ECOLOGY OF A SOUTHWEST NEW ENGLAND FOREST AND ITS INVASION BY A NON NATIVE TREE SPECIES

by

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Abstract

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With the regeneration of vast forested areas in northeastern North America, a renewed interest in studying these recovering areas has arisen in recent years. The process of accurately inventorying existing forested areas and applying statistical methods to recognize forest types and plant associations has become an important aspect of modern ecological study. While forest change is a natural process and each forest has its own individual mosaic of species, the documentation of species within these areas will allow changes to be recognized more accurately, and earlier than in years past.

Using a 31 hectare forest located in southwest Connecticut as a research site, an annotated flora of all non vascular and vascular plant species was conducted. Results included 71 non vascular and 357 vascular species being recorded and vouchered.

Vegetation analyses of the site were performed through the use of 10 x 10m quadrats. This analysis showed a forest dominated by *Fagus grandifolia* followed by *Acer rubrum* and *Betula lenta*. Four distinct forest types exist with a mixed hardwoods forest type dominating.

A non native species, *Phellodendron amurense* was recognized as being the 14th most dominant in importance value ranking. Sites were then identified within the forest to locate areas of high concentration of the species, and within the largest of these areas a comprehensive examination of the invasion was performed. An analysis of the age structure, impacts upon the understory, and pattern of the invasion were investigated by creating a large plot encompassing all the *P. amurense* and gathering cartesian coordinates, diameter at breast height, and age from tree ring analysis.

The results of this thesis provide an accurate and thorough inventory of all non vascular and vascular plants on the site. Furthermore, an examination of the forest types and importance values of the area provide an even better baseline from which future analysis may be based. This thesis also provides significant information regarding a non native invasive species that is currently not recognized as such in much of the pertinent literature.

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I also owe a tremendous thanks to my parents Albert and Nancy Morgan, and my brother, Kurt Morgan, who assumed many of my responsibilities in our business while I was preoccupied with my research. Lastly, I would like to thank Lily K. Leon, who was invaluable in supporting this project, and encouraging its completion.

Table of Contents

List of Tables

List of Figures

Chapter 1

Introduction

The forests of the northeastern United States can be characterized in several ways dependent upon the level of precision and the size of the region being examined. Within the Holarctic kingdom of Takhtajan (1986), the region known as the northeastern United States is further classified as falling within the eastern deciduous forest province (Barbour and Christensen 1993, Braun 1950, Greller 2000). The main site of this study takes place in southwestern Fairfield County, Connecticut, upon the 91 acre grounds of the Bartlett Arboretum in the city of Stamford. This site specifically falls along the border of Takhtajan's Appalachian province and Atlantic and Gulf Coastal Plain Province within his North American Atlantic Region (Takhtajan 1986). On a smaller scale the location is within the glaciated section of the Oak-Chestnut forest region, in what is specifically referred to as the "sprout hardwoods" region of New England (Braun 1950).

Documentation of the flora and vegetation types of this region, and particularly the surrounding regions of New York City has been published on a regular basis for well over a century. Early examples of this include the *Flora of the Vicinity of New York* (Taylor 1915), which encompasses the region of Fairfield County, Connecticut and includes 2631 vascular species in total and the *Flora of Long Island* by Jelliffe (1899), which includes 1383 species of vascular plants. More recent studies of the flora of the surrounding regions include mainly floristic inventories of the woodlands of New York City such as Greller (1977) and DeCandido and Lamont (2004). Vegetation and forest compositional studies have also been performed in the past few decades and include Stalter and Kincaid (2008), Glaeser (2006), Stalter (1982) and

Greller et al. (1979). These studies, while concentrating on regions outside of Fairfield County, are all still located within the "sprout hardwoods" region.

As a method of providing an accurate inventory of the flora of this research site, a non vascular and vascular flora was compiled over the years of 2006 - 2010. Surveys were done throughout the property and resulted in over 1,200 voucher specimens placed in the herbarium of the Bartlett Arboretum (BART). An accurate floristic inventory is neccessary to proceed with more in depth examinations of the vegetation of the site and the ecology of the flora. Chapter two and Chapter three provides a complete list of all plants recorded on the site.

Throughout the region, humans have played a central role in shaping the species composition of the forest from colonial times to the present (Borgi et al. 2000). These forests have undergone many changes over the nearly 400 years since European colonization although documentation is often scarce and based upon evidence such as witness tree records and land deeds. Within the primary research site of this study, the land has transitioned from a cleared pig farm in the late 19th century to the forested habitat it is today; records of past uses are cursory through word of mouth accounts of family descendents of the former property owners.

To provide baseline data from which future changes can be measured, transects were created throughout the forest, along which 10m x 10m quadrats were placed in random fashion. By recording all woody species greater than 2 cm diameter breast height, importance values (Curtis and McIntosh, 1951) were calculated to provide an analysis of ecological dominance of the vegetation on site. By analysis of quadrats, more specific forest types can be determined through cluster analysis and ordination. These processes were performed and are reported in Chapter three.

At this research site and throughout forested ecosystems across the globe, forest change is an unavoidable process which takes place naturally as succession progresses. Numerous natural disturbances also create forest changes in forested areas. Successional change, caused by a variety of factors including natural processes such as drought, windstorms and the like are demonstrated in local comparative studies over time including Stalter and Kincaid (2008) and Stalter (1982). In addition to these natural processes, there are numerous well documented events throughout the region which have changed the structure of this forest over the past century.

A most profound impact upon the forest has been the drastic population increase in white tailed deer throughout the region (Shono 2003). The impacts upon the forest are numerous with documented losses in herb diversity (Rooney and Waller 2003) and disproportionate losses to native spring wildflowers (Webster et al. 2005). Within this study site, the population of white tailed deer is approximately 21-26 based upon personal observations of the author using motion detecting cameras.

While deer are a natural, native component of the local forests, other factors include those species that have been introduced to the region from elsewhere, either intentially or unintentionally. Only a century ago, *Ulmus americana* L., the American elm would likely have been a conspicuous part of the regional flora. Floristic work within the region of this thesis included *Ulmus americana* as "commonly found" in Tolland and Windham Counties, Connecticut (Meyer and Plusnin 1945) and Taylor (1915) determines the species to be "in various situations" throughout the vicinity of (city of) New York. Thischange in abundance from a common species to a rare species was within only a few decades of the introduction of an ascomycete fungus commonly known as Dutch elm disease. This disease, spread by three species of bark beetle, had reduced the elm populations of the eastern United States by the hundreds of thousands by the mid 1940s in spite of the fungus reaching North America as recently as 1928 (Elton 1950).

An even more devastating impact was caused by the introduction of another fungus in 1904. *Cryphonectria parasitica* (Murrill) Barr., the causal agent of chestnut blight, essentially eliminated mature trees of *Castanea dentata* throughout the region within several decades. While Taylor (1915) lists *Castanea dentata* as "throughout the range" and Jelliffe (1899) lists the species as "throughout the island" for Long Island, Meyer and Plussin (1945) describe the forest as having the most valuable chestnut trees killed by the blight although the species continues to be listed as common in their work. Further comments by the authors which allude to the future of *Castanea dentata* are their claims that chestnut "salvage" operations still exist in the forest interior, hinting that many areas were already salvaged of the dying species. To this day mature chestnut trees are non existent, as the remaining sprouts from afflicted trees continue to grow from previously stricken trees, only to be reafflicted, usually prior to the sexual maturity of the individual sprout.

The impact of dutch elm disease and chestnut blight are only two widespread, and devastating examples of the changes brought upon the forest since 1900. Numerous other pathogens have also taken a toll on the region although some are less apparent due to either the lesser importance of the species, the slower spread of the problem or the current lack of time for the organism to spread. More recent examples include the hemlock wooly adelgid which has caused the die off of Hemlock, *Tsuga canadensis* (L.) Carrière, throughout the southern portion of the region. Throughout the New England region, hemlock wooly adelgid has resulted in drastic changes in the stand dynamics of *Tsuga canadensis* causing potential widespread ecosystem impacts (Stadler et al. 2005). Within this research site, *Tsuga canadensis*, while present, is often heavily infected by the insect and suffers needle drop (personal observation). While each of the preceding examples has been the result of introduced parasitic species, another major influence has been the introduction of non native - invasive vascular plants.

In recent decades, beginning with the publication of Charles Elton's *The ecology of invasions by animals and plants* in 1950, more research and attention has been paid to the importance of these organisms, not only as economic problems, but as potentially devastating ecological problems. Within the region of this study, numerous species have been documented to invade native habitats including *Acer platanoides* L. (Fang 2005), *Ailanthus altissima* (Mill.) Swingle (Lawrence et al 1991), *Celastrus orbiculatus* Thunb. (Steward et al. 2003) and *Lythrum salicaria* L. (Blossey et al 2001) to name only a few. New invaders across the globe often have a lag phase of proliferation and spread (Mack et al. 2000). Prior to a noticeable proliferation of an introduced species, many of these will be recognized only as a naturalized species, a member of the flora that has little noticeable impact, slow to moderate growth, and lacks the ability to displace native species. Within this research site, one particular species, *Phellodendron amurense*, fits that exact profile. A native of Asia, *P. amurense* recieves very little recognition as an invasive species in the scientific literature with a few exceptions such as Glaeser (2006) and Glaeser and Kincaid (2005). Many horticultural publications such as Dirr (1990) continue to promote the species as a desireable plant for use in public and private gardens. The abundance, and noticeable impact of *P. amurense* within areas of the forest in which it has proloferated, quickly caused the species to become a major focus of this work.

The first question to be asked regarding this species was where could it be invading outside of its native range. Is there a preferred habitat for invasions by *P. amurense* or is *P. amurense* more general in its requirements. An important factor in determining the potential spread of any invasive is analysing its habitat preference. To accomplish this, sites where the species occurs were located throughout the region of Boston to Philadelphia. These sites were then compared using several methods to look for similarities, and to determine if the invasion by *P. amurense* would be restricted to particular habitats. The results of this work, which are reported within Chapter 4, are that *P. amurense* is capable of invading a number of different forest types and forest densities.

Secondly, the impact of the species upon the surrounding flora was examined. Using the primary research site and an additional site in Queens County, New York, data were collected to compare the understory flora of both the *P. amurense* invaded areas and the adjacent areas not yet invaded by the species. Data showed that across nearly all factors examined, *P. amurense* significantly affected the understory composition, mainly to the detriment of native species. Questions often arise as to the mechanism by which these impacts occur. In an attempt to rule out shading by the invader as is often suspected with other invasive species (Fang 2005), an analysis of light penetration at both sites comparing the canopy of both *P. amurense* and the adjacent native canopy through the use of a leaf area index analysis revealed no significant differences between them. These results are reported in Chapter 5.

Chapter 6 of this thesis begins examining the process of invasion by *P. amurense* into the site over a 46 year period. This time frame represents the time of first occurence in the forest by *P. amurense* until 2008, when all trees were cut down for the tree ring analysis that provided the data for this chapter. In total, 278 *P. amurense* trees were cut and analyzed for age data to provide an approximate history of the invasion. By comparing tree ring data to dbh data, approximations for the composition of the forest over the 46 year period were created, giving a model of the impact that the tree has had upon the forest over that period. This work showed that

P. amurense has increased in both relative density and dominance, to the point where it was a major species within the site at the time of its removal. These findings are reported fully in Chapter 6.

As a way of further analyzing the invasion, significance in the patterns of invasion were were examined using the cartesian data. By applying both Mantel tests and a Ripleys' *K*-function analysis to this data, it was shown that there is indeed a non random pattern to this invasion within the greater surrounding forest. Furthermore, by using these cartesian coordinates and dbh data, descriptive models can be created that will further the understanding of invasives to the general public as well as the scientific community. These results, and sample bubble charts are reported in Chapter 7.

Due to the well documented threats to ecosystems throughout the globe caused by invasive species, this work, which focuses upon a forested area in the Northeastern United States and a recent invader in that forest, will provide a framework for the long term study of a potentially important new invader. This work also highlights the importance for early detection of new invasive species, and the impact that a single species may potentially have upon the surrounding ecosystem. Perhaps most importantly, it will serve as a clarion call to eradicate yet another invader before the lag period of its expansion ends, and eradication as an option is replaced by the option of control.

Chapter 2

The Bryophytes of Bartlett Arboretum Forest, Stamford, Connecticut with a Comparison to Local Floras

[this chapter is modified from this reference:]

Morgan, E. C.; J.A. Sperling & J. Borysiewicz. 2008. The Bryophytes of Bartlett Arboretum Forest, Stamford, Connecticut with a Comparison to Local Floras. Evansia. 25: 8-11.

Abstract

The Bartlett Arboretum Forest in Stamford, Connecticut, is an approximately seventy-six acre deciduous woodland. The bryophyte flora consists of fifty-two species of moss (Class Musci), eighteen species of liverwort (Class Hepaticae) and one species of hornwort (Class Anthocerotae). As a multiple use forest (hiking, botanical education, and research) this list provides baseline data from which to measure future changes in the flora.

Introduction

The Bartlett arboretum is a ninety-one acre public garden owned by the city of Stamford and managed by the Bartlett Arboretum Foundation. The former home and research laboratory of F.A. Bartlett, founder of the Bartlett Tree Expert Company, the site is located in the city of Stamford, Connecticut, in the southwestern portion of the state less than thirty miles from the limits of the greater New York City region. Of the ninety one acre site, approximately seventy-six are left in a semi natural state with only trail maintenance, research, hiking and limited removal of invasive species occurring within its limits. Dog walking is allowed and has had a detrimental impact on bryophytes growing on tree trunks along pathways.

The forest falls within the mixed mesophytic forest zone of the Appalachian Province as described by Greller (2000). Communities within the forest include a seven acre *Acer rubrum* L. swamp, a *Fagus grandifolia* Ehrh. community, *Liriodendron tulipifera* L.– *Carpinus caroliniana* Walt. community, a *Quercus rubra* L. – *Carya ovata* (P.Mill) K. Koch. community and several disturbed areas dominated by non native plants. *Fagus grandifolia* is the dominant tree species in the forest.

Materials and Methods

The site was sampled on a regular basis from Spring 2006 through Fall 2010. More than 130 specimens were collected and identified at the Bartlett Arboretum Laboratory and the Department of Biology, Queens College. Voucher specimens for all species were deposited within the Bartlett Arboretum Herbarium. Identifications in the field and lab were done using the keys of Andrus (1980) for Sphagnaceae, Schuster (1949) for Hepaticae and Crum (1983) for Musci. Nomenclature was updated using the Plants National Database at plants.usda.gov.

Results of this study were compared with the results of Goodwin (2007) and Morgan and Sperling (2006) for an analysis of similarity between the Bartlett site and other local floras.

Results and Discussion

Sixty-seven species of bryophytes were identified including fifty-two moss species (Class Musci), eighteen species of liverworts (Class Hepaticae) and one species of hornwort (Class Anthocerotae). The families with the highest number of species were the Amblystegiaceae, Brachytheciaceae, Dicranaceae, Hypnaceae, Mniaceae and Polytrichaceae with four species in each family. All species recorded for the site are reported in Appendix 2.1.

In comparison the 1122 acre Burnham Brook Preserve in East Haddam Connecticut, has a total of forty-one moss and six liverwort species. While the 1013 acre Alley Pond Park and Cunningham Park sites in New York City, have a total of thirty-eight mosses, eight liverworts, and one hornwort. Burnham Brook is approximately eighty miles east of Bartlett Arboretum while Alley Pond and Cunningham Parks are approximately forty miles south. These results document that the Bartlett Arboretum has the greatest overall species richness.

To compare the bryophyte floras of these three sites both Sørensen’s and Jaccard Similarity Indices were calculated (Pielou 1984). The flora of Bartlett Arboretum was most similar to the Alley Pond and Cunningham Parks sites, however the differences between the two are still substantial. Similarity data are summarized in Table 2.1.

The authors plan to continue monitoring bryophyte populations at all three study sites. With different patterns of land use, forest age and history, as well as slight climatic differences, these results may be useful in measuring changes in both the local and regional bryophyte communities.

Table 2.1.

Comparison of the three sites using two similarity indices

Site	Distance	Musci	Hepaticae	Anthocerotae	Total	S	J
BA	0	52	18	1	71	---	---
APP / CP	40	38	8	1	47	51.5	.345
BB	80	41	6	0	47	48.6	.305

S = Sørensens Index
J = Jaccard Index

BA = Bartlett Arboretum

APP = Alley Pond Park

CP = Cummingham Park

BB = Brunham Brook

Appendix 2.1

BRYIDAE

Amblystegiaceae

Calliergon cordifolium (Hedw.) Kindb.

Leptodictyum humile (P. Beauv.) Ochyra.

Leptodictyum riparium (Hedw.) Warnst.

Warnstorfia exannulata (Schimp in B.S.G.) Loeske.

Anomodontaceae

Anomodon attenuatus (Hedw.) Hub.

Aulacomniaceae

Aulacomnium palustre (Hedw.) Schwaegr.

Bartramiaceae

Philonotis fontana (Hedw.) Brid.

Brachytheciaceae

Brachythecium rutabulum (Hedw.) Schinp in B.S.G.

Brachythecium salesbrosum (Web & Mohr.) Schinp in B.S.G.

Bryoandersonia illecebra (Hedw.) Robins.

Eurhynchium hians (Hedw.) Sande Lac.

Bryaceae

Bryum argenteum Hedw.

Pohlia nutans (Hedw.) Lindb.

Climaciaceae

Climacium americanum Brid.

Dicranaceae

Dicranella heteromalla (Hedw.) Schimp.

Dicranum flagellare Hedw.

Dicranum scoparium Hedw.

Dicranum undulatum Brid.

Ditrichaceae

Ceratodon purpureus (Hedw.) Brid.

Ditrichum pallidum (Hedw.) Hampe.

Fissidentaceae

Fissidens adiantoides Hedw.

Fissidens bushii (Card. & Ther.) Card. & Ther.

Fissidens fontanus (B. Pyl.) Steud.

Funariaceae

Funaria hygrometrica Hedw.

Physcomitrium pyriforme (Hedw.) Hampe.

Grimmiaceae

Schistidium apocarpum (Hedw.) Bruch. & Schimp in B.S.G.

Hypnaceae

Callicladium haldanianum

Hypnum curvifolium Hedw.

Hypnum imponens Hedw.

Platygyrium repens (Brid.) Schimp in B.S.G.

Mniaceae

Mnium hornum Hedw.

Plagiomnium cuspidatum Hedw.

Plagiomnium ellipticum (Brid.) T.Kop.

Rhizomnium punctatum (Hedw.) T. Kop.

Leucobryaceae

Leucobryum glaucum Angstr. *ex* Fr.

Orthotrichaceae

Orthotrichum strangulatum P.-Beauv.

Polytrichaceae

Atrichum crispum (James.) Sull.

Atrichum undulatum (Hedw.) P.-Beauv.

Polytrichum commune Hedw.

Polytrichum juniperinum Hedw.

Pottiaceae

Barbula convuluta Hedw.

Weissia controversa Hedw.

Sphagnaceae

Sphagnum girgensohnii Russ.

Sphagnum lescurii Sull in Gray.

Sphagnum palustre L.

Sphagnum torreyanum Sull.

Tetraphidaceae

Tetraphis pellucida Hedw.

Theliaceae

Thelia asperella Sull. In Sull & Lesq.

Thelia hirtella (Hedw.) Sull. in Sull & Lesq.

Thuidiaceae

Thuidium delicatulum (Hedw.) Schinm in BSG.

HEPATICAE

Calypogeiaceae

Calypogeia fissa (L.) Raddi.

Cephaloziaceae

Cephalozia bicuspidata (L.) Dumort.

Cephalozia connivens (Dicks.) Lindb.

Odontoschisma prostratum (Sw.) Trev.

Conocephalaceae

Conocephalum conicum (L.) Dumort.

Fossombroniaceae

Fossombronia wondrazeckii (Corda) Dumort.

Geocalycaceae

Geocalyx graveolans (Schrad.) Nees.

Lophocolea heterophylla (Schrad.) Dumort.

Jubulaceae

Bazzania trilobata (L.) Gray.

Frullania eboracensis Gott.,

Pallaviciniaceae

Pallavicinia lyellii (Hook.) Carruth.

Pelliaceae

Pellia epiphylla (L.) Corda.

Plagiochilaceae

Plagiochila asplenoides (L.) Dumort.

Porellaceae

Porella platyphylla (L.) Pfeiff.

Ptilidiaceae

Ptilidium pulcherrimum (Weber) Vainio.

Ricciaceae

Riccia fluitans L.

Ricciocarpos natans (L.) Corda.

Scapaniaceae

Scapania nemorea (L.) Grolle.

ANTHOCEROTAE

Anthocerotaceae

Phaeoceros laevis (L.) Prosk.

Chapter 3

The vegetation and vascular flora of the Bartlett Arboretum Forest

[this chapter modified from this reference:]

Morgan, E. C. 2009. The vegetation and vascular flora of the Bartlett Arboretum Forest. Journal of the Torrey Botanical Society. 136: 532-540.

Abstract

The vegetation and vascular flora of the Bartlett Arboretum Forest, Stamford, Connecticut is described. Based upon abundance, frequency, and diameter at breast height (dbh) data from sixty-one, 100m^2 random quadrats collected in summer 2007, calculations of a species area curve, clustering of quadrat data and Importance Values (IV) were performed. Analysis shows a forest dominated by *Fagus grandifolia* (IV, 64.17), followed by *Acer rubrum* (IV 37.41), and *Betula lenta* (IV 33.84). The vascular flora is documented from collections made from fall 2006 through fall 2010 as well as herbarium records. A total of 357 vascular plant species from 95 families are recorded. The most represented families are the Poaceae (31 species), Asteraceae (31 species), Rosaceae (16 species), and Cyperaceae (16 species). These four families comprise 94 species and 26.4 percent of the flora. Exotic species comprise 26.7 percent of the flora with 94 species. Two species, *Eurybia radula* and *Sibbaldiopsis tridentata* are listed as endangered in the state of Connecticut.

Introduction

The Bartlett Arboretum Forest, located in Stamford, Connecticut (41.08N 73.33W), consists of 31 hectares of predominately mixed deciduous forest within the sprout hardwood forest region of the oak-chestnut region as described by Braun (1950), or the deciduous forest of the Appalachian province as described by Greller (2000). Separating much of the forest from the horticultural collections on the south end of the property is Poorhouse Brook, which ultimately runs into the Long Island Sound to the south. The northeastern corner of the property consists of a wetland which was created approximately forty years ago when the reservoir to the north altered its overflow pattern, flooding what once was a stand of *Fraxinus sp*. based upon the few dead trunks still standing. This wetland is essentially devoid of living trees and is not included in the forest analysis. From the wetland, water drains via a small stream which leads into Poorhouse Brook at the property edge.

The forest is part of the Bartlett Arboretum, a publicly accessible arboretum which is the former home of the Bartlett Tree Care Company founder Francis Bartlett, who purchased this site in the late nineteenth century. The site served as Bartlett Tree Care corporate headquarters as well as its training facilities for company arborists. The facilities included what are now the horticultural and botanical living collections and the former research laboratory, which is now the education building and houses the arboretum herbarium. After the death of Francis Bartlett, the property was sold to the state of Connecticut for preservation as an arboretum due to the large collection of horticultural specimen trees including many of the largest trees of particular species in the state. The state later transferred control of the arboretum to the University of Connecticut which managed the property until 2001, when the private not-for-profit Bartlett

Arboretum Association assumed responsibility and manages the site to the present. The association manages the site to this day. This study describes the naturally occurring vegetation which is present outside the area of horticultural collections and within the arboretum forest. There is no evidence in Bartlett Arboretum archives or elsewhere that any horticultural planting has been done in the forested area covered by this study. It is likely however, that the species richness of the site has in fact been influenced by the horticultural collections. Several species including *Aegopodium podograria*, *Pachysandra terminalis*, and *Viburnum sieboldii* are likely the result of these collections since they are documented species in the horticultural collections for much of the arboretums history.

The forest is open to the public for hiking, dog walking, and educational activities however exact information on its previous uses are unavailable. With the exception of the removal of hazardous trees near hiking trails, trail maintenance and the above mentioned activities the forested area has been left undisturbed since the purchase of the property by Frances Bartlett in the late nineteenth century. An invasive plant removal program began after the conclusion of this study and represents the first known significant impact into the forest in over 100 years. White-tailed deer, *Odocoileus virginianus* Zimmerman, are abundant with populations reaching sixty deer per square mile in nearby Greenwich, Connecticut (Shono, 2003). As a result understory vegetation is lacking throughout most of the forest and many wildflower species found on the site are rare. The general impact of white-tailed deer in northeastern North America has been reported in numerous studies (Horsley et al 2003, DeGraaf et al 1991). In fall 2009, a controlled hunt was initiated to lower the population of deer on the property however results of this effort may not be determined for several years.

The bryophyte flora of the forest has been recently documented and consists of fifty-two species of moss, eighteen species of liverwort and one hornwort species have reported for the site (Morgan et al. 2008).

The soils are formed from glacial tills and are classified as Charlton-Hollis soils which are generally sloping to steep and well to excessively drained (Gonick 1979). Site elevation ranges from 83m to 103m. Mean annual temperature for Stamford is 10°C (50.8°F) with an average annual precipitation of 155cm (weatherbase.com 2009).

Materials and Methods

To assess the vegetation of the forest, seven transects were drawn throughout the property in an east west direction on an existing trail map. Individual quadrats measuring 10m by 10m were placed upon these transects by using random numbers between zero and one hundred from a handheld calculator to determine quadrat spacing, then placing quadrats on alternating sides of the transect. To ensure enough quadrats were performed, a species area curve by approximate randomization (1000 randomizations) using JMP 7 (SAS Institute) was performed using a JSL program (Kincaid 2007). The curve showed leveling off after approximately 41 quadrats however 61 total were performed ensuring a thorough sampling (Figure 3.1). Shannon Index and Simpsons Index were calculated for the site as described by Brower et al. (1998).

Within quadrats all woody species measuring 2 centimeters (cm) or more diameter at breast height (dbh), were recorded by both species and dbh. For individuals having multiple stems the dbh of each stem was measured and overall dbh recorded as the diameter that would account for the summed basal area of the multiple stems. Importance values were calculated from all quadrat data as described by Curtis and McIntosh (1951).

Cluster analysis was performed by analyzing the data from the ten highest ranked tree species in importance value. Four clusters were created from the sixty one plots using average centroid clustering method in JMP 7.0 software as described by Pielou (1984). Each cluster was then named based upon its main species and these clusters included as a variant in correspondence analysis.

