Original Research Article

An understory comparison of the exotic *Phellodendron amurense* Rupr. (RUTACEAE) and adjacent native canopy species in an urban and suburban woodland

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ABSTRACT

An understory comparison of the invasive tree species *Phellodendron amurense* Rupr. and surrounding native tree species at two locations in the greater New York metropolitan region is examined. The understory of canopies consisting of *P. amurense* was compared with adjacent canopies consisting of native tree species based upon their species density, richness and native understory composition. 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 (.t < .0032; t < .0088) 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 (t < .0009, t < .0001). There was also a significant difference between the invaded versus native sites in the mean number of total species per m^2 quadrat at one site (t < .0001), while the second site showed a non significant difference (t < .0059).

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 is not likely to play a role in the lower density of understory individuals under *P. amurense.*

1. INTRODUCTION

Human introductions of new species to ecosystems, both accidental and intentional, can have numerous unintended consequences [1, 2]. Since the publication of Charles Elton's *The ecology of invasions by animals and plants* in 1958 [3], 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 [4,5]. 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 [6]. These characteristics make the tree an excellent choice for many horticultural situations and have resulted in *P. amurense* being cultivated throughout the United States, particularly in public gardens and arboreta as summarized by Ma and Branch [7]. Numerous horticultural collections and introductions such as this have resulted in the spread of many invasive plant species in the United States [8] 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 [4] and is likely to join this growing list of aggressive invaders.

Prior to a recent revision of the genus *Phellodendron* [9], the species may have been overlooked as an introduced member of the local flora due to confusion in the nomenclature. Greller [10] and Bertin et al. [11] 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 [12] report the entire 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* [9]. 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, [12] 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 [13,14]. These ecological impacts consist of any significant change in an ecological pattern or process [15], such as the changes examined within this work. 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. A major challenge to the management of invasive species is the conveyance of information to the public [16], a process that may be on hold in many instances until those threats are understood.

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, violating the null hypothesis that there would be no difference between sites. 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

78 analysis comparing invaded versus adjacent uninvaded areas in two separate forests was
79 performed. An analysis of the canopy was then performed by using hemispherical canopy
80 photographs in the sampled areas.
81
2. MATERIAL AND METHODS

84 This study was conducted in the summer of 2009 at two sites where invasions of *P.*
85 *amurense* totaling more than 100 mature trees were present. Site 1 is located within the
86 forested portion of the Bartlett Arboretum, Fairfield County, Connecticut (41.07'N 73.33'W)
87 and consists of 31 hectares of forested lands within a public arboretum managed by a
88 private not for profit corporation. Site 2 is located at Forest Park, Queens County, New York
89 (40.42'N 73.51'W) and is 220 hectares of predominantly forested lands and is owned and
90 operated by the City of New York Department of Parks. Both the Bartlett Arboretum [17] and
91 Forest Park [10, 18] has vegetation which has been documented prior to this analysis. As
92 measured in importance values, Morgan [17] describes the surrounding forest of the Bartlett
93 Arboretum in its entirety to be dominated by *Fagus grandifolia* Ehrh., *Acer rubrum* L. and
94 *Betula lenta* L. Greller et al [10], describes the forest of Forest Park in its entirety as
95 dominated by *Quercus rubra* L., *Q. velutina* Lam., and *Q. alba* L. At both sites, plant
96 communities are patchy with the areas adjacent to the *P. amurense* invasions being
97 dominated by *B. lenta* on this smaller scale relative to the entire forest.

