Distribution and Abundance of Japanese Barberry (*Berberis thunbergii*) in Rondeau Provincial Park

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SUMMARY

Japanese barberry is an example of an invasive shrub that was introduced as a landscaping plant on leased cottage lots in Rondeau Provincial Park that has since become naturalized and widespread. This species was selected to use as a case study for investigating the spread and impacts of an escaped horticultural plant in Rondeau by: 1) mapping its distribution and relative abundance; 2) investigating ecological and human influences on its current distribution, and; 3) assessing the feasibility of management actions.

Mapping of Japanese barberry in 2011 and 2012 confirms that the species is widespread and abundant in Rondeau. Currently, it is present at low abundance throughout much of the park but is dominant and forms dense thickets in about 7% of areas that were surveyed. Highest concentrations are found primarily near the eastern shoreline, where many of the cottage leaseholds are located.

The date of the initial introduction and invasion of Japanese barberry in the park is unknown, but based on past records and anecdotal accounts, it appears to have increased and expanded over a fifteen to twenty year period, dating from its first recorded observation in 1958. By the 1970s, it was well-established in natural areas and was recognized as a species of concern. Although Japanese barberry was eradicated from cottage lots and along some roads and trails in the 1990s, the species continued to increase and spread throughout park ecosystems to its current extent.

Japanese barberry was found predominantly in dry to moderately moist forested and woodland communities and was absent, or present only at low abundance, in lowlands and wetlands. The presence of fruit was associated with higher numbers of Japanese barberry, compared to areas where there was no fruiting observed. Dense stands and fruiting may indicate older, well established areas. Distribution and fruiting appear to be influenced by tree density, as suggested by a negative relationship between the abundance of Japanese barberry, and the presence of fruit, with the basal area of trees.

Statistical analysis did not reveal any strong relationships between anthropogenic features and the current pattern of distribution and abundance of Japanese barberry in the park. The most significant associations were with distances to cottage lots, roads, and roadside observations of Japanese barberry in cottage lots. Because of the

proximity of roads to the cottage lots, it is impossible to identify from these data and analyses which of these is the more important as a source or vector for this invasive.

Deer management and blowdown events may have facilitated the spread of Japanese barberry in the park. Japanese barberry was observed to increase and expand following the resumption of deer herd reductions in the 1990s, while native species that had been preferentially grazed when deer were abundant did not recover. Japanese barberry may also have benefitted from several severe wind storms, which could have had the effect of increasing light levels for growth and reproduction, as well as enhancing edge habitats for bird and small mammal seed dispersers.

Eradication of Japanese barberry from Rondeau seems unlikely, given its broad distribution in the park, but it may be possible to manage populations to reduce its impacts.

INTRODUCTION

Invasive species are a significant threat to the rare and imperilled ecosystems and the habitats of species at risk in Rondeau Provincial Park (OMNR 2001, OMNR 2013). Many alien species have been accidentally or intentionally introduced into Rondeau. Approximately 25% of the plant species in the park are not native to Ontario (Dobbyn and Pasma 2012) and over 30 of these are considered to be invasive (OMNR 2001). Invasive species are defined as “alien species whose introduction or spread threatens the environment, the economy, and/or society including human health” (OMNR 2012). Invasive plants can have many negative effects on ecosystems by: reducing the number of native plants through competition, altering habitats, hybridizing with native species and disrupting plant-animal associations (Terrestrial Plants and Plant Pests Working Group on Invasive Alien Species 2004, Canadian Food Inspection Agency 2011). Once established, invasive plants can spread by natural dispersal of seed and vegetative propagation, or they can be transported to new areas through human activities.

Several invasive species in Rondeau have been introduced on cottage lots and in development zones through their use in gardens and for landscaping (OMNR 2001). Horticultural plants on cottage lots are historical and current sources of invasive species that have spread into natural areas of the park (OMNR 2013). Other ways that invasive species may have been introduced and spread throughout the park include through the activities of park visitors and park operations, or dispersal by natural agents such as wind and birds.

Japanese barberry is an example of an invasive shrub that was introduced into Rondeau as a landscaping plant in cottage gardens (OMNR 2001, Dobbyn and Pasma 2012). Since its introduction, it has become naturalized and widespread in the park (OMNR 2001). We selected Japanese barberry to use as a case study for investigating the spread and impacts of an escaped horticultural species in the park due to its historical use as a landscaping plant, its current prominence in natural areas of the park, and its ranking as one of the park's most problematic invaders (Savanta 2009, Dobbyn and Pasma 2012).

In this study, we investigate the influence of human activities and environmental factors on the introduction and spread of Japanese barberry in the park. Specific objectives are to:

1. Map the distribution and relative abundance of Japanese barberry in Rondeau Provincial Park;
2. Determine factors which have influenced its current distribution in the park by investigating relationships with environmental and anthropogenic factors, and;
3. Assess the feasibility of management actions to reduce the impact of Japanese barberry to the park environment.

The results of the study are intended to provide additional information for a) evaluating a proposal by the Ontario government to extend the cottage leases beyond their current expiry date of December 31, 2017, (http://www.ebr.gov.on.ca/ERS-WEB-External/, EBR Registry Number: 011-1300) and; b) developing conditions for leases, in the event that they are extended. The study will also provide baseline data to inform management of Japanese barberry in the park.

BACKGROUND

Rondeau Provincial Park

Regional Setting

Rondeau Provincial Park is a Natural Environment class park administered by the Ministry of Natural Resources under the Provincial Parks and Conservation Reserves

Act, 2006 (PPCRA). Located in in southwestern Ontario, along the north shore of Lake Erie, Rondeau is the largest provincial protected area in Ecodistrict 7E-1 (Chatham) (OMNR 2010) (Figure 1). Comprised of 3,254 ha, the park includes the vast majority of the Rondeau peninsula, a significant portion of Rondeau Bay, and a portion of Lake Erie (Dobbyn and Pasma 2012). Over half of the park consists of the open waters of Rondeau Bay or Lake Erie, with the remainder split between wetland and terrestrial areas, including dune, grassland, and forest communities (Dobbyn and Pasma 2012).

The park is one of few remaining natural areas in this intensively developed region of the province and is a core biodiversity conservation area (Henson *et al*. 2005). Surrounding land uses are predominantly agriculture, interspersed with rural, urban and cottage development. The region is estimated to have less than 8% natural cover, nearly half of which is wetland, and it has one of the lowest proportions of protected areas in the province (< 1%) (Henson *et al*. 2005, OMNR 2010).

Rondeau provides opportunities for day use activities and camping to over 160,000 visitors annually. The 263-site campground at the north end of the park hosts approximately 70,000 camper nights each year. There are over 28 km of trails for hiking, biking and nature appreciation and seven kilometres of beach that are accessible by the public for swimming and other water-based pastimes. In addition, the park has a cottage community of 286 private leaseholds (as of 2013). These are located predominantly along several kilometres of beach on the eastern shore and in a cottage subdivision at the north end of the park (OMNR 1991, Dobbyn and Pasma 2012) (Figure 4).

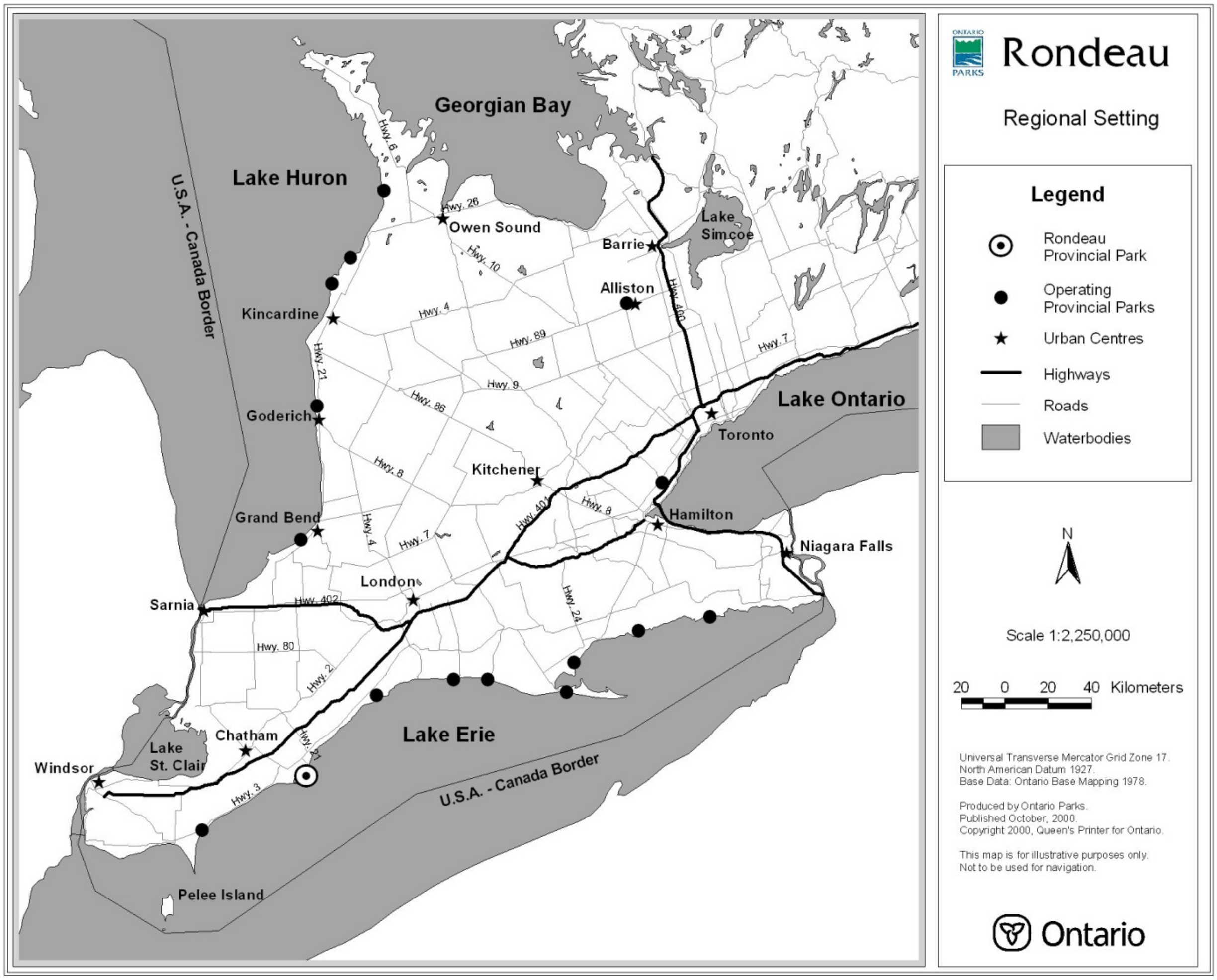

Figure 1. Location of Rondeau Provincial Park - Southern Ontario context (Dobbyn and Pasma 2012).

Historical Summary

Rondeau was first established in 1894, making it Ontario's second oldest provincial park. From the time of its establishment, 21-year renewable leases were made available for lots in the park for private cottage use. Only one cottage was present in Rondeau at that time. By the early 1920s, 140 cottages had been erected in the park, and by 1954, there were 461 cottages (Mann 1978). In 1954, the Provincial Parks Act dedicated provincial parks to the people of Ontario and established a policy to phase out cottages from Rondeau and Algonquin, the only two provincial parks that allow leasing of cottage lots for private use. Between 1954 and 1977, 148 cottage leases in Rondeau lapsed or were acquired by the Crown. Over the next 36 years, the number of cottages was further reduced by fifteen. Currently, there are 286 cottage lots in the park.

Besides cottage development, Rondeau has a history of numerous land uses, before and after becoming a provincial park, that have affected its vegetation communities. Selective logging of target species occurred on an ad hoc basis on the peninsula from the 1790s to 1894 (Mann 1978). Pasturing of cattle was a common practice at the north end of the park from about 1809 to 1915 (Mann 1978). After the park was established there was extensive clearing of trees and underbrush for park developments and to create a more manicured and aesthetically pleasing environment for visitors (Mann 1978). Campgrounds in the park were expanded in the 1950s and 1960s in response to the increasing popularity of camping (Mann 1978). Picnic grounds, campgrounds and cottage lots have all been altered through planting of exotic species of trees, shrubs, grasses and flowers, including some invasive species that have spread to other areas of the park (Mann 1978, Dobbyn and Pasma 2012). Hyper-abundant deer populations, significant windthrow events and a policy of fire suppression are additional factors that have influenced vegetation communities in the park (Dobbyn and Pasma 2012).

Ecological Significance

Rondeau Provincial Park is provincially and nationally significant due to the presence of a high concentration of species at risk, rare and imperilled vegetation communities, and unique landforms found nowhere else in Canada. The park is within the Carolinian zone in southern Ontario, where among the highest frequencies of rare and endangered flora and fauna in Canada occurs. Within this zone, Rondeau supports one of the highest numbers of rare species and species at risk in a protected area in Ontario (Dobbyn and Pasma 2012). A total of 131 provincially significant species (ranked S1 to S3) have been recorded in the park, of which 78 are listed on the Species at Risk in Ontario list (Dobbyn and Pasma 2012). There are 19 provincially significant vegetation communities (ranked as S1 to S3) present, a significant proportion of which are dune, prairie, and savannah communities that are globally rare (Dobbyn and Pasma 2012, OMNR 2001). In addition, Rondeau’s cuspate sandspit is a landform feature that is not represented in a protected area anywhere else in Canada (OMNR 1991). Rondeau also forms part of the largest wetland complex on the Canadian shoreline of Lake Erie and is part of a globally significant Important Bird Area (Dobbyn and Pasma 2012).

Japanese Barberry

Description of Japanese Barberry

Japanese barberry is a popular ornamental deciduous shrub that is commonly used both as a specimen plant and as a hedge. It is valued as a horticultural plant for its branching multi-stem form, leaves that turn dark red or purple in the fall and tolerance for a wide range of growing conditions. It grows from 2 to 3 m high, but reaches a maximum height of 6 to 8 m (Harmon 2006) under ideal conditions.

The early leaf out, high seed production and thicket-forming growth habit of Japanese barberry are characteristics that make it a successful invader of natural areas. It is one of the earliest shrubs to develop leaves in the spring and one of the latest to lose them in the fall. Flowers bloom in mid-April to May, producing red berries from July to October that persist into the winter ((Harmon 2006, Silander and Klepeis 1999). While most seeds fall within one metre of the parent plant, new thickets can form from long-distance dispersal of seeds that are eaten by birds and mammals. The plant also spreads by growth of new stems from root stolons, and rooting of branches that come into contact with the ground. Japanese barberry has a wide range of tolerance for soil, moisture, and light conditions, but prefers well-drained mesic soils in full sun to partial shade. It is less successful on extremely wet or dry sites and in deep shade. In its native Japan, it is an understorey forest shrub in mountainous regions and a source of food for birds and small mammals (Harmon 2006). In North America, where it has escaped cultivation, it is an invader of forests, abandoned fields, roadsides and wetlands.

In invaded forests, Japanese barberry can become the dominant shrub species, outcompeting native woody vegetation and suppressing native forbs (Ehrenfeld 1999, Zouhar 2008). This effect is exacerbated in areas of high deer density because deer will avoid grazing on Japanese barberry while over-grazing on more palatable native browse species (D'Appollonio 2006). Invasion by Japanese barberry results in changes to soil structure, chemistry and biota that are unfavourable for many native plants, including species at risk (Cassidy *et al*. 2004, Allen *et al*. 2006, Zouhar 2008, Elgersma and Ehrenfeld 2011). For example, at Rondeau, Japanese barberry has been identified as a threat to the Nodding Pogonia (*Triphora tranthophora*), due to potential disruption of the mycorrhizal associations that are necessary for the survival of this endangered orchid (Jones *et al*. 2013). Conversely, these altered conditions may facilitate invasion by other invasive species, such as garlic mustard (D'Appollonio 2006). Japanese barberry has also been linked with an increased risk of Lyme disease, caused by the *Borrelia burgdorferi* bacteria (Elias *et al*. 2006, Williams *et al*. 2009). The dense thickets provide moister, cooler microhabitats for juvenile stages of blacklegged ticks (*Ixodes scapularis* Say) that transmit the disease (Elias *et al*. 2006, Williams *et al*. 2009). Both the abundance of ticks and the proportion carrying the Lyme bacteria have been observed to be higher within Japanese barberry thickets than in adjacent areas (Elias *et al*. 2006, Williams *et al*. 2009).

Japanese barberry has become fully naturalized throughout most of the northeastern United States since its introduction in the U.S. in 1885 (Silander and Klepeis 1999). Its current distribution extends south to Georgia and Tennessee and west to Nebraska, Kansas, Wyoming, North Dakota, South Dakota, and five of the eastern provinces: Ontario, Quebec, New Brunswick, Nova Scotia, and Prince Edward Island (United States Department of Agriculture n.d.) (Figure 2). Within Ontario, its observed distribution in natural environments appears discontinuous and limited to southern Ontario (OMOE 2013, EDDMapS 2013) (Figure 3).

Refer to Appendix 1 for a more complete review of the characteristics and invasion ecology of Japanese barberry.

Presence of Japanese Barberry in Rondeau Provincial Park

There are few documented records of Japanese barberry in Rondeau prior to the 1990s; however, its spread in the park has been a concern since the 1970s. Although it was used as a landscaping shrub on cottage lots up until 1995, the period of its original introduction is unknown (OMNR 2001). The first documentation of Japanese barberry in the park is a 1958 herbarium specimen. It began appearing on plant checklists for the park in the 1970s (OMNR 1976 and 1979); however, anecdotally, it was already well established in natural areas by this time and was recognized as a species of concern (A. Woodliffe, pers. comm.). From the 1970s to the present, concerns about the impacts of Japanese barberry on park ecosystems intensified as populations continued to increase and spread. In the 1990s, a rapid expansion was noted in areas adjacent to cottage lots along the eastern shore of the peninsula following deer herd reduction (Bazely *et al*. 2001). In these areas, Japanese barberry increased from 10% of understorey shrubs in 1994 to 26% in 2001. By 2001, Japanese barberry was identified as one of thirty invasive plant species threatening the park’s ecosystems and requiring control (OMNR 2001).

