960s, it resulted in a change of available soil nutrients in eastern Canada and United States. Acid rain has leeched certain elements from the A horizon into lower soil horizons making accesibility to them more difficult for plants. *D. punctilobula* was found to be most abundant in areas where the potassium has been leeched away. The potassium leeched away becuase it was not able to bind in the upper soil horizons (Anundson, 1996). Potassium is considered a macronutrient to most plant species; therefore, if it is not found in the soil, plant growth diminishes and there is little competition against the fern for growing space.

D. punctilobula has the ability to respond quickly to increased light levels. It will germinate and reproduce with light levels as low as 2% full sun and reaches an asymptote of full growing capacity at 15% full sun (Hill & Silander, 2001). Furthermore, this species is capable of efficiently using sunflecks to maintain a positive net photosynthetic rate (Brach *et al*, 1993; Gildner & Larson, 1992; Hollinger, 1987). This developed ability adds to the fern's tenacity at growing in the most difficult places.

Increased light levels and exposed mineral soil are the two factors that determine the growth rate of D. *punctilobula* population. As a result, it was least abundant under shade-tolerant tree species such as *Tsuga canadensis* (Eastern Hemlock) and *Fagus grandifolia* (American Beech) (Hill & Silander, 2001). Hill and Silander (2001) found that these two tree species do not permit high levels of light to permeate through to the understory. Less than 2% full sun was permitted to the understory by these two species and, as a result, the only populations of *D. punctilobula* found were located in canopy gaps.

Fei *et al* (2010) found that an abundance of *Acer rubrum* (Red Maple) in a stand was indicative of there being a population of *D. punctilobula* present in the understory. They noted that after the removal of Red Maple, a dense population of *D. punctilobula* would emerge. The fern was able to grow rapidly, which resulted in a hindrance of tree seedling regeneration if herbicides were not used to create a "window of opportunity" (Fei *et al*, 2010). It is not known what encourages the growth of the fern on Red Maple sites; however, it should be noted that Red Maple indicates that silvicultural treatments are required in these stands post forest harvesting to promote tree seedling regeneration.

Problems *D. punctilobula* Causes to Tree Seedlings

D. punctilobula has been found to decrease growth and survival of all tree seedlings (George & Bazzaz, 1999b). The fern directly impedes the growth of tree seedlings in four ways:

1. The root mat, which consists of the roots, rhizomes, fronds and overstory litter, impedes the germination of new tree seedlings. Tree seedlings are hindered from making contact with the mineral soil and / or are prevented from getting enough light and heat to stimulate the seedlings already stored in the soil (Engelman & Nyland, 2006; Cohen *et al*, 1995; Fenner, 1985). However, once the tree seedlings push past the root mat, they appear to be no longer effected by the fern (Anundson, 1996).
2. The fern frond canopy hinders light quality and alters red and far red ratios of transmitted light to germinating seeds (George & Bazzaz, 1999a; Mayer & Poljakoff-Mayber, 1982). It was recorded by George and Bazzaz (1999a) that *D. punctilobula* reduced light levels

from 3.4% full sun to 1.1% full sun. This low light level is past the acceptable limit for many tree seedlings to be able to germinate.

3. *D. punctilobula* competes for water, food and nutrients (Lyon & Sharpe, 1996).
4. *D. punctilobula* has allelopathic qualities found in its roots and fronds which may inhibit tree seedlings from germinating (Anundson, 1996; Horsley S. B., 1993).

Through *D. punctilobula*'s ability to rapidly spread and create a thick monoculture, it also provides protection to small rodents and insects (George & Bazzaz, 1999a). The thick fronds make it difficult for predators to see their prey and consequently keep rodent populations' in check. The tree seedlings that do establish are then subjected to being eaten by these insects and rodents. This is another hurdle the tree seedlings need to overcome to be successful and grow over the fern canopy.