99 To assess the understory vegetation at each site, a transect was drawn through the *P.*
100 *amurense* invaded sections of the forest. This transect totaled over 120m encompassing the
101 entire site of the invasion. The understory consisted of and is defined as all herbaceous and
102 woody species not reaching 1.3m in height, a method and definition previously used at this
103 site by Greller *et al.*[10]. Along this transect individuals of *P. amurense* within 5 m on either
104 side of the transect, measuring at least 5 cm diameter at breast height (DBH) were selected,
105 and four plots measuring 1m^2 were placed directly North, South, East and West of the tree
106 with the center of the sample plot being 1.5m from the trunk edge. *P. amurense* trees were
107 chosen by their proximity to the transect, and those which resulted in overlapping plots were
108 eliminated. This resulted in 72 plots being analyzed at the Bartlett Arboretum and at Forest
109 Park 96 plots were analyzed for a total of 168 plots under *P. amurense* canopy. To select
110 plots in non invaded areas for comparison, a similar transect was drawn in an area
111 immediately adjacent to each invaded site. At both locations, the non invaded sections were
112 intermittent with the invaded sections of each site. No visible difference in elevation or soil
113 moisture levels were apparent through visual observation. Along this line a similar procedure
114 was used, however *Betula lenta* was substituted for *P. amurense*. At both sites, *B. lenta* had
115 been documented as a major component of the forest in importance value. At the Bartlett
116 Arboretum, 84 plots under *B. lenta* were analyzed and 52 at Forest Park for a total of 136
117 plots under native canopy. This resulted in a total of 304 plots of one square meter being
118 measured at both sites and under all conditions. To analyze this data, all four plots taken
119 under each individual tree of both *B. lenta* and *P. amurense* were then averaged to yield one
120 value for each sample site.

122 Within each plot all vascular plants were identified to species and the number of individuals
123 recorded. No *P. amurense* or *B. lenta* were found within the understory sampling plots, a
124 convenience which eliminated any potential impact of spatial autocorrelation. To ensure
125 adequate sampling, plots were created in late May 2009 when the original surveys were
126 conducted and were repeatedly examined at least once per month over the summer season
127 to account for newly emerged plants. Plot borders were marked with nylon flags to ensure
128 the exact sites were measured each survey. For several prostrate species where individual
129 species counts were difficult, the 1m^2 plot was further divided into one hundred 10 cm by 10

130 cm subplots and an individual was tallied for each of these subplots the plant occurred
131 within.
132
133 To analyze the canopy a CI-110 digital plant canopy imager, (CID Inc. Camas, WA) was
134 used. Data was collected in July 2009 through the creation of hemispherical canopy
135 photographs which were analyzed for calculations of leaf area index. To obtain this data, the
136 imager was used by collecting images along the same transects as used for the creation of
137 plots. To ensure canopies were not duplicated in the analysis; images were taken at least 20
138 m apart in both *P. amurense* invaded and non invaded areas. This resulted in twelve
139 photographs of the native Canopy at the Bartlett Arboretum and eight of the *P. amurense*
140 canopy. Due to the large areas captured by each photograph, the possibility of
141 photographing each sample tree was not possible since it would have led to extensive
142 duplication in the canopy areas sampled. After the original LAI analysis was performed, a
143 second set of data was taken at the Bartlett Arboretum six weeks later to look for changes in
144 significance of the results over a season. At Forest Park, fourteen photographs were taken
145 under native canopy and twelve under *P. amurense*.
146
147 To determine if results were significant, an unpaired 1- tailed t-test was performed for all
148 analyses using JMP 8.0.1 [19].
149
150
151 **3. RESULTS**
152
153 Understory Individual Density. At both the Bartlett Arboretum and Forest Park sites,
154 understory individual density differed significantly with the understory of native *B. lenta*
155 having more individuals than the *P. amurense* understory violating the null hypothesis of
156 equal values and supporting our hypothesis that there is a lower density of individuals at
157 invaded sites. In all cases sites were compared individually based upon native versus *P.*
158 *amurense* canopy through the use of a t-test. At the Bartlett Arboretum mean understory
159 individuals per m^2 measured 19.29 (95% Confidence Interval (95%CI) = 15.2 - 23.0) under
160 the native canopy and 8.95 (95%CI = 6.2-11.8) under *P. amurense* (t < .0032, df = 37).
161 Forest Park, mean understory individuals measured 6.92 (95%CI = 5.3-7.9) under the native
162 canopy and 3.23 (95%CI = 2.3-3.7) under *P. amurense* (t < .0088, df = 35). These results
163 are demonstrated in Figure 1.
164
165 Figure 1.
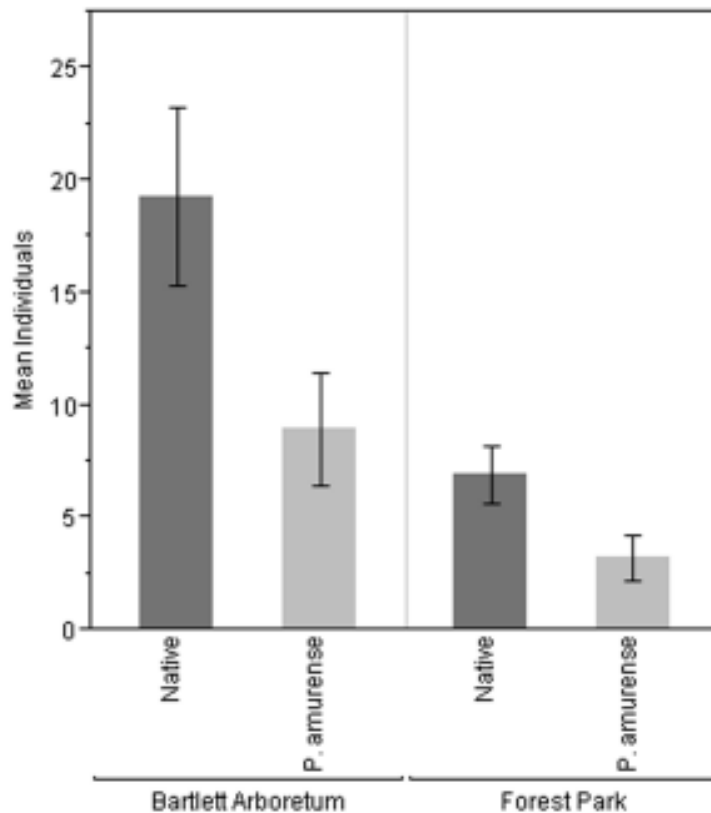
166