To determine the vascular flora of the site, surveys of the forest were done from summer 2006 through fall 2008. Surveys were done at least once weekly from late February through early November. Species identification was done using Gleason and Cronquist (1991). Voucher specimens for all species recorded on site were taken and deposited in the Herbarium of the Bartlett Arboretum (BART) with certain exceptions. If a species was considered rare on site, common but difficult to preserve, or if herbarium material was already on file, no voucher was taken. In total, over 1,000 specimens were taken and deposited in the Bartlett Arboretum Herbarium. A search of the University of Connecticut Herbarium (UCONN) database for specimens collected at the Bartlett Arboretum Forest resulted in the addition of two species to the flora.

Results and Discussion

Within the sixty one, $100m^2$ quadrats a total of 667 stems were identified and measured and included 24 genera and 28 species. The mean number of species per quadrat was 5.23 and the mean number of individuals per quadrat was 10.93. Shannon Index for the site was 2.64 and

Simpsons Index was 0.115 and gave a numeric value for species diversity which can be used as a benchmark from which to measure change.

Importance values for all sixty one quadrats were calculated and show a forest dominated by *Fagus grandifolia* (American beech). *Acer rubrum* (red maple) and *Betula lenta* (birch), are second and third in ecological importance. Beech is the highest ranked species in relative density, relative frequency, and relative dominance with red maple second in relative density and relative dominance, and sweet birch second in relative frequency. The results for all twenty eight woody species are reported in Table 3.1.

Four clusters were created using the data from sixty one quadrats (Figure 3.2). Clusters are named according to their species composition. The Beech-mixed hardwoods cluster consisted of approximately fifty percent *Fagus grandifolia* and fifty percent mixed hardwoods. This cluster, the mixed hardwoods cluster was made up of fourteen quadrats, or 22.9 percent of the total quadrats sampled. The mixed hardwoods cluster had no dominant species with no single species reaching more than fifty percent of the total in a quadrat and none reaching more than twenty-five percent of the total for all quadrats in the cluster combined. The mixed hardwoods cluster was the most common and was comprised of 37 plots, or 60.6 percent of all plots. The red maple cluster consisted of over fifty percent *Acer rubrum* and comprised only 4 plots, or 6.5 percent of the total. The final cluster is the Beech cluster which consisted of plots containing at least sixty-five percent *Fagus grandifolia*. This cluster consisted of 6 plots, 9.8 percent of the total.

Correspondence analysis for the four clusters is shown in Figure 2. Rays represent the four clusters and show a similarity between the Beech – mixed hardwoods cluster and the Beech dominated cluster. The mixed hardwoods cluster and the red maple cluster are distant from each other as well as the beech – mixed hardwoods and beech dominated clusters. Two species, *Fagus grandifolia* and *Amelanchier canadensis*, were found in close association with the beech - hardwood and beech dominated clusters while *Acer rubrum* and *Tilia americana* were most closely affiliated with the red maple cluster. Plants with the distribution least affiliated with any one cluster are *Betula alleghaniensis*, *B. lenta* and *Phellodendron amurense*. *B. alleghaniensis* and *B. lenta* represent early successional species and *P. amurense* is a non native shade intolerant invader perhaps implying the shorter distance from the center represents more recently disturbed areas of the forest.

The vascular flora of the forest consisted of 95 families and 357 species. Non native species comprised 26.7 percent of the flora (94 species). The largest families found in the forest are the Poaceae (31species), Asteraceae (30 species), Rosaceae (16 species) and Cyperaceae (16 species). These four families comprised 26.4 percent of the total flora. Lycopods represented less than 1 percent of the flora (3 species), Pteridophytes represented 4.3 percent (15 species), Pinopsida represented 1.1 percent (4 species), Magnoliopsida represented 70.6 percent (247 species) and Liliopsida represented 23.2 percent (81 species). These results fall within the range of species richness documented by ten other recent floras of the region as reported by Loeb (2006).

Voucher specimens were designated for all species with few exceptions, and are reported in Appendix 1. The earliest collected material of a species deposited in the Bartlett Arboretum Herbarium is designated as the voucher for this study. Vouchers for two species, *Athyrium felix-femina* and *Goodyera pubescens* are deposited in the University of Connecticut Herbarium, UCONN. *Athyrium felix-femina* is currently present on the property but individuals are of poor quality for a voucher so no additional sample was taken. *Goodyera pubescens* is apparently extirpated on the site.

Two species, *Eurybia radula* and *Sibbaldiopsis tridentata* are listed as endangered in the state of Connecticut (USDA, NRCS 2009). *Eurybia radula* occurs within the wetland while *Sibbaldiopsis tridentata* occurs on the property edge bordering an adjacent athletic field. Three species, *Phellodendron amurense*, *Symplocos paniculata*, and *Viburnum dilatatum* represent new records for the state of Connecticut in the USDA plants national database (USDA, NRCS 2009). All three species are planted as ornamentals in the region and have become well established and widespread within the forest.

These results show the forest as a whole can be separated distinctly into several ecological communities; the beech-hardwoods forest, red maple forest, beech forest, mixed hardwoods forest and the wetland and stream. With the permanent preservation of this forest and the initiation of new projects on site such as the removal of deer and invasive plants, this data provides a baseline from which future changes can be measured against.

Appendix 3.1.

Vascular plants of the Bartlett Arboretum Forest, Stamford, Connecticut

Families and lower taxa are arranged alphabetically within divisions. Classification is based upon the plants national database (USDA, NRCS 2009). Taxa considered non native to Connecticut are denoted with an asterisk (*) and species presumed extirpated on the study site are denoted with a cross (†). Species with a frequency of less than five individuals are designated as rare. Collections with no collector name are by the author.

LYCOPODIOPHYTA

Lycopodiaceae

Lycopodium digitatum Dill. ex A. Braun. *0070172*

Lycopodium obscurum L. *0070173*- rare

Selaginellaceae

Selaginella apoda (L.) Spring. *0080170* rare

PTERIDOPHYTA

Dennstaedtiaceae

Dennstaedtia punctilobula (Michx.) T. Moore. *Levine 9820001*

†*Pteridium aquilinum* (L.) Kuhn. *Levine 9820002*

Dryopteridaceae

Deparia acrostichoides (Sw.) M. Kato. *0060142*

Dryopteris carthusiana Vill. H. P Fuchs. *0060136*

Dryopteris intermedia (Muhl. ex WIlld.) A. Gray. *Zlotsky 9790001*

Onoclea sensibilis L. *0060149*

Polystichum acrostichoides Michx. Schott. *0060135*

Ophioglossaceae

Botrychium virginianum L. Sw. *0060098* rare

Osmundaceae

Osmunda cinnamomea L. *0060157*

Osmunda claytoniana L. *Levine 9810001*

Osmunda regalis L. *0060147*

Polypodiaceae

Athyrium filix-femina (L.) Roth. *Levine 692, UCONN*

Polypodium virginianum L. *0060122*

Pteridaceae

Adiantum pedatum L. *0080117* rare

Thelypteridaceae

Thelypteris noveboracensis (L.) Nieuwl. *Levine 9820003*

PINOPHYTA

Cupressaceae

Juniperus virginiana L. *Morgan & Borysiewicz 0070164* - rare

Pinaceae

**Picea abies* (L.) Karst. *0070780* - rare

Pinus strobus L. *Morgan & Borysiewicz 0070163*

Tsuga canadensis (L.) Carr. *0070288*

MAGNOLIOPHYTA

MAGNOLIOPSIDA

Aceraceae

**Acer platanoides* L. *0060030*

Acer rubrum L. *0060128*

Acer saccharum Marsh. *Morgan & Borysiewicz 0070155*

Amaranthaceae

**Amaranthus blitoides* S. Wats. *0070262*

Anacardiaceae

Rhus copallinum L. *0070209*

Rhus glabra L. *0080119*

Toxicodendron radicans (L.) Kuntze. *Not Sampled*

Apiaceae

**Aegopodium podagraria* L. *0070183*

**Aethusa cynapium* L. *Levine 9810705*

Cicuta maculata L. *0070219*

Cryptotaenia canadensis (L.) DC. *Levine 9820778* - rare

**Daucus carota* L. *Zlotsky 9790281*

Sium suave Walter. *0070218*

Apocynaceae

Apocynum cannabinum L. *0070210*

Asclepias incarnata L. *0060152*

Asclepias syriaca L. *0070207*

Araliaceae

**Aralia elata* (Miq.) Seem. *0070358*

Aralia nudicaulis L. *0060159*

Panax trifolius L. *0070120*

Asteraceae

**Achillea millefolium* L. *0070200*

Ageratina altísima (L.) King & H. Rob. *0060125*

Ambrosia artemesiifolia L. *0070245*

**Arctium lappa* L. *0080120*

**Artemisia vulgaris* L. *0070201*

Bidens connata Muhl. ex Willd.*0060132*

Conyza canadensis (L.) Cronq. *0070272*

Erechtites hieraciifolia (L.) Raf. ex D.C. *0070755*

Erigeron annuus (L.) Pers. *0070235*

Eurybia divaricata (L.) G. L. Nesom. *0060130*

Eurybia radula (Aiton.) G. L. Nesom. *0060124* - rare

Euthamia graminifolia (L.) Nutt. *Levine 9790313*

**Galinsoga quadriradiata* Cav. *0070247*

Helianthus decapetalus L. *0060153*

**Hieracium caespitosum* Dumort. *0070142*

Hieracium gronivii L. *0100113*

Lactuca canadensis L. *0070270*

**Lapsana communis* L. *0070293*

**Leucanthemum vulgare* Lam. *0070189*

Mikania scandens (L.) Willd. *0060158*

Prenanthes trifoliata (Cass.) Fern. *Levine 9810705*

**Senecio vulgaris* L. *0070252*

Solidago altissima L. *Levine 9810752*

Solidago caesia L. *0060127*

Solidago flexicaulis L. *0070751*

Solidago juncea Ait. *0070269*

Solidago puberula Nutt. *0070750*

**Sonchus asper* (L.) Hill. *0070271*

Symphyotrichum ericoides (L.) Nesom. *Levine 9810753*

Symphyotrichum racemosum (Elliot) G. L. Nesom. *0060161*

**Taraxacum officinale* F. H. Wigg. *0070132*

Balsaminaceae

Impatiens capensis Meerb. *0060146*

Berberidaceae

**Berberis thunbergii* DC. *Morgan & Borysiewicz 0070181*

Podophyllum peltatum L. *0070131*

Betulaceae

Alnus incana (L.) Moench. *0060140*

Betula alleghaniensis Britton. *Morgan & Borysiewicz 0070175*

Betual lenta L. *0070789*

Carpinus caroliniana Walter. *0060078*

Corylus americana Walter. *080401*

Ostrya virginiana (P. Mill.) K. Koch. *0070301*

Boraginaceae

Hackelia virginiana (L.) I.M. Johnst. *0100114*

Myosotis laxa Lehm. *0070190*

**Myosotis scorpioides* L. *Levine 9810640*

Brassicaceae

**Alliaria petiolata* (M. Bieb.) Cavara & Grande. *0070149*

Capsella bursa-pastoris (L.) Medik. *9810007*

Cardamine bulbosa (Schreb. ex Muhl.) Britton, Sterns & Poggenb. *0080105*

Cardamine diphylla (Michx.) Alph. Wood. *0070125*

**Cardamine hirsuta* L. *0070118*

Cardamine pensylvanica Muhl. ex Wild. *0080103*

Cardamine pratensis L. *0070128*

**Draba verna* L. *0070117*

**Hesperis matronalis* L. *981068*9

Lepidium virginicum L. *Levine 9860005*

Buxaceae

**Pachysandra terminalis* Siebold & Zucc. *0060032*

Callitrichaceae

Callitriche heterophylla Pursh. *0060126*

Campanulaceae

Lobelia cardinalis L. *0060148*

Lobelia inflata L. *0070303*

Triodanus perfoliata (L.) Neiuwl. *0080533*

Caprifoliaceae

**Lonicera japonica* Thunb. *0070220*

**Lonicera maackii* (Rupr.) Herder. *0070127*

Sambucus nigra L. *0060104*

Viburnum acerifolium L. 0060011

**Viburnum dilatatum* Thunb. *Lockwood 9680191*

Viburnum dentatum L. *0070147*

Viburnum nudum L. *0070267*

Viburnum recognitum Fernald. *Morgan & Domina 0070146*

**Viburnum sieboldii* Miq. *0060381*

Caryophyllaceae

**Cerastium fontanum* Baumg. *0070143*

**Dianthus armeria* L. *0070202*

**Sagina procumbens* L. *0070238*

**Scleranthus annuus* L. *0070240*

Stellaria media (L.) Ville. *0070249*

Celastraceae

Celastrus orbiculatus Thunb. *0070159*

Euonymus alatus (Thunb.) Siebold. *0060079*

Euonymus fortunei (Turcz.) Hand-Mas. *0060089)*

Ceratophyllaceae

Ceratophyllum demersum L. *0070261*

Chenopodiaceae

Chenopodium album L. *0070246*

Clethraceae

Clethra alnifolia L. *0060150*

Clusiaceae

Hypericum perforatum L. *Zlotsky 9790034*

Cornaceae

Cornus amomum Mill. 0060155

Cornus florida L. *0070165*

Cornus racemosa Lam. *0080118* - rare

Nyssa sylvatica Marsh. *0060134*

Crassulaceae

Penthorum sedoides L. *0060095*

Cuscutaceae

Cuscuta gronovii Willd. ex J.A. Schultes. *0070393*

Elaeagnaceae

**Elaeagnus angustifolia* L. *0070193*

Ericaceae

Gaultheria procumbens L. *0070753*

Gaylussacia baccata Wangenh. K. Koch. *0070225*

Rhododendron periclymenoides Michx. Shinners. *0070126*

Rhododendron viscosum (L.) Torr. *0060106*

Vaccinium angustifolium Aiton. *0070224*

Vaccinium corymbosum L. *0060077*

Euphorbiaceae

Acalypha virginica L. *0070254*

Chamaesyce maculata (L.) Small. *0070253*

Fabaceae

Amphicarpaea bracteata (L.) Fern. *0070497*

Apios americana Medik. *0060144*

†*Desmodium paniculatum* (L.) DC. *Levine 9810422*

**Medicago lupulina* L. *Morgan & Domina 0070182*

Strophostyles helvola (L.) Elliott. *0080402*- rare

**Trifolium campestre* Schreb. *0070228*

**Trifolium pratense* L. *0070186*

**Trifolium repens* L. *0070154*

Fagaceae

Castanea dentata (Marsh.) Borkh. *0060076*

Fagus grandifolia Ehrh. *0060019*

Quercus alba L. *Morgan & Borysiewicz 0070153*

Quercus bicolor Willd. *0070150* - rare

Quercus coccinea Munchh. 0080379

Quercus palustris Muenchh. *0070337*

Quercus prinus L. *0080391*- rare

Quercus rubra L. *0070134*

Quercus velutina Lam. *0070231*

Geraniaceae

Geranium maculatum L. *0070124*

Hamamelidaceae

Hamamelis virginiana L. *0060021*

Hippocastanaceae

**Aesculus hippocastanum* L. *0070265*

Hydrocharitaceae

Elodea canadensis Michx. *0080126*

Juglandaceae

Carya cordiformis (Wangenh.) K. Koch. *0060410*

Carya glabra (Mill.) Sweet. *0070223*

Carya ovata (Mill.) K. Koch. *0070192*

Lamiaceae

**Ajuga reptans* L. *Levine 9810664*

Clinopodium vulgare L. 0080121

Collinsonia canadensis L. *0060084*

**Glechoma hederacea* L. 0070419

**Lamium amplexicaule* L. *Zlotsky 9790140*

Lycopus americanus Muhl. ex W. Bartram. 0070549

Lycopus rubellus Moench. *0070227*

Prunella vulgaris L. *0070341*

Scutellaria lateriflora L. *0070217*

Lauraceae

Lindera benzoin (L.) Blume. *0060018*

Sassafras albidum (Nutt.) Nees. *0060080*

Lythraceae

**Lythrum salicaria* L. *0060151*

Magnoliaceae

Liriodendron tulipifera L. *0060074*

**Magnolia tripetala* (L.) L. *0070184*

Malvaceae

**Abutilon theophrasti* Medik. *Sadlon 9800010*

Molluginaceae

**Mollugo verticillata* (L.) Pers. *0070250*

Monotropaceae

Monotropa hypopithys L. *0070512*

Monotropa uniflora L. *0060109*

Nymphaeaceae

Nymphaea odorata Ait. *0070266*

Oleaceae

Fraxinus americana L. *0070167*

Fraxinus pensylvanica Marsh. *0060430*

Onagraceae

Circaea lutetiana L. *0060154*

Ludwigia palustris (L.) Elliott. *0060133*

Oenothera biennis L. *Levine 8600011*

Orobanchaceae

Epifagus virginiana (L.) W. Bartram. *0060075*

Oxalidaceae

**Oxalis stricta* L. *0070191*

Papaveraceae

**Chelidonium majus* L. *Levine 9810661*

Sanguinaria canadensis L. *Levine 0810040* - rare

Phytolaccaceae

Phytolacca americana L. *0070242*

Polygalaceae

Polygala ambigua Nutt. *0070760*

Polygonaceae

Polygonum arifolium L. *0070216*

**Polygonum aviculare* L. *0070243*

**Polygonum cuspidatum* Siebold & Zucc. *0070212*

Polygonum hydropiperoides Michx. *0070264*

Polygonum pensylvanicum L. *Zlotsky 9810369*

**Polygonum persicaria* L. *0070213*

Polygonum virginianum L. *0060097*

Polygonum sagittatum L. *Zlotsky 9790033*

**Rumex acetosella* L. *0070188*

**Rumex crispus* L. *Morgan & Domina 0070148*

Plantaginaceae

**Plantago lanceolata* L. *0070248*

**Plantago major* L. *0070316*

Plantago rugelii Dcne. *0070230*

Portulacaceae

Claytonia virginica L. *0070115*

**Portulaca oleracea* L. *0070242*

Primulaceae

Lysimachia ciliata L. *0070215*

Lysimachia quadrifolia L. *Levine 981716*

Lysimachia terrestris (L.) Britton, Sterns & Poggenb. *0070158*

Pyrolaceae

Chimaphila maculata (L.) Pursh *0060020*

Pyrola elliptica Nutt. *0070263*

Ranunculaceae

Actaea pachypoda Ell. *Morgan & Borysiewicz 0070338*

Anemone quinquefolia L. *0070129*

Caltha palustris L. *0070011*

**Ranunculus acris* L. *0070168*

Ranunculus abortivus L. *0070140*

**Ranunculus bulbosus* L. *0070781*

Ranunculus hispidus Michx. *0070141*

Ranunculus recurvatus Poir. *0070782*

**Ranunculus repens* L. *0080099*

Thalictrum pubescens Pursh *0060105*

Thalictrum thalictroides (L.) Eames & B. Boivin *0070113*

Rosaceae

Amelanchier canadensis (L.) Medik. *0070123*

Geum canadense Jacq. *0070229* - rare

Potentilla canadensis L. *Levine 9810054*

**Potentilla intermedia* L. *0070182*

**Potentilla recta* L. *Levine 9810055*

Potentilla simplex Michx. *Sadlon 9800034*

Prunus serotina Ehrh. *0070166*

**Rhodotypos scandens* (Thunb.) Makino. *0070498*

**Rosa multiflora* Thunb. *0070187*

Rosa palustris Marsh. *0060110*

Rubus alleghaniensis Porter. *0070308*

Rubus flagelaris Willd. *0070232*

Rubus hispidus L. *0070195*

**Rubus phoenicolasius* Maxim. *0070236*

Sibbaldiopsis tridentata (Aiton) Rydb. *0080932* - rare

Spiraea tomentosa L. *0060160*

Rubiaceae

Cephalanthus occidentalis L. *0060102*

**Galium mollugo* L. *0070208*

Galium obtusum Bigelow *0070199*

Mitchella repens L. *0060111*

Rutaceae

**Phellodendron amurense* Rupr. *0070257*

Salicaceae

Populus grandidentata Michx. *0080871*

Populus tremuloides Michx. *0070185*

Salix discolor Muhl. *Hessell 9810601* - rare

Scrophulariaceae

Chelone glabra L. *0060129*

**Digitalis purpurea* L. *0070205*

**Linaria vulgaris* Mill. *Morgan & Domina 0070204*

Melampyrum lineare Desr. *Levine 9080100*

Mimulus ringens L. *0070301*

Nuttallanthus canadensis (L.) D.A. Sutton *0070260*

**Verbascum thapsus* L. *Morgan & Domina 0070203*

Veronica serpyllifolia L. *0070251*

Simaroubaceae

Ailanthus altissima (Mill.) Swingle *0070211*

Solanaceae

Physalis longifolia Nutt. *0060532* - rare

Solanum carolinense L. *0070423*

**Solanum dulcamara* L. *0060159*

Solanum ptycanthum Dunal *0070244*

Symplocaceae

**Symplocos paniculata* (Thunb.)Miq. *0060317*

Tiliaceae

Tilia americana L. *0070133*

Ulmaceae

Ulmus americana L. *0080300* - rare

Ulmus rubra Muhl. *0070170*

Urticaceae

Boehmeria cylindrica (L.) Sw. *0060127*

Pilea pumila (L.) A. Gray *0070222*

Urtica dioica L. *0070221*

Violaceae

Viola labradorica Schrank *0070169*

Viola macloskeyi Lloyd. *Levine 9810631*

Viola sororia Willd. *Levine 9810614*

Viola striata Ait. *0070237*

Vitaceae

**Ampelopsis brevipedunculata* (Maxim.) Trautv. *0070206*

Parthenocissus quinquefolia (L.) Planch. *0060081*

Vitis labrusca L. *0070171*

LILIOPSIDA

Alismataceae

Alisma triviale Pursh *0060029*

Araceae

Arisaema triphyllum (L.) Schott *0060031*

Peltandra virginica (L.) Schott *0060101*

Symplocarpus foetidus (L.) Salisb. ex Nutt. *0090301*

Commelinaceae

**Commelina communis* L. *0070178*

Cyperaceae

Bulbostylis capillaris (L.) Kunth ex C.B. Clarke *0080122* - rare

Carex crinita Lam. *0070234*

Carex intumescens Rudge *0060141*

Carex laxiflora Lam. *0070137*

Carex lupulina Muhl. ex Willd. *0070268*

Carex lurida Wahlenb. *0070157* - rare

Carex pensylvanica Lam. *0060108*

Carex rosea Schkuhr ex Willd. *0070233*

Carex scoparia Schkuhr ex Willd. *0070156*

Carex stricta Lam. *0060103*

Carex swanii (Fern.) Mackenzie *0070239* - rare

Carex vulpinoidea Michx.*0060114*

**Cyperus esculentus* L. *0060116*

Cyperus lupulinus (Spreng.) Marcks *0070226*

Eleocharis parvula (Roem. & Schult.) Link ex Bluff, Nees & Schauer *0070179* - rare

Scirpus atrovirens Willd. *Morgan & Domina 0070136*

Dioscoreaceae

Dioscorea villosa L. *0060088*

Iridaceae

Iris pseudacorus L. *Morgan & Domina 0070145*

Iris versicolor M. Bieb. *Morgan & Domina 0070152*

Juncaceae

Juncus bufonius L. *0070334*

Juncus effusus L. *0060118*

Luzula multiflora (Ehrh.) Lej. *0070121*

Lemnaceae

Lemna minor L. (Not Sampled)

Spirodela polyrrhiza (L.) Schleid. *Not Sampled*

Wolffia brasiliensis Weddell *Not Sampled* - rare

Wolffia columbiana Karst *Not Sampled* - rare

Liliaceae

Allium tricoccum Aiton *Morgan 0070258*

Allium vineale L. *Morgan & Borysiewicz 0070180*

Erythronium americanum Ker Gawl. *0070114*

Hypoxis hirsuta (L.) Coville *0100377*

Maianthemum canadense Desf. *0070135*

Maianthemum racemosum (L.) Link *0070162*

Medeola virginica L. *Levine 9810008* - rare

Polygonatum biflorum (Walter) Elliot *0070161*

Trillium cernuum L. *0080102* - rare

Trillium erectum L. *Not Sampled* - rare

Uvularia sessilifolia L. *0070176*

Veratrum viride Aiton *Morgan & Domina 0070144*

Orchidaceae

Cypripedium acaule Ait. *Not Sampled* - rare

**Epipactis helleborine* (L.) Crantz. *0070283*

†*Goodyera pubescens* (Willd.) R. Br. *Levine 744, UCONN*

Poaceae

**Agrostis gigantea* Roth *0070325*

**Agrostis stolonifera* L. *0070138*

**Anthoxanthum odoratum* L. *0070255*

**Arrhenatherum elatius* (L.) P. Beauv. ex. J. Presl. & C. Presl. *Levine 9820007*

Brachyelytrum erectum (Schreb. ex. Spreng.) P. Beauv. *0060094*

Calamagrostis canadensis (Michx.) P. Beauv. *0070555*

**Dactylis glomerata* L. *Levine 9810614*

Dichanthelium acuminatum (Sw.) Gould & CA Clark *0070322*

Dichanthelium boscii (Poir.) Gould & C. A. Clark *0070177* - rare

Dicanthelium clandestinum (L.) Gould *0070311*

Dichanthelium dichotomum (L.) Gould. *0070214*

***Digitaria ischaemum* (Schreb.) Schreb. ex Muhl *0070326*

***Echinochloa crus-galli* (L.) P. Beauv. *0060113*

Elymus canadensis L. *0060119*

Elymus hystrix L. *0060117*

Elymus virginicus L. *0060120*

Eragrostis pectinacea (Michx.) Nees ex Steud. *0070139*

Festuca rubra L. *Levine 9820005*

Hierochloe odorata (L.) Beauv. *0070321*

**Holcus lanatus* L. *0070424*

Leersia oryzoides (L.) Sw. *0060131*

Leersia virginica Willd. *0070511*

**Lolium perenne* L. *0070314*

Muhlenbergia schreberi J.F. Gmel. *0070519*

Panicum capillare L. *0070310*

Panicum virgatum L. *0060112*

**Phleum pratense* L. *0070198*

Poa annua L. *0070256*

Poa pratensis L. *Levine 9820006*

Schizachyrium scoparium (Michx.) Nash *0060115*

Setaria viridis (L.) Beauv. *Levine 9810008*

Potamogetonaceae

**Potamogeton crispus* L. *0060138*

Potamogeton gramineus L. *0060083* - rare

Potamogeton zosteriformis Fernald *Borysiewicz & Morgan 0090258*

Smilacaceae

Smilax glauca Walter *0070196*

Smilax rotundifolia L. *0070197*

Sparganiaceae

**Sparganium emersum* Rehmann *Morgan & Borysiewicz 0070174*

Table 3.1.