Anundson (1996) noted that where *D. punctilobula* was plentiful, Sugar Maple was dying. Furthermore, de la Cretaz and Kelty (1999) noted that other predominant species such as *Quercus rubra* (Red Oak), Red Maple, and *Fraxinus americana* (White Ash) were absent from the taller height classes. This indicates that in the previous forest harvesting, these species were incapable of growing through the fern layer. De la Cretaz and Kelty (1999) found that the only tree species capable of growing through the fern canopy without any silvicultural assistance were *Betula lenta* (black birch) and *Pinus strobus* (white pine). George and Bazzaz (1999) noted that *Betula* spp., *Pinus* spp. and *Quercus* spp. were also hindered by the fern. Maples were completely hindered during the summer growing season, but not completely in the spring season (George & Bazzaz, 1999a). Maples have the ability to break bud earlier, before the fern's fiddleheads unfurl to impede sunlight to the understory. This permits Maples to begin growth earlier in the season and offers a competitive advantage against the fern. Otherwise, all other tree species are incapable of pushing past the fern layer since they are either absent from the overstory in mature forests or have diminished in abundance. Figure 2 depicts a bar graph which depicts the effects of canopy species on fern abundance. Note that, Eastern Hemlock does not provide a good growing habitat for *D. punctilobula* as is evident by the minimal frond density; however, in open areas the frond density increases past 125 no./m². All other species can be seen as being supportive of a *D. punctilobula* understory. Sugar Maple is represented by the acronym

ASCA. Table 1 shows which tree species *D. punctilobula* impedes and the journal articles that studied the resulting growth effects. *D. punctilobula* is represented by the letter 'D'.

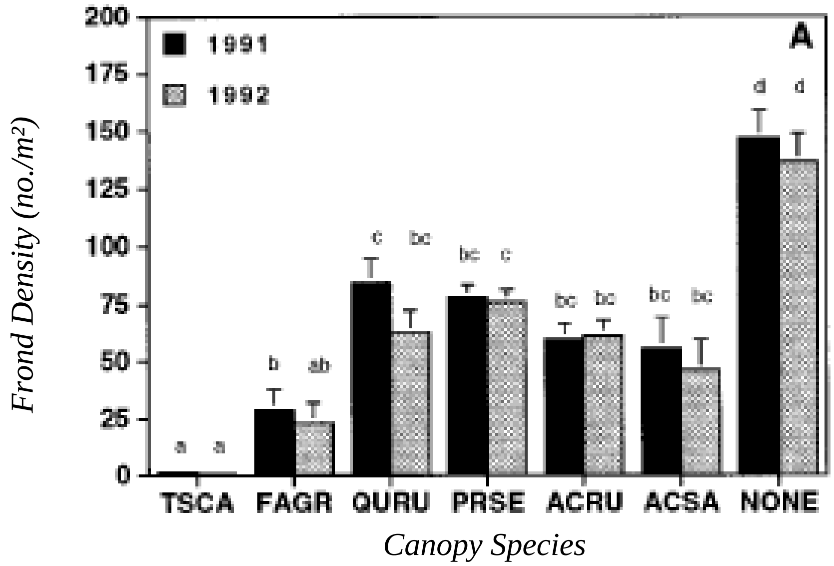

Figure 2: Partial list of tree species inhibited by D. punctilobula (Hill & Silander, 2001). The acronym definitions are: TSCA (*Tsuga canadensis*), FAGR (*fagus grandifolia*), QURU (*Quercus rubra*), PRSE (*Prunus serotina*), ACRU (*Acer rubrum*), ACSA (*Acer saccharum*), and NONE is a gap in the forest canopy. The solid bars represent the study in 1991 and the grey bars are from the 1992 study. Shared letters indicate that the means are not significantly different.