167

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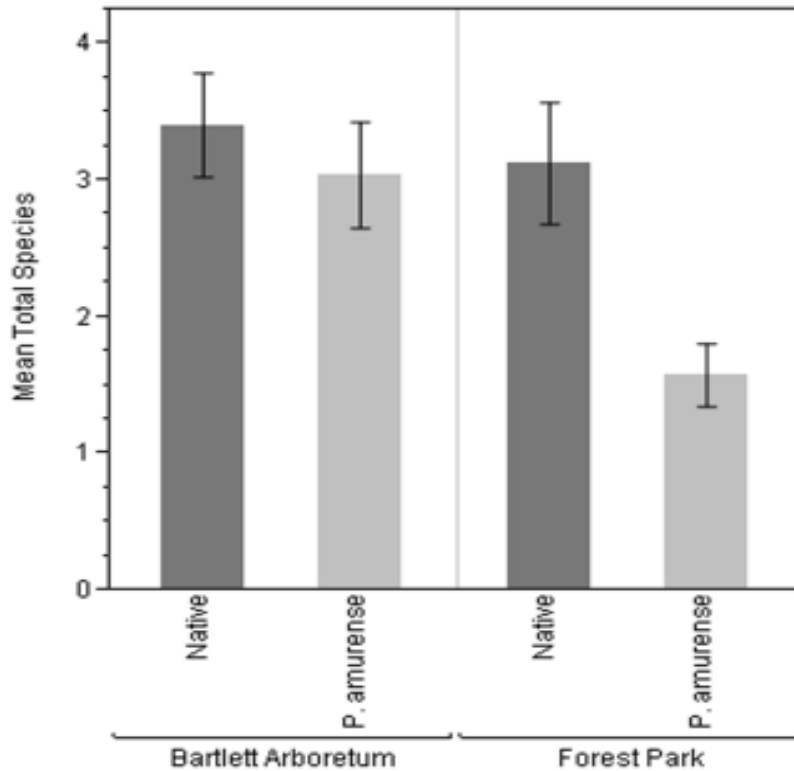169　site. Error Bars represent 95% confidence intervals.