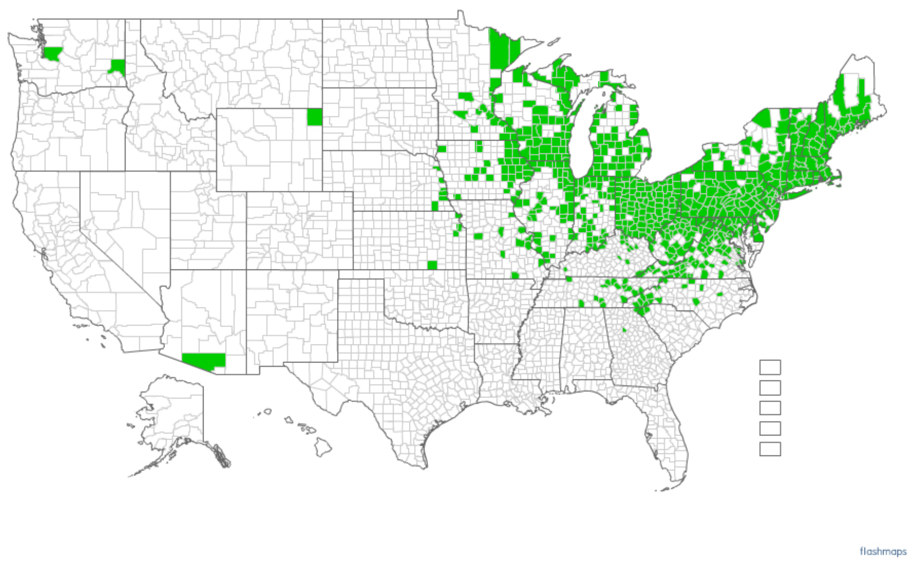

Figure 2. Distribution of Japanese barberry in the United States (EDDMapS 2013).

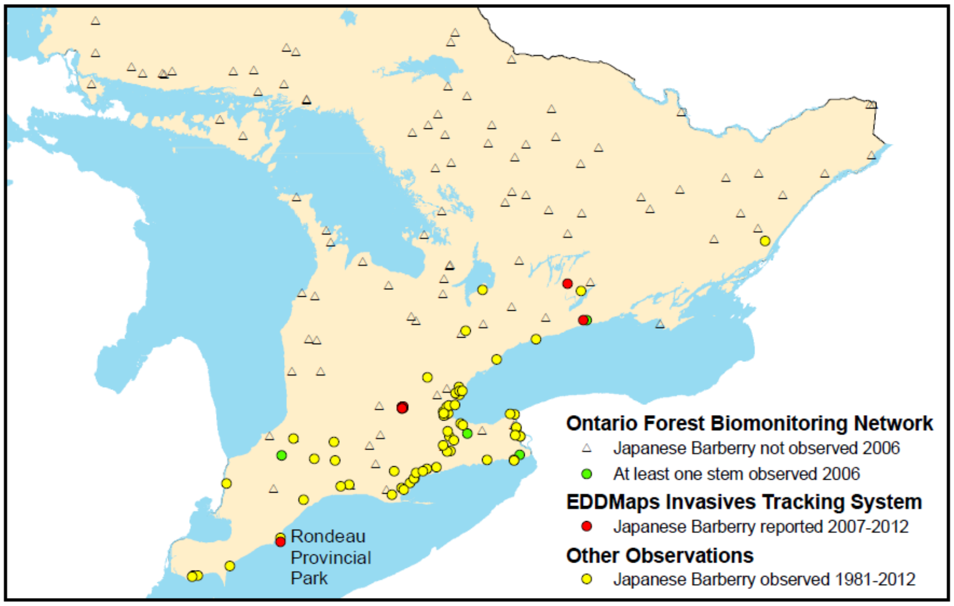

Figure 3. Observations of Japanese barberry in Ontario (dots may represent multiple records). (OMOE 2013, EDDMapS 2013, OMNR unpubl. data).

During a 2003 vegetation survey, it was observed that Japanese barberry had spread to most areas of the park and was abundant and dominant in several communities (Dobbyn and Pasma 2013). In a survey of invasive plants in 2008, Japanese barberry was ranked as one of the top 20 invasive species in the park (Savanta 2009).

Japanese barberry was eradicated from cottage lots in 1995; however, there have been limited control efforts in natural areas. The efficacy of different control techniques was tested on a limited basis in 1994, with greatest success using a combination of cutting and herbicide application (Bazely *et al*. 2001). Spraying was conducted in 2010 in areas where Japanese barberry had encroached into the habitat of Nodding Pogonia (Dobbyn and Pasma 2012). Since then, additional areas have been treated but no systematic control program has been established.

DISTRIBUTION AND ABUNDANCE SURVEYS

Context for the Study

To investigate factors influencing the distribution and abundance of Japanese barberry in the park, we collected data on Japanese barberry presence and abundance and examined the relationship between these data and observed characteristics of the vegetation at the sites (e.g., canopy closure, dominant shrub species, vegetation community type). We hypothesized that greater tree abundance or canopy closure would reduce the abundance of Japanese barberry and therefore, slow the spread of the species in such areas.

To examine the effect of human features and activities, we hypothesized that if there were an effect of these features on Japanese barberry, then we would observe greater abundance of this shrub at plots closer to these features than we would at greater distances. This is based on the assumption that some of these features might have, at one time, been sources of Japanese barberry from which it would have diffused outward, with higher abundance levels closer to the source features, where it had been longer established. To explore the potential effect of prescribed burns on Japanese barberry, we compared its abundance and dominance within burned areas to areas outside but near the burned areas.

We also had available geo-referenced observations of Japanese barberry from an Ecological Land Classification (ELC) survey (Lee *et al*. 1998) conducted in 2003 (Dobbyn and Pasma, 2012), and from a survey of invasive plants undertaken in 2008 by Savanta, Inc., a private consulting firm, and we examined these data in a descriptive, qualitative manner.

Methodology

Study area

The sample area is bounded by Rondeau Avenue at the north end of the park, the Lake Erie shoreline to the south, and from Lakeshore Road in the east to approximately the second dune ridge west of Rondeau Park Road (see Figure 4). The west side of the park was excluded from the study area because of the predominance of wetlands, where Japanese barberry was less likely to be found, and to optimize survey effort in suitable habitat.

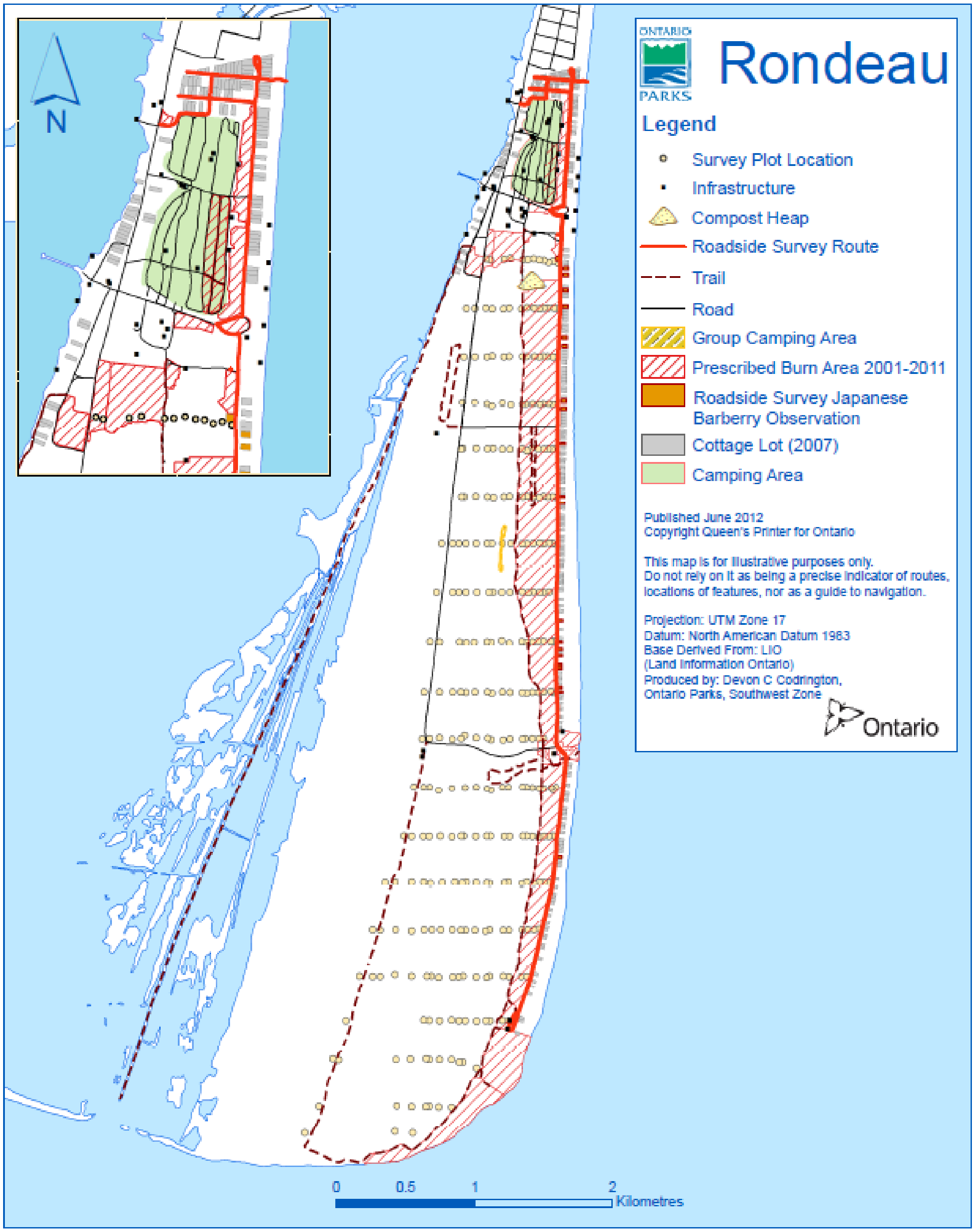

Figure 4. Plot locations, roadside survey route and locations of anthropogenic features used for distance analysis.

Data collection

Japanese barberry data for this study were collected and assembled from a variety of sources.

1. The primary data set of Japanese barberry locations, abundance, and environmental conditions was collected by plot-based field work in the autumn of 2011;
2. Current presence of Japanese barberry on cottage lots was assessed by a roadside survey in April 2012;
3. Japanese barberry occurrences observed during the 2003 ELC survey (Dobbyn and Pasma 2012) were compared with contemporary distributions based on the plot-based dataset;
4. Observations of Japanese barberry made by Savanta, Inc. in 2008 (Savanta, Inc., 2009), also were compared with contemporary distributions.

From mid-September to the end of October, 2011, park staff visited and collected vegetation data from 294 plots 10 m in diameter (0.00785 ha). Plots were established every 350 m on north-south transects which generally followed the tops of low ridges, avoiding the sloughs where conditions are less likely to be suitable for Japanese barberry. Every second ridge was sampled (mean between-transect-distance of 46 m). The coordinates of the location of each plot centre were collected by handheld GPS. Data were collected for: tree (>5m height) canopy closure; number of trees (>10.0 cm diameter-at-breast-height (dbh)) in each of four dbh size classes; basal area; percent cover of the shrub layer (>0.5 m – 2.0 m); and, a list of up to three dominant shrub species. Three related types of Japanese barberry observations were collected: dominance in the shrub layer relative to other woody species, number of stems, and whether barberry fruit were observed. At each site, a photograph was taken from the plot centre facing north.

A roadside survey of Japanese barberry in cottage lots was conducted in the spring of 2012 to provide supplementary information on the distribution of the plant in the park and to assess the effect of eradication efforts that took place on cottage lots in the 1990s. Occupied and phased-out cottage lots east of Lakeshore Road were surveyed on April 5, 2012. Three observers started at the most southern parking lot on Lakeshore Road and drove north, surveying Bowman Avenue, Evangeline Street and Centre Street. Using binoculars from the roadside, areas of all cottage lots that were visible from the road were surveyed for presence or absence of Japanese barberry; the back yards of cottage lots were not inspected. For each species occurrence observed, the lot numbers were noted, the environment was described (i.e., maintained/planted or natural recolonization), and photo documentation was taken from the roadside.

Variables used for analysis, with abbreviations and brief descriptions, are summarized in Table 1. The distribution of Japanese barberry stem counts was positively skewed, so these data were log-transformed; we added 1 to the stem counts to enable the log transformation of stem counts of zero (stem count data ranged from 0 to 250 with a mean of 19.9). The field-recorded dominance data did not separate absence of Japanese Barberry from low dominance, so we recoded this class into two classes, producing a 7-class dominance variable. For purposes of some cross-tabulation analyses where there were insufficient data to meet the assumptions of statistical tests, we combined the top three dominance classes to create a 5-class dominance variable. Mean diameter-at-breast-height (dbh) and basal area were calculated from field counts of trees by size class using size class mid-points. Canopy and shrub layer closure were estimated visually as a percentage of plot area.

We derived additional variables from the field data through spatial analysis. Plot locations were overlaid on a map of the ELC polygons (Dobbyn and Pasma 2012) to assign ELC vegetation type and ecosite codes to each plot. We calculated distances between each plot and a number of types of anthropogenic features that were considered to have a potential effect on the presence and spread of Japanese barberry. The features used were roads, trails, park infrastructure (comfort stations, vault toilets, parking lots, picnic areas, trailer sanitation areas, park office, visitor centre, playground, yacht club, and maintenance yard), main and group campground areas, cottage lots, cottage lots where barberry was observed by roadside survey, areas of prescribed burns, and a central composting location to which park residents were encouraged to bring their yard waste during the early 1990s (E. Slavik, pers. comm.). These anthropogenic features are identified in Figure 4.

We also acquired and mapped other data on occurrences of Japanese barberry. These included observations of Japanese barberry from the 2003 ELC field work (Dobbyn and Pasma 2012), which indicate the presence of Japanese barberry within an ELC vegetation-type polygon, for those polygons which were visited and plant species recorded. We also had access to a dataset of invasive plant observations at 875 plots of

5m radius collected by Savanta, Inc. in 2008 (Savanta, 2009). These data included an abundance assessment at each plot: not present; rare: 1-5 plants; frequent: 6-20 plants; common: 21-50 plants or forming small colonies; and abundant: >50 plants and forming large colonies (Savanta, 2009), which we mapped.

Table 1. Variable codes and descriptions (M=variable was measured in the field; D=variable was derived from field or other data).

Variable Code	Variable Description
Easting	UTM Easting Zone 17 NAD83
Northing	UTM Northing Zone 17 NAD83
Unique_ID	Transect and Plot IDs as unique identifier in form Txx-Pyy
Response Variables	
JB_Count	Count of all Japanese barberry shrubs in the plot. (M)
JB_Ln_Count	Natural log transformation of the count data (JB_Count) to reduce skew to the right - added 1 to counts (which range from 0-250, with mean of 19.9) so that zero counts can be transformed. (D)
JB_Dom	Original 6 class JB Dominance (M) 0 – No occurrences of barberry or less than 20 individuals under 30 cm tall. 1 – Few established barberry shrubs or between 20-50 individuals under 30 cm tall 2 – Many established barberry shrubs or up to 80 individuals under 30 cm tall 3 – Majority of barberry found in the plot are established and/or between 80 – 100 individuals under 30 cm tall 4 – At least half the plot covered with established barberry plants 5 – Whole plot dominated by established barberry plants
JB_Dom_0-6	Modified 7 class Dominance variable (D),: Adds one to the original JB_Dom, by separating 0 dominance class into 2 classes: Class 0= 0 stems and Class 1= < 20 stems under 30 cm 0 – No occurrences of barberry 1 – present, but fewer than 20 individuals under 30 cm tall. 2 – Few established barberry shrubs or between 20-50 individuals under 30 cm tall 3 – Many established barberry shrubs or up to 80 individuals under 30 cm tall 4 – Majority of Barberry found in the plot are established and/or between 80 – 100 individuals under 30 cm tall

Variable Code	Variable Description
	5 – At least half the plot covered with established barberry plants 6 – Whole plot dominated by established barberry plants
JB_Dom_0-4	A modified 5 class Dominance variable (D): recoded classes 5&6 as 4, since the top two classes had only 5 observations (1.7% of plots surveyed).
JB_Pres	Presence/absence of Japanese barberry (0: absent or 1:present) (D)
JB_Fruit	Presence/absence of fruiting by Japanese barberry shrubs, coded as y or n (M)
JB_Frt_Bin	Presence of fruit, recoded to 0 or 1 - #NA# for missing data where there were no Japanese barberry observed (D)
Ecological Predictor Variables	
Canopy_closure	Visual area cover estimate of the closure of the canopy layer (trees >5 m) (%) (M)
Basal_Area	Estimate of basal area based on a count of the number of trees with a diameter-at-breast-height (dbh) between 10 to 25 cm; 25 to 40 cm; 40 to 80 cm, and; >80 cm. Assumed all stems within 10 m radius plot were counted. Used mid-point of class as diameter and assumed 90 cm as diameter for > 80 cm (D)
Mean_DBH	Grouped data mean, using 17.5, 32.5, 60 and 90 cm as class mid-points (D)
Shrub_Closure	Visual area cover estimate of the canopy of the shrub layer (including Japanese barberry) (%) (M)
Shrub1	Species code for the dominant shrub in the shrub layer by area cover (M)
Shrub2	Species code for the 2nd most dominant shrub in shrub layer by area cover (M)
Shrub3	Species code for the 3rd most dominant shrub in shrub layer by area cover (M)

Variable Code	Variable Description
VegType	Southern Ontario Ecological Land Classification (Lee *et al*., 1998): vegetation type description (D)
Ecosite	Southern Ontario Ecological Land Classification (Lee *et al*., 1998): ecosite code. (D)
Anthropogenic Features	
Road_Dm	Distance in metres to nearest road in and surrounding Rondeau P.P. Road data from Ontario Road Network augmented with aerial photography. (D)
Infra_Dm	Distance in metres to nearest park infrastructure: comfort stations, vault toilets, parking lots, picnic areas, trailer sanitation areas, park office, visitor centre, playground, yacht club, and maintenance yard (D)
Trail_Dm	Distance in metres to nearest trails in Rondeau P.P. from geo-referenced field data (D)
Cottage_Dm	Distance in metres to nearest cottage lot boundary (D)
MCamp_Dm	Distance in metres to the polygon outlining the main campsite area (D)
GCamp_Dm	Distance in metres to the polygon outlining the group campsite area (D)
RdSS_Dm	Distance in metres to boundary of nearest cottage lot property where Japanese barberry was observed by roadside survey in April 2012 (D)
PB_Dm	Distance in metres to boundary of nearest Prescribed Burn polygon,; where the plot is inside polygon, distances are negative (D)

Analytical methods

The three response variables, stem count, dominance, and fruiting, are likely to be very highly correlated with each other and would be expected to produce similar analytical results. However, analysis of the presence of fruiting may indicate some of the environmental determinants or correlates of successful seed reproduction in Japanese barberry. Similarly, we expected collinearity among the other variables in the dataset, which would make clear attribution of influence on Japanese barberry distribution difficult. To identify and assess the correlation structure, we performed a principal components analysis (PCA), which demonstrates graphically and quantitatively correlations among the variables.