Tree	Fern	Source
Abies balsamea	P	Place 1952; Cody and Crompton 1975
Abies grandis	P	Ferguson and Adams 1994
Acer rubrum	D	Maquire and Forman 1983; George and Bazzaz 1999a
Betula allegheniensis	D	George and Bazzaz 1999a
Fraxinus america	D	Bowersox and McCormick 1987
Liriodendron tulipifera	D	Bowersox and McCormick 1987, McCormick and Bowersox 1997
Picea engelmannii	P	Comeau et al. 1993
Picea glauca	P	Place 1952; Cody and Crompton 1975
Picea rubens	P	Place 1952; Cody and Crompton 1975
Pinus contorta	P	Ferguson and Adams 1994
Pinus radiata	P	Karjalainen and Boomsma 1989
Pinus strobus	D	George and Bazzaz 1999a
Pinus sylvestris	P	Jones 1947, Dolling 1996b
Populus spp.	P	Dolling 1996a
Prunus serotina	D	Horsley and Marquis 1983, Horsley 1977b, 1989, 1993a, Drew 1990
Prunus serotina	P	Horsley 1977a
Prunus serotina	T	Horsley 1977b
Pseudotsuga menquisii	P	McCulloch 1942, Stewart 1975, Stewart et al. 1979
Quercus rubra	D	Hanson and Dixon 1985, 1987, Bowersox and McCormick 1987, McCormick and Bowersox 1997, Lyon and Sharpe 1996, George and Bazzaz 1999a, 1999b

Table 1: A list of tree species that are inhibited by *D. punctilobula* – 'D' (Engelman & Nyland, 2006).

Deer Browsing

The fronds of *D. punctilobula* are inedible to insects, rodents and deer because of their secondary phenolic compounds (Cody *et al*, 1977; Bohm & Tryon, 1967). This indicates that there has been no evolutionary predator to control the population of this fern.

Tree seedlings have difficulty surpassing the fern root mat, the frond canopy, the competition for nutrient resources and the need to grow counter the attacks of insects and rodents found underneath the frond canopy. If the tree seedlings are able to surpass all aforementioned deterrents, they also have to compete with deer in many areas upon surpassing the frond canopy. The majority of seedlings that push through the frond canopy are subjected to deer browsing. The fern protects the seedlings from browsing when young and hidden by the frond canopy. White-tailed deer (*Odocoileus virginianus* Boddaert) aid *D. punctilobula* at creating a monoculture in an area by eliminating the tree seedling competition. White-tailed deer eat the new growth of tree seedlings and can sometimes browse the previous year's growth as well. If the tree seedlings were permitted to grow above the fern canopy and not be hindered by browsing, they would eventually grow into the overstory. Eventually, the tree's shading of the forest floor would limit the growing environment of the fern (de la Cretaz & Kelty, 1999). Even in high deer browsing areas, white-tailed deer cannot completely hinder the growth of tree seedlings into the overstory. Fifteen years or more is needed of high grazing in an area for a complete monoculture of *D. punctilobula* to be created (de la Cretaz & Kelty, 1999). Figure 3 depicts the regeneration pattern of *D. punctilobula* depending on the use of different silvicultural treatments.