Importance Values of all woody species over 2cm dbh from sixty-one quadrats

Rank	Species	Rel. Dens.	Rel Freq.	Rel. Dom.	IV/1
1	*Fagus grandiflolia*	27.28	14.95	21.94	64.17
2	*Acer rubrum*	11.24	10.59	15.58	37.41
3	*Betula lenta*	8.54	10.9	14.4	33.84
4	*Quercus alba*	3.59	5.29	10.45	19.33
5	*Euonymus alata*	9.15	4.67	1.78	15.6
6	*Carpinus caroliniana*	4.94	6.85	1.31	13.1
7	*Acer saccharum*	4.19	5.61	3.19	12.99
8	*Carya ovata*	3.15	4.98	4.79	12.92
9	*Betula alleghaniensis*	3.74	5.6	3.25	12.59
10	*Quercus rubra*	2.39	4.36	5.67	12.42
11	*Fraxinus pennsylvanica*	1.95	3.73	4.61	10.29
12	*Acer platanoides*	2.69	3.11	2.47	8.27
13	*Nyssa sylvatica*	2.39	2.49	1.49	6.37
14	*Phellodendron amurense*	2.85	1.87	1.14	5.86
15	*Hamamelis virginiana*	1.79	3.11	0.68	5.58
16	*Lindera benzoin*	2.55	1.87	0.45	4.87
17	*Tsuga canadensis*	2.09	0.93	1.84	4.86
18	*Liriodendron tulipifera*	0.74	0.93	1.79	3.46
19	*Ostrya virginica*	0.75	1.24	1.23	3.22

20	*Cornus florida*	0.89	1.55	0.5	2.94
21	*Ulmus rubra*	0.59	1.24	0.63	2.46
22	*Tilia americana*	0.45	0.93	0.34	1.72
23	*Castanea dentata*	0.59	0.93	0.09	1.61
24	*Prunus serotina*	0.59	0.62	0.15	1.36
25	*Ilex verticillata*	0.29	0.62	0.04	0.95
26	*Celastrus orbiculatus*	0.15	0.31	0.07	0.53
27	*Amelanchier canadensis*	0.15	0.31	0.06	0.52
28	*Viburnum dentatum*	0.15	0.31	0.02	0.48

Figure 3.1

Species area curve of quadrats using approximate randomization (NS = 1000).

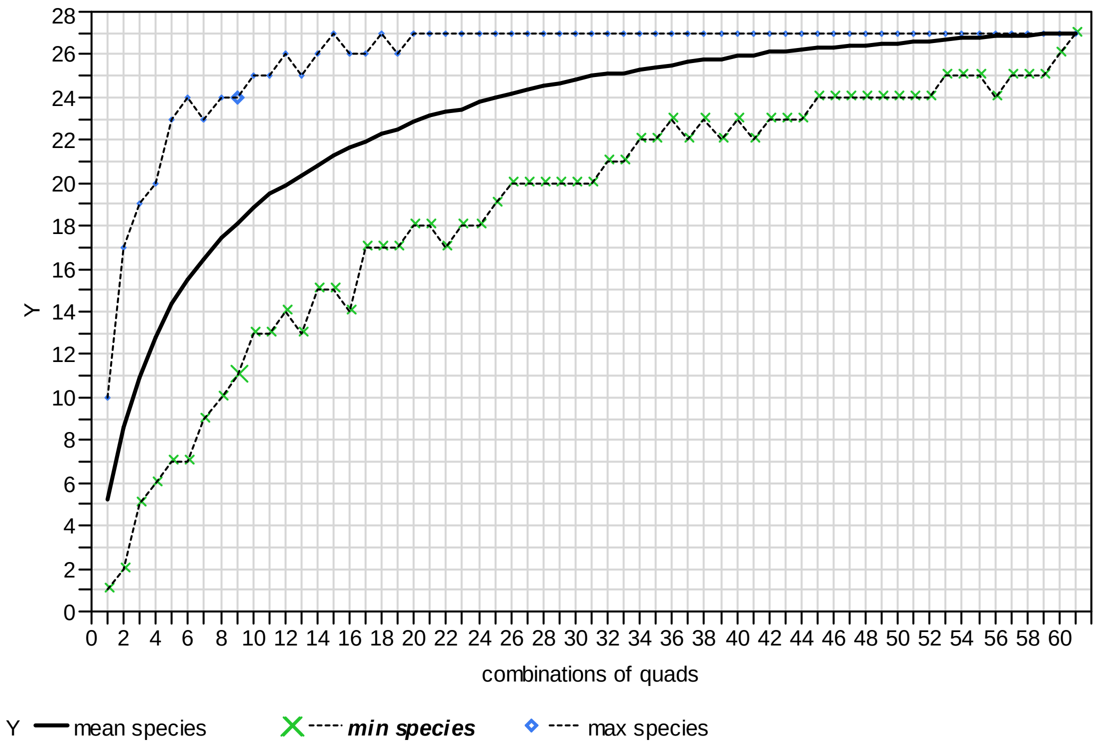

Figure 3.2.

Cluster Diagram of sixty one quadrats in the Bartlett Arboretum Forest using the ten most important woody species in importance value based upon average centroid clustering. This pattern shows the red maple cluster and beech dominated cluster to be the least common forest types while beech - mixed hardwoods and mixed hardwood types dominate much of the forest.

Figure 1 Legend

■ - Beech - Mixed hardwoods Cluster

□ - Mixed Hardwoods Cluster

x - Red Maple Cluster

+ - Beech Dominated Cluster

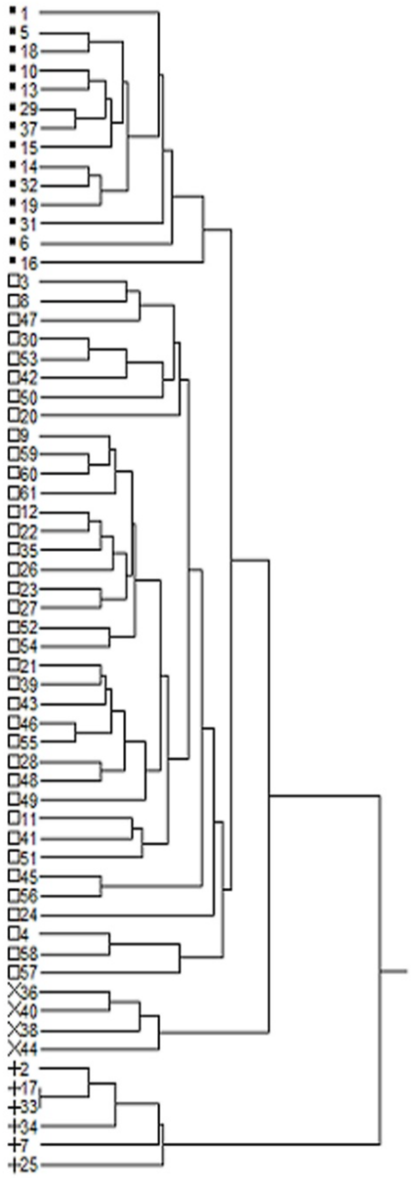
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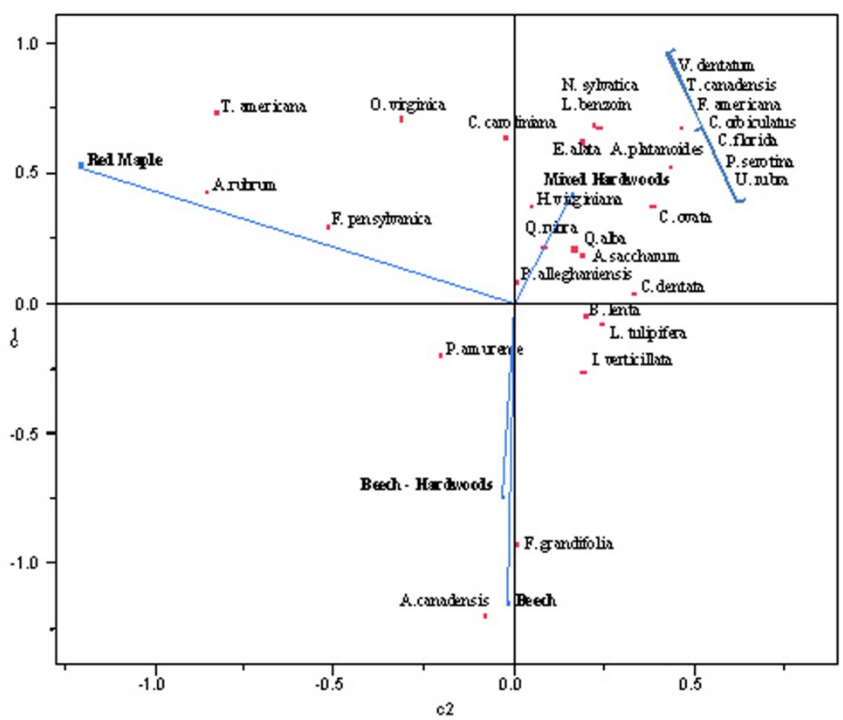
Figure 3.3.

Correspondence Analysis ordinating the forest clusters with all arborescent species based upon cluster type and species present. Quantity of each species per quadrat is applied as a frequency value. Species are as follows: *Fagus grandifolia*; *Acer rubrum*; *Betula lenta*; *Quercus alba*; *Euonymus alata*; *Carpinus caroliniana*; *Acer saccharum*; *Carya ovata*; *Betula alleghaniensis*; *Quercus rubra*; *Fraxinus pennsylvanica*; *Acer platanoides*; *Nyssa sylvatica*; *Phellodendron amurense*; *Hamamelis virginiana*; *Lindera benzoin*; *Tsuga canadensis, Liriodendron tulipifera*; *Ostrya virginica*; *Cornus florida*; *Ulmus rubra*; *Tilia americana*; *Castanea dentata*; *Prunus serotina*; *Ilex verticillata*; *Celastrus orbiculatus*; *Amelanchier canadensis*; *Viburnum dentatum*.



Chapter 4

The Invasion of *Phellodendron amurense* Rupr. into the Urban and Suburban Woodlands of the New York City Region

[this chapter modified from this reference:]

Morgan, E. C. and J.A. Borysiewicz. 2011. The Invasion of *Phellodendron amurense* Rupr. into the Urban and Suburban Woodlands of the New York City Region. Urban Habitats. *In Press*.

Abstract

Phellodendron amurense Rupr. is an introduced, exotic tree species from eastern Asia that has been used in ornamental horticulture throughout urban and suburban areas of the northeast. In recent years, even as more focus has been placed upon the impact of invasive species, *Phellodendron amurense* and other non native species have continued to be planted even though little or no examination of their potential impact and spread has been undertaken. In 2008 and 2009, surveys were performed at sites where *Phellodendron amurense*, a non native tree species was reported to have been found growing adventively. From these sites, five invasions consisting of reproducing populations were identified and investigated further. These five sites, located in Bronx County, NY; Fairfield County, CT; Philadelphia County, PA; Queens County, NY and Tolland County CT, were then investigated to look for similarities in their forest composition which may help to explain forest susceptibility to invasion by *P. amurense*. This work reports that *P. amurense* is a much more widespread invader than previous literature reports suggest, and that the invasion is not limited to any particular forest type. Of the five main invasion sites examined here, none share the same top species in Importance Value calculations with correspondence analysis showing little similarity between four of the five sites. Tree density, which ranges from 55 to 643 trees per hectare is also shown not to affect the ability to invade a particular site. These data provides strong evidence of the need for closer monitoring and potentially removal of *P. amurense* before populations in the region reach a point at which removal will no longer be an option.

Introduction

Since publication of the landmark work *The Ecology of Invasions by Animals and Plants* by Charles Elton (1958), increased attention has been paid towards the problems associated with non-native invasive species. More recently, the monetary costs of these invasions has begun to be examined with some estimates as high as $137 billion per year (Pimentel et al. 2000). In spite of the more than fifty years of research and potentially staggering costs, new species continue to be introduced into the United States either intentionally or accidentally on a regular basis. While the pace of research has increased in the past decade with entire journals now dedicated to the topic of studying invasions, relatively little is known about the vast majority of invasive organisms, including invasive vascular plants.

In the surrounding regions of New York City, from Boston to Philadelphia, there are numerous invasive plants which have been well documented and researched including *Acer platanoides* L. (Fang 2005), *Ailanthus altissima* (Mill.) Swingle (Knapp and Canham 2000), *Lythrum salicaria* L. (Blossey et al 2001) and *Berberis thunbergii* DC. (Ehrenfeld 1997). Numerous other species including *Viburnum lantana* L. and *Spiraea japonica* L. f. show invasive potential in the region (Martine et al 2008) and will likely receive closer monitoring for invasion in the coming years. One species of particular interest here is *Phellodendron amurense* Rupr., commonly known as the Chinese or Amur cork tree. A dioecious member of the Rutaceae, *P. amurense* is proving to be a relatively widespread invasive plant throughout this region. In New York City, Glaeser and Kincaid (2005), reported *P. amurense* as ranking third in overall dominance based upon importance value within a woodland showing the need for further examination of the species. In spite of this there is still very little recognition in the literature of the invasive potential, spread and ecological impact of this species.

Phellodendron amurense is currently grown throughout the northeastern United States for its ornamental value. Dirr (1990) describes *P. amurense* as an excellent tree for parks and other large areas. A native of Asia which is very cold tolerant *Phellodendron amurense* has apparently never established itself as a major horticultural species as it is currently only available through specialty nurseries and mail order. This is possibly due to its large adult size of ten to fifteen meters in height and potentially greater spread as described by Dirr (1990). The lack of horticultural availability makes the appearance of reproducing populations of this plant even more important to monitor since they can easily be overlooked until long after they are unable to be removed.

The early identification, monitoring, and removal of potentially invasive plants is a topic which is often difficult to convey. In a recent study of nursery professionals in Connecticut, forty-nine percent of those surveyed still worked with *Acer platanoides* and sixty-six percent with *Berberis thunbergii*, (Gagliardi and Brand 2007), both of which are well documented and notoriously invasive plant species with major environmental impacts (Wycoff and Webb 1996, Ehrenfeld 1997). The early recognition of invasive tendencies in a particular species can prevent problems which may arise later when trying to control it. When invasive species are already well established in both the natural landscape as well as in the nursery trade, control is unlikely. This paper presents evidence that *P. amurense* is established over a large range in the New York City region, is capable of establishing in a wide variety of habitats, and should warrant more aggressive removal policies before the tree becomes a major problem in our region.

Methods

In the summer of 2008 and 2009, field surveys were performed throughout the state of Connecticut, the New York City region, Long Island, New Jersey and the Philadelphia region to locate spontaneous, non horticultural populations of *P. amurense*. These sites were selected based upon author observations, herbarium records, literature reviews and the results of a request for sighting information which was distributed in early 2008 to botanical organizations and universities. Over twenty sites were documented, fourteen of which were found to contain reproducing populations of *P. amurense* with both male and female trees, and were analyzed further to determine the extent of the invasion. Five of these fourteen reproducing sites had at least five mature trees and were then analyzed to determine the surrounding vegetation types in which *P. amurense* had established itself. These five sites, the Bartlett Arboretum, Fairfield County, CT (41.07N 73.33W); Forest Park, Queens County, NY (40.42N 73.50W); Goodwin State Forest, Tolland County, Ct (41.46N 72.05W); Morris Arboretum, Philadelphia County, PA (40.05N 75.13W); The New York Botanical Garden, Bronx County, NY (40.51N 73.52W), were all surveyed further in 2009.

Each site was analyzed to calculate Importance Values (Curtis and McIntosh, 1951) for the surrounding vegetation. To perform this analysis, a variation of the Point-Center-Quarter (PCQ) method was used as follows. Transects were placed through the area invaded by *P. amurense* creating the longest route through the invaded area at each location. An additional transect was placed at both the Bartlett Arboretum and New York Botanic Garden to sufficiently sample the larger invasion sites. Points were then chosen by using the closest *P. amurense* tree within 10 meters to the transect and over 5cm diameter at breast height (dbh) as point one. The dbh for each tree closest to the *P. amurense* point in each quarter was then recorded as well as its species identification and radius to the center point. If the closest tree in the quarter was another *P. amurense*, the second closest tree was sampled and so forth. If no tree other than *P. amurense* was found within 20m of the center point, the species determination was listed as open, to represent an opening in the forest. The radius for that value was recorded at 20m. Point two along each transect was chosen by selecting the next *P. amurense* greater than 5cm dbh within 10 m of the transect which did not have any tree in a quarter overlapping a tree in the previous PCQ data set. This process was repeated until no more data sets could be collected without overlap. A total of twenty-seven different tree species were recorded at all five sites combined. Importance values were calculated as described by Curtiss and McIntosh (1951). With *P. amurense* individuals acting as the centroid points, they were not included in calculations of Importance Values. A bootstrap method in JMP 7.0 created by Kincaid (2008), was used to create an upper boundary importance value and a lower boundary importance value representing 95 percent confidence intervals. To determine the density of woody plants within the surrounding area, a bootstrap method by Kincaid (2008) was performed in JMP 7.0. Correspondence analysis was done using JMP 8.0 by analyzing the species by site occurrence matrix.

Results and Discussion

Site visits revealed that there are at least fourteen sites in the region where *P. amurense* has successfully invaded. An additional eight sites were found by searching the databases of several herbaria and a review of the literature. These results are summarized in Table 1. Sites of invasion range from several individuals to over 350 individuals. All sites had more than one individual, although in several cases only one tree greater than 5 cm was found and the confirmation of a female plant to ensure continued reproduction was not possible.

Importance values calculated for the five main sites of invasion reveal vast differences between the sites. With open space being calculated as a taxon value as is done here, none of the five sites share a similarity among their highest ranked taxa. The New York Botanical Garden and Forest Park, which are also the two closest sites geographically, share four of the top five taxa in importance, however *Quercus rubra* L. ranks first at Forest Park with an IV= 130.6 while at The New York Botanical Garden *Q. rubra* ranks third, IV=38.6, while *Prunus serotina* Ehrh. ranks first (IV = 75.3). The additional three sites are all led in importance values by different species, with the Bartlett Arboretum led by *Acer rubrum* (IV= 93.1), Morris Arboretum by *Acer negundo* L. (IV= 141.4), and Goodwin State Forest by open space (IV= 143.8). These results are summarized in Table 2.

Calculations of absolute density of forest trees also show a vast difference in the surrounding vegetation of the invaded sites. The radius of measurements taken between the centroid *P. amurense* at each point on the transect and the nearest non *P. amurense*, revealed that the radius ranged from 3.9 m at the Bartlett Arboretum to 7.8 m at Goodwin State Forest. A bootstrap resampling of these data revealed that the average density of non *Phellodendron* trees at each site ranged from a low of 55 trees per hectare at Goodwin State Forest to 643 trees per hectare at the Bartlett Arboretum Forest. Bootstrapping to obtain minimum 95 percent confidence interval and maximum 95 percent confidence interval density values for each site revealed variation in these values however only the New York Botanical Garden and Forest Park consisted of values which would potentially overlap. These results are reported in Table 3.

Correspondence analysis confirms the data from importance value calculations with more insight onto the site differences. The New York Botanical Garden and Forest Park are the most similar sites to each other, and along with the Bartlett Arboretum Forest, are all most closely aligned with the centroid. Morris Arboretum and Goodwin State Forest show the most deviation from the centroid.

The extent to which *P. amurense* has invaded the region is much more extensive than previously reported. Gleason and Cronquist (1991) report *P. amurense* as occasionally escaped and Lamont and Young (2002), report *P. amurense* as occurring at only two sites within the approximate range of this work. This work documents numerous sites, including several of which are comprised of hundreds of trees. This work also shows that *P. amurense* is invading a range of forests throughout the region studied, and has invaded both open areas as well as established woodlands. Yoshida and Kamitani (1999), describe *P. amurense* as a shade intolerant species in the forests of central Japan, however the evidence presented here contradicts their observations made within the plant's native range. These discrepancies can be due to a number of factors. The surrounding species composition in the plants native range may impact *P. amurense* in ways that the regional flora in its invaded area cannot, including leaf emergence and leaf drop times being longer or shorter for species surrounding *P. amurense* in either site. An additional possibility may be due to the apparent variability within the species, and the potential for hybrid vigor between varieties of this species. Williams et al. (2005) showed that in *Schinus terebinthifolius* Raddi, an exotic invasive species in Florida, intraspecific hybridization between two distinct introductions of the plant resulted in an intraspecific hybrid variety, which is the genotype of the plant spreading across the state of Florida. As in the case of *S. terebinthifolius, P. amurense* has well documented previously recognized varieties of the species. Ma et al.

(2006) later revised the genus *Phellodendron* to contain only two species, *P. amurense* and *P. chinense* C.K. Schneid. Prior to this revision, the genus contained over ten species and numerous other varieties based upon collections within their native range. Several studies (Greller 1977, Bertin 2005) within the geographic range of this paper have reported former names for *P. amurense*, possibly due to the apparent variation within the species leading to the original splitting of the genus. In an earlier study of *Phellodendron* within the New York Botanical Garden, de la Cruz and Nee (2003), specimens collected among horticultural and escaped individuals showed variation in both leaf base shape and hairiness of leaf undersides. de la Cruz and Nee also document three separate plantings at the New York Botanical Garden originally determined as three separate species, *P. amurense, P. japonicum,* and *P. sakhaliense*. All three of which are now *P. amurense* sensu J. Ma, increasing the chances that intraspecific hybridization between subspecies may indeed play a role in the species' invasion.

The calculation of importance values for the five sites revealed a difference in the surrounding forest types for each invaded site. The results reported here show all five sites as having different dominant species, with Goodwin State forest being characterized by open land. The Goodwin State forest location is in the process of removing the *P. amurense* from the main invasion site, allowing access to tree rings of many trees. All the *P. amurense* specimens with rings available for counting were aged 27-29 years of age. These dates coincide with a documented late spring storm which destroyed a large stand of pines (species unknown), 29 years before the survey of the site (Goodwin State Forest interpretive signage). This would show that *P. amurense* almost immediately colonized this open space after the disturbance. The invasion history at other locations is less clear. Morris Arboretum, which is dominated by large individuals of *Lonicera tatarica* L. and *Acer negundo* L., also has a significant amount of open space, and with the lower growing species heights of both *L. tatarica* and *A. negundo*, could potentially be seen as a relatively open space as well.

The remaining three sites yield more intriguing results. At the Bartlett Arboretum Forest, *Acer rubrum* dominates the area of forest with the heaviest *P. amurense* invasion and has a mean density of 643 non *P. amurense* trees per hectare. This density, along with a mean dbh of 21.8 indicates an established, mature forest which has been invaded. The forests of the New York Botanical Garden with a density of 367 mean trees per hectare and a mean dbh of 20.4, and Forest Park with a mean density of 307 trees per hectare and a mean dbh of 28.9 also provide evidence that *P. amurense* is invading not only open habitats, but well established forests of different densities as well. Unlike the Bartlett Arboretum site, the surrounding forest of the New York Botanical Garden is dominated by *Prunus serotina*, and Forest Park is dominated by *Q. rubra*. The dominance by three different species at these three sites provides evidence that *P. amurense* is capable of invading a variety of ecological niches in addition to different levels of forest establishment.

The correspondence analysis performed for the five sites provides further evidence of the differences between sites. Only the New York Botanical Garden and Forest Park fall within the same quadrant, which would correspond with the importance value data which shows four of the top five species are the same for both sites, although in different orders of importance. All three additional sites are found in separate quadrants with the Morris Arboretum and Goodwin State Forest showing the greatest deviation from the centroid.

This study shows that the invasion of *P. amurense* in the region of New York City is much more widespread than earlier works have reported and that *P. amurense* is capable of establishing itself within a large range of the forests of the eastern United States. While additional data is needed for the exact current distribution, it is likely that with better field recognition of the species it may be found throughout many additional parcels of forest in the region. As is the case in many invasives, early detection and eradication is important, and *P. amurense* presents itself as a candidate for invasive removal programs as well as designation by both government and nongovernmental organizations as an invasive and or noxious weed.

Table 4.1.

Confirmed sites of invasion by *Phellodendron amurense* in the New York City region.

State	County	Approximate Minimum Population Size	Source
CT	Fairfield	350	Site visit
CT	Tolland	1	Site visit
CT	Tolland	50	Site visit
CT	Fairfield	20	Site visit
CT	New Haven	1	Orsen et. al
MA	Worcester	3	Bertin et al. 2005
NJ	Bergen	Unknown	BKL
NJ	Mercer	8	Site visit; BART
NY	Bronx	300	Site visit, NY
NY	Bronx	1	Site visit,NY
NY	Nassau	10	Site Visit
NY	Nassau	7	Site visit
NY	Orange	25	BKL
NY	Queens	1	Site visit
NY	Queens	100	Site visit; Glaeser 2005
NY	Queens	Unknown	Greller (1977)
NY	Richmond	1	BKL
NY	Suffolk	1	Site visit

NY	Westchester	Unknown	BKL
PA	Philadelphia	5	Site visit
PA	Philadelphia	30	Site visit
PA	Montgomery	Unknown	GH

Table 4.2.

Importance values for areas of invasion by *Phellodendron amurense*. Upper Bound (UB and Lower Bound (LB) bootstrap 95% confidence intervals are provided for Importance Values.