The natural log of Japanese barberry stem counts was chosen as the primary response variable in subsequent analyses, since it contains the most information about abundance (n=294). To examine effects on seed-based reproduction, analysis of fruiting was conducted on the subset of plots where Japanese barberry was observed (n=244).

We summarised the Japanese barberry data from the 2011 summer surveys in cross-tabulations for categorical data, and as means and standard deviations for continuous data. Data were mapped at the plot level as point symbols, and also as surfaces or contour maps as measures of relative abundance. We created the surfaces by isotropic ordinary kriging using the geostatistical package GS+ (Robertson, 2008). Roadside survey data were mapped as point symbols showing presence or absence of Japanese barberry in surveyed cottage lots. Japanese barberry presence/absence data from the ELC survey of 2003 (Dobbyn and Pasma 2012) were mapped at the ELC polygon level, and for context, as a crude measure of effort, we mapped the total number of plant species recorded in each polygon. Savanta, Inc. data (Savanta 2009) were mapped as a point symbol map showing observed abundance.

Spatial autocorrelation (e.g., plots nearer each other are more similar than plots located further from each other) is very evident in the distribution of Japanese barberry in the plot maps (Figure 5), and is to be expected both because of the short-range mechanisms of dispersal and colonization and because of the scale of variability in environmental conditions. Autocorrelation is both an object of interest, as it is the characteristic which we use to assess the relationship between anthropogenic features and Japanese barberry, and a statistical nuisance. The lack of independence of data from plots close together means that the degrees of freedom used in assessing statistical significance are inflated, with the effect that statistical significance may be overestimated (i.e., the data may indicate a significant relationship when one is not present). We used Moran's I statistic to estimate the degree of spatial autocorrelation in the data, and correlograms of Moran's I to show the range over which the autocorrelation is present. The kriging method used to construct the contour maps explicitly accounts for the structure of the spatial autocorrelation. It was also accounted for in assessing the statistical significance of correlation relationships, with degrees of freedom corrected by the procedure of Clifford, Richardson, and Hémon (1989), and computed using spatial analysis package PASSaGE (Rosenberg and Anderson, 2011).

We examined the relationship between response variables and natural ecological predictor variables graphically and descriptively by creating box and whisker plots for categorical variables showing median, quartiles and outliers of the response variables by category. We assessed the strength of relationships between abundance and other continuous variables, both ecological and anthropogenic, using Pearson's product-moment correlation coefficient, with significance corrected for the presence of spatial autocorrelation (Clifford, Richardson, and Hémon, 1989). We used the same procedure to assess relationships between continuous and binary variables, assuming equivalence of Pearson's correlation coefficient and the point bi-serial correlation coefficient. To assess the significance of the relationship of prescribed burn areas to Japanese barberry abundance, we limited the survey plots to those within the bounds of prescribed burn areas and those outside, but within 100 m of, the prescribed burn areas.

We inferred the effect of anthropogenic features on Japanese barberry by assessing the relationship between Japanese barberry abundance and distance to each feature; plots further from a potential Japanese barberry source are expected to have lower abundance, lower dominance, to have been established more recently, and to be less likely to exhibit fruiting. We calculated straight-line distances between each plot and the nearest feature of the set of candidate features which might be considered to have an effect on Japanese barberry distribution. The strength of these relationships was estimated by significance probabilities (p-values) for the correlations (r), corrected for the presence of auto-correlation. In interpreting and inferring relationships from these data, we recognize that the independent variables are not independent of each other, so in many cases, no single variable can unequivocally be identified as influencing the presence and distribution of Japanese barberry; the PCA plots are particularly helpful in identifying clusters of variables which vary together.

RESULTS

Distribution and Abundance

In Rondeau Park in 2011, Japanese barberry was present in 83% of the 294 plots surveyed; of the 244 plots where barberry was present, we observed fruiting in 32% (Table 2).

There was an average of about 20 Japanese barberry stems in plots where it was present and a maximum of 250 stems (Table 3). Plots with fruiting had an average of 48 stems compared to about 10 stems in plots with no fruiting. The distribution of Japanese barberry stem counts in plots with and without fruiting is shown in Figure 5.

Most plots with Japanese barberry fell into dominance class 1 (46%) or 2 (20%), with only a small proportion in class 5 (1%) or 6 (1%) (Figure 6). We observed fruiting at plots in all dominance classes; however, plots with fruiting exceeded those without fruiting only in dominance classes 3 to 6.

The correlation matrix and Principal Components Analysis (see Appendix 2) demonstrated clearly the high degree of collinearity in the data with 71% of the variance in the data set of 20 variables accounted for by the first four components. The first component identified variation in east-west and north-south directions to be highly correlated with distance to all human disturbance, except to trails and park infrastructure; the second represented Japanese barberry abundance/dominance; the third and fourth related to ecological variables of canopy closure (3rd) and basal area, mean tree dbh and number of trees in plots (4th).

Table 2. Presence and absence of Japanese barberry in survey plots, with and without fruiting observed.

	Present	**Absent**	**Total (% of all plots)**
No fruiting observed (% of plots with Japanese barberry)	166 (68%)	50	216 (73%)
Fruiting observed (% of plots with Japanese barberry)	78 (32%)	0	78 (27%)
Total (% of all plots)	244 (83%)	50 (17%)	294

Table 3. Stem Counts of Japanese barberry, with and without fruiting observed.

	No Fruiting	Fruiting	All Plots
Minimum	0.	2	0
Maximum	84	250	250
Median	4	30	7.5
Mean	9.65	48.13	19.86
Standard Deviation	14.66	48.67	32.71
Number of Plots	216	78	294

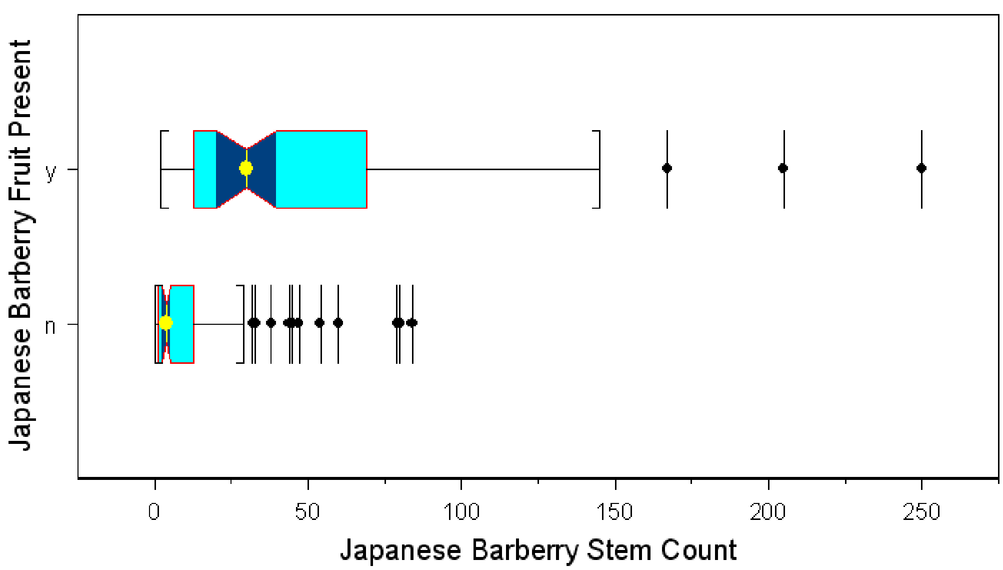

Figure 5. Distribution of stem counts of Japanese barberry with and without fruiting observed, showing median (yellow dot in notched bar), 95% confidence interval on the median (dark blue notched bar) inter-quartile range (cyan and blue bars) and range and outliers (black dots).

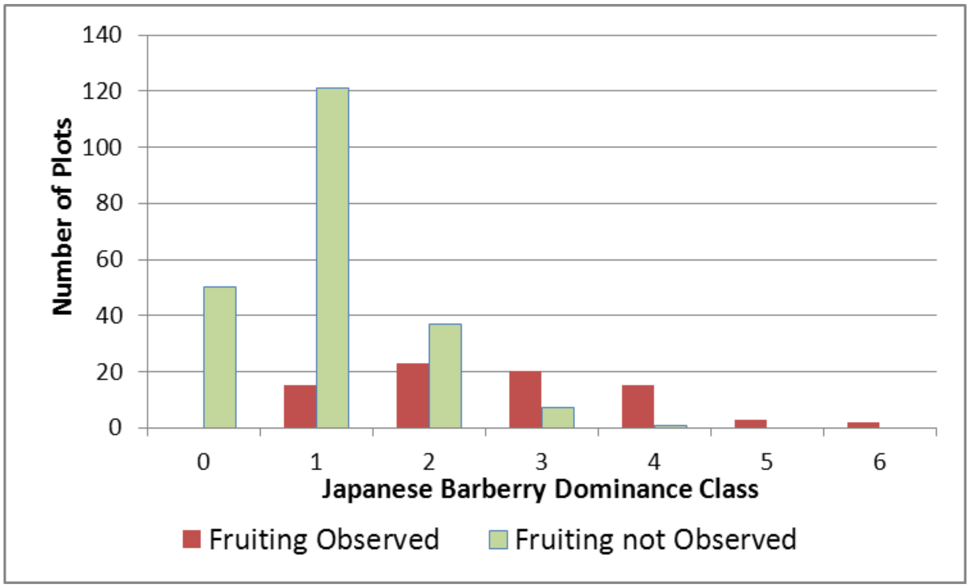

Figure 6. Distributions of Japanese barberry dominance class with and without fruiting observed as histograms showing the number of plots in each dominance category.

The Moran's I statistic confirms the presence of significant spatial autocorrelation in the abundance and dominance response variables. The fruiting correlogram had less significant spatial autocorrelation, with one significant Moran's I value at 50-100 m (see correlograms in Appendix 2).

The three response variables were mapped as dot maps and surface maps (Figures 7-9). As expected, the three maps show similar patterns. The greatest concentration of Japanese barberry lies in the centre of the park, just north of Gardiner Avenue; there are two concentrations south of this, one on the east side near Lakeshore Road, the other at the south point. To the north, there are also two additional concentrations, one due north, but south of Bennett Avenue, the other on the eastern shore at the northern limit of the study area.

The results of the Japanese barberry roadside survey of cottage lots are shown in Figures 4 and 8. Cottage lots with Japanese barberry are symbolized as small red rectangles; lots with no barberry observed are shown as small gray rectangles. We observed Japanese barberry in 20 lots along Lakeshore Road. All observations were in naturalized areas of occupied cottage lots, in vacant lots or in rights-of-way. There was a single Japanese barberry shrub in a cultivated area of a cottage lot. Otherwise, there was no other evidence of Japanese barberry planted in cottage gardens or cultivated areas of occupied lots that were visible from the road. The Savanta 2008 plot-based data and the roadside survey of cottage lots in 2012 (Figure 10) are consistent with the observations of our 2011 survey, and are not sufficiently different to indicate change in distribution over time.

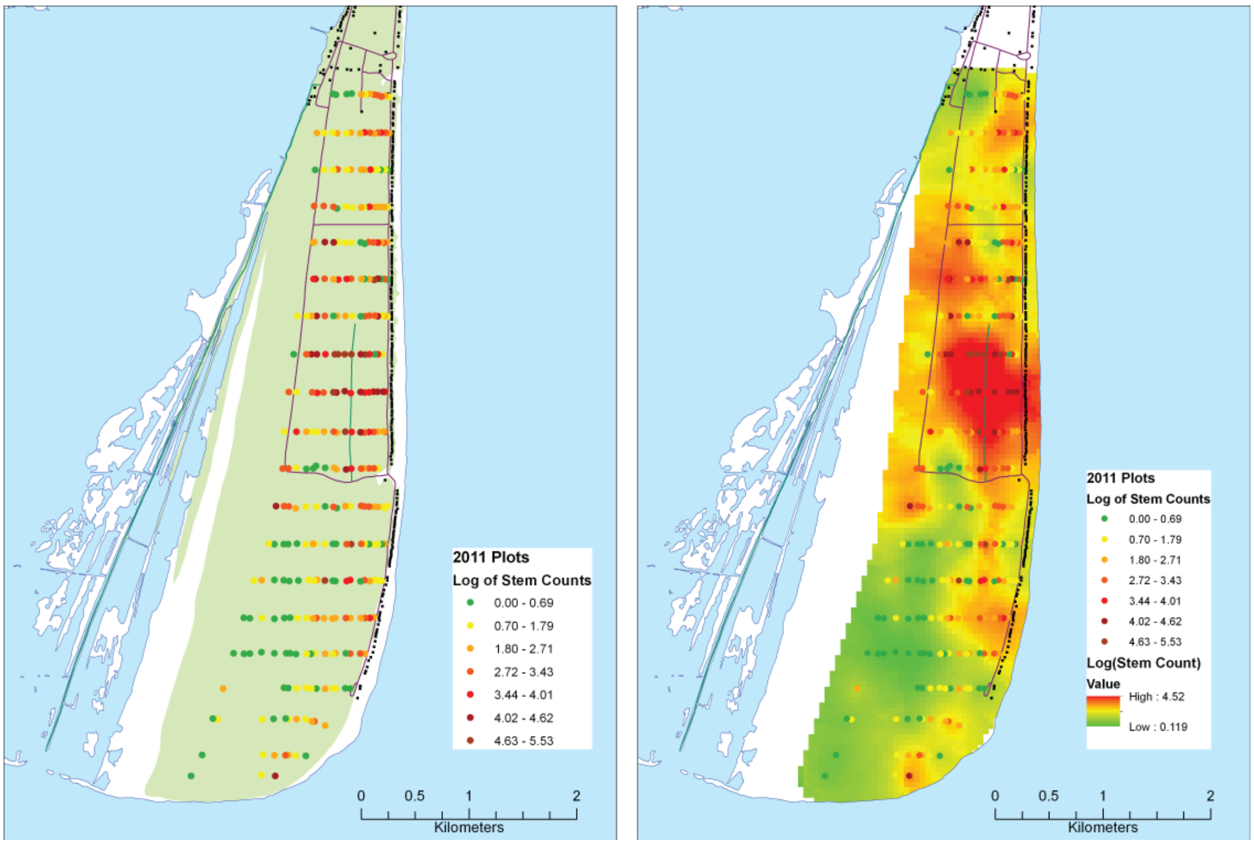

Figure 7. Dot and surface maps of Japanese barberry response variables (Stem Counts).