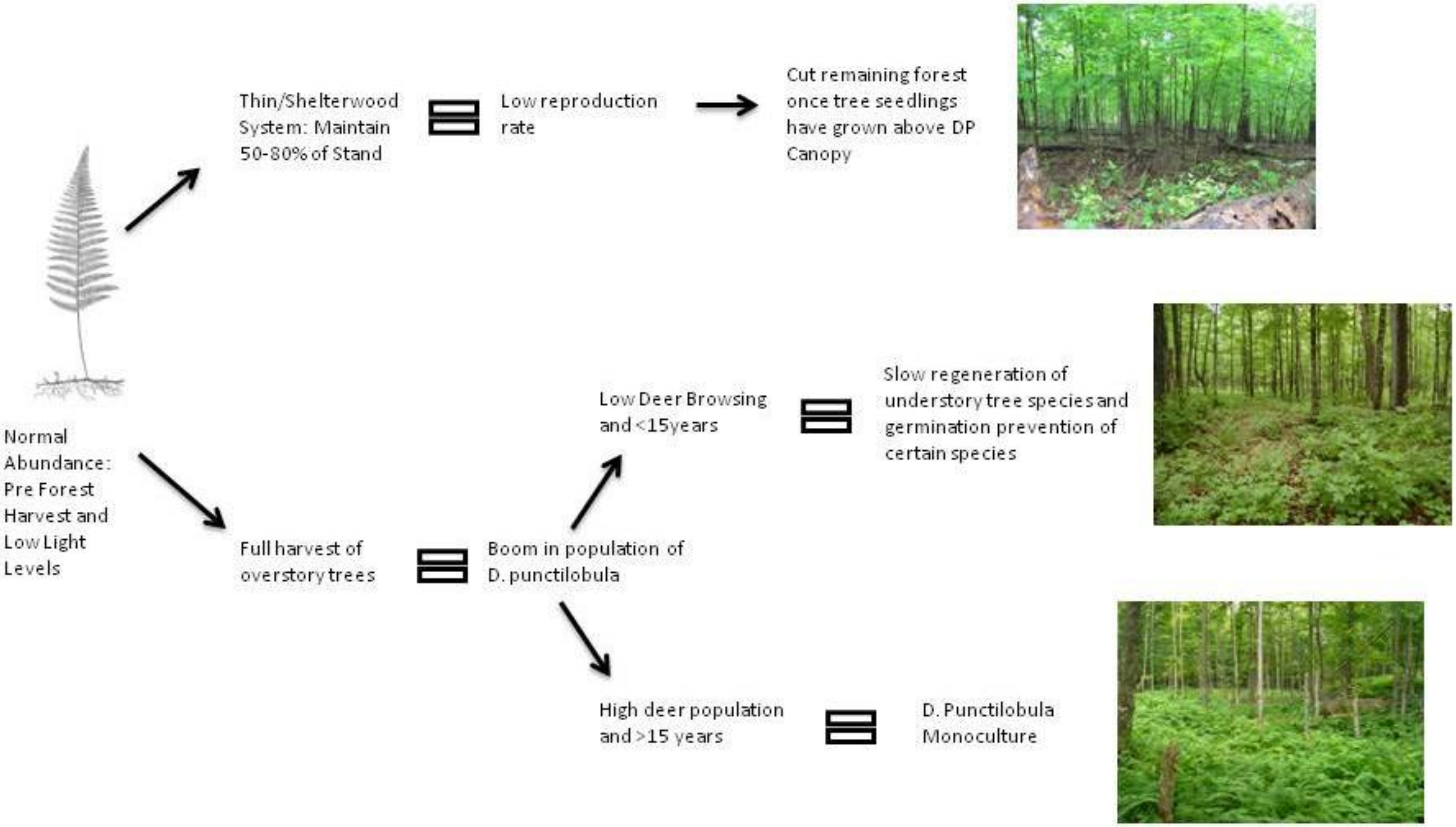

Figure 3: Regeneration pattern of *D. punctilobula* depending on different silvicultural treatments. Fern photo from Paulton, (1979) and top right photo taken from Wilson (2011).

Current Mitigation Methods

The mitigation methods used with *D. punctilobula* are listed below. They range from: adopting alternative forest harvesting methods, fencing a harvested area to prevent excessive deer browsing, scarification, mowing, scalping and herbicide use.