170

171

172　Total Species Richness. At the Bartlett Arboretum site, species richness per quadrat was
173　higher under the native canopy (3.39 species, 95%CI = 3.0 – 3.8)) than under *P. amurense*
174　canopy (3.03 species, 95%CI = 2.6-3.4), however these results were not statistically
175　significant. (t < .0059, df = 37. At the Forest Park site a significant difference existed with
176　mean species richness under native canopy trees measuring 3.11 species (95%CI = 2.7 –
177　3.6) and mean species richness under *P. amurense* measuring 1.56 species (95%CI = 1.3-
178　1.7) (t < .0001, df = 35). Both sites were analyzed by the use of a t-test. These results are
179　demonstrated in Figure 2 and at the Bartlett Arboretum site our null hypothesis is not
180　rejected, while at the Forest Park site the null hypothesis of equal values is violated and our
181　hypothesis that there is lower species richness under *P. amurense* invaded sites is
182　supported in only one location. In total, 43 species were identified under *P. amurense* at the
183　Bartlett Arboretum and 44 under native canopies. At forest Park a total of 27 species were
184　identified under *P. amurense* and 32 under native species. These species are listed as
185　Appendix 1.

186

187　Figure 2.

188

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

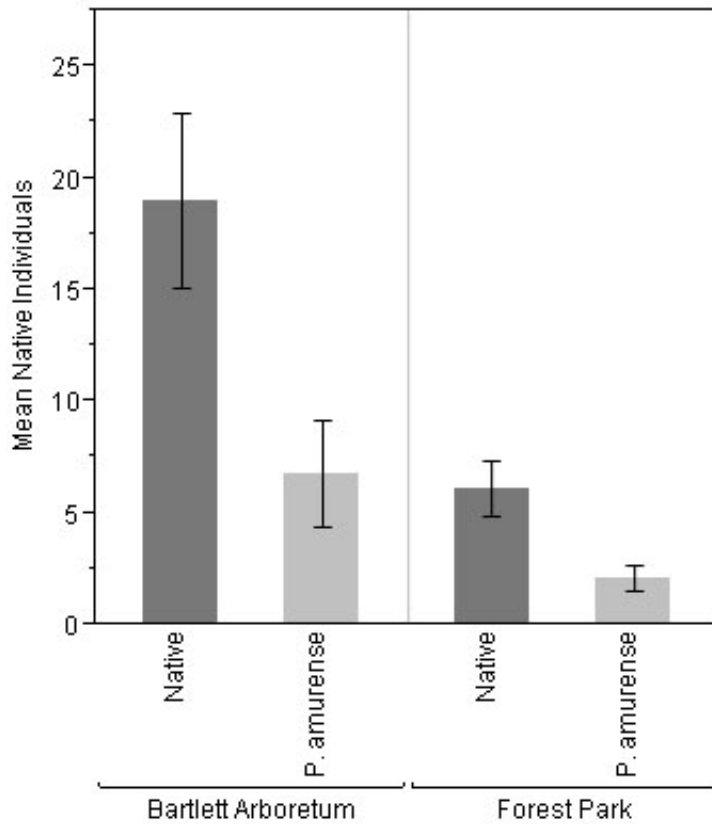Total Native Individuals. At both sites, a significant difference existed within each site
between the number of native individuals per quadrat under native canopy versus *P.
amurense* canopy with more native individuals being present under native canopy. At the
Bartlett Arboretum, mean native individuals measured 19.00 (95%CI = 15.0 - 22.6) under the
native canopy while measuring 6.75 (95%CI = 4.0 – 8.7) individuals under *P. amurense* (t <
.0009, df = 37). Forest Park mean native individuals measured 6.11 (95%CI = 4.8 - 7.4)
under native canopy and 2.08 (95%CI = 1.2 – 2.5) under *P. amurense* canopy (t < .0001, df
= 146). These results are demonstrated in Figure 3 and data from both sites violates the null
hypothesis of equal values and supports our hypothesis that total native individuals is lower
in invaded areas.

Figure 3.