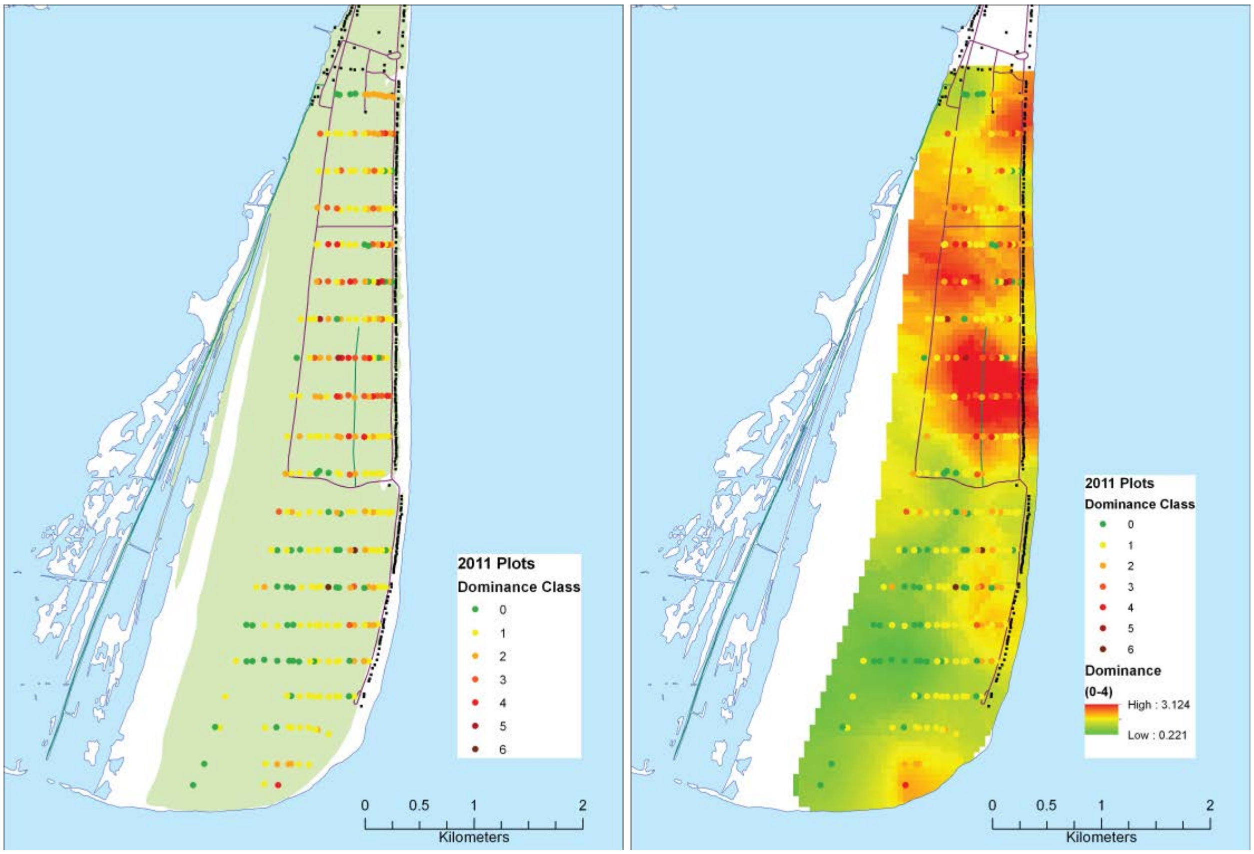

Figure 8. Dot and surface maps of Japanese barberry response variables (Dominance Classes).

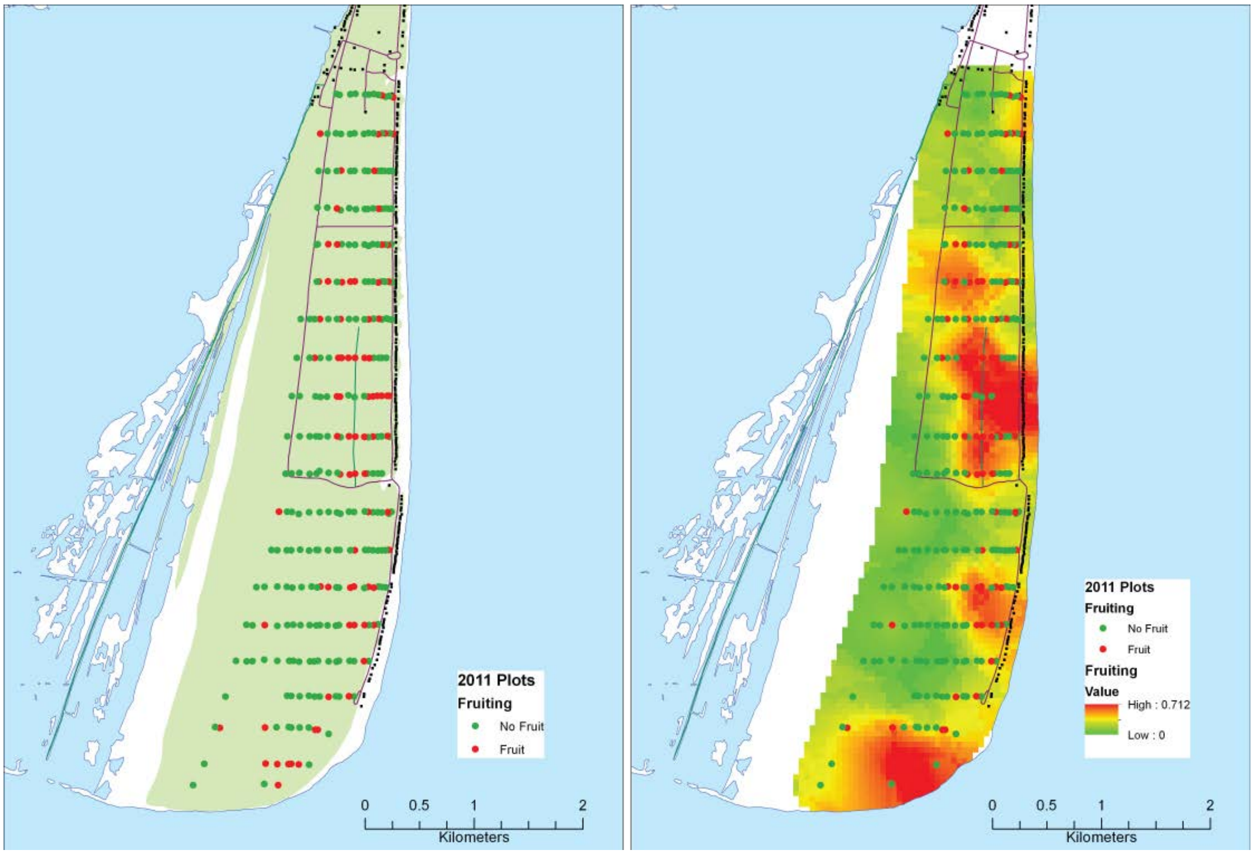

Figure 9. Dot and surface maps of Japanese barberry response variables (Fruiting).

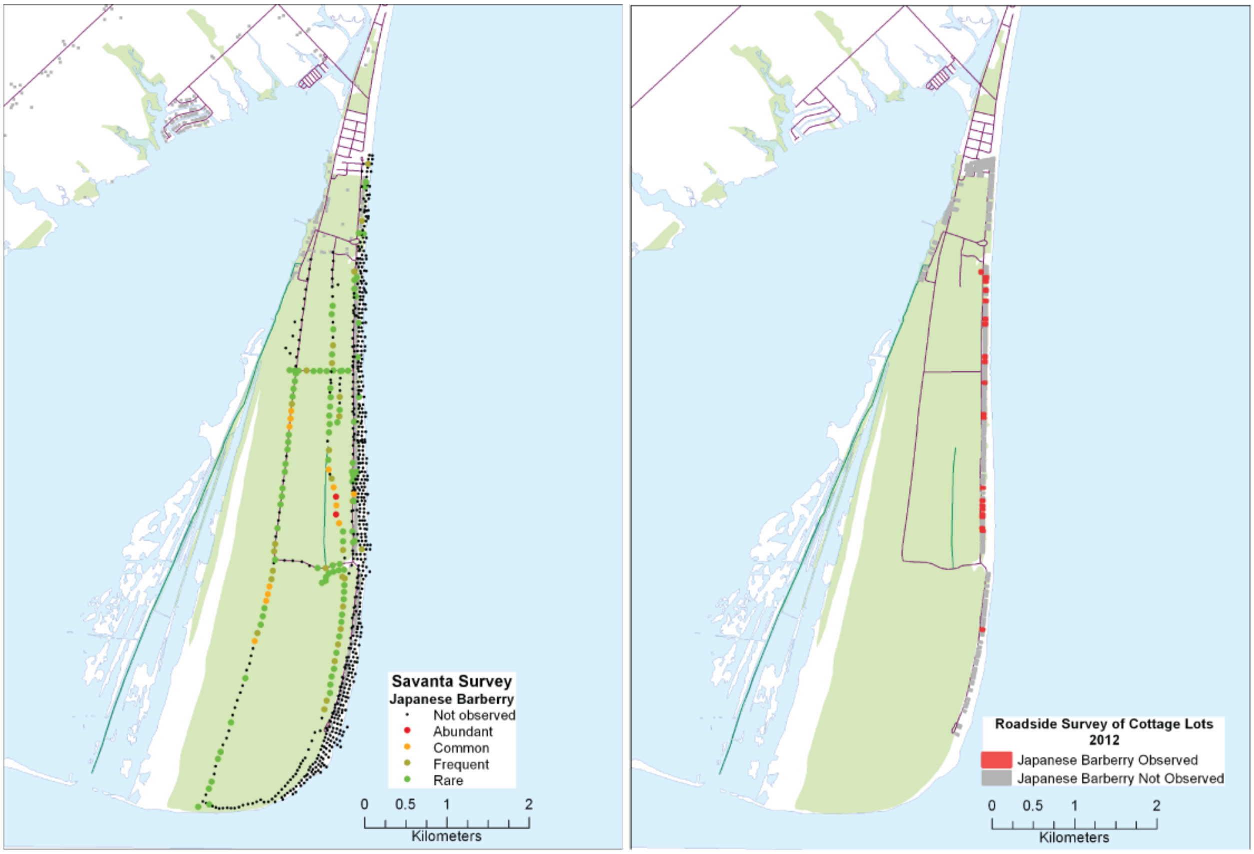

Figure 10. Comparison of Japanese barberry observations by Savanta in 2008 (Savanta 2009) and roadside survey in 2012.

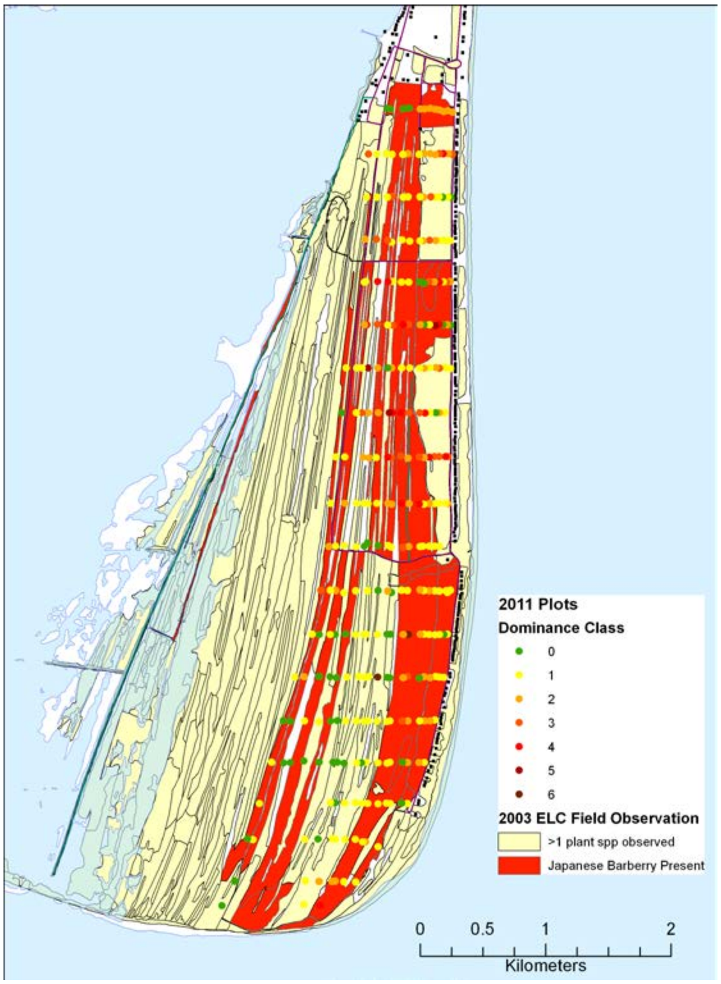

Figure 11. ELC field observations of vegetation types with Japanese barberry.

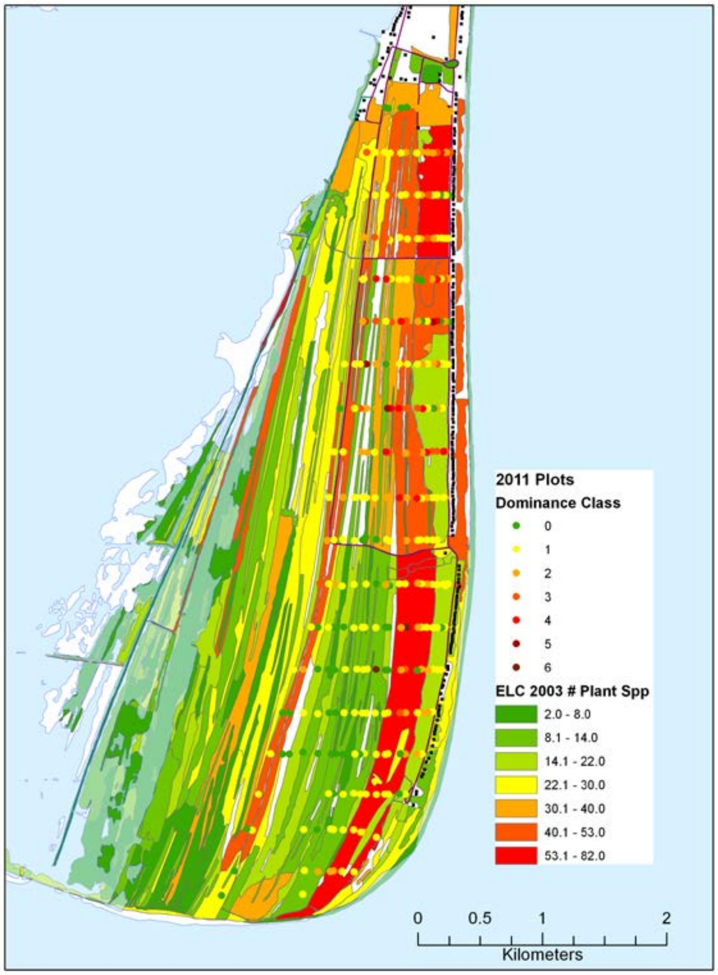

Figure 12. ELC field observations of the number of plant species recorded per ELC polygon.

The ELC data were mapped (Figures 11 and 12) as both presence of Japanese barberry and also number of plant species observed in the ELC polygons; the variation in this latter map indicates that consistent plant species observation effort was not applied, and so the indication of absence is not likely reliable. However, the map of presence does show observations of the shrub outside of the 2011 study area, particularly on a number of sandbars on the west side in Rondeau Bay.

Japanese Barberry and Ecological Characteristics

The environmental variables measured at each plot were canopy closure, basal area of trees, mean tree diameter at breast height, percent shrub closure, and 3 most dominant shrub species. Overlaying the plot locations on the ELC polygons enabled us to assign ELC Ecosite and Vegetation Type classes to each plot and to examine the associations of Japanese barberry with these broader-scale characteristics.

The relationships between environmental and Japanese barberry variables were assessed with Pearson correlation coefficients (r) with significance estimates accounting for spatial autocorrelation (Table 4). Basal area is negatively correlated with Japanese barberry fruiting, and shrub closure is positively correlated with fruiting, likely because of the association of fruiting with dense stands of shrubs, of which Japanese barberry would form a significant component. The association of Japanese barberry, indicated by dominance class, is shown in Figure 10, where there is a consistent monotonic trend, assessed visually, appears to be negative with basal area medians; similarly there is a visually identifiable positive trend in association with shrub cover.

The relationships between Japanese barberry response variables and ecosite are summarised in Tables 5 and 6. Japanese barberry was found in a wide range of vegetation communities in the park, occurring in 11 of the 13 ecosites that were sampled. We observed it with highest average dominance and abundance in four ecosites: in Fresh-Moist Sugar Maple Deciduous Forest, which was also the most frequently sampled ecosite; Fresh - Moist Carolinian Deciduous Forest; Fresh - Moist Oak-Maple-Hickory Deciduous Forest, and; Dry-Fresh Oak Deciduous Woodland. Three of these ecosites also had the only plots in the highest dominance classes (>Class 3): Fresh-Moist Sugar Maple Deciduous Forest; Fresh - Moist Carolinian Deciduous Forest, and; Fresh - Moist Oak-Maple-Hickory Deciduous Forest. Abundance and dominance were generally lower in marshes and swamps. It was absent only in Fresh-Moist Lowland Deciduous Forest and Dogwood Mineral Deciduous Thicket Swamp. The proportion of plots with fruit was highest in Fresh-Moist Carolinian Deciduous Forest; although, average fruiting was also relatively high in Dry-Fresh Oak Tallgrass Deciduous Woodland.

The dominant shrub species in the shrub layer in plots are listed by average Japanese barberry dominance in Table 6. In five plots with high average Japanese barberry dominance (2.20), fragrant sumac was the dominant shrub species. Tartarian honeysuckle was the most abundant shrub in 22 plots with an average Japanese barberry dominance of 1.52, and spicebush was dominant in 70 plots with average Japanese barberry abundance of 1.44. Blue beech and American beech saplings were found to be the dominant shrub species in a total of 57 plots with average Japanese barberry abundance of 1.36 and 1.11, respectively. A final notable association is with grey dogwood, found to be the predominant shrub in 24 plots, which had an average Japanese barberry dominance class of 1.25.