Bartlett Arboretum, Fairfield, CT

	LB IV	UB IV	IV
Acer rubrum	71.43	120.41	91.14
Betula lenta	39.92	78.46	56.83
Quercus alba	9.91	41.98	22.78
Carya ovata	4.60	29.67	17.99
Acer saccharum	5.53	27.44	17.55

New York Botanic Garden, Bronx, NY

	LB IV	UB IV	IV
Prunus serotina	60.15	114.53	75.36
Liriodendron tulipifera	7.07	68.19	44.91
Quercus rubra	16.31	62.67	38.59
Fagus grandifolia	9.06	41.24	26.11
Carya glabra	4.12	42.44	21.74

Forest Park, Queens, NY

	LB IV	UB IV	IV
Quercus rubra	99.35	158.71	130.59

Betula lenta	21.44	48.41	36.15
Prunus serotina	13.59	41.59	26.28
Liriodendron tulipifera	15.49	41.65	25.72
Carya glabra	5.24	30.92	19.14

Goodwin State Forest, Tolland, CT

	LB IV	UB IV	IV
Open	119.22	181.29	143.83
Acer rubrum	49.23	101.69	72.36
Hamamelis virginiana	3.52	48.39	23.84
Prunus serotina	0	32.65	19.84
Liriodendron tulipifera	0	29.75	11.90

Morris Arboretum, Philadelphia, PA

	LB IV	UB IV	IV
Acer negundo	70.26	200.66	141.41
Lonicera tatarica	34.51	156.32	86.90
Open	21.83	118.89	71.69

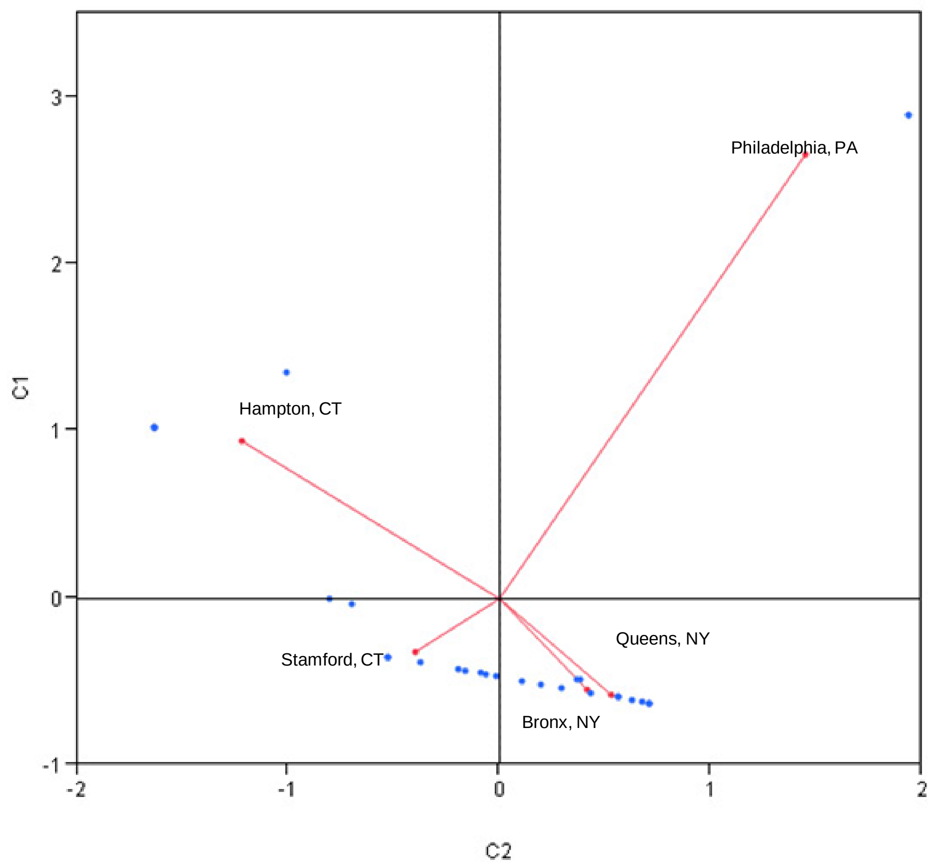
Table 4.3.

Radius values (r), average dbh (dbh), and bootstrap 95% confidence intervals of non *Phellodendron amurense* forest tree minimum (min), mean (m), and maximum (max) density per hectare at invaded sites, as based on point center quarter method.

Site	r	dbh	95% min	mean	95% max
Bartlett Arboretum	3.9	21.8	526	643	792
Forest Park	5.7	28.9	239	307	396
Goodwin State Forest	7.8	22.0	42	55	78
Morris Arboretum	4.5	6.2	79	179	661
New York Botanical Garden	5.2	20.4	302	367	454

Figure 4.1.

Correspondence analysis of invasion site locations. Sites included. Hampton, CT (Goodwin State Forest), Philadelphia, PA (Morris Arboretum), Queens, NY (Forest Park), Bronx, NY (New York Botanical Garden), Stamford, CT (Bartlett Arboretum). Plant species present clockwise from top; *Acer negundo*, *Lonicera tatarica*, *Cornus florida*, *Juglans cinerea*, *Tsuga canadensis*, *Quercus rubra*, *Carya glabra*, *Acer pseudoplatanus*, *Tilia cordata*, *Quercus velutina*, *Acer platanoides*, *Sassafras albidum*, *Fraxinus americana*, *Liriodendron tulipifera*, *Prunus serotina*, *Fagus grandifolia*, *Betula lenta*, *Quercus alba*, *Nyssa sylvatica*, *Carpinus caroliniana*, *Carya ovata*, *Acer saccharum*, *Magnolia tripetala*, *Ostrya virginica*, *Populus tremuloides*, *T. americana*, *Hamamelis virginiana*.



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C1
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C2
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Hampton, CT
Queens, NY
Stamford, CT
Bronx, NY

Chapter 5

Understory comparison of native canopy species and the exotic *Phellodendron amurense* Rupr. (RUTACEAE)

Abstract

The understory impacts of the invasive tree species *Phellodendron amurense* Rupr. upon invaded sites at two locations in the greater New York metropolitan region are examined. The understory of canopies consisting of *P. amurense* was compared with adjacent canopies consisting of native tree species. To determine if differences can be accounted for by shade cast by the canopy, leaf area indices were compared between the two canopy types at both locations.

At both locations there was a significantly lower number of individual plants per m^2 quadrat under *P. amurense* than under native canopy. When looking at only native understory species, there was also a highly significant difference with *P. amurense* canopies having lower numbers of native individuals present per quadrat. There was no difference between the invaded versus native site in the mean number of total species per m^2 quadrat at one location while the second location showed significance.

Canopy Analysis revealed no significant differences in leaf area index between canopy types at either site although leaf area index was higher under native species at both locations indicating that shading does not play a role in the lower density of understory individuals under *P. amurense.*

Introduction

Human introductions of new species to ecosystems, both accidental and intentional, can have numerous unintended consequences (Webb & Kauzinger 1993, Chornesky & Randall 2003). Since the publication of Charles Elton's (1958) *The ecology of invasions by animals and plants*, much more attention has been paid to the problem of non native introduced species, as well as their ecological and economical costs. However, as species are introduced to new regions of the globe each year, research into the impact and spread of each of these new invaders is often lacking and lags behind any potential point at which a problematic invader can be controlled effectively.

In the northeastern United States, the non native *Phellodendron amurense* Rupr. (Rutaceae), known commonly as Chinese or Amur cork tree, has invaded a number of forested sites in both urban and suburban woodlands (Morgan & Borysiewicz 2010, Glaeser & Kincaid 2005). Introduced to North America in 1856, *P. amurense* is a dioecious tree growing to 38m in height, is free of pests and withstands a variety of conditions making the tree excellent for parks and large landscapes (Dirr 1998). These characteristics make the tree an excellent choice for many horticultural situations and has resulted in *P. amurense* being cultivated throughout the United States, particularly in public gardens and arboreta as summarized by Ma and Branch (2007). Numerous horticultural collections and introductions such as this have resulted in the spread of many invasive plant species in the United States (Reichard and White 2001) including *Schinus terebinthifolius* Raddi. (Brazilian peppertree) in Florida and *Acer platanoides* L. (Norway maple) throughout the northeastern United States. Currently *P. amurense* appears to be spreading throughout the lower northeastern region (Morgan & Borysiewicz 2010) and is likely to join this growing list of aggressive invaders.

Prior to a revision of the genus *Phellodendron* (Ma et al. 2006), the species may have been overlooked as an introduced member of the local flora due to confusion in the nomenclature. Greller (1977) and Bertin et al. (2005) both reported *P. japonicum*, a species now included within the variable *P. amurense*, as a part of their floristic works in the northeastern region. de la Cruz and Nee (2003) report the genus *Phellodendron* as aggressively invading the hemlock forest of the New York Botanical Garden, Bronx County, New York. Their work reports that cultivated collections at the New York Botanical Garden contained *P. amurense*, *P. chinense*, *P. japonicum*, *P. lavallei* and *P. sachalinense*. With the exception of *P. chinense*, the additional four species have all now been designated as *P. amurense* (Ma et al 2006). At the site of a large invasion within the hemlock forest of the New York Botanical Garden, the *P. amurense* population has shown wide diversity in its morphology in both the leaflet base shape and the leaflet tomentum, (de la Cruz and Nee 2003) possible character differences which may continue to lead to confusion in correctly identifying this species. With the recent clarity given to this genera's taxonomy, it is very likely that the species will be recognized as a more common component of the regional flora.

In recent years, studies have begun to address the impacts of established invasive plant species through comparative analyses of invaded and non invaded habitats by a particular species (Gould and Gorchov 2000, Collier and Vankat 2002). However, this type of assessment has only been done for a small percentage of the many plant species which have now been introduced into new regions, and even fewer studies have been done upon the impact of species not yet fully recognized as widespread invasive species.

As a result of working with *P. amurense* invasions over the past several seasons, we hypothesized that the understory flora of these areas had lower species richness, lower overall individual abundances and contained a lower percentage of native species than adjacent areas of the same forest which did not contain *P. amurense* trees. We also attempted to gain insight of reasons for a difference in understory by measuring the leaf area index of both the *P. amurense* and adjacent non *P. amurense* canopy, enabling us to determine if a difference in shading could lead to differences in the understory composition. To assess the impact of *P. amurense* upon the understory flora of areas which have been invaded, a quadrat based analysis comparing invaded versus adjacent uninvaded areas in two separate forests was performed. An analysis of the canopy was then performed by using hemispherical canopy photographs in the sampled areas.

Materials and Methods

This study was conducted in the summer of 2009 at two sites where invasions of *P. amurense* totaling more than 100 mature trees were present. Site 1 is located within the forested portion of the Bartlett Arboretum, Fairfield County, Connecticut (41.07N 73.33W) and consists of 31 hectares of forested lands within a public arboretum managed by a private not for profit corporation. Site 2 is located at Forest Park, Queens County, New York (40.42N 73.50W) and is 220 hectares of predominantly forested lands and is owned and operated by the City of New York Department of Parks. Both the Bartlett Arboretum (Morgan 2009) and Forest Park (Greller et al. 1979, Glaeser 2006) have floras and vegetation which have been documented prior to this analysis. As measured in importance values Morgan (2009) describes the surrounding forest of the Bartlett Arboretum in its entirety to be dominated by *Fagus grandifolia* Ehrh., *Acer rubrum* L. and *Betula lenta* L. Greller et al 1979, describes the forest of Forest Park in its entirety as dominated by *Quercus rubra* L., *Q. velutina* Lam., and *Q. alba* L..

To assess the understory vegetation at each site, a transect was drawn through the *P. amurense* invaded sections of the forest. Along this transect individuals of *P. amurense* within 5 m on either side of the transect, measuring at least 5 cm diameter at breast height (DBH) were selected, and four plots measuring $1m^2$ were placed directly north, south, east and west of the tree with the center of the sample plot being 1.5m from the trunk edge. *P. amurense* trees were chosen by their proximity to the transect, and those which resulted in overlapping plots were eliminated. This resulted in 72 plots being analyzed at the Bartlett Arboretum and at Forest Park 96 plots were analyzed for a total of 168 plots under *P. amurense* canopy. To select plots in non invaded areas for comparison, a similar transect was drawn in an area immediately adjacent to each invaded site. At both locations, the non invaded sections were intermittent with the invaded sections of each site. No visible difference in elevation or soil moisture levels were apparent through visual observation. Along this line a similar procedure was used, however *Betula lenta* was substituted for *P. amurense*. At both sites, *B. lenta* had been documented as a major component of the forest in importance value. At the Bartlett Arboretum, 84 plots under *B. lenta* were analyzed and 52 at Forest Park for a total of 136 plots under native canopy. This resulted in a total of 304 $1m^2$ plots being measured at both sites and under all conditions.

Within each plot all vascular plants were identified to species and the number of individuals recorded. An inventory of species occurence data in relation to individual plots is presented as a supplemental data set to this thesis. To ensure adequate sampling, plots were created in late May 2009 when the original surveys were conducted and were repeatedly examined at least once per month over the summer season to account for newly emerged plants. Plot borders were marked with nylon flags to ensure the exact sited were measured each survey. For several prostrate species where individual species counts were difficult, the $1m^2$ plot was further divided into one hundred 10 cm by 10 cm subplots and an individual was tallied for each of these subplots the plant occurred within.

To analyze the canopy a CI-110 digital plant canopy imager, (CID Inc. Camas, WA) was used. Data was collected in July 2009 through the creation of hemispherical canopy photographs which were analyzed for calculations of leaf area index. To obtain this data, the imager was used by collecting images along the same transects as used for the creation of plots. To assure canopies were not duplicated in the analysis, images were taken at least 20 m apart in both *P. amurense* invaded and non invaded areas. This resulted in 12 photographs of the native Canopy at the Bartlett Arboretum and 8 of the *P. amurense* canopy. After the original LAI analysis was performed, a second set of data was taken at the Bartlett Arboretum six weeks later to look for changes in significance of the results over a season. At Forest Park, 14 photographs were taken under native canopy and 12 under *P. amurense*.

All data was analyzed using JMP 8.0.1 (SAS Institute 2008).

Results and Discussion

Understory Individual Density. At both the Bartlett Arboretum and Forest Park sites, understory individual density differed significantly with the understory of native *B. lenta* having more individuals than the *P. amurense* understory. At the Bartlett Arboretum mean understory individuals per m^2 measured 19.29 under the native canopy and 8.95 under *P. amurense* ($F_{1,154}$ = 17.8, P <.0001). Forest Park, mean understory individuals measured 6.92 under the native canopy and 3.23 under *P. amurense* ($F_{1,146}$ = 19.5, P < .0001). These results are demonstrated in Figure 1.

The appearance of a lower density of individuals in areas invaded by *P. amurense* was the initial visual clue leading to this study although only the visual assessments, not numerical evidence was present prior to this work. This statistically lower density under *P. amurense* at both sites reported here confirms our hypothesis of lower density, and showed that across both sites (Bartlett 19.28 native canopy, 8.9 *P. amurense* canopy and Forest Park 6.92 native canopy, 3.22 *P. amurense* canopy), the trend of lower individuals under *P. amurense* remains consistent even though the level of individual density varied between the two.

Total Species Richness. At the Bartlett Arboretum site, species richness per quadrat was higher under the native canopy (3.39 species) than under *P. amurense* canopy (3.03 species), however these results were not significant ($F_{1,154}$ = 1.77, P = .1855). At the Forest Park site a significant difference existed with mean species richness under native canopy trees measuring 3.11 species and mean species richness under *P. amurense* measuring 1.56 species ($F_{1,146}$ = 47.32, P < .0001). These results are demonstrated in Figure 2. In total, 43 species were identified under *P. amurense* at the Bartlett Arboretum and 44 under native canopies. At Forest Park a total of 27 species were identified under *P. amurense* and 32 under native species.

Total Native Individuals. At both sites, a significant difference existed between the number of native individuals per quadrat under native canopy versus *P. amurense* canopy with more native individuals being present under native canopy. At the Bartlett Arboretum, mean native individuals measured 19.00 under the native canopy while measuring 6.75 individuals under *P. amurense* ($F_{1,154}$ = 25.77, P < .0001). Forest Park mean native individuals measured 6.11 under native canopy and 2.08 under *P. amurense* canopy ($F_{1,146}$ = 43.49, P<.0001). These results are demonstrated in Figure 3.

Canopy Analysis. Comparisons of the canopy of *P. amurense* invaded versus non invaded areas showed no significant difference in leaf area index for the Bartlett Arboretum site or Forest Park. Leaf Area Index (LAI) at the Bartlett Arboretum measured 2.839 under *P. amurense* canopy and 4.020 under native canopy ($F_{1,18} = 2.961$, $P = .1024$) at the time of the first measurements. At Forest Park, LAI measured 3.642 under *P. amurense* canopy and 3.727 under native canopy ($F_{1,24} = 0.0516$, $P = .8222$). These results are demonstrated in Figure 4. The second set of measurements resulted in a LAI of 2.433 under *P. amurense* canopy of and 2.348 under native canopy ($F_{1,18} =.313$, $P = .5830$). These later results reaffirm the non significant differences in the early canopy photographs and are not included in Figure 4.

These results support the hypothesis that *P. amurense* understory composition will have lower overall individual abundances, lower species richness and contain a lower percentage of native species than adjacent areas of the same forest not containing *P. amurense*. However, these results do not provide insight into the mechanism by which this process occurs. Specifically, we find no significant differences in the level of leaf area index between native canopy and that of *P. amurense*.

Invasive plant species are well documented to have negative effects upon the native plants of the area into which they invade (Gould and Gorchov 2000, Hobbs and Mooney 1986, Martin 1999) as well as impacts upon the entire community (Wycoff and Webb 1996, Webb and Kauzinger 1993). Many invasive species go unnoticed as members of the communities until they have reached levels which are no longer easily controlled.

The spread of *Phellodendron amurense* into the forests of the northeastern United States has the potential to affect both the richness and abundance of the surrounding flora. With the pronounced effects reported here upon the number of native individuals between canopy types, this invasion is likely to impact native populations of plants more than other individuals which are naturalized from outside the region. While this work shows a significant difference between the understory density of native plants between the two canopies, there is still the question of whether the *P. amurense* trees caused this difference, or if they invaded upon degraded sites with a prior difference in understory composition due to factors such as soil quality or disturbance. These results provide the first step in identifying a problem and show the strong need for further assessment of this invasive tree species.

Shading is often reported in secondary publications to be the cause in the case of other invasive tree species and their impact upon the understory (Spongberg 1990), however we find no evidence of a significant difference in shade cast between the surrounding native canopy and that created by mature trees of *P. amurense* when measured using leaf area index. Visual observations also indicate that the leaves of *P. amurense* at both locations fully emerge eight or more days after all the species in the adjacent native canopies. This would eliminate an earlier leaf emergence, and consequentially an earlier shading by *P. amurense* as a factor in the understory differences that are reported.

Most importantly, these results indicate that there is a strong need for addressing the invasion of *P. amurense* in the forested areas of the northeastern United States. While the exact causes of the decreased number of native individuals and lower species richness under *P. amurense* is undetermined, these results highlight the importance for more aggressive monitoring of this and other invasive species not yet targeted by government and private agencies, as well as the importance of control and removal programs in affected areas.

Further study of *P. amurense* is needed to establish the mechanisms by which the lower understory native individuals and species richness occurs. Additionally, an investigation into the biological attributes of *P. amurense* such as seed production, dispersal, seedling survival, allelopathic potential, and growth rates etc. all need to be further examined in this potentially high impact invader.

Figure 5.1.

Mean number of total individuals per m^2 quadrat of all species under each canopy type at each site. Error Bars represent 95% confidence intervals.

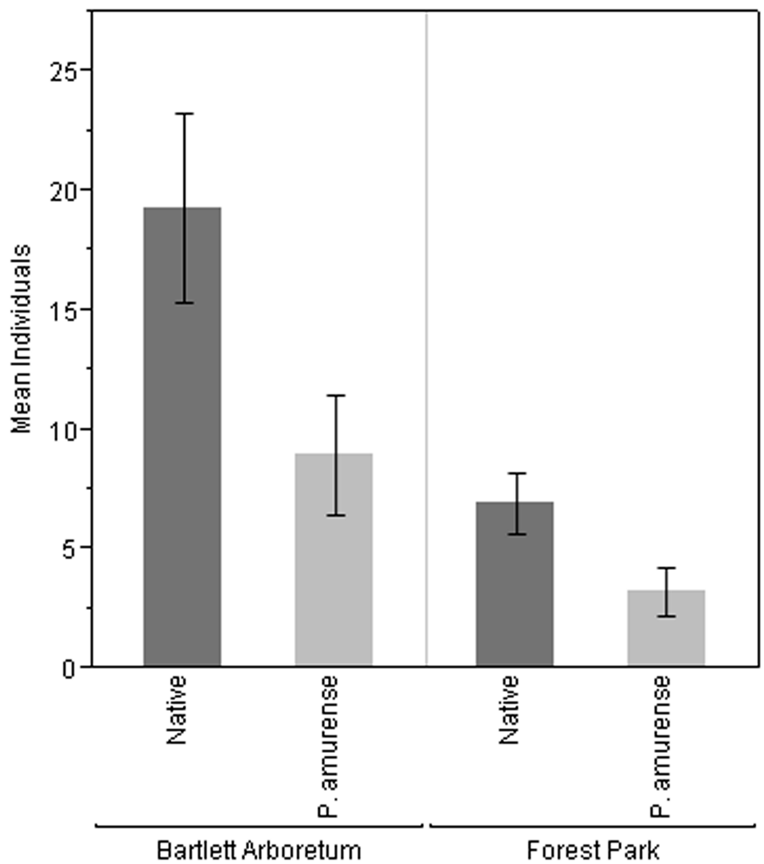


Figure 5.2.

Mean number of total species per m^2 quadrat under each canopy type at each site. Error bars represent 95% confidence intervals.

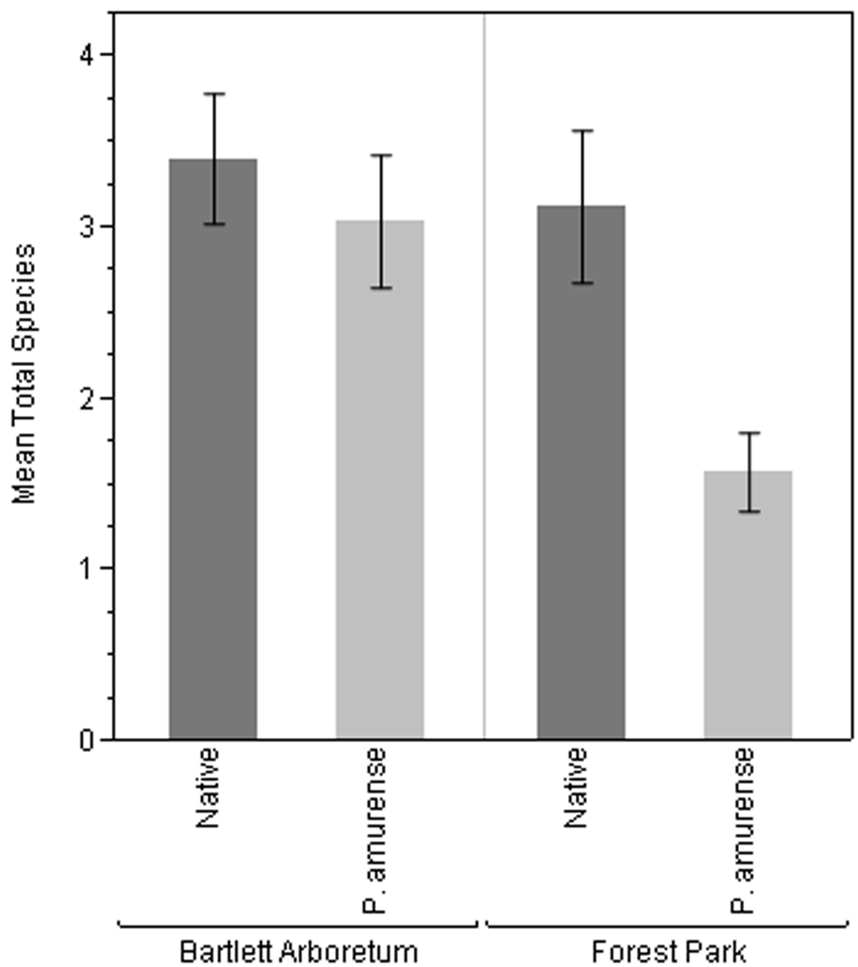


Figure 5.3.

Mean number of total native individuals per m^2 quadrat under each canopy type at each site.

Error bars represent 95% confidence intervals.

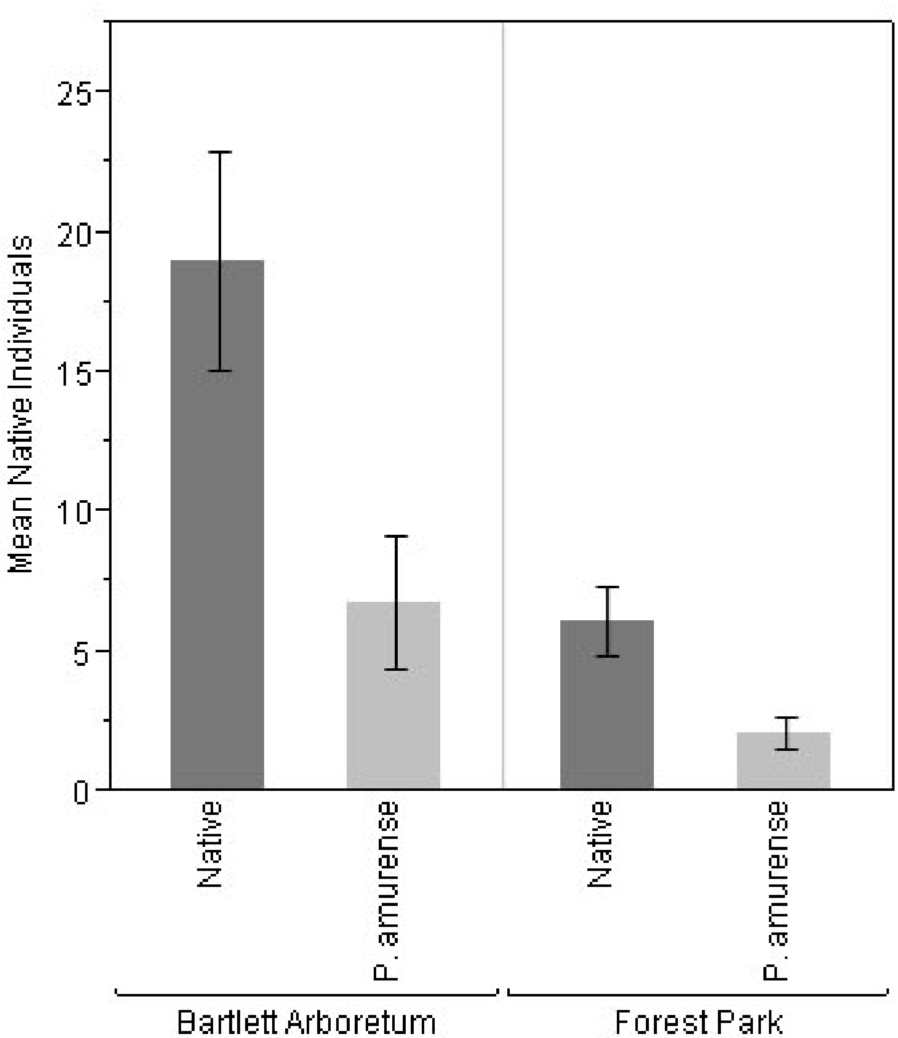
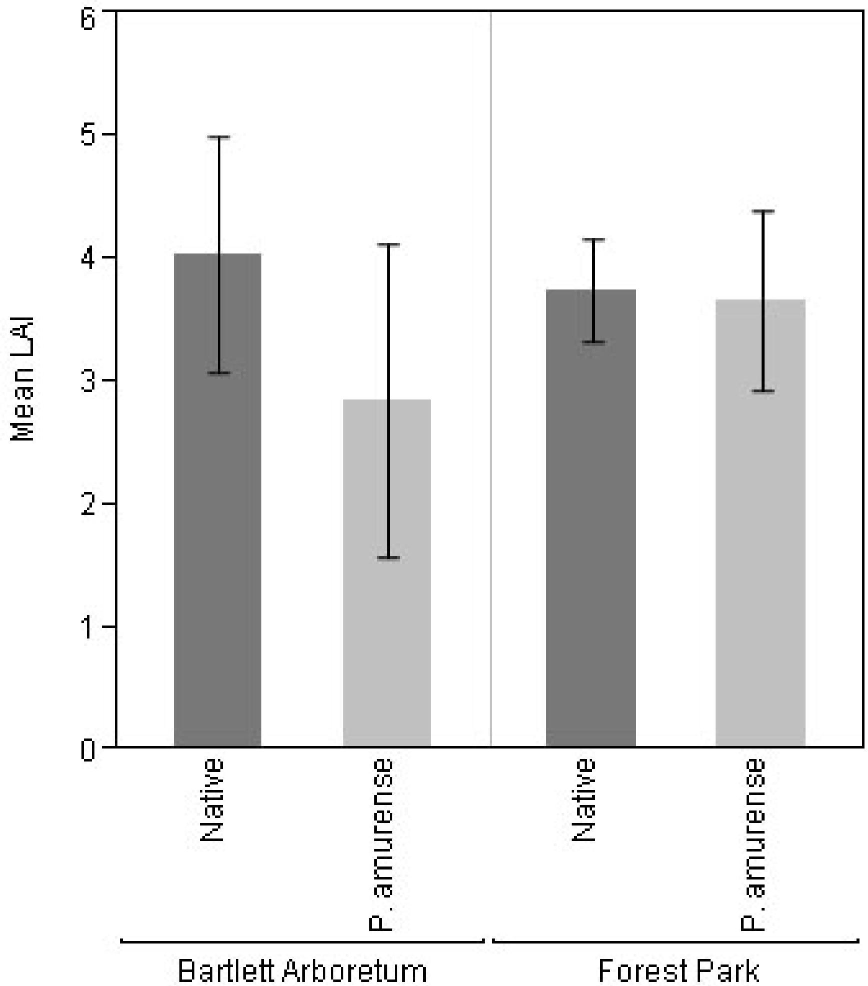


Figure 5.4.