25 —

20 —

15 —

10 —

5 —

0 —

Mean Native Individuals

Native | P. amurense | Native | P. amurense

Bartlett Arboretum | Forest Park

205

206   Mean number of total native individuals per quadrat under each canopy type at each site.
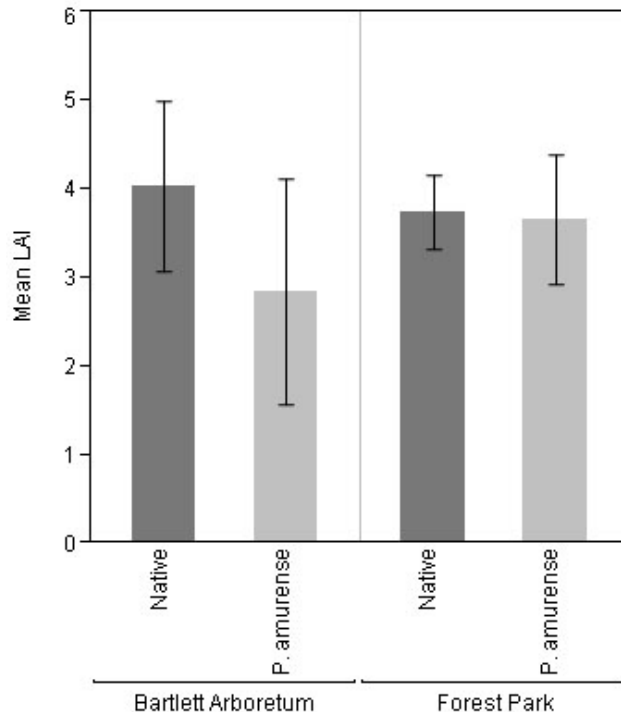207   Error bars represent 95% confidence intervals.

208

209

210   Canopy Analysis. Comparisons of the canopy of *P. amurense* invaded versus non invaded
211   areas showed no significant difference in leaf area index for the Bartlett Arboretum site or
212   Forest Park. Leaf Area Index (LAI) at the Bartlett Arboretum measured 2.84 (95%CI = 1.5 –
213   4.1) under *P. amurense* canopy and 4.02 (95%CI = 3.1 - 5.0) under native canopy t =
214   .1071, df = 18) at the time of the first measurements. At Forest Park, LAI measured 3.64
215   (95%CI = 2.9 – 4.3) under *P. amurense* canopy and 3.73 (95%CI = 3.2 – 4.2)under native
216   canopy (t < .8287, df = 24). These results are demonstrated in Figure 4. The second set of
217   measurements resulted in a LAI of 2.43 under *P. amurense* canopy of and 2.348 under
218   native canopy (t < .5830, df =18). These later results reaffirm the non significant differences
219   in the early canopy photographs and are not included in Figure 4.

220

221   Figure 4.

222
223 Mean leaf area index under each canopy type at each site. Error Bars represent 95%
224 confidence intervals.
225
226
227 <mark>Our results support the hypothesis that *P. amurense* understory composition will have lower</mark>
228 <mark>overall individual abundances</mark>, lower species richness and contain a lower percentage of
229 native species than adjacent areas of the same forest not containing *P. amurense*. However,
230 these results do not provide insight into the mechanism by which this process occurs.
231 Specifically, we find no significant differences in the level of leaf area index between native
232 canopy and that of *P. amurense*.
233
234 ## 4. DISCUSSION
235
236 Invasive plant species are well documented to have negative effects upon the native plants
237 of the area into which they invade [13, 20, 21] as well as impacts upon the entire community
238 [1,22]. Many invasive species go unnoticed as members of the communities until they have
239 reached levels which are no longer easily controlled.
240
241 The spread of *Phellodendron amurense* into the forests of the northeastern United States
242 has the potential to affect both the richness and abundance of the surrounding flora. With
243 the differences reported here upon the number of native individuals between canopy types,
244 this invasion is likely to impact native populations of plants more than other individuals which
245 are naturalized from outside the region. In spite of the differences in canopy species, the
246 understory flora under either invaded or non invaded plots is quite similar in composition,
247 differing primarily in the number of individuals and richness per plot. This can be seen by
248 calculating the Sørensens similarity index for each site using the species listed in Appendix
249 1, which yields a Sørensens index of .85 at the Bartlett Arboretum and .64 at Forest Park
250 when comparing the invaded to native understory floristic composition. 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.