A land manager can do intelligent silviculture prescriptions to prevent a land base from being taken over by *D. punctilobula*. For example, upon harvesting a stand, a shelterwood system could be used to limit the amount of light accessing the forest floor. It is recommended that 50 to 60% of the residual trees be left to provide seedling stock and to shade the forest floor (Kelty, 1986). When harvesting a stand, soil compaction issues and ground scuffing need to be addressed and minimized as much as possible. Soil compaction and ground scuffed sites offer ideal growing habitat for *D. punctilobula*. Mou *et al*. (1993) found that on severely disturbed sites where soil compaction occured, fewer American beech **(***Fagus grandifolia*) and Sugar Maple stems regrew. Furthermore, both the trees' biomasses and densities were lessened as a result when they did grow. This indicates that seedlings have difficulty germinating on the compact soil and when they do germinate, they are smaller than normal. Therefore, the tree seedlings are less able to combat against the aggressive nature of the fern's growth on compacted and scuffed sites caused by heavy machinery**.** In addition, to minimize the compacted area of a site, a harvesting plan should be created to minimize skid trails. When extracting timber from an area, the methods should be an light as possible. The harvesting plan should minimize the amount of soil scuffing to prevent mineral soil from being exposed and creating germinating areas for *D. punctilobula.*

Fencing of an area can limit the effects of browsing on regenating tree seedlings (Engelman & Nyland, 2006). If the area being fenced is too large and would cost too much to create a useful perimiter, increased hunting in an area is also a solution. Horsley *et al.*(2003) found that a deer density of 8 deer/km^2 would permit regeneration over a large landscape for many tree species. Engelman and Nyland (2006) also found that a deer density 5-10 deer/km^2 would also permit regeneration. Therefore, if a deer population is high, it is suggested that more hunting permits be distributed for a hunting season to diminish the deer population.

Scientists have researched the effects of scarification, mowing and scalping on harvested sites to determine how it would alter the relationship between *D. punctilobula* in competition with the growth of tree seedlings. Scarification mixes the forest organic layer with the mineral soil below it (de la Cretaz & Kelty, 1999). Mowing cuts the vegetation growing on the soil's surface without churning the humus and mineral soil (de la Cretaz & Kelty, 1999). Scalping, or root-raking, removes the organic layer off the forest floor to expose the mineral soil beneath (de la Cretaz & Kelty, 1999).

Numerous studies have shown that scarification only encourages the growth of *D. punctilobula* (de la Cretaz & Kelty, 1999). By mixing the nutrient rich organic matter in with the mineral soil, it provides an ideal growing habitat for the fern. The effect is magnified if *D. punctilobula* grew on the site prior to harvesting and the fern's root mat was already in place. By scarifying the site, it breaks apart the root mat and spreads the rhizomes faster than the fern could have done naturally within a growing season.

Mowing has proven a useful deterrent to the fern's growth. By clipping the fronds and leaving them to fall to the litter layer, it provides nutrients to the growing tree seedlings through the frond's decomposition and their weight also helps suppress the germination of other tree and shrub seedlings found in the soil that have not yet grown (Engelman & Nyland, 2006). When mowing is done repeatedly over the mature fronds, it prevents them from fully regenerating which depletes their starch reserves which are necessary to produce new fronds (Cox, 1915). When mowing is done for a minimum of two years, tree seedlings are able to capitalize on the available sunlight and can grow rapidly (de la Cretaz & Kelty, 1999). Most landowners preferred this method of fern suppression because it requires no herbicides and only needed to be done twice a year for a two year period (de la Cretaz & Kelty, 1999).

Scalping was also found to be useful in areas that were not predisposed to *D. punctilobula*. Although it does remove the nutritious organic layer, it provides ample growing habitat for emerging tree seedlings (de la Cretaz & Kelty, 1999). Mou *et al* (1993) did find that seedlings grew significantly slower without the presence of nutrients from the organic layer. Furthermore, one of the main concerns with scalping is that it can result in competition from grasses and other herbaceous plants. If the area is predisposed to *D. punctilobula*, then scalping typically increases the abundance of the fern after forest harvesting due to its ability to reproduce quickly and spread vegetatively in mineral soil. Therefore, if the area is not predisposed to *D. punctilobula* growth, then scalping is a recommended silviculture procedure.