Mean leaf area index under each canopy type at each site. Error Bars represent 95% confidence intervals.



Chapter 6

Stand dynamics of a forty-six year invasion by *Phellodendron amurense* Rupr. in an eastern North American forest

[this chapter is modified from this reference:]

Morgan, E. C. 2011. Stand dynamics of a forty-six year invasion by *Phellodendron amurense* Rupr. in an eastern North American forest. Castanea. In press

Abstract

An invasion by *Phellodendron amurense* Rupr. provided an opportunity to examine the subsequent changes in the forest composition which took place since the invasion began. Through the removal of 278 individual trees of *P. amurense*, tree ring analysis allowed a re-creation of the forest over the forty-six years since the species first arrived at the site. This analysis shows that *P. amurense* demonstrates the ability to invade additional areas and, over time increase both its relative density and relative dominance. Through an analysis of both living and standing dead individual trees, *P. amurense* appears to be poised to continue its gradual increased influence over the forest. This highlights the need for better recognition of the species as an invasive plant, and a more vigorous effort to control existing invasions.

Introduction

Invasive species have been shown to have negative consequences in many areas including ecological impacts (Gould and Gorchov 2000, Collier *et al* 2002) and economical costs which have been estimated to nearly 120 billion (Pimentel *et al* 2005). In spite of this importance, it wasn't until the 1958 publication of Charles Eltons' the ecology of invasions by animals and plants (Elton 1958) that the problems brought about by invasive species began to be recognized and examined.

In recent years, an emphasis has been placed upon the early recognition and control of invasive plant species, and in the case of horticultural and agricultural imports, numerous attempts have been made to set up a framework for examining the early introduction of these species (Moles *et al* 2008) as well as analyses of traits which may lead to invasiveness in a particular species (Rejmánek and Richardson 1996, Muth and Pigliucci 2006). Yet recent evidence has shown that while many species have particular invasive traits (Aronson et al 2007), a variety of factors such as hybridization may cause others to take many years to achieve their potential as invasive species (Williams et al. 2005). In the eastern United States, *Phellodendron amurense* Rupr. may be achieving its invasive potential throughout a significant portion of the region from Philadelphia to Boston (Morgan and Borysiewicz 2010), and possibly much further over a century after its original introduction.

Growing to fifteen meters high with compound leaves, *Phellodendron amurense*, Rutaceae, is a dioecious species native to eastern Asia including northeastern China, Taiwan, Japan, Korean peninsula and the Russian far east. It's cold tolerance and other admirable horticultural qualities (Dirr 1998) has made *P. amurense* a common tree at public gardens throughout the United States, and an occasionally available species in the horticultural trade. A survey of the cultivated *Phellodendron* in North America revealed a long history of introductions of the species of various provenance, as well as extensive confusion and overlap in the nomenclature (Ma and Branch 2007). Recently, the genus *Phellodendron* has been revised resulting in the inclusion of *P. japonicum*, *P. lavallei* and *P. sachaliense* within *P. amurense* (Ma 2006). Previous separation of these species may have been a factor in *P. amurense* being overlooked as an invasive species (Morgan & Borysiewicz 2010), although recent work has begun to examine the species *sensu lato* for both its invasion (Glaeser and Kincaid 2005) and its potential impacts (Morgan and Borysiewicz 2011).

Although numerous studies upon the biology, impact and economic importance of invasive species exists, chronological data for the invasion of individual species is often lacking and concise analysis of the small scale invasion of invaders is nearly non existent with few exceptions such as Fang (2005). An analysis of the effect of a particular species upon the forest composition can have wider implications for both its long term potential to invade new areas and can stress the importance of early recognition of invasive tendencies such as the progressive displacement of native species in the habitat. This work aims to address these issues for *P. amurense* in an eastern North American forest through an analysis of changes in an eastern North American forest over forty-six years.

Materials and Methods

The Bartlett Arboretum Forest, located in southwestern Fairfield County, Connecticut (43˚33N 73˚33W), is a 31 hectare mixed-deciduous forest with four main vegetation types including a *Fagus grandifolia* Ehrh. dominated area, a beech-mixed hardwoods area, *Acer rubrum* L. wetland, and a mixed hardwoods area (Morgan 2009). In the summer of 2008 a research plot was established within this forest which included all the individuals of *P. amurense* found in an area of the forest that had a visibly high concentration of *P. amurense* trees. As an arboretum, significant land use records exist for the forested areas, however no disturbance to the forest has been recorded for this area. Using surveying flags a transect was marked through the longest point of the invasion marking each meter upon the flags. Perpendicular to this line additional transects were marked throughout the area of invasion in an east to west orientation creating a grid pattern for the collection of cartesian coordinate data. Each tree within the grid pattern was marked with flagging tape and its cartesian coordinates, species identification and diameter breast height (dbh) were recorded. In total, 755 individuals were marked and recorded including 278 individuals of *P. amurense*.

In the Winter of 2009 - 2010, all individuals of *P. amurense* were cut down at 10 cm above ground and from the upper portion of the cut stump a 3-4 cm thick disk was cut level and labeled to create slices of the trees for tree ring analysis. In preparation for tree ring analysis, slices were sanded with progressively finer sandpaper allowing for clearer reading of ring numbers and then treated with beeswax to prevent checking of the slices. To analyze tree age, the rings were counted first with the naked eye and then confirmed by recounting under a stereo microscope. Data from this analysis is provided as Data Set 1.

With the creation of a single plot designed to include all *P. amurense* trees, the relative frequency aspect of a traditional importance value as described by Curtis & McIntosh (1951) was not applicable. Therefore the measurements of relative abundance and relative density were used as standalone measurements. To model the previous forest composition, *P. amurense* specimens were compared with their age data and were given average growth rates over the forty two years and modeled backwards using the average growth per year. This growth per year was applied to both *P. amurense* and non *P. amurense* equally giving a generalized model of the stand. All calculations and corresponding figures were created using Sigma Plot 10.0.

Results and Discussion

A total of 755 individuals consisting of thirty species of woody plant with dbh of 2.0 cm or greater were recorded and measured to calculate their relative density and relative dominance. The 278 individuals of *P. amurense* ranged from a dbh of 2.0 cm, which was the smallest size recorded here, up to 29.4 cm dbh. The age of *P. amurense* for these individuals ranged from 4 years old to 46 years at the time of removal. The size distribution histogram shows a typical Type III survivorship curve (Figure 6.1), however, the age distribution histogram does not follow this pattern (Figure 6.2). Plotting the age of individuals by their dbh shows a general trend of increasing dbh with age (Figure 3), however this relationship is statistically weak with a linear regression R^2 of 0.5086.

The 278 individuals of *P. amurense* examined included 9 individuals or 3.23% of all *P. amurense* individuals which were dead at the time this study was performed. Of the 477 individuals of non *P. amurense* trees in the study area, 46 or 9.64% were dead at the time of this study.

At the time of the removal of *P. amurense* in 2009-2010, the top five species in both relative density and relative dominance included seven total species and are, alphabetically, *Acer rubrum* L., *Betula alleghaniensis* Britton, *B. lenta* L., *Fagus grandifolia* Ehrh., *P. amurense*, *Quercus alba* L. and *Q. rubra* L.. Between 1962 and 2008, *P. amurense* and *F. grandifolia* replaced *Q. alba* and *Q. rubra* in the top five in relative density and *P. amurense* replaced *Q. alba* in the top five in relative dominance between 1962 and 2008. Over the course of the invasion by *P. amurense* its relative density increased from 0 in 1962 to 14.5 in 1985 and 36.8 in 2008 (Figure 4. Over the same time period, the relative density of the five most common species in 1962 all declined through 2008. By 1985, *P. amurense* had the third highest relative density and by 2008 was the highest in relative density at 36.8 with *A. rubrum* second with a relative density of 10.4. The relative dominance of *P. amurense* also increased from 0 in 1962 to 6.7 in 1985 and 15.8 in 2008. The relative dominance of the five most common species in 1962 all decreased as well over the same period of time (Figure 5). In 2008 only *A. rubrum* (19.9) and *B. lenta* (18.0) had higher relative dominance values then *P. amurense* (15.8).

The use of dbh as an indicator of plant age has been used in previous studies as a method of analyzing plant population structure, including in the study of invasive plants. Within this study, results show only a moderate correlation between the age and dbh of *P. amurense* throughout the study area (Fig. 3). This does not negate results of this or prior studies using that method as it underemphasizes the drastic increase in *P. amurense* over the time frame of the study. It does however, highlight the need for verification efforts such as increment coring and tree ring analysis to verify results whenever possible such as those performed here.

The histogram of dbh versus number of *P. amurense* individuals (Fig. 1) shows a population with a tendency towards a large number of individuals establishing, but a steep dropoff in the number of those individuals surviving to adulthood which is the general Type III survivorship curve found in many species. In comparing this to the histogram of age versus number of *P. amurense* invividuals (Fig. 2), the data for the latter resemble more of a gaussian distribution, and do not reflect the trend found in Figure 1. Since there is no record of disturbance on site throughout the area of the invasion, the most likely cause for the distributions in Figure 1 and 2 are the result of *P. amurense* being able to maintain a long period in the understory until gaps occur which will result in the production of substantially more growth when these opportunities are present. The gaussian distribution of Figure 2 suggests that fluctuations in rates of seedling establishment may be the result of other factors such as weather. This data showing the potential ability to survive long periods of shading is contrary to the findings of Yoshida and Kamitani (1999) who report *P. amurense* as shade intolerant.

Gaps in the canopy, which may be created by a number of events including normal tree mortality, are a likely cause of the increased growth found in many *P. amurense* trees in spite of their young age. An analysis of standing dead trees shows a mortality rate nearly three times as high for non *P. amurense* (9.64%) compared to *P. amurense* (3.23%) showing that there will be ample gap opportunity for *P. amurense* seedlings to survive. This data would also predict that at current rates, *P. amurense* would continue to increase its relative density in the study area, a prediction that has proven true from the period of 1962-2008.

The relative density and relative dominance of *P. amurense* from the years 1962-2008, both show increases from being absent, to becoming a dominant species in each category. The relative dominance results are results are reported in Figure 4 and relative density results are results are reported in Figure 5. In both categories, the values of all other species showed declines with the exception of *Fagus grandifolia*, indicating that the expansion of the species is at the expense of other, mainly native, species within the flora. Additional factors may come into play when considering the subsequent increase of *F. grandifolia* along with *P. amurense*. While *F. grandifolia* is a native member of the flora which was present in 1962, the increase in ungulate herbivores in the region may be playing a role in the plants success as well as that of *P. amurense.* In the region, browsing upon native species such as *Q. alba*, *Q. rubra* and *A. rubrum* is common (Healy 1997), while throughout this study no browsing upon either *F. grandifolia* or *P. amurense* was observed (Morgan pers. obs.).

While a number of interrelated factors may be responsible for the initial success and continued expansion of *P. amurense,* the species has demonstrated the need for control measures even though it is not as widespread as other woody invaders such as *Acer platanoides* L. in the northeast, *Triadica sebifera* (L.)Small. in the southeast and *Tamarix ramosissima* Ledeb. in the southwest. *P. amurense* provides not only an opportunity to control an apparent invasive species, but to gather important data about the early stages of invasion by a woody tree species. However, based upon the continued increase in density and dominance reported here, coupled with the ability to rapidly take advantage of light gaps as demonstrated by the differences in the age and dnh histograms, *P. amurense* may be approaching a critical mass. Presently, invasions occur throughout the region from Phiadelphia to Boston althought these are often isolated from each other by many miles. As populations grow, and new sightings occur this window of opportunity for study and control will quickly close.

Figure 6.1

Age classes of *Phellodendron amurense*.

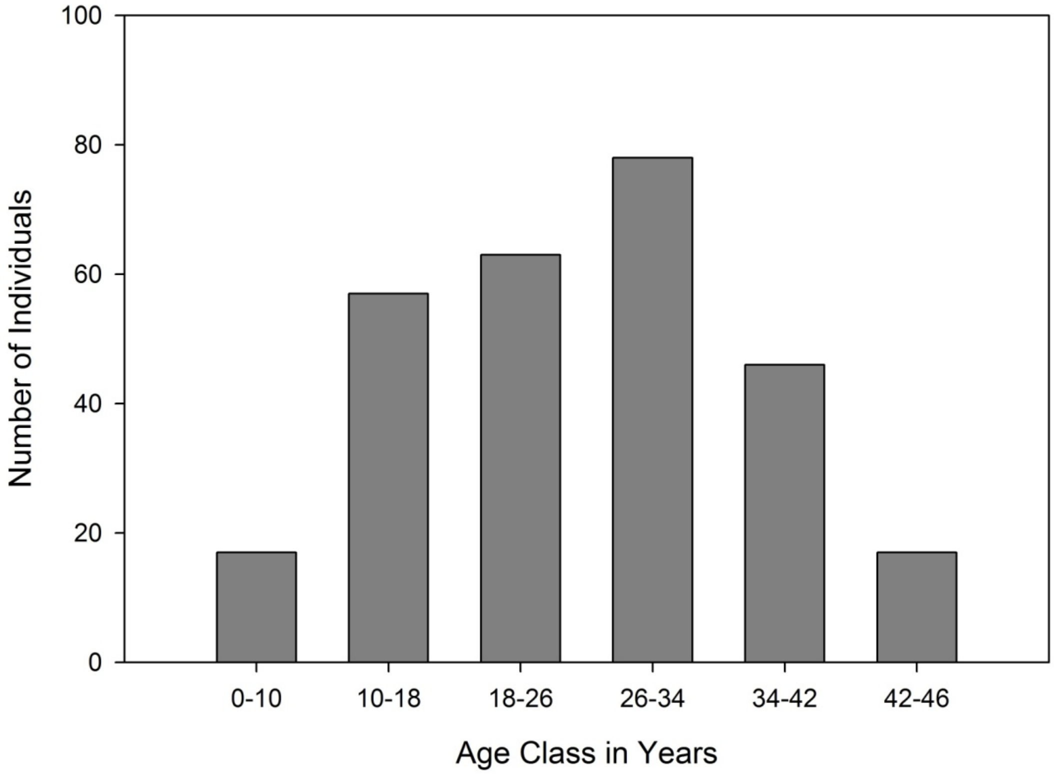


Figure 6.2

Diameter breat height classes of *Phellodendron amurense*

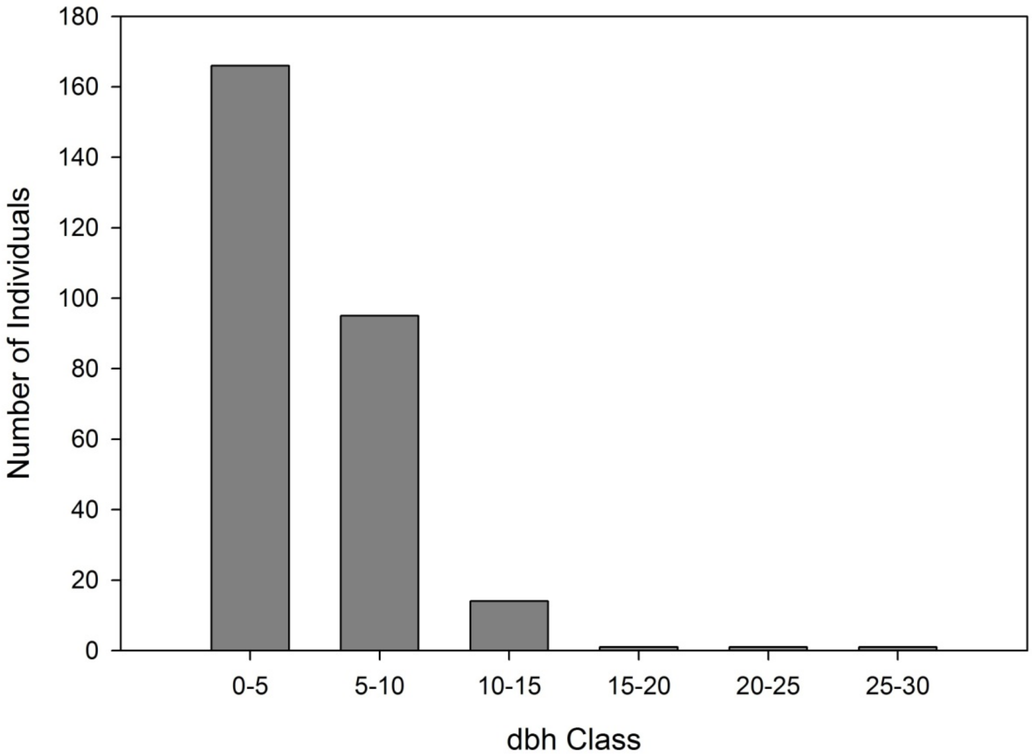


Figure 6.3
Relationship between age and diameter breat height of *Phellodendron amurense*

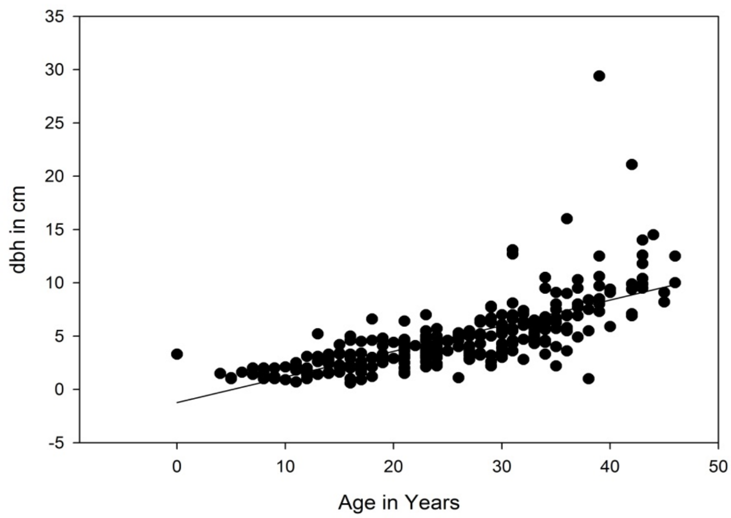


Figure 6.4
Approximate changes in relative density of the top species over 46 years

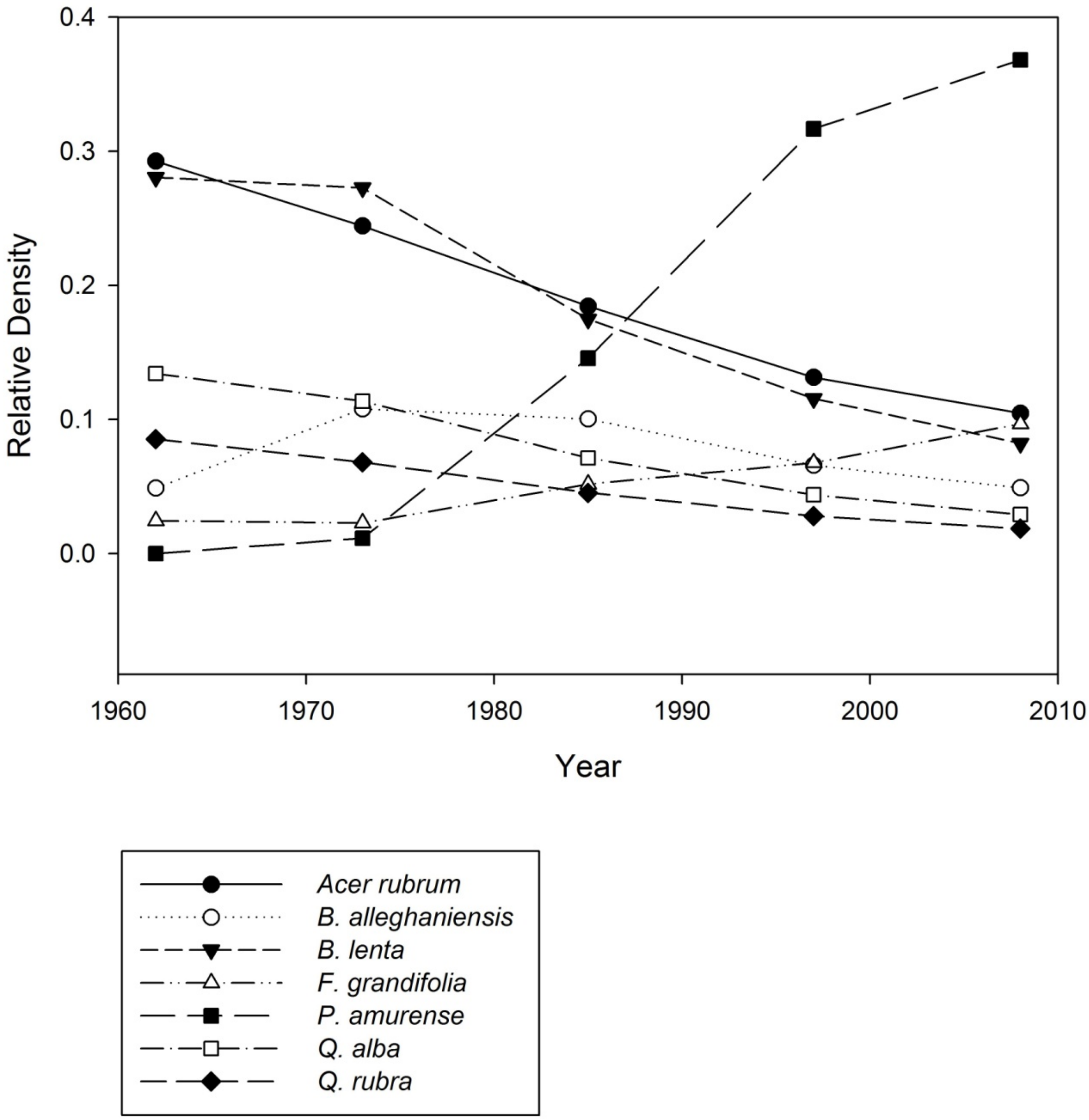
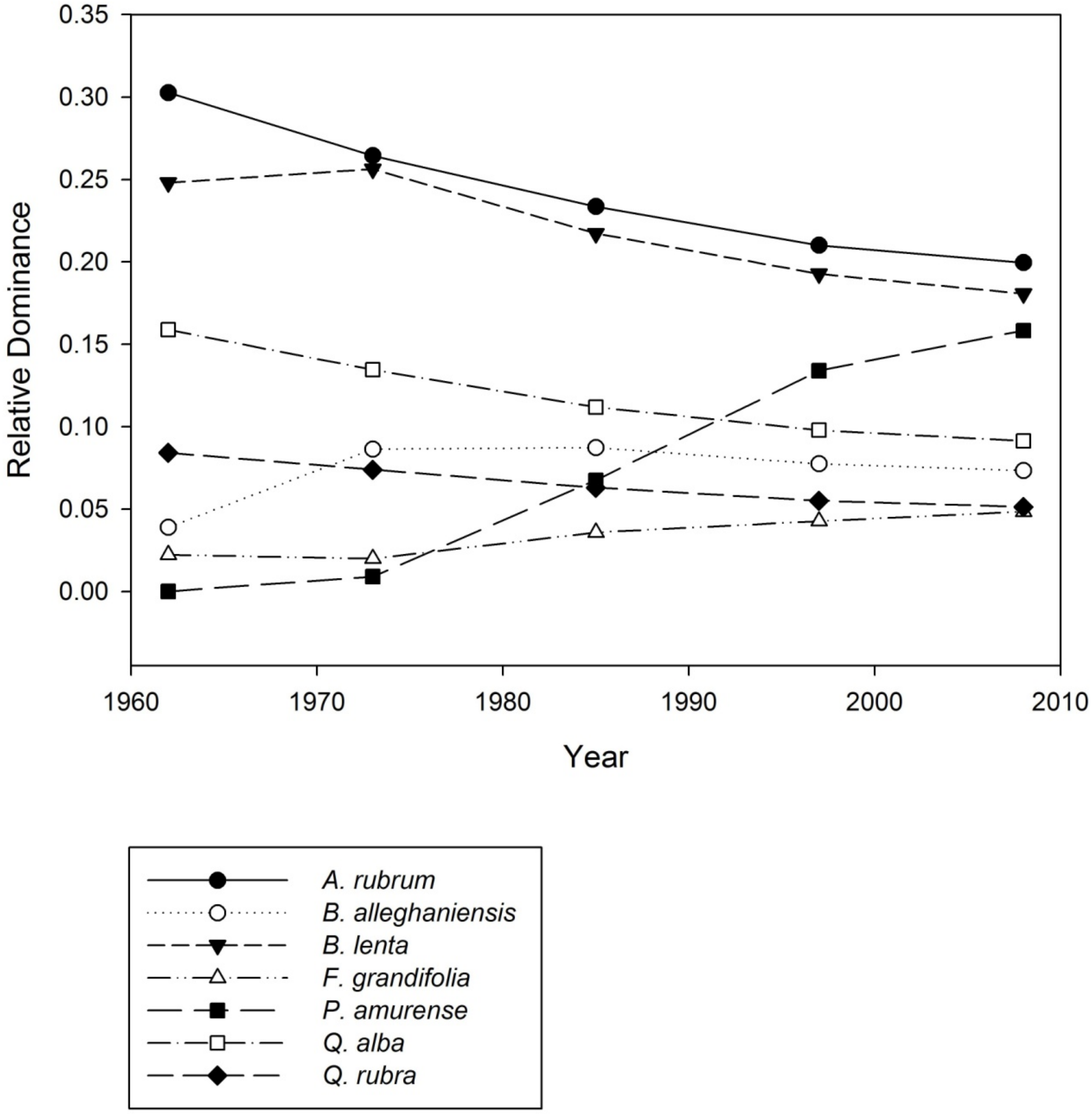


Figure 6.5
Approximate changes in relative dominance of the top species over 46 years



Chapter 7

Spatial Analysis of an Invasion by *Phellodendron amurense* within a southwestern New England Forest

Abstract

The invasion of a southwestern New England forest by a non native tree species is examined through an analysis of spatial data. *Phellodendron amurense* Rupr., trees were mapped out and cut down to allow for an examination of the relationships between their age, diameter at breast height, and spatial distribution to look for patterns which could help understand the way in which the species is spreading. Through these analyses and a comparison of the spatial data of *P. amurense* trees with the surrounding forest, it can be clearly shown that *P. amurense* has the ability to spread throughout a forest, regardless of proximity to older trees. It is also shown that these trees succeed within the clearings created within the surrounding forest at both small and large scales.