Table 4. Pearson Correlation coefficients (r) and significance probabilities (p) for the relationships among environmental variables and with Japanese barberry; shaded areas indicate significant relationships at a 5% significance level. (n = 294; except for Fruiting, where analysis was of 244 plots where Japanese barberry was present)

	Shrub Closure	Mean DBH	Basal Area	Canopy closure
Log JB Count	r = 0.0765 p = 0.50598	r = -0.09025 P = 0.24163	r = -0.18287 p = 0.07179	r = 0.07143 p = 0.67953
Fruiting (n=244)	r = 0.14465 p = 0.03282	r = -0.05048 p = 0.41154	r = -0.15508 p = 0.01189	r = -0.05802 p = 0.38581

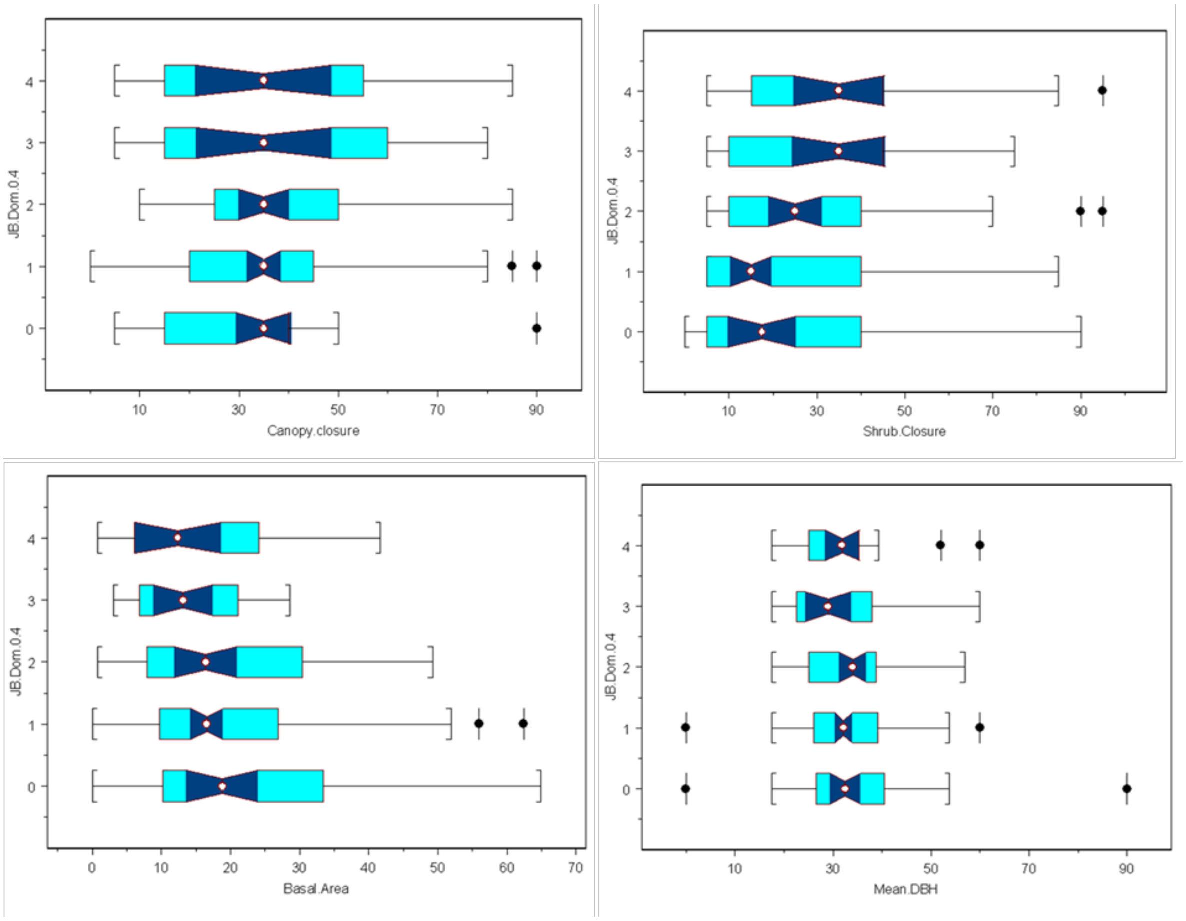

Figure 13. Environmental variable distributions by dominance class (0-4), showing median (white dot in notched bar), 95% confidence interval on the median (dark blue notched bar) inter-quartile range (cyan and blue bars) and range and outliers (black dots).

Table 5. Japanese barberry stem counts and dominance class means and standard deviations and percent fruiting (including all plots) by ecosite class.

Ecosite Description	Ecosite Code	No. of plots	Average of JB_Dom_ 0-6	Average of JB_Count	Average of JB_Frt_Bin
Dry - Fresh Oak Deciduous Woodland	WODM 3	8	2.00	12.25	25.0%
Fresh - Moist Carolinian Deciduous Forest	FODM1 0	55	1.96	32.67	34.5%
Fresh - Moist Oak-Maple-Hickory Deciduous Forest	FODM9	34	1.62	12.88	20.6%
Fresh - Moist Sugar Maple Deciduous Forest	FODM6	142	1.45	22.38	29.6%
Dry - Fresh Oak Tallgrass Deciduous Woodland	WODM 1	18	1.11	9.44	33.3%
Recreational	CGL_4	1	1.00	8.00	0.0%
Transportation	CVI_1-3	2	1.00	2.00	0.0%
Ash Mineral Deciduous Swamp	SWDM2	11	0.73	6.27	9.1%
Maple Mineral Deciduous Swamp	SWDM3	13	0.69	4.62	15.4%
Mineral Deciduous Thicket Swamp	SWTM5	3	0.67	3.00	0.0%
Graminoid Mineral Shallow Marsh	MASM1	2	0.50	4.00	0.0%
Fresh - Moist Lowland Deciduous Forest	FODM7	4	0.00	0.00	0.0%
Dogwood Mineral Deciduous Thicket Swamp	SWTM2	1	0.00	0.00	0.0%
Grand Total		294	1.46	19.86	26.9%

Table 6. Distribution of Japanese barberry dominance values by ecosite class - number of plots.

Ecosite_Description	0	1	2	3	4	5	6	Total
Dry - Fresh Oak Deciduous Woodland			8					8
Fresh - Moist Carolinian Deciduous Forest	7	18	11	10	7	2		55
Fresh - Moist Oak-Maple-Hickory Deciduous Forest	2	17	8	6	1			34
Fresh - Moist Sugar Maple Deciduous Forest	19	76	27	9	8	1	2	142
Dry - Fresh Oak Tallgrass Deciduous Woodland	2	12	4					18
Recreational		1						1
Transportation		2						2
Ash Mineral Deciduous Swamp	5	5		1				11
Maple Mineral Deciduous Swamp	8	2	2	1				13
Mineral Deciduous Thicket Swamp	1	2						3
Graminoid Mineral Shallow Marsh	1	1						2
Fresh - Moist Lowland Deciduous Forest	4							4
Dogwood Mineral Deciduous Thicket Swamp	1							1
Total	50	136	60	27	16	3	2	294

Table 7. Japanese barberry stem counts and dominance class means and standard deviations and percent fruiting (including all plots) by most dominant shrub species.

Common Name (number of plots)	Scientific Name	Average of JB_Dom_ 0-6	Average of JB_Count	Average of JB_Frt_Bin
Japanese Barberry (41)	*Berberis thunbergii*	2.73	61.20	71%
Fragrant Sumac (5)	*Rhus aromatica*	2.20	19.20	20%
Tartarian Honeysuckle(25)	*Lonicera tatarica*	1.52	14.00	36%
Chokecherry (2)	*Prunus virginiana*	1.50	15.50	0%
Riverbank Grape (2)	*Vitis riparia*	1.50	11.00	0%
Spicebush (79)	*Lindera benzoin*	1.44	17.73	23%
Blue Beech sapling (22)	*Carpinus caroliniana*	1.36	18.55	14%
Sassafras sapling (3)	*Sassafras albidum*	1.33	10.67	33%
Grey Dogwood (24)	*Cornus racemosa*	1.25	12.21	21%
American Beech sapling (35)	*Fagus grandifolia*	1.11	11.83	14%
Tuliptree sapling (2)	*Liriodendron tulipifera*	1.00	5.00	0%
Hop Hornbeam (1)	*Ostrya virginiana*	1.00	19.00	0%
Wild Raspberry (36)	*Rubus idaeus*	0.92	5.97	17%
Ash sp. sapling (10)	*Fraxinus spp.*	0.70	3.90	10%
Buttonbush (4)	*Cephalanthus occidentalis*	0.00	0.00	0%
Roughleaf Dogwood (1)	*Cornus drummondii*	0.00	0.00	0%

Common Name (number of plots)	Scientific Name	Average of JB_Dom_ 0-6	Average of JB_Count	Average of JB_Frt_Bin
	Overall	1.45	19.86	27%

Japanese Barberry and Anthropogenic Features

Finding a negative relationship of abundance with distance to an anthropogenic feature (i.e. as distance increases, abundance or fruiting decreases) we assume indicates a dependency of Japanese barberry on that feature. With diffusion of the invasive species over time from these putative sources, we would expect higher abundance and greater likelihood of fruiting in areas closer (lower distances) to a hypothesized Japanese barberry source feature where the barberry would have been longer established. Tables 7 and 8 show the correlation coefficients and the p-values for the relationships of abundance and fruiting, with the distance to the nearest of each of the anthropogenic feature types. None of these relationships were significant at the 5% level. However, because of the small effect size expected and the low statistical power, in part due to spatial autocorrelation, we relaxed the Type I error rate from 5% to 10%. We found three features to be significantly related: distances to nearest cottage lot, distance to nearest road, and distance to nearest cottage lot on which Japanese barberry was observed in the roadside survey. None of the relationships between distance and fruiting were significant.

Table 8. Correlations between Japanese barberry abundance (JB_Ln_Count) and distances to anthropogenic features; shaded area indicates significant correlations at 10% level, taking into account spatial autocorrelation (N=292, except where noted).

	Correlation Coefficient (r)	Significance Probability (p)
Distance to cottage lot	-0.25445	0.07302
Distance to road	-0.29905	0.08091
Distance to cottage lot with barberry	-0.31869	0.08466
Distance to group campground	-0.40493	0.15075
Distance to trail	-0.11104	0.24021
Distance to central compost facility	-0.24832	0.32079
Distance to main campground	-0.24059	0.33167
Distance to edge of prescribed burn	-0.07596	0.50723 (n = 126)
Distance to park Infrastructure	-0.01264	0.91550

Table 9. Correlations between presence of Japanese barberry fruit (JB_Frt_Bin) and distances to anthropogenic features where Japanese barberry is present (N=244, except where noted).

	Correlation Coefficient (r)	Significance Probability (p)
Distance to park Infrastructure	0.14586	0.13976
Distance to road	0.06974	0.31394
Distance to trail	-0.08244	0.34089
Distance to cottage lot	-0.07562	0.39589
Distance to central compost facility	0.04301	0.42402
Distance to main campground	0.04342	0.42561
Distance to group campground	-0.03213	0.49576
Distance to edge of prescribed burn	-0.03166	0.76212 (n=110)
Distance to cottage lot with barberry	-0.01610	0.83723

DISCUSSION

Distribution and abundance

Japanese barberry is widespread and well established in Rondeau Provincial Park. It occurs mostly at low abundance, but is dominant and forms dense thickets in about 7% of plots. This pattern is similar to the structure of populations in deciduous forests of New Jersey which were dominated by many small individuals with a lower frequency of medium and large plants (Ehrenfeld 1999). Areas of highest dominance and abundance are located primarily north of Gardiner Avenue. Plants were generally less abundant south of Gardiner Avenue, except for an invasion front trailing from the north and “hot spots” radiating westward from Lakeshore Road and the Lake Erie shoreline. The few sites where Japanese barberry was not detected were located mostly in plots in the southwestern extent of the study area.

The distribution of Japanese barberry observed in 2011 is generally consistent with incidental observations of the species that were made during an ELC survey in 2003 (Dobbyn and Pasma 2012) and with records from a survey of invasive plants by Savanta, Inc. in 2008 (Savanta 2009). Each of these surveys, however, detected

Japanese barberry outside of the current study area. Shrubs were found growing on sand bars on the west shore during the ELC survey. The Savanta study noted additional locations of Japanese barberry along transects between Lakeshore Road and the Lake Erie shoreline, excluding leaseholds, which were not surveyed. Otherwise, the highest dominance and abundance on the 2011 plots corresponded with ecosites where the species was described as being abundant and dominant by the ELC survey. In addition to the dune transects, Savanta also sampled roads and trails every 50 to 100m. Highest abundance of Japanese barberry recorded by the Savanta study corresponded with the “hot spots” in the vicinity of roads and trails that were detected in the 2011 survey.

The history and pattern of invasion of Japanese barberry in Rondeau over the last 50 years can be inferred from these and other records of the species, as well as anecdotal accounts. Over a fifteen to twenty year period, from the earliest documented occurrence in 1958 to the 1970s, Japanese barberry became well-established in natural areas on the east side of the park (A. Woodliffe, pers. comm., OMNR 1976, OMNR 1979, Bazely *et al*. 2001). A rapid increase in abundance and westward expansion followed deer herd reduction in the 1990s (Bazely *et al*. 2001). Expansion continued in the 2000s, with Japanese barberry found on the west shore of the park in 2003 (Dobbyn and Pasma 2012). The 2011 survey, the first systematic inventory of Japanese barberry in Rondeau, confirms empirically that it is currently both widespread and abundant in the park.

Japanese Barberry and Ecological Characteristics

Japanese barberry was found predominantly in dry to mesic forested and woodland communities in the park. Its preference for mesic conditions on well drained soils in other locations (Silander and Klepeis 1999, Zouhar 2008, Lubell and Brand 2011) corresponds with its distribution in Rondeau. The prevalence of Japanese barberry in forests and woodlands of Rondeau is also consistent with patterns of distribution observed in the U.S. where it is commonly found growing in second growth forest on abandoned agricultural lands, as well as in relatively undisturbed forest (Ehrenfeld 1999, Zouhar 2008, Mosher *et al*. 2009). Japanese barberry was absent, or present only at low dominance and abundance, in lowlands and wetlands, although these communities were sampled less frequently. High soil moisture, such as that found in wetlands and lowlands, has been observed to be a limiting factor in other studies (Silander and Klepeis 1999, Lubell and Brand 2011).

Among the environmental variables that were measured, only basal area, presumed to be an indirect surrogate for light levels, was significantly negatively correlated with stem counts of Japanese barberry. It is surprising that the relationship of canopy closure, which would directly influence shrub layer light levels, is not significant. However, canopy closure in the sites surveyed may not have been sufficient (mean and median = 35%) to limit Japanese Barberry growth and reproduction. The timing and duration of the survey from mid to late fall when trees were losing their leaves is another factor that may have influenced the results. Estimates of canopy closure from plots sampled later in the season may have been under-estimated relative to those surveyed at the beginning of the study. Japanese barberry can tolerate a wide range of light levels; however, it is rarely found in sites with less than 1% to 2% of full sun (Silander and Klepeis 1999). Although it does well in full sun, it is more tolerant of lower light levels than other fast-growing woody species. Because of this competitive advantage, it can become the dominant species in the shrub layer when growing under forest canopy (Zouhar 2008). This seems to be the case in Rondeau, where plots with the highest dominance (>Class 3) were only found in forested communities.

Fruiting was associated with areas of higher mean abundance and distribution of Japanese barberry compared to plots with no fruit. Fruiting, stem growth, and biomass are highest in full sun to partial shade although seed production and growth can occur at low light levels (Silander and Klepeis 1999). Light levels may be affecting seed production in Rondeau, as there was a negative relationship between basal area and the presence of fruit. Density of stems and production of fruit may indicate older, well established stands, since Japanese barberry spreads vegetatively by suckering from the root collar, rooting of branches in contact with the ground, and sprouting from root rhizomes (Cassidy *et al*. 2004, Ehrenfeld 1999, Silander and Klepeis 1999). Most seeds drop within one metre of the parent plant (Zouhar 2008). The absence of fruit and low density of plants may indicate newly invaded areas or marginal sites that are not conducive to plant growth and seed production.

Japanese Barberry and Anthropogenic Features

Statistical analysis did not reveal any strong relationships between anthropogenic features and the current pattern of distribution and abundance of Japanese barberry in the park. The most significant associations were with distances to cottage lots, roads, and observations of Japanese barberry in the roadside survey. Roads and trails are known vectors for the spread of invasive plants (Jordan 2000, Taylor *et al*. 2011).

Propagules of Japanese barberry could be transported along these vectors by the fruit becoming embedded in the soles of footwear or tire treads and attachment of the thorny branches to clothing. Clearings and edges along roads and trails provide the full to intermediate light levels preferred by Japanese barberry, and may also be favoured habitats for seed dispersers, such as fruit-eating birds (Mosher *et al*. 2009). The use of Japanese barberry for gardening and landscaping on the cottage lots in the past, and its presence in 2012 on naturalizing areas of some vacant and occupied lots, suggest that it was an historical, and may be a current source for the spread of the species. Because of the proximity of roads and the cottage lots, and the spatial co-incidence of cottage lots and cottage lots with Japanese barberry, it is impossible to identify from these data and analyses which of these is the ultimate causal factor.

It is unknown when Japanese barberry was first introduced to the park, but the first herbarium specimen was collected in 1958. Silander and Klepeis (1999) proposed that exotic species are often collected in early stages of invasion when they are still considered to be a novelty. Time since establishment cannot be estimated by aging stems of Japanese barberry because they die and are replaced within two to three years, up to a maximum of seven years (Silander and Klepeis 1999). Japanese barberry could have been planted on cottage lots in Rondeau much earlier than the 1950s, based on its availability in U.S. and Canadian nurseries. U.S. nurseries were promoting the species as early as the 1920s (Harmon 2006). Eradication programs in Canada in the 1940s to prevent the spread of black stem rust to grain crops from hybrids of Japanese and common barberry indicate that it was already well-established in some parts of the country at that time (R. Ormrod, pers. comm. 2012). It was the top-selling deciduous shrub in Ontario in 1966, at the time of a ban on the importation and movement of Japanese barberry in Canada (Drysdale 2000). Despite the ban, existing stocks were allowed to be sold legally until the early 1970s. In 2001, the Plant Protection Regulations under the Plant Protection Act were amended to allow importation and domestic movement of certain varieties of Japanese barberry that have been determined to be resistant to black stem rust (Canada Gazette 2001).