Herbicide application has been explored extensively for controlling the growth of *D. punctilobula.* Extensive literature can be found on currently available herbicides, quantities used and proper application methods (Engelman & Nyland, 2006). Many people dislike the use of herbicides for fear of bioaccumulation in the plants and animals that eat them. They also have the ability to affect other non-target species which can result in a loss of species diversity in the forest.

Most herbicide treatments limit the growth of ferns by killing their rhizomes (Engelman & Nyland, 2006). The highest mortality of ferns occurs just before or during the growing season and needs three to four days to determine the mortality rate (Anundson, 1996). Numerous studies have analyzed which herbicides are best used to combat *D. punctilobula* (Fei *et al*, 2010; Engelman & Nyland, 2006; Anundson, 1996; Cody *et al*, 1977). The two main herbicides that produced the best results were glyphostae and sulfometuron methyl (Oust). A detailed rate of application can be seen in table 2 and is described in detail by Engelman & Nyland (2006).

Table 2: Application rate and timing for herbicides used to deter the growth of *D. punctilobula* (Engelman & Nyland, 2006). *D. punctilobula* is referred to in this table with the consonant 'D'.

Chemical	Target	Timing, rates, and comments
Sulfometuron methyl	D, T	Late season with 2 oz product ac^{-1} (46.3 ml ha^{-1}) using a low-pressure sprayer
Glyphosate	D, T	July 1 to September 1 with 1 lb ai ac^{-1} (1.1 ai kg ha^{-1}) using a small compressed-air garden sprayer
	P	August to September 1 with 1 lb ai ac^{-1} (1.1 ai kg ha^{-1}) using a small compressed-air garden sprayer

Herbicides are proven to act as an effective deterrent to *D. punctilobula* growth. Spraying can produce results anywhere from three to eight years (Engelman & Nyland, 2006). However, Anundson (1996) indicates that the application of the appropriate lethal dosage would cost between $100 and $150 per acre. This price does not include the $2 per lineal foot for deer fencing if the area has a deer browsing issue. In total, each acre would cost over $300. This is not economically viable on a large scale. However, if small plots were sprayed, or patch spraying was done where the worst of *D. punctilobula* was found, this could be a solution assuming herbicide spraying was permitted.

Potential Solutions for Prevention

The above section mentioned some methods already used to deter the growth of *D. punctilobula.* This section suggests further prescriptive strategies that forest managers could use to prevent the growth of *D. punctilobula*. If a fern population is already present, there are tree species that are better adapted at overcoming the fern's competitive nature. However, this means that a diverse understory is likely not possible unless there are measures taken to prevent a monoculture or the loss of many species (de la Cretaz & Kelty, 1999). Engelman and Nyland (2006) noted that 70% of a stand must be free of fern cover for a period of three to four years to promote a diverse tree seedling understory. This can be done with simple measures, like delaying thinning until extensive deer browsing can be controlled (de la Cretaz & Kelty, 1999). When harvesting, it is important to ensure that the soil is not compacted or disturbed in an excessive manner as this would hinder the growth of tree seedlings and expose mineral soil. Feathering the edges of a harvested area would promote shading of adjacent deforested areas and maintaining an overstory canopy would prevent full sunlight levels from reaching the forest floor (Aikens *et al*, 2007). It is proven that low intensity disturbances encourage the growth of dormant herbs and shrubs located in the seed bank (Aikens *et al*, 2007). Therefore, the lighter the disturbance caused by forest harvesting, the better it will be for the landscape. Other methods that prevent germination of *D. punctilobula* involve harvesting in dry periods or during the winter when the soil is frozen or covered with snow. This will deter soil compaction and disturbance (Engelman & Nyland, 2006). *Rubus* spp. are natural competitors against *D. punctilobula,* therefore, their growth should be encouraged. (de la Cretaz & Kelty, 1999).