Introduction

With the increase of species introduced to habitats outside their native range, and the subsequent homogenization of the worlds flora and fauna, the impacts of these introduced species provide opportunities to examine a species invasion from the onset of its occurrence as it succeeds or fails in its new environs. While most introduced species fail, the percentage of these species that ultimately take hold in the new habitat, reproduce and spread can have a measurable impact upon the surrounding native flora and fauna. With vascular plant species, this impact can range from the simple occupying of space no longer available to native species, causing the slow replacement of natives in the flora, to the more aggressive species which choke out and directly impact the native surrounding vegetation. Recently, additional mechanisms such as the interruption of insect pollination due to the presence of an invader has also been shown to be of significant impact (Baskett et al., 2011). Those species having a measurable impact in their foreign habitat are generally referred to as invasive species, and their impact can be extraordinary in both ecological (Simberloff et al., 1997) and economic terms (Pimentel et al., 2005).

In the northeastern United States, the Asian tree *Phellodendron amurense* Rupr., is becoming a common invasive species throughout the region from Boston, Massachusetts to Philadelphia, Pennsylvania (Morgan and Borysiewicz 2010). This species, which has gone unrecognized as a serious invader in the primary literature until recently, (Glaeser 2006, Morgan & Borysiewicz 2010) has been shown to be aggressively invading both urban and rural forests, often having hundreds of adult size trees which displace native tree species (Morgan 2011). A member of the Rutaceae, *Phellodendron amurense* is a large tree growing ten to fifteen meters in height with a potentially greater spread. Native to much of northeast Asia including China, Japan, Korea and Russia, *P. amurense* is considered a common broad leaved species within the coniferous Picea-Abies forests along their more southern borders (Wang, 1961). Outside it's native range, *P. amurense* is a desirable tree in cultivated areas where ample space is available due to its ornamental characteristics (Dirr 1990) and is often promoted as such in horticultural publications.

While *P. amurense* is recorded as being introduced horticulturally as early as 1856 (Dirr 1990) and early reports by Sargent (1894) state that *P. amurense* is found in most large botanical collections in the United States at the time of his writing, as of the early 21st century there were few published reports of the species becoming problematic. This may be due to both a lag time in the expansion of the species, as well as a lack of *P. amurense* being listed in the taxonomic keys often used throughout the northeastern United States including Gleason and Cronquist (1991) and Petrides (1988). A more comprehensive examination of the misidentification and overlooking of *P. amurense* in the northeast can be found within Morgan and Borysiewicz (2010).

Through an analysis of cultivated specimens of *P. amurense* in North America, including their range and proper identification, Ma and Branch (2007) report that *P. amurense* has rarely escaped and become naturalized in only a few places in northeastern North America around the vicinity of Botanic Gardens and Parks. This statement has increasingly been disputed as numerous additional sites have been documented in recent years, over twenty of which are reported by Morgan and Borysiewicz (2010). Furthermore, Ma and Branch report that there has been no damage to the native flora although the potential exists for *P. amurense* to become an invasive in the future. There is now evidence showing a relationship between *P. amurense* and the understory flora of invaded areas, with *P. amurense* being significantly related to a diminished native species richness (Morgan 2011). Additionally, the importance value of *P. amurense* in several studies throughout the northeastern United States (Glaeser 2006, and Morgan, 2010) shows that it is having an influence on forest composition worth recognizing.

Spatial analysis of invasive species can often provide valuable data into determining the pattern, if any, that an invasive species will present. This data can then be used to determine a variety of factors such as invasion speed, pattern and even habitat preference if site data is available. This work examines the null hypothesis that there is no relationship between the pattern of *P. amurense* establishment and growth in relation to existing *P. amurense* trees in the surrounding area or the surrounding arborescent trees of additional species.

Methods

Within the 31 hectare mixed-deciduous forested portion of the Bartlett Arboretum, (43˚33N 73˚33W), a plot was established by creating a grid layout encompassing a population of 278 *P. amurense* trees. Using surveying flags a transect was marked through the longest point of the invasion marking each meter upon the flags. Perpendicular to this line additional transects were marked throughout the area of invasion in an east to west orientation creating a grid pattern for the collection of cartesian coordinate data. Each tree greater than 2cm diameter breast height (dbh) within the grid pattern was marked with flagging tape and its cartesian coordinates, species identification and dbh were recorded. In total, 755 individuals were marked and recorded including all 278 individuals of *P. amurense*. This data is reported in Final Appendix 1.

In the Winter of 2009 - 2010, all the individuals of *P. amurense* were cut down at 10 cm above ground and from the upper portion of the cut stump a 3-4 cm thick disk was cut level and labeled to create slices of the trees for tree ring analysis. In preparation for tree ring analysis, slices were sanded with progressively finer sandpaper allowing for clearer reading of ring numbers and then treated with beeswax to prevent checking of the slices. To analyze tree age, the rings were counted first with the naked eye and then confirmed by recounting under a stereo microscope.

To determine if correlations existed between the numerical difference in dbh between individuals and the geographic euclidian distance between cartesian coordinates of those individuals, or if patterns existed between the numerical age differences and the geographic euclidian distances between pairs of trees, Mantel tests were performed using the software PASSaGe 2.0.1. To perform these tests, a 278 x 278 distance matrix was first created for all three parameters using PASSaGE 2.0.1. The Mantel test was the checked for significance by running 100,000 permutations.

To analyze the cartesian points and determine if they are random or clustered, Ripleys *K* function analyses were performed using PASSaGE 2.0.1. To perform these, randomization tests were performed with 100,000 permutations.

Results and Discussion

The null hypotheses that there is no relationship between geographic distance and age for *P. amurense*, or between geographic distance and dbh, were tested by using the Mantel test (Mantel 1967), which works by randomization of two distance matrices and comparing to the calculated observed statistic. With this data set, the 278 x 278 matrices are sufficiently large enough to then further the data by performing a permutation test to obtain a p value for each test.

Mantel tests reveal no correlation (-0.008), and no significance (p= .63) between the geographic distance and age distance of *P. amurense* trees. Mantel tests also revealed a low correlation (0.07), of significant value ($p = 0.02$) between the geographic distance and dbh size distance of *P. amurense* trees. These results indicate that the initial establishment of *P. amurense* is not strongly correlated to distance from other *P. amurense* trees nor is the growth of these trees after establishment correlated to that distance. These results can be interpreted as evidence that *P. amurense* is reproducing consistently throughout the area of an existing invasion, and growing regardless of proximity to other *P. amurense* trees.

Currently, there is conflicting evidence as to the requirements of *P. amurense* to succeed. Yoshida and Kamitani (1998) report it as a shade intolerant species within a coppice forest, however Yoshida et al (2005) report a negative impact of light upon the survival of *P. amurense* seedlings in recently cleared bamboo stands. Examining these past works, it is possible that *P. amurense* will colonize and succeed in neither large clearings or shaded environments, but may thrive in the semi openness of gaps within an otherwise intact forest. This possibility is supported by Sakai et al (1999) who demonstrated that *P. amurense* occurs only in small patches among established trees on terraces, where light can penetrate through the forest. If canopy gaps are responsible for any correlation between distance and growth of *P. amurense,* the population would show a clustered distribution, presumably due to the more rapid growth in such gaps.

The Ripley's L statistic, is a standardized representation of the Ripley's K function (Ripley 1976) which measures the average density of individuals from a point within a plane by analyzing the cartesian coordinate data and euclidian distance data of a set of observed points. Through approximate randomization, confidence intervals can be created to show significance of the observed versus expected values of the data. Values of Ripleys L below the expected value would represent significant clustering while values above the expected distributions would represent significant overdispersion.

Using Ripley's L function to determine any clustering or overdispersion of *P. amurense* trees in relation to each other revealed clustering that was highly significant (Figure 7.1). This pattern was highly significant throughout all distances in the Ripley's L analysis. These results show that while no significant pattern between age and geographic distance can be recognized, the trees are growing in a highly clustered pattern amongst other individuals of *P. amurense*.

To better analyze this process, a second Ripley's L analysis was performed using all individuals within the plot consisting of 278 *P. amurense* and 477 non *P. amurense* trees. To specifically examine the pattern of *P. amurense* in relation to the surrounding trees, a third data set was added to include species identification as *P. amurense* or non *P. amurense*. An analysis was then performed allowing *P. amurense* trees to be analyzed only in relation to the non *P. amurense* trees in the matrix, whose coordinates remain fixed and are not included in the randomization tests. This Ripleys' L analysis shows a significant pattern of overdispersion by *P. amurense* in relation to non *P. amurense* trees (Figure 7.2).

These results show a clear pattern of distribution for *P. amurense* throughout the study area. The lack of relationship between age and distance of the trees shows that the species can spread throughout an area regardless of proximity to the original point of invasion. The results of the subsequent Ripley's L analysis show that *P. amurense* can colonize clearings throughout a forest, whether near or far to the seed source. The combined results of both the Mantel tests and Ripley's L analysis show that the species can colonize an area by filling gaps within the canopy, regardless of the position of the original seed source. The non significant Mantel results combined with the highly significant Ripley's L analyses show that these gaps in a forest do not have to be large, but can be in a patchy distribution created by single dead trees, and not necessarily the wide clearings such as those seen in windthrows and other disturbance events.

With the high number of in invasive species spreading throughout the globe each year, a thorough analyses of each new invasion is not always possible. With *P. amurense*, there is now strong evidence of the species spreading throughout a large geographic area (Morgan and Borysiewicz 2011), and this work demonstrates its ability to colonize clearings within a forested area and spread in a pattern regardless of proximity to an immediate seed source. This analysis of *P. amurense* is one additional species for which there is an in depth examination of its invasion and will provide more evidence of the impact these species can have upon the native environment. This data further supports the need for measures to prevent the introduction of invasive species as opposed to controlling already established species.

Figure 7.1

Ripley's L analysis of *Phellodendron amurense* trees in relation to other *P. amurense* trees showing significant clustering.

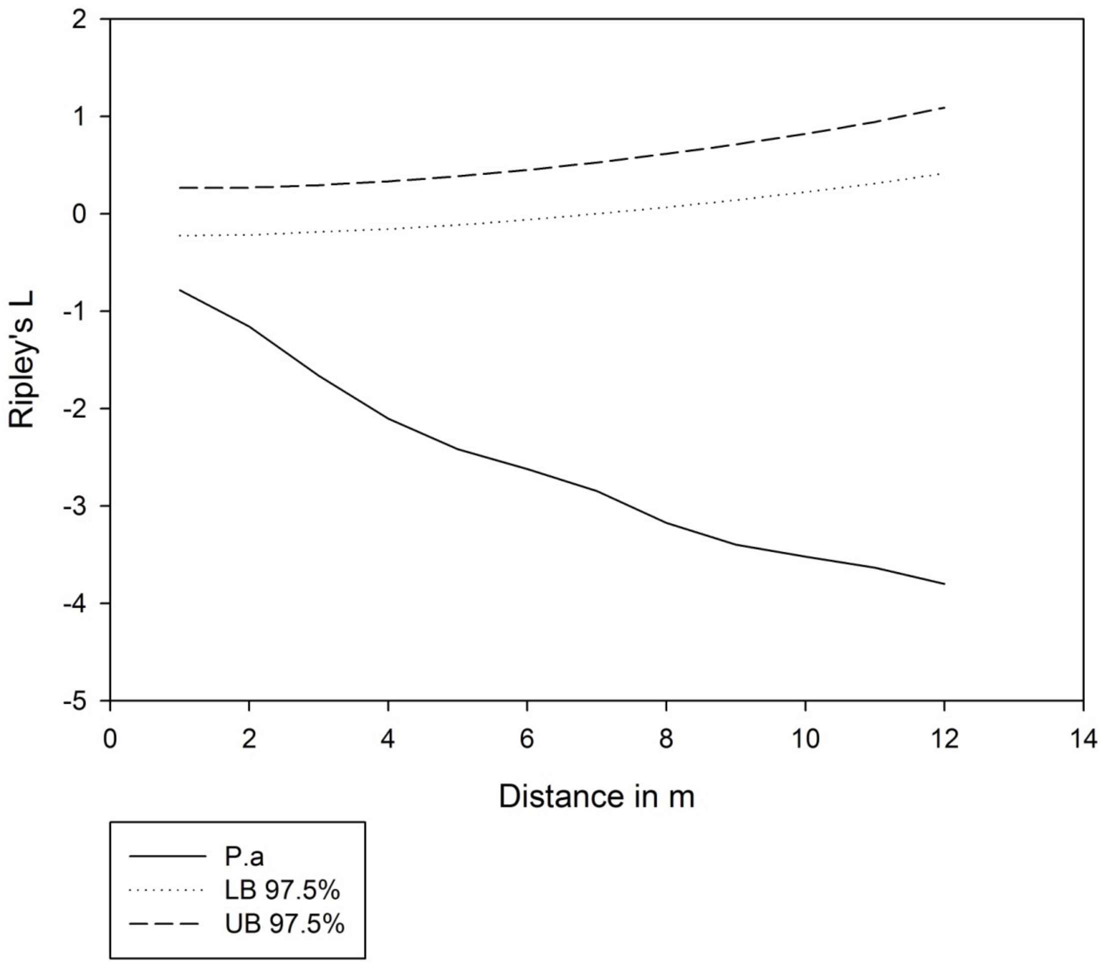
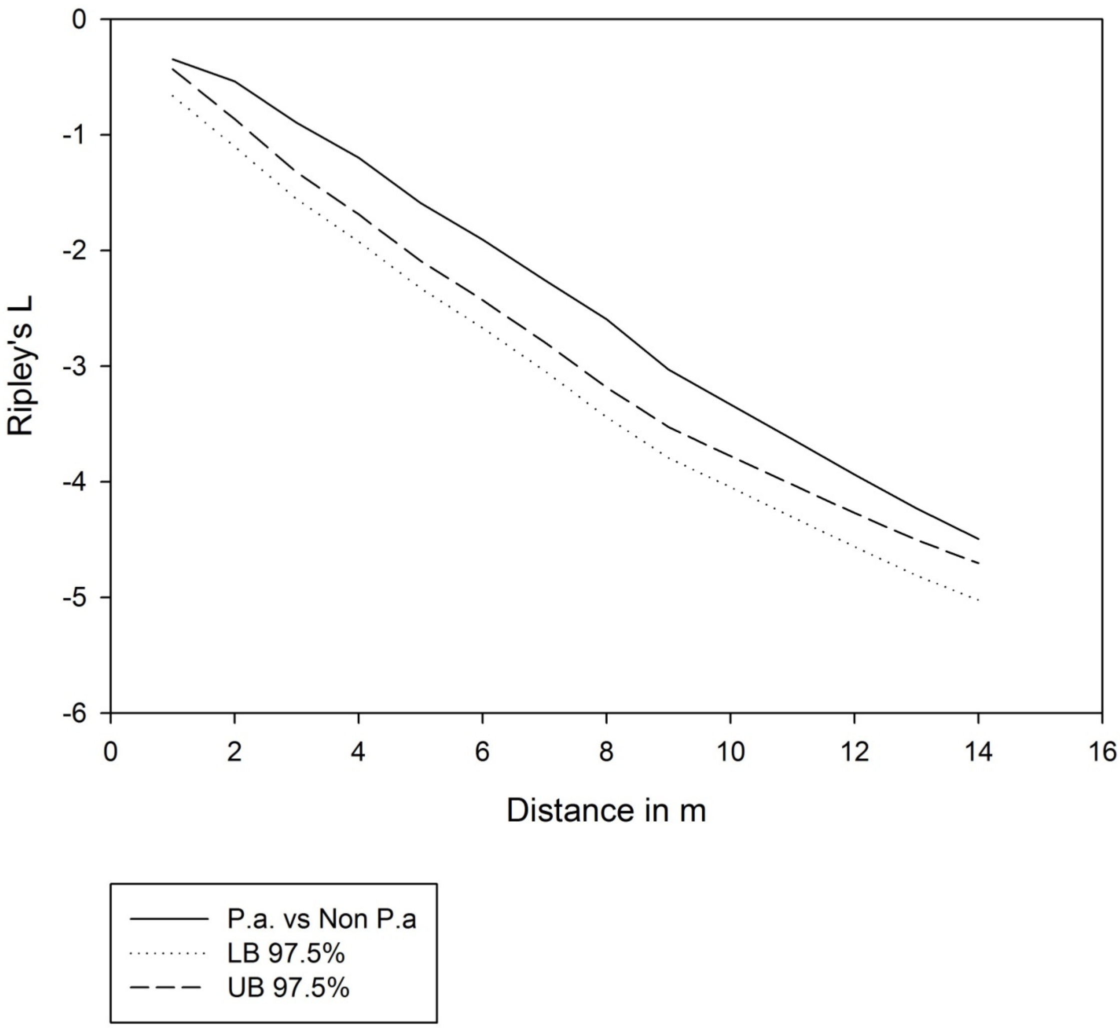


Figure 7.2

Ripley's L analysis of *Phellodendron amurense* trees in relation to the surrounding tree species, with *P. amurense* showing significant overdispersion in relation to the surrounding tree species.



Chapter 8

The Creation of Bubble plots as a visualization tool to examine invasive species

Abstract

Using an invasion by the non native invasive *Phellodendron amurense* Rupr., the creation of bubble plots showing the pattern of invasion over its history allows for a simple way to recreate and visualize the invasion and spread of a particular species into a new environment. While the ability to collect data for tree rings is not always available, examples such as this can be used as a general model to demonstrate the rapid colonization and increase in influence a new introduction can have and can provide researchers with an additional tool to expose both the scientific and non scientific public to the importance of invasive species.

Materials and Methods

Within the 31 hectare mixed-deciduous forested portion of the Bartlett Arboretum, (43˚33N 73˚33W), a plot was established by creating a grid layout encompassing a population of 278 *P. amurense* trees. Using surveying flags a transect was marked through the longest point of the invasion marking each meter upon the flags. Perpendicular to this line additional transects were marked throughout the area of invasion in an east to west orientation creating a grid pattern for the collection of cartesian coordinate data. Each tree within the grid pattern was marked with flagging tape and its cartesian coordinates, species identification and diameter breast height (dbh) were recorded. In total, 755 individuals were marked and recorded including 278 individuals of *P. amurense*.

In the Winter of 2009 - 2010, all individuals of *P. amurense* were cut down at 10 cm above ground and from the upper portion of the cut stump a 3-4 cm thick disk was cut level and labeled to create slices of the trees for tree ring analysis. In preparation for tree ring analysis, slices were sanded with progressively finer sandpaper allowing for clearer reading of ring numbers and then treated with beeswax to prevent checking of the slices. To analyze tree age, the rings were counted first with the naked eye and then confirmed by recounting under a stereo microscope.

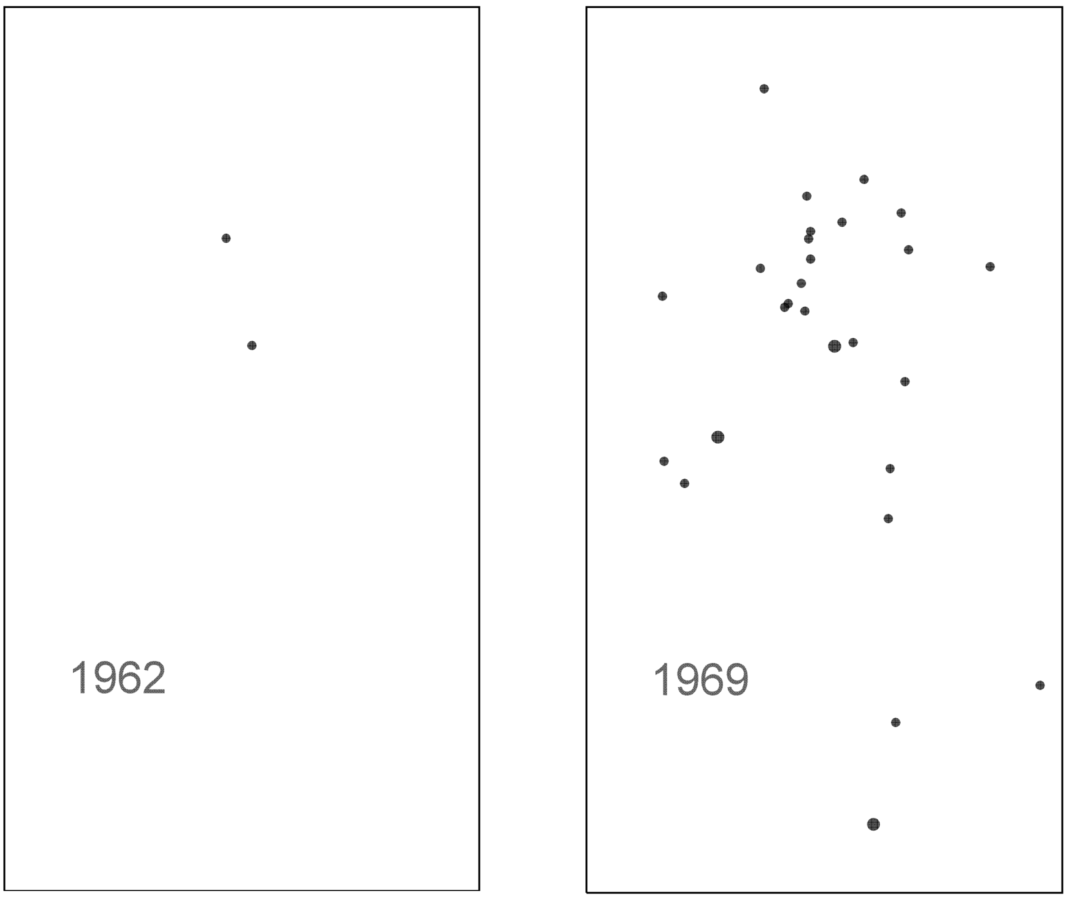
To visialize the data, bubble plots were created showing the progression *of P. amurense* within the plot from 1962 through 2008 using JMP 8.0.1, with dbh as the determining factor for bubble size. The dbh of each *P. amurense* in a given year was approximated by dividing the dbh at the time of removal by the final age of the tree multiplied by the age at each year examined as previously described in Chapter 6 of this work.