Records and anecdotal accounts of Japanese barberry in Rondeau suggest a pattern of invasion similar to that in New England. In the U.S., Japanese barberry was first planted in an arboretum in Boston in 1875 (Silander and Klepeis 1999). Naturalized populations in the countryside outside of Boston and New York in the 1920s were attributed to escapees from vacation homes (Silander and Klepeis 1999). It was still considered to be rare in the U.S. in the 1950s (Silander and Klepeis 1999). By the 1960s and 1970s, it was beginning to be recognized as a serious invader of natural areas. Unlike in Canada, Japanese barberry was never banned in the U.S.

Management of white-tailed deer in the park may have had a greater influence on the spread of Japanese barberry than any of the anthropogenic variables that were assessed. Hyper-abundant deer populations have been controlled through periodic deer herd reductions since 1912 (Dobbyn and Pasma 2012). Deer herd reductions were suspended for a 15 year period from 1978 to 1992, during which time vegetation communities and forest conditions were altered by intensive grazing (Bazely *et al*.2001, Dobbyn and Pasma 2012). Following the resumption of deer herd reductions in 1993, Japanese barberry was observed to increase significantly (Bazely *et al*. 2001). A similar response was observed by buckthorn, (Rhamnus sp.), another invasive browse-resistant shrub, after deer control in Presqu'ile Provincial Park (pers. comm. C. Brdar). Since Japanese barberry is not preferred by deer due to its thorny stems, it may recover more readily from grazing pressure than preferred native species (Silander and Klepeis 1999, Zouhar 2008). In New Jersey, Japanese barberry persisted in areas where other shrubs were eradicated by dense deer populations (Zouhar 2008). Bazely *et al*. (2001) speculated that deer may have acted as a vector for the dispersal of Japanese barberry in Rondeau, but they did not find evidence of this at a time of reduced population levels in 2001 when alternative foods were available. Although deer do not preferentially browse the foliage, they have been observed to eat the fruit and are known to disperse the seed of other Berberis species in North America (Zouhar 2008). Poor regeneration of woody species caused by deer grazing may be another factor that favoured the expansion of Japanese barberry and other invasive species, due to increased light levels and drier conditions in the forest understorey (Dobbyn and Pasma 2012).

Several blowdown events in the park during the putative time that Japanese barberry was becoming established could have contributed to its expansion by creating forest openings. Significant wind storms resulting in the fall of large numbers of trees occurred between 1934 and 1998 (Dobbyn and Pasma 2012). Almost 50% of trees were lost from some localized areas of the park during a storm in 1998. Disturbances, such as blowdowns, create edges characterized by intermediate light levels that are preferred by Japanese barberry and other invasive shrubs, and may attract seed dispersers (Mosher *et al*. 2009). Distance to edges was an important predictor of

Japanese barberry and other woody plant invasions in central Connecticut (Mosher *et al*. 2009) but was not investigated for this study.

Conclusions about the sources of Japanese barberry and the mechanisms of its spread would be strengthened if historical data were examined to assess the pattern of Japanese barberry spread over time and the effect of deer exclosures on the occurrence of Japanese barberry. We are pursuing historical records, from earlier vegetation surveys, but have not yet compiled them for this type of assessment.

Management of Japanese Barberry

Results of this survey confirm that Japanese barberry is widespread and well established in Rondeau Provincial Park. Eradication seems unlikely given its broad distribution in the park, but it may be possible to manage populations to reduce impacts. There have been limited efforts to control Japanese barberry in the park in the past. In 1995, shrubs were removed from cottage lots and along portions of some roads and trails (Dobbyn and Pasma 2012) by cutting and treating the stumps with glyphosate (E. Slavik, pers. comm.). These efforts were partially successful in that no individuals were found in cultivated areas of cottage lots in 2012; however, it was present in areas that were not under cultivation, including naturalized areas of occupied lots, several vacant lots, and unmaintained road rights-of-way. These types of early successional habitats are prime areas for invasion by Japanese barberry. Although restoration of cottage lots and other disturbed areas is desirable, passive naturalization may not be a good practice, because it is likely to favour Japanese barberry and other invasive species (Mosher *et al*. 2009)

Japanese barberry can be controlled using various methods, including cutting, hand-pulling, herbicide treatment, and prescribed burning (Silander and Klepeis 1999, Zouhar 2008, Mosher *et al*. 2009, Mandle *et al*. 2011). A combination of treatments is likely to be most effective. Control treatments consisting of cutting, pulling, and application of herbicide were tested in the park in 1994 and 1995 (Bazely *et al*. 2001). Only cutting followed by herbicide treatment was 100% effective; cutting alone resulted in 91% re-sprouting and hand-pulling resulted in 23% re-sprouting. Japanese barberry readily re-sprouts from cut stems or root fragments, so cutting or hand-pulling by themselves will not eradicate the species, but may help to reduce populations and prevent spread to new areas (Silander and Klepeis 1999). Cutting followed by herbicide treatment of cut stumps has been effective for large, densely populated sites (Pennsylvania Department of Conservation and Natural Resources 2012). Prescribed burning in combination with cutting has resulted in a decrease of up to 90% of Japanese barberry for over one year (Zouhar 2008); however, our analysis of observational data did not indicate an effect of prescribed burns on the abundance of Japanese barberry in Rondeau. Burning, however, may enhance growth and establishment by opening the canopy and creating preferred light levels (Zouhar 2008). Whatever the methods used, control of Japanese barberry will require on-going management over many years.

The recovery of native vegetation following Japanese barberry control may be delayed. Trials to investigate the response of understorey vegetation to cutting or herbicide treatment of Japanese barberry found little to no growth or recruitment of herbs or other shrubs within one growing season, except under high light levels (Silander and Klepeis 1999). Some researchers have suggested that Japanese barberry can alter vegetation communities through changes in soil chemistry and biota (Elgersma and Ehrenfeld 2011), while others propose that earthworms may help create conditions that favour the species (Zouhar 2008). Soil pH, nitrates, earthworm densities and bacteria have been found to be higher under Japanese barberry than under native vegetation (Cassidy *et al*. 2004, Zouhar 2008, Elgersma and Ehrenfeld 2011). It has been suggested that persistence of these conditions after Japanese barberry is removed may inhibit ecosystem recovery (Zouhar 2008).

Setting priorities for management can be challenging, since the distribution of the species in the park is so extensive. Considerations in developing a management strategy include: preventing the invasion of uninfested areas; eradicating recently established populations; reducing populations in sensitive areas; decreasing long distance dispersal by targeting fruiting individuals; and preventing the transport of seeds and propagules to uninfested areas outside the park. Additional surveying is needed to fully map the distribution of Japanese barberry, since it is known to occur outside the study area on sandbars on the western shore and the eastern dunes. The western sandbar occurrences appear to be more recently established and may be candidates for eradication efforts. Reducing populations in the habitat of species at risk or in rare vegetation communities is another strategy and should be a priority. In infested areas, targeting large plants in sparse to moderately dense populations has been recommended to prevent the formation of new thickets (Ehrenfeld 1999). This may also help to decrease long-distance seed dispersal outside the park by removing the most productive plant.

REFERENCES

Allen, C. R., A.S. Garmestani, J.A. LaBram, A.E. Peck and L.B. Prevost. 2006. When landscaping goes bad: the incipient invasion of *Mahonia bealei* in the southeastern United States. Biological Invasions 8:169–176.

Bazely, D.R., S. Koh, S. Chopra, and K.E. Hynes. 2001. Movement of Japanese barberry (*Berberis thunbergii*) in forests browsed by white-tailed deer (*Odocoileus virginianus*). Unpublished report. 9 pp.

Canada Gazette. 2001. Regulations amending the Plant Protection Regulations. Vol. 135, No. 17.

Canadian Food Inspection Agency. 2011. Canadian invasive plant framework- A collaborative approach to addressing invasive plants in Canada. Canadian Food Inspection Agency, Winnipeg, Manitoba. 28 pp.

Cassidy, T. M., J.H. Fownes, and R.A. Harrington. 2004. Nitrogen limits an invasive perennial shrub in forest understory. Biological Invasions 6: 113–121.

Clifford, P., S. Richardson, and D. Hémon. 1989. Assessing the significance of the correlation between two spatial processes. Biometrics 45: 123-134.

D'Appollonio, J. 2006. Regeneration strategies of Japanese barberry (*Berberis thunbergii* DC.) in coastal forests of Maine. Electronic Theses and Dissertations. Paper 433. http://digitalcommons.library.umaine.edu/etd/433

Dobbyn, S. and L. Pasma. 2012. A life science inventory and evaluation of Rondeau Provincial Park. Ontario Parks, Southwest Zone, London, Ontario.viii + 207 pp. + map.

Drysdale, A. 2000. For almost 40 years we've been denied the use of the beautiful barberry shrubs! Http://artdrysdale.com/april2000.html. Accessed Feb. 6, 2012.

EDDMapS. 2013. Early detection & distribution mapping system. The University of Georgia - Center for Invasive Species and Ecosystem Health. Available online at http://www.eddmaps.org/ and http://www.eddmaps.org/ontario. Accessed May 15, 2013

Ehrenfeld, J.G. 1999. Structure and dynamics of populations of Japanese barberry (*Berberis thunbergii* DC.) in deciduous forests of New Jersey. Biological Invasions 1: 203–213.

Elias, S.P., C.B. Lubelczyk, P.W. Rand, E.H. Lacombe, M.S. Holman and R.P. Smith Jr. 2006. Deer browse resistant exotic-invasive understory: An indicator of elevated human risk of exposure to *Ixodes scapularis* (Acari: Ixodidae) in southern coastal Maine woodlands. Journal of Medical Entomology 43(6): 1142-1152.

Elgersma, K. J. and J.G. Ehrenfeld. 2011. Linear and non-linear impacts of a non-native plant invasion on soil microbial community structure and function. Biological Invasions 13: 757–768.

Government of Canada. 2004. An invasive alien species strategy for Canada. Ottawa, Ontario.

Harmon, E. 2006. Introduced species summary project - Japanese barberry (*Berberis thunbergii*). Introduced Species Summary Project, Columbia University. http://www.columbia.edu/itc/cerc/danoff-burg/invasion_bio/inv_spp_summ/Berberis_thunbergii.html. Accessed Feb. 6, 2012.

Henson, B.L, K.E. Brodribb and J.L. Riley. 2005. Great Lakes conservation blueprint for terrestrial biodiversity. Volume 1. Nature Conservancy of Canada under licence with the Ontario Ministry of Natural Resources, Queen's Printer for Ontario. 157 pp.

Jones, J., J.V. Jalava, and J. Ambrose. 2013. Recovery strategy for the nodding pogonia (Triphora trianthophora) in Ontario. Ontario Recovery Strategy Series. Prepared for the Ontario Ministry of Natural Resources, Peterborough, Ontario. v + 29 pp.

Jordan, M. 2000. Ecological impacts of recreational use of trails: A literature review. The Nature Conservancy.

Lee, H., W. Bakowsky, J. Riley, J. Bowles, M. Puddister, and P. Uhlig. 1998. Ecological land classification for southern Ontario: First approximation and its application. Ontario Ministry of Natural Resources, North Bay, Ontario.

Lubell, J. D. and M.H. Brand. 2011. Germination, growth and survival of *Berberis thunbergii* DC. (Berberidaceae) and *Berberis thunbergii* var. *atropurpurea* in five natural environments. Biological Invasions 13:135–141.

Mandle, L., J.L. Bufford., I.B. Schmidt and C.C. Daehler. 2011. Woody exotic plant invasions and fire: reciprocal impacts and consequences for native ecosystems. Biological Invasions 13:1815–1827.

Mann, D. 1978. The changing Rondeau landscape. M.A. Thesis, Geography Department, University of Waterloo, Waterloo, Ontario. 297 pp.

Mosher, E.S., J.A. Silander Jr, and A.M. Latimer. 2009. The role of land-use history in major invasions by woody plant species in the northeastern North American landscape. Biological Invasions 11:2317–2328.

Ontario Ministry of Environment. 2013. Ontario forest biomonitoring network-Observations of Japanese barberry. Ontario Ministry of Environment, unpubl. data.

Ontario Ministry of Natural Resources. 1976. Checklist of trees, shrubs and woody vines of Rondeau Provincial Park. Rondeau Provincial Park, Ontario. 7 pp.

Ontario Ministry of Natural Resources. 1979. Checklist of plants of Rondeau Provincial Park. Rondeau Provincial Park, Ontario.

Ontario Ministry of Natural Resources. 2001. Rondeau vegetation management plan. Ontario Parks, Ministry of Natural Resources, London, Ontario. 69 pp.

Ontario Ministry of Natural Resources. 2010. Gap Tool base case results 2010-Ecodistrict 7E-1. Parks and Protected Areas Policy Section, Natural Heritage, Lands and Protected Spaces Branch, Peterborough, Ontario, unpubl. data.

Ontario Ministry of Natural Resources. 2012. Ontario invasive species strategic plan. Toronto: Queen's Printer for Ontario. 58 pp.

Ontario Ministry of Natural Resources. 2013. Cottages in Rondeau Provincial Park – Summary of selected ecological values and pressures. Parks and Protected Areas Policy Section, Natural Heritage, Lands and Protected Spaces Branch, Peterborough, Ontario.

Pennsylvania Department of Conservation and Natural Resources. 2012. Invasive plants in Pennsylvania: Japanese barberry and European barberry. Pennsylvania Department of Conservation and Natural Resources. 2 pp.

Robertson, G.P. 2008. GS+: Geostatistics for the environmental sciences. Gamma Design Software, Plainwell, Michigan USA.

Rosenberg, M. S., & C.D. Anderson. 2011. PASSaGE: pattern analysis, spatial statistics and geographic exegesis. Version 2. Methods in Ecology and Evolution, 2(3), 229-232.

Savanta Inc. 2009.Lake Erie sand spit savannas & species at risk: Invasive species inventory & vegetation restoration strategy. Savanta Inc., St. Catharines, Ontario. 149 pp.

Silander Jr, J. A. and D.M. Klepeis. 1999. The invasion ecology of Japanese barberry (*Berberis thunbergii*) in the New England landscape. Biological Invasions 1:189–201.

Taylor, K., J. Mangold, and L.J. Rew. 2011. Weed seed dispersal by vehicles. MontGuide, Montana State University Extension.

Terrestrial Plants and Plant Pests Working Group on Invasive Alien Species. 2004. Proposed action plan for invasive alien terrestrial plants and plant pests- Phase 1. Terrestrial Plants and Plant Pests Working Group on Invasive Alien Species. 36 pp.

United States Department of Agriculture. (n.d.). Plants profile: Japanese barberry. http://plants.usda.gov/java/nameSearch?keywordquery=JAPANESE+BARBERRY&mode=comname&submit.x=16&submit.y=8. Accessed July 16, 2013.

Williams, S.C., J.S. Ward, T.E. Worthley and K.C. Stafford III. 2009. Managing Japanese barberry (Ranunculales: Berberidaceae) infestations reduces blacklegged tick (Acari: Ixodidae) abundance and infection prevalence with *Borrelia burgdorferi* (Spirochaetales: Spirochaetaceae). Environmental Entomology 38(4): 977-984.

Zouhar, Kris. 2008. *Berberis thunbergii*. In: Fire effects information system, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/. Accessed October 28, 2011.

Additional References

Benson, J. 2011. Deer are hosts for adult deer ticks and Japanese Barberry provides them a nursery. The Day, New London, Connecticut, U.S.A. http://www.theday.com/article/20110620/NWS01/306209953/-1/NWS. Accessed December 2011.

Jones, B. 2011. Barberry, bambi and bugs: the link between Japanese barberry and Lyme disease. Scientific American. http://blogs.scientificamerican.com/guest-blog/2011/03/30/barberry-bambi-and-bugs-the-link-between-japanese-barberry-and-lyme-disease/ Accessed December 2011.

Muma, W. 2011. Ontario trees and shrubs: Japanese barberry. http://ontariotrees.com/main/species.php?id=21. Accessed October 2011.

Myers, J. and D. Bazely. 2003. Ecology and control of invasive plants. Cambridge University Press, U.K.

Ontario Department of Agriculture and Food. 1968. Rid Ontario of common barberry and European buckthorn. Information Branch, Ontario Department of Agriculture and Food, Toronto. 8 PP.

Ontario Ministry of Agriculture and Food. 2011. Common Barberry and European buckthorn alternate hosts of cereal rust diseases. http://www.omafra.gov.on.ca/english/crops/facts/91-009.htm. Accessed October 2011.

Pearl, D. L., S. Koh, D. Bazely, D.R. Voigt, M. Tang and W. Soo. 1995. Interactions between deer and vegetation in southern Ontario, Canada: Monitoring and restoration of overgrazed plant communities in Pinery and Rondeau Provincial Parks. Unpublished report prepared for Southern Region Science & Technology Transfer Unit, OMNR.

Pennsylvania Department of Conservation and Natural Resources. 2011. Invasive exotic plant tutorial for natural lands managers. Species management and control information: Japanese barberry and European barberry. http://www.dcnr.state.pa.us/forestry/invasivetutorial/japanese_euro_barberry_M_C.htm. Accessed on October 2011.

Wisconsin Department of Natural Resources. 2005 (draft). Invasive plants in forestry - management guide: Japanese barberry (*Berberis thunbergii*). Wisconsin Department of Natural Resources, Division of Forestry. 2 pp.

Appendix 1- Excerpts from Literature Sources

The following summary includes information and excerpts from the peer-reviewed scientific literature and other reports that were reviewed in the preparation of this report.

Native Habitat:

- Japanese barberry is native to Japan and eastern Asia (Harmon 2006).
- The native habitat of Japanese barberry is found in the mountains of Japan where it grows as an understory forest shrub and functions in controlling erosion of the forest floor and as a food source for birds and small mammals. Populations in its native range are limited by island biogeography, climate and soil conditions (Harmon 2006).