Many trees produce seed crops every few years. Therefore, a stand should be scheduled for harvesting when it is known that the previous growing season had a large seed crop of the overstory species. For example, *Quercus* spp. (Oaks) are known to produce large acorn crops every four to six years (Fei *et al,* 2010). If Oak trees are desired or abundant in an area, then using a large seed crop to naturally restore the stand can be economically and silviculturally wise. Mou *et al* (1993) noted in their study that Sugar Maple regrew very well in 1988 due to a heavy seed crop the previous year. Having a high seed density increases the chances of germination. The size of a tree seed also affects the germination potential of a seedling. George and Bazzaz (1999) noted in their study that the tree seedlings that grew the most in the first year were the ones that were larger in size. The larger the seed, the larger the food reserves available to support initial growth. In a high seed crop year, the probability of having large tree seeds dispersed is higher.

As discussed above under current mitigation methods, scalping and mowing are two potential methods for deterring the growth of *D. punctilobula* while still encouraging the growth of tree seedlings. Scalping, the method of removing the top organic layer to reveal the mineral soil, resulted in excellent first year germination of tree seedlings. However, it did also promote the growth of grasses and other herbaceous and woody species (de la Cretaz & Kelty, 1999). Using scalping and planting of *Betula* sp. appeared to be the most effective way at producing new tree seedlings (de la Cretaz & Kelty, 1999). However, this method does not promote a diverse forest environment to ensue.

Mowing is also an effective tool at preventing the growth of *D. punctilobula.* It is less damaging to the environment than scalping because it keeps the humus layer on top of the mineral soil which retains the nutrients on the site. Mowing prevents mature fronds from transferring photosynthate to the roots and rhizomes. The lack of nutrients declines the vigor of the fern and depletes the starch reserves needed to make the fern grow (de la Cretaz & Kelty, 1999). If mowing is done for two growing seasons, the population of ferns greatly decreases and therefore permits the growth of tree seedlings (de la Cretaz & Kelty, 1999). Furthermore, mowing provides nutrients to the growing seedling through the decomposition of the fern fronds (de la Cretaz & Kelty, 1999). The weight of the fronds on the litter layer suppresses the growth of other herbaceous species and decreases the density of tree seedlings that do germinate (de la Cretaz & Kelty, 1999). This ensures that the healthiest and most vigorous tree seedlings germinate successfully without needless competition from a high abundance of less vigorous trees. The downfall of mowing is that this treatment can be very costly and is labour intensive if done by hand. If done with a machine, there is a risk of cutting the already germinated tree seedlings and compacting the soil if the machinery is heavy. It may be a viable option if done in patches or strips in a stand (de la Cretaz & Kelty, 1999).

Cody *et al* (1977) found that *D. punctilobula* will not grow on land where the fronds are continuously broken off through trampling. Therefore, agriculture and pasture lands could provide an option in areas to hinder the growth of *D. punctilobula*. Seedlings already growing in the area could be coned to protect against the animal's trampling and grazing.

The use of herbicides has proved to be successful against the growth of *D. punctilobula.* However, the risks of herbicides are well known. As stated above, they are not widely used on forest lands because of the negative effects they can have on an ecosystem. Bioaccumulation within the food chain is always a concern for people who hunt game in the area. Furthermore, some herbicides used have been known to alter the growth of the tree seedlings and inhibit their growth when this is clearly not the desired effect. Therefore, although chemical use has been proven to be effective, many people are not comfortable using it on public lands where extenuating factors can be effected by their application, such as wind speed, daytime temperature, and animal consumption.

Future Outlook for Eastern Forests

The future outlook for eastern forests is in flux. With climate change affecting seasonal growth and potential growing days, it is getting harder to determine what the future forests will look like.