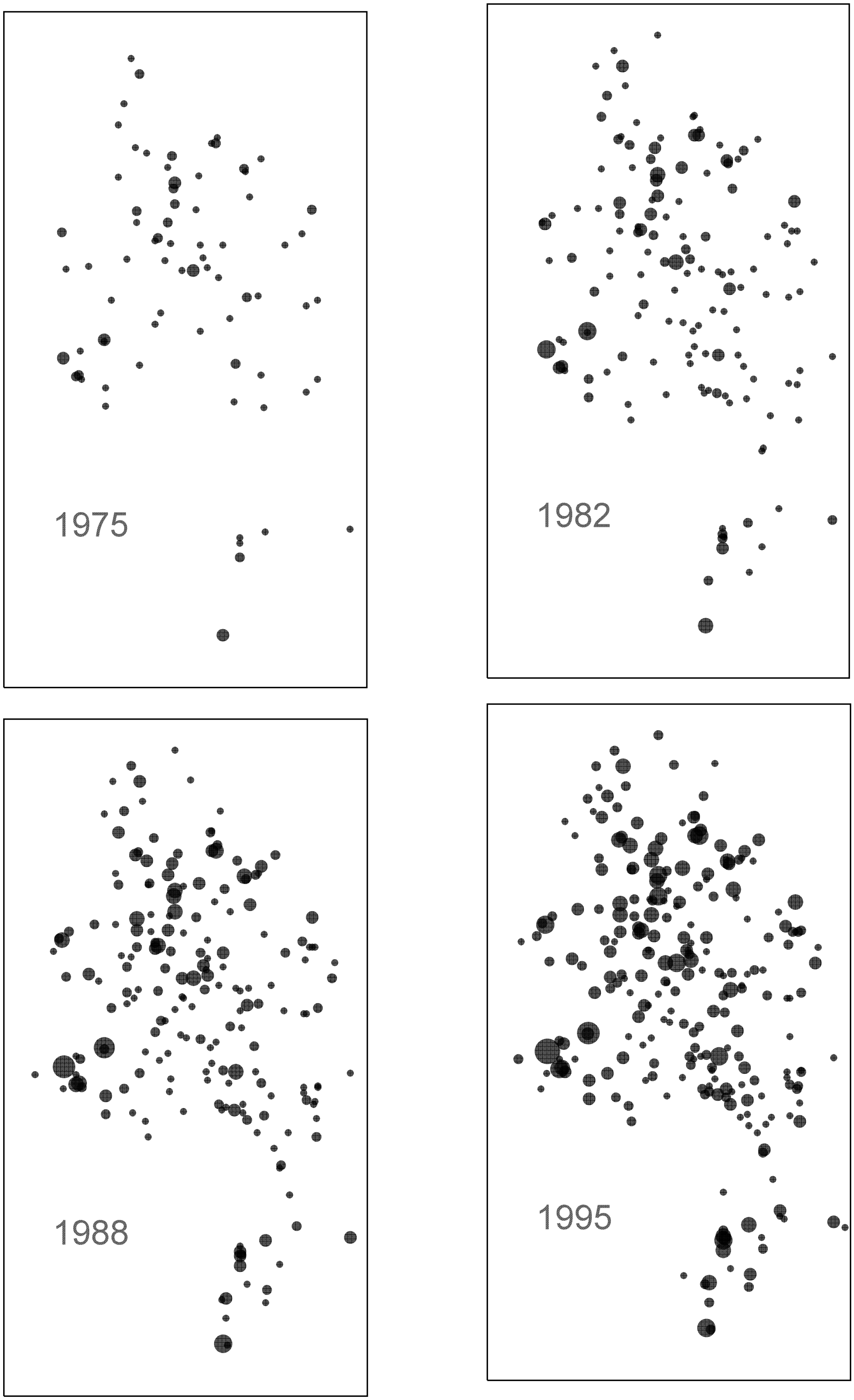
Results and Discussion

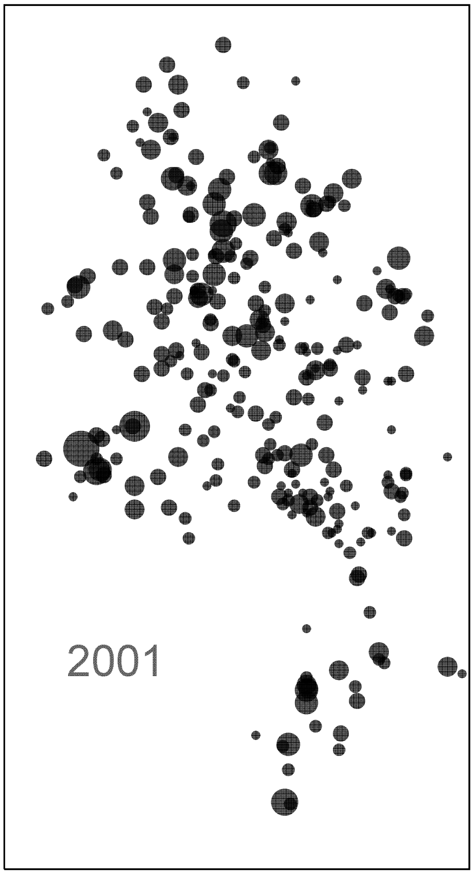
With invasive species costing the United States over 100 billion dollars per year (Pimental et al, 2005), the need to explain the importance of such invasions to both the scientific and non scientific public is of paramount importance. Visual representations of the spread of particular invasive can be a simple way to express the speed with which a new invader, even a long lived tree species, can invade new areas. This method of using bubble plots, several screenshots of whicy are included in Figure 8.1, can be easily transferred into animation in numerous media formats for use in public presentations, replacing or complementing the former methods of using descriptive statistics to a mixed audience which.

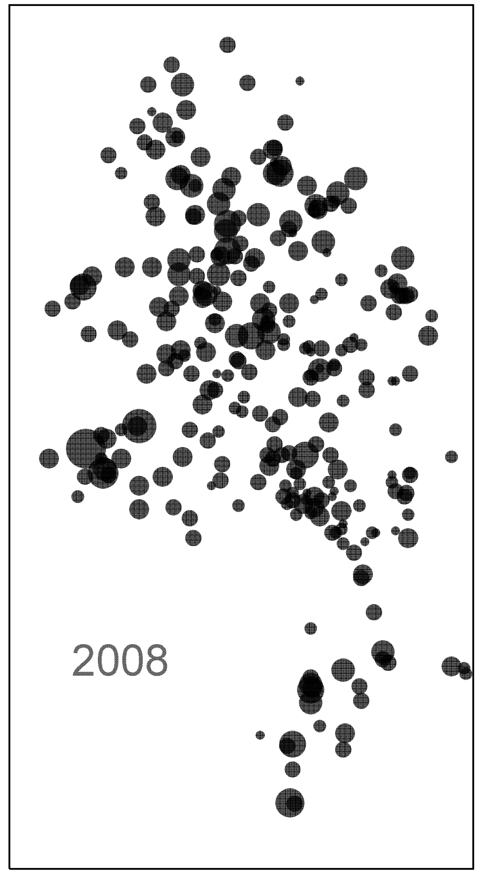
Figure 8.1

Screenshots of the video of an invasion by *P. amurense* from the period between 1962 and 2008.




1975
1982
1988
1995


2001


2008

Data Set 1.
All arborescent tree species recorded within the highly invaded plot, including theic cartesian coordinates, diameter breast height and status as alive (A) or dead

Number	Species	X	Y	DBH	Status
1	*P. amurense*	-0.1	0.8	8.0	A
2	*P. amurense*	2.0	-0.3	2.0	A
3	*P. amurense*	-0.4	1.9	5.0	A
4	*P. amurense*	-0.8	2.7	1.5	A
5	*P. amurense*	-0.1	4.2	3.3	A
6	*P. amurense*	-1.0	2.8	8.0	A
7	*P. amurense*	-2.9	0.2	12.5	A
8	*P. amurense*	-5.1	0.1	8.4	A
9	*P. amurense*	-10.7	-0.9	2.0	A
10	*P. amurense*	2.1	-1.1	2.2	A
11	*P. amurense*	5.9	-1.3	2.0	A
12	*P. amurense*	5.3	-1.7	3.0	A
13	*P. amurense*	7.9	-1.6	4.0	A
14	*P. amurense*	12.3	-1.0	5.0	A
15	*P. amurense*	24.1	0.2	7.0	A
16	*P. amurense*	-4.9	-3.7	3.5	A
17	*P. amurense*	-5.3	-3.4	4.0	A
18	*P. amurense*	-0.7	-2.0	7.0	A
19	*P. amurense*	-9.8	-2.3	6.0	A
20	*P. amurense*	12.9	-0.1	1.0	A
21	*P. amurense*	14.0	-1.0	3.0	A
22	*P. amurense*	14.9	5.0	5.0	A
23	*P. amurense*	18.9	3.7	5.0	A
24	*P. amurense*	18.2	7.4	6.5	A
25	*P. amurense*	19.7	6.1	4.6	A
26	*P. amurense*	20.1	6.3	3.8	A
27	*P. amurense*	20.9	6.1	5.0	A
28	*P. amurense*	21.2	6.4	4.8	A
29	*P. amurense*	19.5	8.0	3.3	dead
30	*P. amurense*	18.9	7.4	1.0	A
31	*P. amurense*	24.7	3.2	3.1	A
32	*P. amurense*	16.9	10.1	2.2	A
33	*P. amurense*	20.2	11.9	9.4	A
34	*P. amurense*	-21.4	-0.2	5.0	A
35	*P. amurense*	-23.5	1.0	7.5	A
36	*P. amurense*	-27.9	0.6	4.5	A
37	*P. amurense*	-33.4	4.4	4.6	A

38	*P. amurense*	-30.3	5.4	4.0	A
39	*P. amurense*	-28.7	7.6	12.5	A
40	*P. amurense*	-29.2	7.9	5.2	A
41	*P. amurense*	-27.3	9.2	5.2	A
42	*P. amurense*	-17.2	4.6	5.7	A
43	*P. amurense*	-15.2	4.3	3.2	A
44	*P. amurense*	-16.0	2.3	6.5	A
45	*P. amurense*	-14.1	6.2	5.5	A
46	*P. amurense*	-22.2	10.5	5.6	A
47	*P. amurense*	-18.3	10.6	5.3	A
48	*P. amurense*	-17.5	18.3	5.7	A
49	*P. amurense*	-18.3	20.4	4.5	A
50	*P. amurense*	-24.8	27.5	4.6	A
51	*P. amurense*	-22.9	24.6	3.0	A
52	*P. amurense*	-19.3	29.3	3.1	A
53	*P. amurense*	-20.4	31.9	3.6	A
54	*P. amurense*	-16.6	32.4	6.7	A
55	*P. amurense*	-18.3	34.0	1.2	A
56	*P. amurense*	-17.5	28.2	6.9	A
57	*P. amurense*	-14.7	30.2	6.6	A
58	*P. amurense*	-12.9	34.2	5.3	A
59	*P. amurense*	-8.6	2.7	2.9	A
60	*P. amurense*	-8.6	2.0	6.2	A
61	*P. amurense*	-7.5	5.4	5.9	A
62	*P. amurense*	-8.1	7.0	1.0	A
63	*P. amurense*	-4.9	9.0	3.4	A
64	*P. amurense*	-7.9	9.5	9.4	A
65	*P. amurense*	-5.6	12.1	3.4	dead
66	*P. amurense*	-3.1	11.1	3.3	A
67	*P. amurense*	-2.4	11.9	6.1	A
68	*P. amurense*	-0.3	7.7	2.4	A
69	*P. amurense*	-1.5	5.0	5.7	A
70	*P. amurense*	2.8	5.2	7.0	A
71	*P. amurense*	2.9	2.4	2.1	A
72	*P. amurense*	1.1	15.0	4.7	A
73	*P. amurense*	-1.9	18.4	9.7	A
74	*P. amurense*	3.1	17.3	7.8	A
75	*P. amurense*	-4.6	14.0	3.3	dead
76	*P. amurense*	-6.5	12.9	11.8	A
77	*P. amurense*	-7.6	12.2	5.2	A
78	*P. amurense*	-8.3	12.6	2.7	dead
79	*P. amurense*	-11.3	12.5	4.4	A
80	*P. amurense*	-11.3	9.3	4.6	A

81	*P. amurense*	-10.4	7.1	6.6	A
82	*P. amurense*	-10.9	7.1	1.0	A
83	*P. amurense*	-9.9	6.4	10.4	A
84	*P. amurense*	-10.5	6.0	7.3	A
85	*P. amurense*	-14.0	9.5	8.0	A
86	*P. amurense*	-14.1	11.6	9.9	A
87	*P. amurense*	-11.7	18.3	4.0	A
88	*P. amurense*	-11.6	18.5	6.3	A
89	*P. amurense*	13.0	24.0	7.7	A
90	*P. amurense*	-13.8	24.5	6.3	A
91	*P. amurense*	-14.2	24.0	9.5	A
92	*P. amurense*	-5.9	24.2	6.5	A
93	*P. amurense*	-7.1	22.3	9.5	A
94	*P. amurense*	-10.6	27.1	5.8	A
95	*P. amurense*	-1.9	27.1	4.5	A
96	*P. amurense*	0.7	24.6	10.3	A
97	*P. amurense*	1.5	24.7	12.6	A
98	*P. amurense*	0.6	26.4	1.2	dead
99	*P. amurense*	1.8	25.9	5.5	A
100	*P. amurense*	0.2	28.3	7.1	A
101	*P. amurense*	0.6	28.4	3.2	A
102	*P. amurense*	7.9	6.5	1.5	A
103	*P. amurense*	6.7	5.8	1.4	A
104	*P. amurense*	10.8	8.6	2.2	A
105	*P. amurense*	8.2	14.4	8.5	A
106	*P. amurense*	8.6	12.8	1.4	A
107	*P. amurense*	2.8	16.2	4.7	A
108	*P. amurense*	3.5	15.7	1.0	A
109	*P. amurense*	4.3	12.9	5.5	A
110	*P. amurense*	7.3	19.2	5.5	A
111	*P. amurense*	6.8	19.1	2.4	A
112	*P. amurense*	6.9	19.8	9.9	A
113	*P. amurense*	6.8	20.2	1.0	A
114	*P. amurense*	5.7	22.9	5.7	A
115	*P. amurense*	9.3	20.0	4.7	A
116	*P. amurense*	9.6	20.4	3.0	A
117	*P. amurense*	10.3	21.8	7.7	A
118	*P. amurense*	2.3	32.2	4.9	A
119	*P. amurense*	4.6	38.6	1.6	A
120	*P. amurense*	-6.5	44.0	4.3	A
121	*P. amurense*	-3.4	38.4	4.1	A
122	*P. amurense*	11.8	19.8	3.2	A
123	*P. amurense*	18.7	-6.5	1.6	A

124	*P. amurense*	19.1	-6.5	1.0	A
125	*P. amurense*	21.3	-5.6	4.0	A
126	*P. amurense*	-5.4	-10.7	2.0	A
127	*P. amurense*	-4.4	-11.3	2.6	A
128	*P. amurense*	-3.2	-5.1	3.6	A
129	*P. amurense*	-1.6	-11.4	4.3	A
130	*P. amurense*	0.2	-13.2	3.6	A
131	*P. amurense*	1.4	-11.9	4.0	A
132	*P. amurense*	4.3	-9.1	5.7	A
133	*P. amurense*	6.5	-9.4	3.2	A
134	*P. amurense*	7.4	-4.7	1.0	A
135	*P. amurense*	7.6	-5.0	8.2	A
136	*P. amurense*	6.2	-2.2	1.1	A
137	*P. amurense*	9.7	-4.1	3.0	A
138	*P. amurense*	9.7	-4.8	4.4	A
139	*P. amurense*	6.0	-6.0	4.6	dead
140	*P. amurense*	6.1	-5.7	2.1	A
141	*P. amurense*	10.9	-1.9	2.1	A
142	*P. amurense*	14.6	-7.9	3.1	A
143	*P. amurense*	14.6	-5.9	4.3	A
144	*P. amurense*	11.1	-9.6	1.8	A
145	*P. amurense*	19.2	-13.9	2.0	A
146	*P. amurense*	27.6	-17.9	2.2	A
147	*P. amurense*	21.4	-20.4	3.1	A
148	*P. amurense*	21.4	-20.8	3.3	A
149	*P. amurense*	2.7	-17.4	4.7	A
150	*P. amurense*	1.6	-17.6	3.3	A
151	*P. amurense*	0.4	-18.3	3.2	A
152	*P. amurense*	0.7	-16.1	3.9	A
153	*P. amurense*	-0.6	-17.6	5.0	A
154	*P. amurense*	-0.3	-19.3	5.3	A
155	*P. amurense*	2.3	-22.3	2.0	A
156	*P. amurense*	3.9	-19.9	5.7	A
157	*P. amurense*	4.0	-20.4	1.8	A
158	*P. amurense*	2.1	-23.9	4.6	A
159	*P. amurense*	2.5	-25.0	3.1	A
160	*P. amurense*	3.5	-24.5	3.2	A
161	*P. amurense*	3.4	-23.5	2.2	A
162	*P. amurense*	5.4	-17.6	12.6	A
163	*P. amurense*	6.9	-16.1	4.1	A
164	*P. amurense*	9.1	-17.8	5.0	A
165	*P. amurense*	8.9	-12.9	6.4	A
166	*P. amurense*	-13.7	-1.9	5.7	A

167	*P. amurense*	-13.3	-2.7	2.1	A
168	*P. amurense*	-12.1	-5.5	5.0	A
169	*P. amurense*	-14.7	-3.6	4.3	A
170	*P. amurense*	-16.0	-2.5	6.7	A
171	*P. amurense*	-16.1	-4.6	4.7	A
172	*P. amurense*	-9.2	-7.8	6.3	A
173	*P. amurense*	-8.5	-7.9	3.4	A
174	*P. amurense*	-8.3	-5.6	1.5	A
175	*P. amurense*	-6.7	-5.8	3.0	A
176	*P. amurense*	-4.0	-9.1	2.9	A
177	*P. amurense*	-10.4	-10.1	6.3	A
178	*P. amurense*	-2.0	-21.9	3.3	A
179	*P. amurense*	-7.3	-19.0	3.4	A
180	*P. amurense*	-7.9	-14.1	3.0	A
181	*P. amurense*	-9.5	-15.5	3.2	A
182	*P. amurense*	-12.3	-13.8	3.6	A
183	*P. amurense*	-20.5	-13.0	21.1	A
184	*P. amurense*	-23.0	-14.0	2.5	A
185	*P. amurense*	-20.5	-13.5	5.7	A
186	*P. amurense*	-19.0	-5.4	5.8	A
187	*P. amurense*	-25.8	-14.8	5.1	A
188	*P. amurense*	-25.2	-15.3	6.4	A
189	*P. amurense*	-28.4	-16.5	29.4	A
190	*P. amurense*	-26.0	-20.1	16.0	A
191	*P. amurense*	-25.8	-18.3	2.5	A
192	*P. amurense*	-25.4	-19.8	10.6	A
193	*P. amurense*	-24.9	-20.6	4.9	A
194	*P. amurense*	-28.5	-21.1	3.6	A
195	*P. amurense*	-29.4	-24.0	2.0	A
196	*P. amurense*	-33.9	-18.2	6.4	A
197	*P. amurense*	-23.0	-18.2	5.2	A
198	*P. amurense*	-20.1	-22.4	7.5	A
199	*P. amurense*	-20.2	-25.8	6.9	A
200	*P. amurense*	-16.4	-21.1	6.0	A
201	*P. amurense*	-14.9	-25.7	4.6	A
202	*P. amurense*	-13.6	-18.0	6.8	A
203	*P. amurense*	-7.8	-21.5	4.1	A
204	*P. amurense*	-9.1	-22.4	1.6	A
205	*P. amurense*	-5.0	-25.3	2.9	A
206	*P. amurense*	-11.8	-30.1	3.5	A
207	*P. amurense*	-12.4	-27.3	4.1	A
208	*P. amurense*	8.8	-21.9	2.0	A
209	*P. amurense*	9.6	-23.1	1.6	A

210	*P. amurense*	7.9	-24.5	3.3	A
211	*P. amurense*	6.7	-25.7	5.5	A
212	*P. amurense*	7.5	-26.9	6.7	A
213	*P. amurense*	6.0	-26.5	2.0	A
214	*P. amurense*	4.9	-25.0	7.1	A
215	*P. amurense*	4.0	-26.8	2.2	dead
216	*P. amurense*	5.4	-24.6	1.1	A
217	*P. amurense*	5.6	-23.4	1.2	A
218	*P. amurense*	6.6	-24.0	7.0	A
219	*P. amurense*	4.5	-22.0	2.5	A
220	*P. amurense*	10.4	-19.9	5.3	A
221	*P. amurense*	12.1	-22.3	2.8	A
222	*P. amurense*	18.6	-21.9	2.6	A
223	*P. amurense*	18.7	-20.7	1.5	A
224	*P. amurense*	19.1	-23.1	4.8	A
225	*P. amurense*	20.4	-24.1	4.6	A
226	*P. amurense*	20.8	-23.5	3.2	A
227	*P. amurense*	21.1	-26.8	2.4	A
228	*P. amurense*	13.5	-25.4	3.0	A
229	*P. amurense*	9.4	-24.1	0.7	A
230	*P. amurense*	10.7	-26.1	5.6	A
231	*P. amurense*	11.2	-28.0	1.4	A
232	*P. amurense*	10.8	-29.0	2.6	A
233	*P. amurense*	9.9	-29.3	1.6	A
234	*P. amurense*	9.4	-29.4	3.2	A
235	*P. amurense*	11.1	-31.1	2.4	A
236	*P. amurense*	16.1	-29.5	0.9	A
237	*P. amurense*	15.4	-29.3	2.8	A
238	*P. amurense*	19.1	-29.1	1.5	dead
239	*P. amurense*	21.0	-30.3	6.3	A
240	*P. amurense*	6.0	-52.2	9.5	A
241	*P. amurense*	6.2	-53.1	13.1	dead
242	*P. amurense*	6.4	-52.8	7.4	A
243	*P. amurense*	6.0	-55.1	9.1	A
244	*P. amurense*	6.1	-51.1	3.6	A
245	*P. amurense*	11.0	-50.1	9.0	A
246	*P. amurense*	17.1	-47.4	8.1	A
247	*P. amurense*	18.0	-49.1	4.2	A
248	*P. amurense*	15.8	-41.3	3.6	A
249	*P. amurense*	14.2	-35.8	6.1	A
250	*P. amurense*	13.9	-36.3	4.4	A
251	*P. amurense*	12.7	-32.4	3.6	A
252	*P. amurense*	14.4	-30.8	0.6	A

253	*P. amurense*	-1.5	-60.0	0.9	A
254	*P. amurense*	3.4	-61.3	12.7	A
255	*P. amurense*	2.6	-61.4	4.5	A
256	*P. amurense*	27.8	-49.6	6.9	A
257	*P. amurense*	29.7	-49.9	1.6	A
258	*P. amurense*	29.9	-50.6	2.3	A
259	*P. amurense*	2.8	-70.0	14.5	A
260	*P. amurense*	3.6	-70.3	4.0	A
261	*P. amurense*	3.3	-65.0	3.5	A
262	*P. amurense*	7.6	-58.6	2.9	A
263	*P. amurense*	11.5	-59.6	5.5	A
264	*P. amurense*	11.1	-62.0	4.3	A
265	*P. amurense*	13.6	-52.6	3.4	A
266	*P. amurense*	13.8	-54.6	4.3	A
267	*P. amurense*	6.1	-43.8	2.6	A
268	*P. amurense*	-18.8	37.9	5.0	A
269	*P. amurense*	-15.2	40.9	4.6	A
270	*P. amurense*	-13.6	38.0	9.1	A
271	*P. amurense*	-12.0	22.9	9.1	A
272	*P. amurense*	-11.5	22.7	1.8	A
273	*P. amurense*	-14.2	30.1	1.6	A
274	*P. amurense*	-8.0	20.0	10.5	A
275	*P. amurense*	-6.5	17.0	14.0	A
276	*P. amurense*	-6.9	16.0	10.0	A
277	*P. amurense*	-5.0	18.0	4.7	A
278	*P. amurense*	17.1	-48.4	4.5	A
1	*F. grandifolia*	22.8	-0.7	4.5	A
2	*A. canadensis*	23.6	1.0	1.5	A
3	*B. lenta*	23.9	2.2	21.0	A
4	*B. lenta*	21.0	1.3	25.0	A
5	*P. serotina*	22.2	2.5	2.6	A
6	*P. serotina*	18.9	0.8	1.9	A
7	*P. serotina*	20.4	-1.4	3.0	A
8	*P. serotina*	16.6	-0.5	3.0	A
9	*E. alata*	16.3	-3.1	4.3	A
10	*B. lenta*	15.6	-2.5	44.7	A
11	*N. sylvatica*	13.5	-0.3	7.5	A
12	*C. ovata*	9.2	-0.3	13.5	A
13	*C. ovata*	9.7	-1.1	13.5	A
14	*A. rubrum*	3.5	-2.0	51.0	A
15	*C. florida*	1.0	-3.1	8.0	A
16	*B. lenta*	-0.5	-4.8	36.0	A
17	*C. ovata*	-1.5	-4.5	10.0	A

18	*L. tulipifera*	-3.1	1.5	86.0	A
19	*Q. alba*	-11.2	-1.2	25.0	A
20	*A. platanoides*	-15.5	-1.0	4.5	A
21	*F. americana*	-18.3	-0.9	40.5	Dead
22	*A. rubrum*	-18.5	-2.1	9.0	A
23	*L. benzoin*	-19.4	-0.6	1.0	A
24	*Q. rubra*	-25.9	-1.0	39.5	A
25	*A. rubrum*	-29.2	0.3	34.0	A
26	*B. alleghaniensis*	-30.8	0.4	27.5	A
27	*V. labrusca*	-31.0	1.0	5.5	A
28	*O. virginica*	-29.2	-1.9	12.0	A
29	*Q. alba*	-28.9	7.2	37.3	A
30	*C. ovata*	-26.6	11.4	19.0	A
31	*B. alleghaniensis*	-25.9	14.3	9.3	Dead
32	*B. lenta*	-26.4	17.1	36.6	A
33	*Q. alba*	-18.5	4.7	23.2	A
34	*A. rubrum*	-13.7	3.3	13.5	A
35	*Q. rubra*	-13.5	5.5	27.3	A
36	*B. lenta*	-19.2	6.3	5.5	Dead
37	*A. platanoides*	-22.3	5.0	9.9	A
38	*A. rubrum*	-21.4	7.4	34.1	A
39	*B. lenta*	-17.8	11.8	26.8	A
40	*B. alleghaniensis*	-19.5	13.7	25.1	A
41	*C. caroliniana*	-19.0	15.0	4.0	A
42	*A. rubrum*	-16.9	15.7	18.7	A
43	*B. lenta*	-17.9	21.6	34.6	Dead
44	*B. lenta*	-21.2	20.7	18.3	A
45	*C. caroliniana*	-20.3	19.6	6.7	A
46	*B. lenta*	-19.6	23.0	25.5	A
47	*C. caroliniana*	-17.7	25.7	3.4	A
48	*F. grandifolia*	-19.4	26.1	13.2	A
49	*B. alleghaniensis*	-19.7	27.2	25.8	Dead
50	*B. lenta*	-17.3	27.3	1.3	A
51	*B. lenta*	-21.3	23.9	25.5	A
52	*B. lenta*	-24.5	24.0	40.1	A
53	*P. serotina*	-24.8	23.0	4.3	A
54	*B. lenta*	-26.2	23.1	16.7	A
55	*B. lenta*	-20.4	29.4	22.5	A
56	*C. caroliniana*	-18.7	33.8	5.0	A
57	*N. sylvatica*	-14.0	30.9	7.1	A
58	*B. lenta*	-13.2	31.0	33.3	A
59	*N. sylvatica*	-6.0	11.0	6.6	A
60	*B. lenta*	-1.6	8.0	33.9	A