Biology/Ecology:

General:

- Japanese barberry was introduced into North America from Japan around1875 (Wisconsin Department of Natural Resources 2005).
- It was first planted as an alternative to common barberry (*Berberis vulgaris*) and is not a host for black stem grain rust (Silander Jr., *et al*. 1999).
- It grows up to 1.8 m in height (Wisconsin Department of Natural Resources 2005).
- Japanese barberry can hybridize with common barberry (Silander Jr., *et al*. 1999).
- *B. thunbergii* (green form) is more vigorous and has a heavier dry weight than B. *thunbergii* var. *atropurpurea* (purple form) but both are equally capable of invasion (Silander Jr., *et al*. 1999).
- It forms dense stands in deciduous forests, abandoned fields, and roadsides (Silander Jr., *et al*. 1999).
- Factors leading to high density invasion of plants include: unpalatability to deer, high seed output, clonal spread by layering or root suckering, casting deep shade while surviving shade of present native species (Cassidy, *et al*. 2004).

Light and Soil Conditions:

- Japanese barberry is often associated with fertile, base-rich soils although it is also capable of tolerating moderately acidic soils (Cassidy, *et al*. 2004).
- It occurs on a variety of microsites, ranging from wetlands with saturated, organic soils to xeric ridgetops but it seems to prefer mesic conditions and is not as common on extremely wet or dry sites. Dense populations of Japanese barberry often occur

on soils derived from glacial till with loamy textures that are well drained to excessively well drained (Zouhar 2008).

- In northern New Jersey, Japanese barberry populations were associated with overstory canopies having a higher proportion of *Fraxinus americana* and lower proportion of Quercus species, and with understory layers having abundant *Microstegium vimineum* and decreased abundance of *Vaccinium*. These vegetation differences were correlated with an increased soil pH of 6.5 relative to 4.5 in adjacent areas, and decreased leaf litter and organic soil thickness. Dense barberry populations also had higher nitrogen availability and alien earthworm densities compared with uninvaded sites (Cassidy, *et al*. 2004).
- In one study (northern New Jersey), total soil carbon, total soil nitrogen, and net ammonification rates were higher under native vegetation. Soil pH, available nitrate, and net potential nitrification were significantly higher (P<0.001) in soils under Japanese barberry. Nitrate reductase activities were much higher in the leaves of Japanese barberry than in leaves of most native species tested, suggesting that Japanese barberry is better able to utilize the higher nitrate supplies. Earthworm densities were also higher in the soil under Japanese barberry as compared with soils under native blueberry and huckleberry (*Vaccinium* spp.). Because earthworms are associated with surface litter incorporation, increased pH, and increased nitrification, the authors suggest that the worms may have helped create a soil environment that promotes the growth of Japanese barberry more than native shrubs (Zouhar 2008).
- Nitrogen availability limited barberry growth and productivity but soil acidity or rock-derived nutrients (calcium, phosphorus, potassium, and manganese) did not (Zouhar 2008).
- According to one study of 35 sample sites in Storrs, Connecticut, soil conditions varied from moderately well-drained Dystrochrepts to poorly-drained Humaquept soils. Light varied from 1% to 89% of full sun and soil moisture varied from 10% to 42% (Silander Jr., *et al*. 1999).
- Survival of *B. thunbergii* was found to drop significantly only at very low light levels (Allen, *et al*. 2006)
- Japanese barberry can tolerate a wide range of light levels (as little as <1-2% full sun, however is rarely found under such dark canopy positions) and soil conditions. In full sun conditions it effectively competes with other fast growing woody species (*Rosa multiflora*, *Rhus toxicodendron L*., *Rubus* spp., *Celastrus orbiculatus*, and

various tree seedling and saplings) but does not dominate the system as it can under tree canopy or with persistent light grazing in pastures (Silander Jr., *et al*. 1999).

- A study of dense, continuous stands of Japanese barberry in the University of Connecticut Forest found that Japanese barberry fruit production varied with light level, but some seeds were produced even under very low light levels (≤4% full sun) (Zouhar 2008).
- Transplant experiments in the greenhouse suggest that Japanese barberry tolerates a full range of soil moisture regimes from very poorly drained soils with soil moisture content greater than 40%; to dry ridgetops with thin soil; to coarse-textured, extremely well-drained soils with soil moisture less than 10%. However, established adults were not found on these extreme sites in the field, probably because seedlings could not establish under those conditions (Zouhar 2008).
- While Japanese barberry often occurs on soils with higher pH and available nitrate than uninvaded sites these soil characteristics likely resulted from Japanese barberry invasion, rather than the reverse (Zouhar 2008).
- Invasion by woody shrubs may create a shift in forest under- and mid-story composition, which in turn may alter primary production, nutrient cycling, and carbon storage (Allen, *et al*. 2006)
- In one experiment a shift in the soil toward a relatively more bacterial-dominated system occurred when *B. thunbergii* was present in any quantity. In fact, replacing only 2.5% of the canopy litter with *B. thunbergii* litter nearly doubled the amount of bacteria relative to fungi. This suggests that during the initial stages of *B. thunbergii* invasion, there is a rapid and dramatic change in the soil microbial community, with a sudden increase in the relative abundance of bacteria (Elgersma, *et al*. 2011).

Germination/Survival:

- Japanese barberry is one of the first woody plants to leaf out in the spring and one of the last to drop its leaves in the fall (a characteristic found in other invasive shrubs) (Silander Jr., *et al*. 1999).
- Flowering occurs from mid-April to May in the northeast (USA) and fruits mature from July to October (Silander Jr., *et al*. 1999).
- Pollination of the flowers is affected by large and small bees. (Allen, *et al*. 2006)
- Plants produce large amounts of bird dispersed fruit (Silander Jr., *et al*. 1999).
- Seed can persist in the soil for over ten years (Harmon 2006).

- In New Jersey, it was observed that most berries simply drop to the ground beneath the parent plant. Similarly, of the 525 first-year seedlings mapped on Connecticut study sites, 92% were found underneath or within 3 feet (1 m) of the canopy of a Japanese barberry shrub (Zouhar 2008).
- Germination in ideal greenhouse conditions was 3 times greater than the cumulative rates in natural conditions over a 3 year study period (Lubell, *et al*. 2011).
- Estimating age is difficult since old stems die after 2 or 3 years and are replaced with new stems (Silander Jr., *et al*. 1999).
- The seeds germinate readily following cold stratification. Plants consist of multiple stems originating from the root collar, plus shoots arising from stolons and/or rhizomes within one to several decimetres of the roots. Shoots also arise from the rooting of long stems which touch the ground at some distance (1–2 m) from the root base (Ehrenfeld 1999).
- Barberry populations are notable for utilizing a large number of reproductive methods (seeds, above-ground and below-ground horizontal spread and genesis of clonal shoots, and layering), all affected by the vegetative increase in shoot number per plant (Ehrenfeld 1999).
- Barberry can form dense stands because of the high initiation rate and low mortality rate of stems grown from existing root collars, high rates of seedling recruitment, and the clonal spread by layering or root suckering (Cassidy, *et al*. 2004).
- Frequent grass-fueled fires can limit or prevent recruitment of woody species, including invasives (Mandle, *et al*. 2011).
- There was very low survival (11%) in pine woods environment due to the thick needle duff layer and possibly low soil nutrient content and pH. By the end of the 3 year study *B. thunbergii* (green form) had a higher survival rate of 15.7% than *B. thunbergii* var. *atropurpurea* (purple form) at 6.9% (Lubell, *et al*. 2011).
- Japanese barberry competes poorly with grasses and may succumb to drought conditions (Wisconsin Department of Natural Resources 2005).
- New England study: The dry deciduous woods, full sun meadow and edge of woods environments had 2 year survival greater than 10% , which is substantial given the large number of seeds that can be produced by mature barberries. It seems likely that the survivors at these three environments could start an invasion since most of them had reached a large enough size where continued survival would be expected. Survival at the edge of woods environment dropped dramatically from 41.3% in 2005 to 13.5% in 2006. The rapid decline in survival was likely due to competition from

encroaching vegetation, especially bittersweet. Survival in the moist woods environment was relatively poor and may be attributable to root zone environment that was too moist for barberry, which prefers well-drained soils. Heavy slug feeding on barberry in the moist woods environment was also noted. Dramatic decreases in survival rates from 2005 to 2006 were not found at the dry deciduous woods and full sun meadow environments. No seedlings survived for 2 years at the pine woods environment due to poor initial germination and the thick litter layer that prevented seedling roots from reaching consistently moist soil (Lubell, *et al*. 2011).

- Japanese barberry has a large, shallow root system with rhizomes and many fine roots radiating from a root crown. Japanese barberry populations studied on invaded sites at 3 locations in northern New Jersey produced large amounts of fine-root biomass in the surface soils, about 3 times the root biomass of native blueberries in the same areas. Sprouts occur from rhizomes at variable distances from the root base and form diffuse swarms of stems (Zouhar 2008).
- Following damage or removal of aboveground stems, Japanese barberry can regenerate by sprouting from stumps, root crowns, and underground organs (Zouhar 2008).
- It is suggested that even if Japanese barberry is removed, it is very likely that differences in the soils will persist for a prolonged period after that, which might significantly impede the restoration of native flora in the cleared sites (Zouhar 2008).

Habitat:

- It occurs in upland and riparian settings, wetlands, pastures, and meadows. It occurs more frequently and is more abundant in postagricultural forests than in less disturbed, continuously wooded sites (Zouhar 2008).
- In general, Japanese barberry seems to prefer mesic conditions, and invasive populations often occur near homesites, roads, and trails (Zouhar 2008).
- Japanese barberry can occur in relatively undisturbed forest and invasive populations are often described in second-growth forests that were formerly cleared for agriculture or timber harvest especially former pastures (Zouhar 2008).
- It is suggest that the northern limits of Japanese barberry distribution are probably set by low temperature tolerances, the southern limits by cold stratification requirements and the western limits by drought tolerance (Zouhar 2008).
- Japanese barberry forms dense stands in deciduous forests, abandoned fields, and roadsides (Silander Jr., *et al*. 1999).

- Looking at land-use history, the preferred (New England) habitat was pasture turned to forest areas, with post-agricultural settings have the highest incidence of invasion. Areas developed for residential/commercial use regardless of use history, had significantly lower invasive prevalence. Areas that have not undergone any change in land use since 1934 (stable forests and continuously cultivated fields) have the lowest incidence of woody plant invasions. Therefore invasions appear strongly connected to a pattern of agricultural abandonment (Mosher, *et al*. 2009).
- Japanese barberry is frequently found in (New Jersey) protected forest areas in metropolitan regions, even in relatively large parks and forests (>8000 ha). It occurs in a wide variety of forest types and habitat conditions, ranging from wetlands with saturated, organic soils to xeric ridgetops, although it tends to be less abundant on northwestfacing slopes and in oak-dominated forests. Although in many invaded forests the shrub occurs as sparse, scattered individuals, it also forms dense, nearly impenetrable thickets, even under closed canopies. In these thickets, native shrub species are absent (Kourtev *et al*. 1998), and the diversity of native herb species is also low (Ehrenfeld 1999).
- Open meadow sites that receive high sunlight are more at risk for barberry invasion than wooded environments, and wooded environments with adequate soil moisture content are more at risk than wooded sites having a dry, thick leaf litter layer (Lubell, *et al*. 2011).
- The strong relationship between modern abundance of Japanese barberry (USA) and historical agriculture suggests that Japanese barberry established in open fields and persisted as sites succeeded to forest (Zouhar 2008).

Range:

- In Canada, Japanese barberry is found in southern Ontario and Quebec, New Brunswick and Nova Scotia (Muma 2011).
- In North America, the range of Japanese barberry extends from Nova Scotia south to North Carolina, and westward to Montana (Wisconsin Department of Natural Resources 2005).
- Japanese barberry distribution in North America (2008) is from Quebec and Ontario in Canada, south to Georgia and Tennessee, and westward to the eastern edge of North and South Dakota, Nebraska, and Kansas. In the United States it is most abundant throughout the northeast with the exception of northern Maine and northern Vermont (Zouhar 2008).

Fire:

- Woody species can alter fire regimes (frequency, intensity, seasonality). Intrinsic fuel properties include the amount of moisture present in plant tissues, ignitability, and the heat released during combustion (Mandle, *et al*. 2011).
- It is suggested that Japanese barberry is likely to survive low-severity fire and maintain its population size after a burn, but that it may be reduced in community importance after repeated (annually consecutive for at least 2 to 5 years), growing-season (spring to early summer) fires (Zouhar 2008).
- One study reports establishment of Japanese barberry four years after a prescribed fire in a mature stand of red pine (*Pinus resinosa*) and eastern white pine (*Pinus strobus*) in Michigan. Japanese barberry seedlings were absent from all plots subject to biennial burning (1991, 1993, and 1995) when sampled in 1994 and 1995, and were absent from once-burned (in 1991) and unburned control plots in 1994. In 1995, Japanese barberry occurred at 0.9% relative frequency and 0.33% cover on once-burned plots and at 0.4% relative frequency and 0.03% cover on unburned control plots (Zouhar 2008).
- One study evaluated the effectiveness of applying cutting and burning treatments at different times of year in reducing sprout "vigor". All treatments, regardless of timing, reduced Japanese barberry cover for over 1 year, with a decrease of nearly 90% in treatments that included a burn. Sprout height, biomass, and density were generally similar between cut plots and burned plots but were not compared to control plots (Zouhar 2008).
- Managers should be alert to the possibility of post-fire establishment given the ability of Japanese barberry to establish in early successional environments (Zouhar 2008).
- It is suggested that an ideal treatment scenario to control woody invasives would include cutting early in the growing season followed by burning later in the season but before sprouting plants have fully recovered their root total nonstructural carbohydrate reserves. This would force the plants to sprout again and further deplete their reserves. If the fire treatment occurs in mid- to late summer, plants would enter the dormant season with substantially reduced potential for "vigorous" growth the next spring. Reserves can be further depleted by treating multiple times during the growing season, although several years of treatments would still be required. Generally, the first treatment should be mechanical followed by a prescribed burn to remove slash. Removal treatments after fire would have to be mechanical, because the prescribed burn would leave insufficient fine fuels to allow

a second burn within the same season. Japanese barberry leafs out much earlier than native species. Therefore, it may be possible to apply an early spring treatment after root carbohydrate depletion begins in Japanese barberry but prior to depletion of native species' reserves (Zouhar 2008).

- Custom fuel models were constructed for Japanese barberry under 3 conditions: untreated control, growing-season cut, and dormant-season cut. The custom fuel model predicted fire behaviour well in the dormant season, but predicted greater flame length and rate of spread than was observed in the growing season. Generally, these custom fuel models did not perform any better than standard fuel models for predicting fire behaviour in Japanese barberry (Zouhar 2008).

Wildlife Use:

- Deer herd population in Rondeau Provincial Park affects the existence of Japanese barberry. Deer do not prefer to graze it and so *B. thunbergii* may have a competitive advantage over native species in recovering grazed areas. Following reduced deer densities, *B. thunbergii* continued to increase significantly (Pearl *et al.*1995, Myers and Bazely 2003).
- It is suggested that high densities of deer may contribute to the spread of Japanese barberry because deer dislike it and browse on natives, giving Japanese barberry an advantage. On one site in northern New Jersey, researchers observed that heavy white-tailed deer browsing eliminated most other shrubs. A study in deciduous forest in Rondeau Provincial Park, Ontario, found that Japanese barberry occurrence was characteristic of plots grazed by white-tailed deer (Zouhar 2008).
- Although white-tailed deer do not browse the foliage of *B. thunbergii*, it is suggested that dense populations of white-tailed deer in the Northeast may be agents of long-distance dispersal of Japanese barberry fruits, because hoofed browsers, especially white-tailed deer, eat barberries (*Berberis* spp.) "freely" and are known to disperse fruits of other *Berberis* species in western North America (Zouhar 2008).
- Ground dwelling fauna (turkey, chipmunk, grouse, rabbits, etc.) were observed to be equal or more important in seed dispersal than passerine birds (Ehrenfeld 1999).
- Japanese barberry also provides nesting areas for white-footed mice and other rodents (Jones 2011).
- Veeries build nests in Japanese barberry more often than in any other substrate in forests of southeastern New York. Ground nests are second most common. Predation rates did not differ between nests in Japanese barberry and those in

native shrubs, but predation rates were higher in nests on the ground than in nests in either shrub type. In a study examining 4,085 gray catbird nests over a 27-year period (1934-1960) in Michigan, Ohio, Kentucky, and Ontario, 138 nests (3.4% of the nests observed) were located in Japanese barberry shrubs (Zouhar 2008).

- Recent increases in wild turkey populations may contribute to Japanese barberry spread (Zouhar 2008).
- Birds that disperse barberries either feed directly on the fruit pulp and discard the seeds locally or ingest the entire fruit and defecate the seeds elsewhere. Several ground-dwelling birds including ruffed grouse, northern bobwhite, ring-necked pheasant, and wild turkey are listed as dispersal agents for Japanese barberry seed, and observations suggest that these and other ground-dwelling fauna may be as or more important than passerine birds for regional dispersal Wild turkey and grouse are known to use Japanese barberry fruits heavily. The brightly colored fruits of Japanese barberry are available to birds throughout the winter, but they do not seem to be preferred and are generally a low-priority food item for many birds. These birds eat them primarily late in the season and in critical periods when other foods are scarce or absent (Zouhar 2008).

Link to Lyme Disease:

- In forests with high deer populations that eat most every other plant - Japanese barberry forms thick canopies, which also creates moist, cool shelters that harbour ticks that carry the Lyme disease bacteria (Benson, J. 2011).
- Deer serve as hosts for adult ticks, while the barberry functions as a nursery for ticks in their juvenile stages (Benson, J. 2011).
- Tick abundance (28 study areas in Connecticut) in barberry-infested areas is 67% higher than those where native plants are predominant. The percentage of ticks that carry the Lyme bacteria is higher - 126 infected ticks per acre versus per acre in barberry-free areas, though the reason for that is as yet unclear. After barberry removal tick populations drop as much as 80% (Benson, J. 2011).
- Japanese barberry has denser foliage than most native species. As a result, the plants retain higher humidity levels. Ticks need humidity and become desiccated when levels drop below 80 percent. Relative humidity under a barberry is about 100 percent at night (Jones 2011).