The most adapted and competitive species against *D. punctilobula* tend to be those that have slower growth rates and complete height growth earlier in the growing season (Bicknell, 1982). *Betula* spp. tended to grow quickly in high light environments and can compete successfully against *D. punctilobula* (Aikens *et al*, 2007).*Quercus* spp. also did well around the edges of openings where light was made available (Aikens *et al*, 2007); however they were also subject to deer browsing and appealed to rodents found beneath the frond layer. Given the opportunity, Red Maple will grow better than Oak in heavily populated fern stands (Fei *et al*, 2010). *Pinus strobus*

(Eastern White Pine) was also found to be a good competitor against *D. punctilobula* (de la Cretaz & Kelty, 1999). Areas where *Rubus* spp. grow in competition with *D. punctilobula* should not be removed or altered because they act as nutrient and sunlight competitors to the fern and can grow easily through the frond canopy (Engelman & Nyland, 2006) to eventually overshadow and cut the fern's access to sunlight.

Sugar Maple**,** Ash and Beech species grew quickly and set bud early the first year of germination; however, in subsequent years their growth rate declined and they became less competitive against the frond canopy (Bicknell, 1982). As discussed previously, *D. punctilobula* has the ability to limit nutrient uptake in many seedlings. Mou *et al* (1993) found that Sugar Maple nutrients were diminishing as they became less competitive with time. It was not until they were able to surpass the frond layer that they were able to grow steadily. This could indicate that the light interception done by the frond layer is a large deterrent to Sugar Maple growth. Figure 4 from Mou *et al* (1993) demonstrates the size frequency of the species examined in their study. As can be seen, Sugar Maple does well at initial growth, but afterward quickly diminishes and is not a great competitor to *D. punctilobula.*

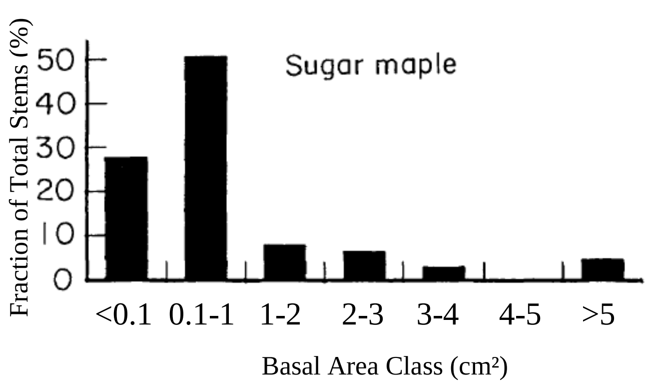

Figure 4: Size frequency of sugar maple (Mou *et al*, 1993).

Predictive computer models can also provide potential future outcomes of a forest. *Regrow* (Mou & Fahey, 1993) is a program that specializes in determining interactions in mixed age, mixed species, and spatial plant communities. It was analyzed for its effectiveness at determining future forest outcomes. This program still lacks the ability to determine accurate outlooks; however, it has promise to develop into a useful program that forest managers could use to determine cutting and planting designs. One of its problems is that it lacks the ability to predict mortality under intensely competitive stands with mixed or singular species stands (Mou & Fahey, 1993). Perhaps with time and further work, this program could provide help to forests infested with *D. punctilobula.*

Conclusion

For many tree species, specifically Sugar Maple, growth is being hindered in eastern North America by *D. punctilobula.* This fern species has the capability of deterring germination of tree seedlings though light interception by its frond layer, a thick root mat that causes a physical barrier between the organic layer and the nutritious mineral soil below, its allelopathic qualities and its ability to regenerate quickly in disturbed areas and full light scenarios. Through different silvicultural practices, like shelterwood systems, this will limit the light availability to the understory which is a key component of the fern's ability to regenerate quickly. Furthermore, through scalping, mowing or herbicide use, the persistence of the fern can be hindered for a period sufficient to permit the germination of tree seedlings. Once the tree seedlings are well established and have grown above the fern frond canopy, they merely have to contend with deer browsing until they are of a suitable height where the deer can no longer eat the new growth. Therefore, with proper planning and intelligent forestry practices, the tree seedling germination issues surrounding *D. punctilobula* can be mitigated.

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