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.

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 [23], 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 earlier leaf emergence, and consequentially earlier shading by *P. amurense* as a factor in the understory differences that are reported here.

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.

5. CONCLUSION

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 all need to be further examined in this potentially high impact invader. Recent work to address the question of allelopathy has been performed in a laboratory setting [24], but whether this may play in an ecological context remains to be seen.

The demographic processes of successful invading organisms may result in the alteration of the character or community of a landscape [25]. This work begins to address some of the many questions that currently prevent a full understanding of the importance, significance and potential severity of further invasion by *P. amurense* into the forests of the region.

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382
383
384 Appendix 1.
385
386 Total species list for all plots sampled. Forest Park Native Canopy (FPN); Forest Park *Phellodendron* Canopy (FPPA);
387 Bartlett Arboretum Native Canopy (BAN); Bartlett Arboretum *Phellodendron* Canopy (BAPA)
388

	FPN	FPPA	BAN	BAPA
Ailanthus altissima	x			
Acer platanoides	x	x		x
A. rubrum			x	x
A. saccharum			x	x
Alliaria petiolata	x	x	x	x
Amelanchier canadensis			x	x
Aralia nudicaulis			x	
Arisaema triphyllum	x	x	x	x
Betula alleghaniensis			x	
B. lenta		x	x	
Carpinus caroliniana			x	x
Carya ovata			x	x
C. cordiformis	x	x		
Celastrus orbiculatus	x	x	x	x
Chimaphila maculata			x	

#	Species				
405	*Clethra alnifolia*			x	
406	*Commelina communis*		x		
407	*Circaea lutetiana*		x		
408	*Cornus florida*	x			x
409	*Carex pensylvanica*	x		x	x
410	*C. laxiflora*				x
411	*Deparia acrostichoides*	x	x	x	
412	*Euonymus alata*			x	x
413	*Eurybia divaricata*	x	x	x	x
414	*Fagus grandifolia*			x	x
415	*Fraxinus pensylvanica*		x	x	x
416	*Gaylusaccia brachycera*			x	x
417	*Hamamelis virginiana*			x	x
418	*Ilex verticillata*			x	x
419	*Impatiens capensis*		x		
420	*Lindera benzoin*		x	x	x
421	*Liriodendron tulipifera*	x			
422	*Lonicera japonica*		x	x	x
423	*L. sempervirens*	x			
424	*Maianthemum canadense*	x		x	x
425	*M. racemosum*	x	x		x
426	*Mitchella repens*			x	x
427	*Nyssa sylvatica*			x	x
428	*Parthenocissus quinquefolia*	x	x	x	x
429	*Persicaria virginiana*	x	x		
430	*Phytolacca americana*	x			
431	*Polygonatum biflorum*		x	x	x
432	*Polystichum acrostichoides*			x	x
433	*Prunus serotina*	x		x	x
434	*Pyrola elliptica*	x			x
435	*Quercus alba*	x	x	x	x
436	*Q. rubra*	x	x		
437	*Rhododendron periclymenoides*			x	
438	*Rosa multiflora*	x	x		x
439	*Rubus hispidus*	x	x	x	x
440	*R. phoenicolasius*			x	x
441	*Sassafras albidum*	x	x		
442	*Solidago caesia*			x	x
443	*S. canadense*	x			
444	*S. juncea*	x			
445	*Smilax rotundifolia*	x		x	x
446	*Thelypteris noveboracensis*			x	x
447	*Toxicodendron radicans*	x	x	x	x
448	*Uvularia sessilifolia*			x	x
449	*Vaccinium angustifolium*			x	x
450	*Viburnum acerifolium*	x	x	x	x
451	*V. dilatatum*	x	x	x	x
452	*V. dentatum*	x	x		
453	*V. sieboldii*			x	x
454	*V. setigerum*	x			
455					
456					
457					