61	*B. lenta*	0.6	6.5	26.8	A
62	*B. lenta*	-0.6	4.9	16.6	A
63	*A. saccharum*	-0.9	5.3	2.0	A
64	*B. alleghaniensis*	0.6	11.5	24.4	Dead
65	*A. rubrum*	0.0	16.2	46.4	A
66	*S. paniculata*	-1.5	19.1	4.3	A
67	*A. rubrum*	-6.0	15.2	33.1	A
68	*A. saccharum*	-6.3	14.2	1.1	A
69	*A. rubrum*	-10.4	11.1	28.4	A
70	*N. sylvatica*	-12.1	9.4	8.9	A
71	*A. rubrum*	-11.8	16.1	42.3	A
72	*A. rubrum*	-14.6	13.4	14.6	A
73	*S. paniculata*	-12.3	16.1	2.1	A
74	*Q. rubra*	-10.9	19.1	26.6	A
75	*N. sylvatica*	-12.7	19.8	14.0	A
76	*N. sylvatica*	-12.9	21.0	12.7	A
77	*N. sylvatica*	-13.5	23.5	15.8	A
78	*N. sylvatica*	-15.2	25.1	18.2	A
79	*C. florida*	-14.8	25.4	6.2	Dead
80	*A. rubrum*	-10.3	27.2	22.2	A
81	*S. albidum*	-1.5	23.8	17.7	Dead
82	*S. paniculata*	-1.1	26.7	2.7	A
83	*A. rubrum*	-2.5	26.8	60.8	A
84	*C. caroliniana*	-1.0	32.3	1.7	A
85	*C. caroliniana*	-1.6	32.6	1.7	A
86	*A. rubrum*	-2.8	31.8	21.1	A
87	*Q. alba*	0.6	40.4	38.5	A
88	*A. platanoides*	-0.9	38.2	1.1	A
89	*A. saccharum*	-1.5	36.5	3.5	A
90	*P. serotina*	-0.1	35.7	1.8	A
91	*F. grandifolia*	8.2	2.3	17.3	A
92	*O. virginica*	7.1	2.6	7.1	A
93	*A. rubrum*	10.4	7.0	79.6	A
94	*A. rubrum*	8.8	11.6	22.8	A
95	*C. caroliniana*	10.6	5.5	8.1	A
96	*B. lenta*	5.2	7.5	21.9	A
97	*A. saccharum*	5.9	8.1	4.0	A
98	*C. caroliniana*	6.4	7.0	1.0	A
99	*C. caroliniana*	9.6	13.5	2.3	A
100	*A. rubrum*	10.1	15.9	38.5	A
101	*Q. alba*	4.0	16.3	33.9	A
102	*A. rubrum*	6.1	15.5	10.0	A
103	*A. saccharum*	8.9	20.4	6.8	A

104	*A. rubrum*	10.6	24.1	24.6	Dead
105	*A. rubrum*	10.5	27.1	75.7	A
106	*C. caroliniana*	10.2	28.7	1.6	A
107	*C. ovata*	1.1	32.0	22.3	A
108	*C. florida*	0.2	37.2	8.6	Dead
109	*A. rubrum*	3.4	33.1	5.5	Dead
110	*A. rubrum*	3.4	30.7	2.4	A
111	*A. rubrum*	5.0	39.0	35.6	A
112	*C. caroliniana*	-0.2	39.3	1.4	A
113	*C. caroliniana*	1.2	38.5	1.4	A
114	*C. caroliniana*	2.3	37.4	2.4	A
115	*A. platanoides*	0.1	39.9	2.8	A
116	*Q. rubra*	-5.4	39.9	35.9	A
117	*A. rubrum*	-3.8	41.0	2.0	A
118	*A. rubrum*	-5.8	40.3	3.2	A
119	*A. rubrum*	-3.0	39.2	2.5	Dead
120	*A. rubrum*	-8.1	39.1	30.4	A
121	*A. rubrum*	-7.4	32.0	47.1	A
122	*A. rubrum*	-6.1	33.9	29.6	A
123	*A. rubrum*	-7.3	34.1	16.3	A
124	*N. sylvatica*	-8.2	32.4	5.5	A
125	*F. grandifolia*	2.9	11.3	10.7	A
126	*A. rubrum*	13.3	12.9	33.1	A
127	*Q. rubra*	14.9	15.0	32.8	A
128	*F. grandifolia*	13.1	12.7	4.3	A
129	*F. grandifolia*	13.1	12.4	4.2	A
130	*C. caroliniana*	13.9	13.0	3.5	A
131	*C. caroliniana*	11.0	18.3	3.2	A
132	*C. caroliniana*	11.3	19.6	2.5	A
133	*C. caroliniana*	12.0	19.4	1.9	A
134	*P. occidentalis*	12.0	21.5	18.5	A
135	*A. platanoides*	11.0	21.9	3.2	A
136	*C. caroliniana*	12.4	22.0	2.1	A
137	*C. caroliniana*	13.5	22.2	2.6	A
138	*N. sylvatica*	11.2	26.0	9.6	A
139	*C. caroliniana*	8.5	23.6	2.2	A
140	*C. caroliniana*	8.2	24.1	2.4	A
141	*A. rubrum*	15.4	20.6	37.1	A
142	*C. ovata*	15.4	21.1	4.0	A
143	*A. rubrum*	15.2	21.5	6.0	Dead
144	*N. sylvatica*	13.8	14.6	5.2	A
145	*N. sylvatica*	16.0	16.1	2.7	A
146	*F. grandifolia*	20.8	12.0	7.0	A

147	*F. grandifolia*	21.8	12.7	1.6	A
148	*F. grandifolia*	22.2	9.6	4.6	A
149	*F. grandifolia*	16.9	6.0	9.8	A
150	*A. rubrum*	19.9	4.5	42.3	A
151	*C. caroliniana*	17.9	3.2	4.7	A
152	*C. caroliniana*	19.3	3.4	3.2	A
153	*B. lenta*	17.1	10.1	4.4	A
154	*F. grandifolia*	17.4	9.6	1.3	A
155	*F. grandifolia*	18.4	9.5	2.2	A
156	*F. grandifolia*	22.4	8.4	4.2	A
157	*F. grandifolia*	21.5	-2.7	5.6	A
158	*N. sylvatica*	21.0	-7.3	11.1	A
159	*N. sylvatica*	21.3	-5.0	7.5	A
160	*F. grandifolia*	21.1	-5.2	1.9	A
161	*F. americana*	3.2	-9.0	21.6	Dead
162	*A. rubrum*	2.1	-10.4	4.2	Dead
163	*C. caroliniana*	-0.8	-9.1	5.6	A
164	*B. lenta*	-1.3	-6.7	30.6	A
165	*Q. rubra*	-3.3	-10.1	12.6	A
166	*C. caroliniana*	-1.5	-11.3	2.5	A
167	*C. caroliniana*	-5.6	-10.5	3.9	A
168	*Q. rubra*	-3.0	-14.0	40.0	A
169	*C. caroliniana*	7.0	-8.9	3.5	A
170	*B. lenta*	13.4	-7.3	46.3	A
171	*A. rubrum*	11.2	-7.3	46.3	A
172	*Q. rubra*	10.6	-7.6	18.0	A
173	*C. ovata*	11.4	-10.2	2.6	A
174	*C. caroliniana*	16.7	-17.8	4.6	A
175	*Q. rubra*	14.9	-15.0	34.6	A
176	*A. rubrum*	15.6	-18.7	36.9	A
177	*N. sylvatica*	18.2	-14.5	8.7	A
178	*S. paniculata*	17.0	-13.9	2.7	A
179	*A. rubrum*	21.6	-15.0	41.0	A
180	*S. paniculata*	24.0	-18.0	3.6	A
181	*F. grandifolia*	26.3	-18.3	2.0	A
182	*O. virginica*	28.0	-17.0	10.0	A
183	*F. grandifolia*	28.6	-17.0	1.3	A
184	*B. lenta*	28.9	-16.7	13.6	A
185	*B. lenta*	28.0	-14.9	39.2	A
186	*F. grandifolia*	29.2	-19.5	3.1	A
187	*F. grandifolia*	28.9	-19.7	2.0	A
188	*F. grandifolia*	24.9	-20.4	3.3	A
189	*C. florida*	25.0	-21.6	6.8	Dead

190	*C. ovata*	20.2	-18.3	7.8	A
191	*B. lenta*	0.5	-18.0	30.2	A
192	*Q. prinus*	4.0	-20.1	21.7	A
193	*A. rubrum*	4.0	-24.2	7.7	A
194	*B. lenta*	8.4	-15.7	27.8	A
195	*N. sylvatica*	9.5	-16.1	8.6	A
196	*C. caroliniana*	10.9	-15.2	4.8	Dead
197	*B. lenta*	12.4	-13.2	44.4	A
198	*Q. rubra*	13.8	-11.5	15.5	Dead
199	*A. rubrum*	15.0	-7.7	2.6	A
200	*C. ovata*	16.0	-7.4	10.4	A
201	*F. grandifolia*	16.5	-7.8	2.1	A
202	*B. lenta*	16.8	-9.0	33.3	A
203	*P. serotina*	17.3	-10.3	1.5	A
204	*F. grandifolia*	17.6	-10.2	1.5	A
205	*F. grandifolia*	18.9	-9.1	1.2	A
206	*N. sylvatica*	19.9	-8.7	8.3	Dead
207	*F. grandifolia*	23.1	-9.0	5.0	A
208	*N. sylvatica*	22.2	-7.6	15.3	A
209	*N. sylvatica*	23.9	-8.1	10.5	A
210	*P. serotina*	24.5	-7.9	2.5	A
211	*B. lenta*	21.8	-12.0	32.2	A
212	*A. rubrum*	19.7	-10.9	28.8	A
213	*A. saccharum*	-5.0	0.8	1.3	A
214	*A. rubrum*	-12.1	-3.9	6.5	Dead
215	*Q. alba*	-16.1	-4.2	15.1	Dead
216	*Q. alba*	-13.9	-7.8	27.0	A
217	*C. caroliniana*	-10.8	-6.3	1.6	A
218	*B. lenta*	-10.4	-7.0	32.9	A
219	*A. rubrum*	-9.8	-4.7	28.1	A
220	*C. caroliniana*	-8.4	-5.2	4.3	Dead
221	*C. caroliniana*	-8.5	-6.2	4.1	Dead
222	*C. caroliniana*	-7.0	-12.1	4.3	A
223	*Q. alba*	-9.5	-10.4	18.7	A
224	*C. caroliniana*	-12.0	-11.7	6.2	A
225	*B. lenta*	-12.0	-11.0	37.4	A
226	*C. caroliniana*	-4.2	-14.0	3.5	Dead
227	*B. lenta*	-3.5	-17.3	30.3	A
228	*F. grandifolia*	-5.1	-16.5	14.7	A
229	*A. rubrum*	-5.9	-16.5	8.6	A
230	*Q. alba*	-7.2	-18.4	16.3	Dead
231	*B. lenta*	2.0	-28.0	32.0	A
232	*A. saccharum*	0.5	-29.2	2.7	A

233	*B. alleghaniensis*	-0.5	-28.7	26.5	A
234	*B. lenta*	-1.5	-27.4	16.1	Dead
235	*A. rubrum*	0.4	-27.5	1.3	A
236	*C. caroliniana*	-10.8	-14.5	7.7	A
237	*Q. velutina*	-13.9	-14.1	38.9	A
238	*B. lenta*	-15.1	-12.4	26.7	A
239	*P. serotina*	-15.9	-15.1	3.7	A
240	*C. caroliniana*	-16.7	-14.4	6.5	A
241	*C. caroliniana*	-19.6	-12.2	8.4	A
242	*A. saccharum*	-20.8	-13.3	2.8	A
243	*A. rubrum*	-20.8	-8.9	22.0	A
244	*S. paniculata*	-22.5	-3.7	3.8	A
245	*B. lenta*	-22.9	-4.7	18.2	A
246	*B. alleghaniensis*	-23.7	-5.7	9.5	A
247	*C. ovata*	-25.3	-5.7	18.4	A
248	*A. rubrum*	-29.6	-6.3	12.9	A
249	*S. paniculata*	-27.4	-9.7	3.7	A
250	*A. rubrum*	-24.9	-11.6	26.7	A
251	*F. grandifolia*	-27.9	-13.8	1.2	A
252	*B. alleghaniensis*	-32.3	-10.9	26.1	A
253	*A. platanoides*	-33.0	-13.2	6.6	A
254	*F. grandifolia*	-32.0	-13.6	1.8	A
255	*B. alleghaniensis*	-30.3	-15.7	31.1	A
256	*A. platanoides*	-32.0	-15.1	6.0	A
257	*A. saccharum*	-23.0	-7.6	4.0	A
258	*B. alleghaniensis*	-26.7	-22.4	29.7	A
259	*Q. alba*	-32.3	-27.0	80.5	A
260	*A. platanoides*	-29.4	-24.0	4.6	A
261	*F. grandifolia*	-36.5	-19.5	41.1	A
262	*F. grandifolia*	-34.2	-21.2	5.2	A
263	*F. grandifolia*	-33.5	-18.3	1.0	A
264	*F. grandifolia*	-39.2	-9.9	10.4	A
265	*F. grandifolia*	-40.0	-16.8	11.5	A
266	*A. rubrum*	-39.4	-19.8	31.2	A
267	*F. grandifolia*	-38.4	-20.0	6.2	A
268	*O. virginica*	-32.5	6.8	11.9	A
269	*A. rubrum*	-32.3	14.9	6.5	A
270	*F. americana*	-37.2	12.7	40.8	A
271	*F. grandifolia*	-36.6	10.0	18.5	A
272	*B. alleghaniensis*	-33.5	11.3	32.0	Dead
273	*B. lenta*	-24.9	21.6	23.1	A
274	*A. platanoides*	-21.9	15.0	7.7	A
275	*A. rubrum*	-37.0	4.7	24.2	A

276	*A. saccharum*	-36.1	-2.9	28.2	A
277	*A. platanoides*	-33.3	-2.8	3.2	A
278	*F. grandifolia*	-33.4	-4.1	6.4	A
279	*B. alleghaniensis*	-21.6	-17.1	26.4	A
280	*F. grandifolia*	-21.1	-16.7	11.1	A
281	*A. rubrum*	-22.1	-19.3	3.0	Dead
282	*B. alleghaniensis*	-22.3	-22.8	4.1	Dead
283	*B. alleghaniensis*	-20.0	-18.7	10.5	A
284	*B. alleghaniensis*	-11.9	-17.2	7.7	A
285	*C. caroliniana*	-12.4	-18.9	3.6	Dead
286	*B. alleghaniensis*	-14.0	-23.8	22.1	A
287	*Q. alba*	-8.0	-22.4	19.4	A
288	*C. caroliniana*	-9.3	-21.7	6.7	A
289	*C. ovata*	-4.7	-21.8	25.0	A
290	*B. lenta*	-8.2	-26.3	22.6	A
291	*B. alleghaniensis*	-7.2	-25.8	5.0	Dead
292	*B. alleghaniensis*	-6.9	-24.6	9.0	Dead
293	*P. serotina*	-6.7	-26.1	2.3	A
294	*A. saccharum*	-7.4	-27.3	2.8	A
295	*B. lenta*	-9.9	-25.8	5.0	A
296	*B. alleghaniensis*	-11.6	-26.4	7.9	A
297	*F. grandifolia*	-10.9	-28.5	1.5	A
298	*F. grandifolia*	-11.2	-28.8	2.9	A
299	*B. alleghaniensis*	-8.2	-30.6	12.7	A
300	*B. alleghaniensis*	-3.7	-31.0	39.0	A
301	*A. canadensis*	-4.5	-31.0	1.0	Dead
302	*B. alleghaniensis*	-1.2	-34.9	8.1	A
303	*B. alleghaniensis*	-0.4	-31.9	2.2	A
304	*B. lenta*	-3.6	-33.4	27.5	A
305	*C. caroliniana*	-4.2	-32.3	2.0	A
306	*F. grandifolia*	-3.6	-28.5	3.0	A
307	*F. grandifolia*	-4.1	-28.6	3.7	A
308	*F. grandifolia*	-5.3	-28.4	5.0	A
309	*B. lenta*	-4.1	-27.2	32.5	A
310	*C. caroliniana*	-2.9	-25.0	1.8	A
311	*B. alleghaniensis*	3.9	-32.3	14.1	A
312	*B. alleghaniensis*	6.0	-32.4	18.3	A
313	*A. platanoides*	4.1	-31.1	7.5	A
314	*F. grandifolia*	2.6	-33.4	5.6	A
315	*B. lenta*	2.9	-33.9	24.5	A
316	*A. rubrum*	3.3	-33.8	4.3	A
317	*F. grandifolia*	7.7	-30.5	2.0	A
318	*C. caroliniana*	1.7	-36.4	4.1	A

319	*Q. alba*	8.1	-19.7	19.4	A
320	*A. platanoides*	5.1	-25.2	2.1	A
321	*B. alleghaniensis*	14.8	-21.2	13.8	A
322	*P. serotina*	11.1	-21.6	1.8	A
323	*S. albidum*	19.1	-22.2	9.1	Dead
324	*A. platanoides*	22.0	-24.4	25.6	A
325	*A. rubrum*	21.8	-26.8	9.8	A
326	*B. lenta*	19.5	-26.8	22.3	A
327	*A. platanoides*	17.1	-25.4	7.2	A
328	*C. caroliniana*	15.2	-24.6	7.2	A
329	*C. glabra*	12.1	-28.7	35.4	A
330	*A. rubrum*	11.6	-29.7	15.0	A
331	*C. glabra*	13.4	-29.9	33.8	A
332	*S. paniculata*	18.6	31.4	2.2	A
333	*M. tripetala*	19.4	-32.0	4.9	A
334	*B. alleghaniensis*	18.7	-33.2	24.6	Dead
335	*F. grandifolia*	17.6	-32.9	1.0	A
336	*C. caroliniana*	17.4	-32.5	7.0	A
337	*C. ovata*	19.8	-31.9	1.1	A
338	*P. serotina*	19.1	-30.5	2.0	Dead
339	*P. serotina*	19.7	-30.7	1.6	Dead
340	*P. serotina*	21.6	-31.3	2.2	A
341	*A. rubrum*	21.7	-34.0	22.5	A
342	*P. serotina*	20.2	-33.9	2.0	A
343	*P. serotina*	20.1	-34.7	1.5	A
344	*B. lenta*	20.3	-35.4	36.7	A
345	*B. lenta*	17.6	-36.2	19.6	A
346	*B. lenta*	18.8	-36.9	25.7	A
347	*B. lenta*	14.4	-34.0	37.0	A
348	*A. rubrum*	14.6	-33.3	3.7	A
349	*A. rubrum*	16.0	-55.5	43.7	A
350	*A. rubrum*	16.6	-54.8	8.3	Dead
351	*C. florida*	14.2	-53.2	6.1	A
352	*A. rubrum*	11.8	-55.0	42.7	A
353	*A. canadensis*	14.9	-52.6	1.3	A
354	*S. paniculata*	16.1	-52.1	1.1	A
355	*Q. rubra*	7.1	-55.3	44.4	A
356	*B. alleghaniensis*	4.0	-52.3	3.3	A
357	*Q. alba*	2.0	-51.6	64.3	A
358	*N. sylvatica*	10.9	-47.7	22.1	A
359	*B. lenta*	19.6	-47.8	44.8	A
360	*F. grandifolia*	14.1	-46.8	9.4	A
361	*A. rubrum*	22.9	-48.5	18.8	A

362	*A. rubrum*	15.3	-42.0	16.0	A
363	*C. glabra*	19.9	-42.3	16.6	A
364	*F. grandifolia*	20.5	-40.2	12.2	A
365	*F. grandifolia*	20.3	-39.4	2.2	A
366	*A. rubrum*	14.8	-37.0	5.8	Dead
367	*F. grandifolia*	5.3	-35.1	1.8	A
368	*B. lenta*	5.4	-36.0	20.8	A
369	*A. rubrum*	7.2	-35.1	2.0	A
370	*B. alleghaniensis*	7.2	-35.7	20.3	A
371	*F. grandifolia*	7.3	-36.3	0.8	A
372	*A. platanoides*	7.4	-36.9	3.5	A
373	*A. rubrum*	8.4	-36.3	2.1	A
374	*A. rubrum*	14.0	-34.8	1.0	A
375	*B. alleghaniensis*	15.6	-35.1	2.2	Dead
376	*A. rubrum*	13.5	-37.8	8.2	A
377	*Q. rubra*	10.1	-42.9	58.3	A
378	*A. rubrum*	12.0	-41.4	7.4	A
379	*A. saccharum*	9.4	-45.8	20.3	A
380	*A. rubrum*	10.3	-45.1	4.0	A
381	*C. caroliniana*	8.1	-54.3	5.6	A
382	*Q. alba*	2.8	-61.9	33.5	A
383	*L. tulipifera*	1.2	-58.0	19.9	A
384	*F. grandifolia*	34.3	-40.3	1.5	A
385	*Q. alba*	33.3	-40.5	23.5	A
386	*F. grandifolia*	31.6	-41.1	3.0	A
387	*F. grandifolia*	30.7	-38.9	2.7	A
388	*F. grandifolia*	34.8	-38.1	2.0	A
389	*F. grandifolia*	33.2	-38.3	2.8	A
390	*Q. rubra*	33.0	-37.0	28.1	A
391	*B. lenta*	29.6	-37.1	24.4	A
392	*A. rubrum*	28.7	-36.7	21.2	A
393	*P. grandidentata*	26.7	-36.7	29.2	A
394	*B. lenta*	25.7	-38.8	3.0	A
395	*F. grandifolia*	27.6	-36.4	34.2	A
396	*F. grandifolia*	33.4	-41.9	2.8	A
397	*Q. palustris*	32.8	-46.5	31.8	A
398	*F. grandifolia*	41.8	-45.3	12.4	A
399	*F. grandifolia*	33.8	-45.7	4.9	A
400	*F. grandifolia*	34.0	-46.9	1.0	A
401	*F. grandifolia*	31.7	-42.4	0.9	A
402	*B. alleghaniensis*	31.6	-48.2	18.2	A
403	*F. grandifolia*	34.4	-48.7	1.0	A
404	*B. alleghaniensis*	29.5	-45.9	25.5	A

405	*F. grandifolia*	28.5	-46.7	2.0	A
406	*F. grandifolia*	28.2	-41.7	3.6	A
407	*F. grandifolia*	27.3	-43.7	1.6	A
408	*F. grandifolia*	27.0	-42.3	1.3	A
409	*N. sylvatica*	26.3	-42.0	8.7	A
410	*B. lenta*	26.4	-43.7	3.2	Dead
411	*B. lenta*	25.6	-42.3	0.9	A
412	*F. grandifolia*	24.6	-40.7	0.8	A
413	*C. caroliniana*	23.3	-41.0	2.8	A
414	*N. sylvatica*	24.6	-43.7	4.3	A
415	*B. alleghaniensis*	24.0	-46.2	10.9	A
416	*B. alleghaniensis*	25.2	-46.5	21.1	A
417	*A. rubrum*	25.8	-46.5	28.9	A
418	*A. rubrum*	29.6	-50.8	17.7	A
419	*B. alleghaniensis*	29.7	-52.8	2.0	A
420	*A. rubrum*	29.5	-54.3	3.2	A
421	*B. lenta*	27.8	-53.6	27.3	A
422	*U. rubra*	2.0	-68.0	4.3	A
423	*B. alleghaniensis*	2.5	-66.9	18.6	A
424	*A. rubrum*	3.3	-59.8	28.0	A
425	*C. ovata*	-1.7	-56.0	1.5	A
426	*A. rubrum*	-2.1	-56.4	1.8	A
427	*F. grandifolia*	-3.0	-56.3	4.5	A
428	*F. grandifolia*	-3.6	-57.8	12.0	A
429	*F. americana*	-2.7	-63.4	11.6	A
430	*Q. alba*	-3.9	-64.0	62.0	A
431	*U. americana*	-1.7	-70.4	41.4	A
432	*Q. alba*	4.9	-71.6	46.4	A
433	*Q. alba*	7.9	-71.4	42.1	A
434	*N. sylvatica*	10.3	-69.0	34.5	A
435	*U. rubra*	14.2	-63.0	30.2	A
436	*U. rubra*	13.1	-62.1	22.0	A
437	*B. alleghaniensis*	17.2	-62.0	14.4	Dead
438	*N. sylvatica*	15.5	60.3	12.9	A
439	*B. lenta*	7.1	41.8	14.5	A
440	*N. sylvatica*	-13.5	35.9	6.5	A
441	*A. saccharum*	-14.0	35.6	3.2	A
442	*N. sylvatica*	-14.2	33.8	9.6	A
443	*P. serotina*	-14.3	32.0	2.0	A
444	*B. lenta*	-19.9	40.6	11.6	Dead
445	*A. rubrum*	-18.3	40.4	19.0	A
446	*A. platanoides*	-19.0	39.2	4.6	A
447	*L. tulipifera*	-19.3	38.8	80.1	A

448	*B. lenta*	-18.6	40.8	18.4	A
449	*Q. alba*	-13.0	43.2	29.2	A
450	*A. rubrum*	-10.5	44.9	26.5	A
451	*N. sylvatica*	-9.8	40.6	7.5	A
452	*N. sylvatica*	-9.8	38.7	7.4	A
453	*A. rubrum*	-12.6	3.4	34.5	A
454	*N. sylvatica*	-10.8	30.3	4.2	A
455	*Q. alba*	-9.6	30.1	27.4	Dead
456	*C. caroliniana*	-9.2	30.4	6.5	Dead
457	*P. serotina*	-10.1	28.4	2.9	A
458	*Q. alba*	-11.0	23.1	40.7	A
459	*P. serotina*	-12.5	30.3	2.2	A
460	*P. serotina*	-11.9	30.5	2.4	A
461	*F. grandifolia*	1.6	43.3	5.0	A
462	*B. lenta*	3.8	43.3	42.4	A
463	*Q. rubra*	4.7	43.2	27.0	A
464	*F. grandifolia*	4.5	43.0	1.5	A
465	*C. ovata*	27.0	42.0	3.0	Dead
466	*F. grandifolia*	32.0	43.0	2.6	A
467	*F. grandifolia*	0.4	45.2	12.0	A
468	*F. grandifolia*	0.4	44.2	5.2	A
469	*A. rubrum*	-1.5	46.9	3.2	A
470	*Q. alba*	-1.5	47.9	59.5	A
471	*U. rubra*	-7.2	48.3	13.1	A
472	*A. platanoides*	-6.2	49.0	5.7	A
473	*B. lenta*	24.3	-31.0	26.5	A
474	*C. caroliniana*	25.5	-31.1	26.5	A
475	*B. lenta*	25.7	-31.0	21.6	A
476	*P. serotina*	24.9	-29.6	2.4	A
477	*B. lenta*	25.0	-34.2	6.0	A

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