- Japanese barberry also provides nesting areas for white-footed mice and other rodents, which are primary sources for larval ticks' first blood meal, and reservoirs for *Borrelia burgdorferi* (Jones 2011).
- In the open, ticks can only be active for 15-16 hours per day, but when they're protected by Japanese barberry, that number increases to 23 or 24 (Jones 2011).
- One study suggests that understory types dominated by deer browse-resistant exotic-invasive shrub species (65% Japanese barberry) had higher abundance of both adult and nymphal blacklegged ticks than in understory types dominated by native shrubs and that the blacklegged tick can complete its entire lifecycle in an exotic-invasive understory type (Elias, *et al*. 2006).

Control:

- The herbicide glyphosphate (Roundup) is up to 100% effective, when applied correctly, in early April at first leaf out while little or nothing else was in leaf and had no effect on other present vegetation (Silander Jr., *et al*. 1999).
- Manual removal is less effective because it is time consuming, difficult and because Japanese barberry will resprout from stem fragments left in the ground. However, control methods of mechanical cutting and then burning of Japanese barberry clumps were successful in reducing Japanese barberry cover from 62% to 3% over a two year study (Williams *et al*. 2009).
- Control may be most effective by focusing on small newly expanding populations (Silander Jr., *et al*. 1999).
- In a study in Rondeau Provincial Park (June-July 1994) showed that plants that were only cut had regrowth shortly after but plants that were pulled or cut with spraying treatments showed no regrowth by the end of the field season (Pearl *et al*.1995).
- Fire can be a successful means of control if followed with herbicide application (Mandle, *et al*. 2011).
- Japanese barberry may be relatively easy to control in fire-adapted communities. Fire is thought to kill these plants and prevent future establishment (Wisconsin Department of Natural Resources 2005).
- Cutting, pulling or digging are effective in areas where there are only a few plants (Wisconsin Department of Natural Resources 2005).
- Triclopyr has been used as a cut-stump treatment with success. Other herbicides labeled for brush control, such as glyphosate, can be effective. Care in application is

essential because glyphosate is a non-selective herbicide that can kill native species as well (Wisconsin Department of Natural Resources 2005).

- It is suggested that an ideal treatment scenario to control woody invasives would include cutting early in the growing season followed by burning later in the season but before sprouting plants have fully recovered their root total nonstructural carbohydrate reserves. This would force the plants to sprout again and further deplete their reserves. If the fire treatment occurs in mid- to late summer, plants would enter the dormant season with substantially reduced potential for "vigorous" growth the next spring. Reserves can be further depleted by treating multiple times during the growing season, although several years of treatments would still be required. Generally, the first treatment should be mechanical followed by a prescribed burn to remove slash. Removal treatments after fire would have to be mechanical, because the prescribed burn would leave insufficient fine fuels to allow a second burn within the same season. Japanese barberry leafs out much earlier than native species. Therefore, it may be possible to apply an early spring treatment after root carbohydrate depletion begins in Japanese barberry but prior to depletion of native species' reserves (Zouhar 2008).
- Hand Pull: This method of control is effective for small populations of Japanese barberry, since plants pull up easily in most forested habitats. Hand-pulling is an extremely effective method of reducing population and seed productivity; this can be done during most of the year. Barberry is especially easy to see in the winter and early spring before deciduous plants leaf out. If plants have fruit present, they should be bagged and disposed of to prevent seed dispersal. Care should be taken to minimize soil disturbance (Pennsylvania Department of Conservation and Natural Resources 2011).
- Mowing/Cutting: This method is appropriate for initial small populations or environmentally sensitive areas where herbicides cannot be used. Repeated mowing or cutting will control the spread of Japanese barberry but will not eradicate it. Stems should be cut at least once per growing season as close to ground level as possible. Hand-cutting of established clumps is difficult and time consuming due to the long arching stems and prolific thorns (Pennsylvania Department of Conservation and Natural Resources 2011).
- Treatments using the systemic herbicides glyphosate (e.g., Roundup) and triclopyr (e.g., Garlon) have been effective in managing Japanese barberry infestations that are too large for hand pulling. For whole plant treatment, apply a 2% solution of

glyphosate mixed with water and a surfactant. This non-selective herbicide should be used with care to avoid impacting non-target native plants. Application early in the season before native vegetation has matured may minimize non-target impacts. However, application in late summer during fruiting may be most effective. Triclopyr or glyphosphate may be used on cut stumps or as a basal bark application in a 25% solution with water, covering the outer 20% of the stump (Pennsylvania Department of Conservation and Natural Resources 2011).

- Foliar Spray Method: This method should be considered for large thickets of barberry where risk to non-target species is minimal. Air temperature should be above 65 °F to ensure absorption of herbicides. Glyphosate: Apply a 2% solution of glyphosate and water plus a 0.5% non-ionic surfactant to thoroughly wet all leaves. Use a low pressure and coarse spray pat-tern to reduce spray drift damage to non-target species. Glyphosate is a non-selective systemic herbicide that may kill non-target partially-sprayed plants. Triclopyr: Apply a 2% solution of triclopyr and water plus a 0.5% non-ionic surfactant to thoroughly wet all leaves. Use a low pressure and coarse spray pattern to reduce spray drift damage to non-target species. Triclopyr is a selective herbicide for broadleaf species. In areas where desirable grasses are growing under or around Japanese barberry, triclopyr can be used without non-target damage (Pennsylvania Department of Conservation and Natural Resources 2011).
- Cut Stump Method: This control method should be considered when treating individual bushes or where the presence of desirable species precludes foliar application. Stump treatments can be used as long as the ground is not frozen. Glyphosate: Horizontally cut barberry stems at or near ground level. Immediately apply a 25% solution of glyphosate and water to the cut stump, covering the outer 20% of the stump. Triclopyr: Horizontally cut barberry stems at or near ground level. Immediately apply a 25% solution of triclopyr and water to the cut stump, covering the outer 20% of the stump (Pennsylvania Department of Conservation and Natural Resources 2011).
- No one life-stage or size-class can be targeted. Because of the presence of multiple forms of spread and the density-dependence of recruitment, both large and small individuals need to be managed. Large individuals are important sources of seeds; one large individual is probably responsible for the genesis of many dense populations. However, small stems are the source of much of the stem density in all populations; removing barberry populations necessarily means removing or treating

with herbicide the numerous small stems. Furthermore, the very low to non-existent mortality of plants that are still fairly small (three stems) suggests that unless even small plants are manually removed, they will persist indefinitely. Clearly, the removal of isolated individuals of any size should be a priority, in order to prevent its local spread. Finally, when faced with limited resources and large infested areas, targeting large plants, particularly in sparse to moderate populations, might be the most effective way to at least prevent the genesis of new thickets (Ehrenfeld 1999).

- Banning the sale of Japanese barberry has been recommended to assist with control. Gardeners should be encouraged not to plant Japanese barberry (Harmon 2006). Development of varieties with low seed production may be an approach to reduce invasiveness (Ormrod, pers. comm. 2012).

Introduction of Japanese Barberry in North America

- Japanese barberry was first planted in an arboretum in Boston in 1875 (Silander and Klepeis 1999), although it may have been documented in the U.S. as early as 1818 (Zouhar 2008).
- Japanese barberry was not commonly marketed as an ornamental shrub before the 1900's. It began to be promoted as a substitute for common barberry at the time that this species was being eradicated during the early part of the 20th century (Silander and Klepeis 1999).
- There is little evidence of it becoming naturalized before 1910. Since 1910, it has become fully naturalized throughout most of the northeastern states and is considered to be the most widely planted exotic shrub in the U.S. (Silander and Klepeis 1999).
- During the 1920's, Japanese barberry began to be promoted for landscaping to replace the common barberry (*Berberis vulgaris*). Common barberry, a naturalized European shrub, was the focus of eradication efforts during the 1910's because it was an alternate host for black stem rust, a disease of wheat and other cereal crops (Harmon 2006).
- Japanese barberry became popular as a hedge along walkways or to demarcate property boundaries, but was also used to stabilize slopes or as a specimen plant, and was promoted as being resistant to deer browsing (Harmon 2006, Ormrod, pers. comm. 2012).
- By the 1960's naturalized populations were widely dispersed in the U.S. (Harmon 2006).

- It is now present in 32 eastern and north central states and five Canadian provinces, including Ontario, Quebec, New Brunswick, Nova Scotia and Prince Edward Island (United States Department of Agriculture n.d.).
- Japanese barberry is considered invasive in 20 U.S. states. Its distribution and invasiveness is probably limited in the south by requirements for cold stratification of seeds for germination and to the west by drought (Harmon 2006). Winter hardiness may limit its establishment in Canadian prairie provinces (Canada Gazette 2001).
- The potential invasiveness of Japanese barberry was considered by the Canadian Food Inspection Agency in making the decision to amend the Plant Protection Regulations in 2001. A survey of scientific experts in all provinces indicated that while Japanese barberry was established in scattered locations in many provinces, it was not considered by provincial experts to be an invasive plant (Canada Gazette 2001).

Regulation of Japanese Barberry in Canada

- The importation and movement of Japanese barberry in Canada was banned between 1966 and 2001 (Canada Gazette 2001, Drysdale 2000).
- The ban was enacted due to the potential for Japanese barberry to act as an alternate host for black stem rust, a disease of wheat and other cereal crops. Japanese barberry readily hybridizes with common barberry, a known alternate host for the rust (Canada Gazette 2001).
- In addition to the 1966 ban, there were Japanese barberry eradication programs in Canada around the 1940's before breeding programs were conducted to develop wheat that was resistant to black stem rust. Alternate hosts for the rust continued to be suppressed from the 1960's to 2000. Eradication programs were probably focused on agricultural areas and may not have been as aggressively pursued in southern Ontario as in wheat-producing areas in the prairies (Ormrod, pers. comm. 2012).
- A 1968 brochure by the Ontario Department of Agriculture and Food promotes the eradication of common barberry and European buckthorn to help control stem rust infection of agricultural crops. The "harmless Japanese barberry" is described as one of the most widely planted kinds of barberry that that can be grown without risk of stem rust to grains (Ontario Department of Agriculture and Food 1968).
- At the time of the ban, Japanese barberry cultivars were the top selling deciduous shrub (Drysdale 2000).

- After 1966, existing stocks were allowed to be sold legally until the early 1970's (Drysdale 2000). Some nurseries may have continued to sell Japanese barberry illegally (Ormrod, pers. comm. 2012, Drysdale 2000).
- Japanese barberry was not banned in the U.S. and continued to be legally available as a landscaping shrub during the period of the prohibition in Canada (Canada Gazette 2001).
- Seed dispersal by birds migrating from the U.S., where Japanese barberry was never banned, may be a factor in the establishment of populations in Ontario (Ormrod, pers. comm. 2012).
- In 2001, the Plant Protection Regulations under the Plant Protection Act were amended to allow the importation from the U.S., domestic movement and vegetative propagation in Canada of certain varieties of Japanese barberry that have been determined to be resistant to black stem rust. Only vegetative propagation is allowed to reduce the potential for non-resistant cultivars or hybrids produced through sexual reproduction (Canada Gazette 2001).
- The benefits to the nursery industry of the regulation change are estimated at $1.3M per year. Plants are expected to be imported mainly into Ontario, British Columbia and Quebec (Canada Gazette 2001).
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Appendix 2- Correlation and Principal Component Analysis

Table 10. Correlation Matrix for all variables and PCA biplots

	Easting	Northing	Canopy.closure	Basal.Area	Mean.DBH	N.Trees	Shrub.Closure	JB.Ln.Count	JB.Dom.0.6	JB.Dom.0.4	JB.Frt.Bin	Road.Dm	Infra.Dm	Trail.Dm	Cottage.Dm	GCamp.Dm	MCamp.Dm	RdSS.Dm	PB.Dm	Comp.Dm
Easting	1.000	0.547	-0.006	-0.206	-0.080	-0.195	0.204	0.323	0.275	0.289	0.129	-0.793	-0.208	-0.302	-0.961	-0.522	-0.565	-0.876	-0.865	-0.568
Northing	0.547	1.000	0.516	-0.211	-0.111	-0.176	0.267	0.234	0.262	0.282	0.003	-0.620	-0.080	-0.121	-0.439	-0.733	-1.000	-0.727	-0.413	-0.999
Canopy.closure	-0.006	0.516	1.000	0.153	-0.011	0.178	-0.098	0.071	0.093	0.115	-0.058	-0.131	-0.067	0.027	0.056	-0.266	-0.508	-0.105	-0.026	-0.506
Basal.Area	-0.206	-0.211	0.153	1.000	0.566	0.605	-0.204	-0.183	-0.152	-0.148	-0.155	0.297	0.105	-0.004	0.185	0.284	0.213	0.217	0.190	0.216
Mean.DBH	-0.080	-0.111	-0.011	0.566	1.000	-0.104	-0.070	-0.090	-0.074	-0.064	-0.050	0.136	-0.048	-0.138	0.069	0.155	0.113	0.093	0.089	0.118
N.Trees	-0.195	-0.176	0.178	0.605	-0.104	1.000	-0.313	-0.112	-0.088	-0.092	-0.111	0.243	0.158	0.155	0.187	0.196	0.178	0.185	0.177	0.175
Shrub.Closure	0.204	0.267	-0.098	-0.204	-0.070	-0.313	1.000	0.077	0.171	0.144	0.145	-0.246	-0.119	0.001	-0.233	-0.018	-0.268	-0.154	-0.219	-0.262
JB.Ln.Co	0.3	0.2	0.0	-	-	-	0.0	1.0	0.8	0.8	0.5	-	-	-	-	-	-	-	-	-

	Easting	Northing	Canopy.closure	Basal.Area	Mean.DBH	N.Trees	Shrub.Closure	JB.Ln.Count	JB.Dom.0.6	JB.Dom.0.4	JB.Frt.Bin	Road.Dm	Infra.Dm	Trail.Dm	Cottage.Dm	GCamp.Dm	MCamp.Dm	RdSS.Dm	PB.Dm	Comp.Dm
unt	23	34	71	0.183	0.090	0.112	77	00	68	80	48	0.299	0.013	0.111	0.254	0.405	0.241	0.319	0.301	0.248
JB.Dom.0.6	0.275	0.262	0.093	-0.152	-0.074	-0.088	0.171	0.868	1.000	0.987	0.625	-0.223	0.036	-0.090	-0.218	-0.341	-0.266	-0.282	-0.276	-0.272
JB.Dom.0.4	0.289	0.282	0.115	-0.148	-0.064	-0.092	0.144	0.880	0.987	1.000	0.629	-0.239	0.021	-0.108	-0.231	-0.356	-0.286	-0.292	-0.293	-0.292
JB.Frt.Bin	0.129	0.003	-0.058	-0.155	-0.050	-0.111	0.145	0.548	0.625	0.629	1.000	-0.030	0.082	-0.089	-0.125	-0.083	-0.007	-0.066	-0.203	-0.008
Road.Dm	-0.793	-0.620	-0.131	0.297	0.136	0.243	-0.246	-0.299	-0.223	-0.239	-0.030	1.000	0.443	0.095	0.748	0.617	0.630	0.757	0.611	0.633
Infra.Dm	-0.208	-0.080	-0.067	0.105	-0.048	0.158	-0.119	-0.013	0.036	0.021	0.082	0.443	1.000	0.134	0.241	-0.065	0.084	0.120	0.081	0.073
Trail.Dm	-0.302	-0.121	0.027	-0.004	-0.138	0.155	0.001	-0.111	-0.090	-0.108	-0.089	0.095	0.134	1.000	0.289	0.025	0.125	0.185	0.372	0.125
Cottage.Dm	-0.9	-0.4	0.056	0.185	0.069	0.187	-0.2	-0.2	-0.2	-0.2	-0.1	0.748	0.241	0.289	1.000	0.353	0.457	0.770	0.890	0.456

	Easting	Northing	Canopy.closure	Basal.Area	Mean.DBH	N.Trees	Shrub.Closure	JB.Ln.Count	JB.Dom.0.6	JB.Dom.0.4	JB.Frt.Bin	Road.Dm	Infra.Dm	Trail.Dm	Cottage.Dm	GCamp.Dm	MCamp.Dm	RdSS.Dm	PB.Dm	Comp.Dm
	61	39					33	54	18	31	25									
GCamp.Dm	-0.522	-0.733	-0.266	0.284	0.155	0.196	-0.018	-0.405	-0.341	-0.356	-0.083	0.617	-0.065	0.025	0.353	1.000	0.737	0.743	0.303	0.751
MCamp.Dm	-0.565	-1.000	-0.508	0.213	0.113	0.178	-0.268	-0.241	-0.266	-0.286	-0.007	0.630	0.084	0.125	0.457	0.737	1.000	0.739	0.429	0.999
RdSS.Dm	-0.876	-0.727	-0.105	0.217	0.093	0.185	-0.154	-0.319	-0.282	-0.292	-0.066	0.757	0.120	0.185	0.770	0.743	0.739	1.000	0.594	0.743
PB.Dm	-0.865	-0.413	-0.026	0.190	0.089	0.177	-0.219	-0.301	-0.276	-0.293	-0.203	0.611	0.081	0.372	0.890	0.303	0.429	0.594	1.000	0.430
Comp.Dm	-0.568	-0.999	-0.506	0.216	0.118	0.175	-0.262	-0.248	-0.272	-0.292	-0.008	0.633	0.073	0.125	0.456	0.751	0.999	0.743	0.430	1.000

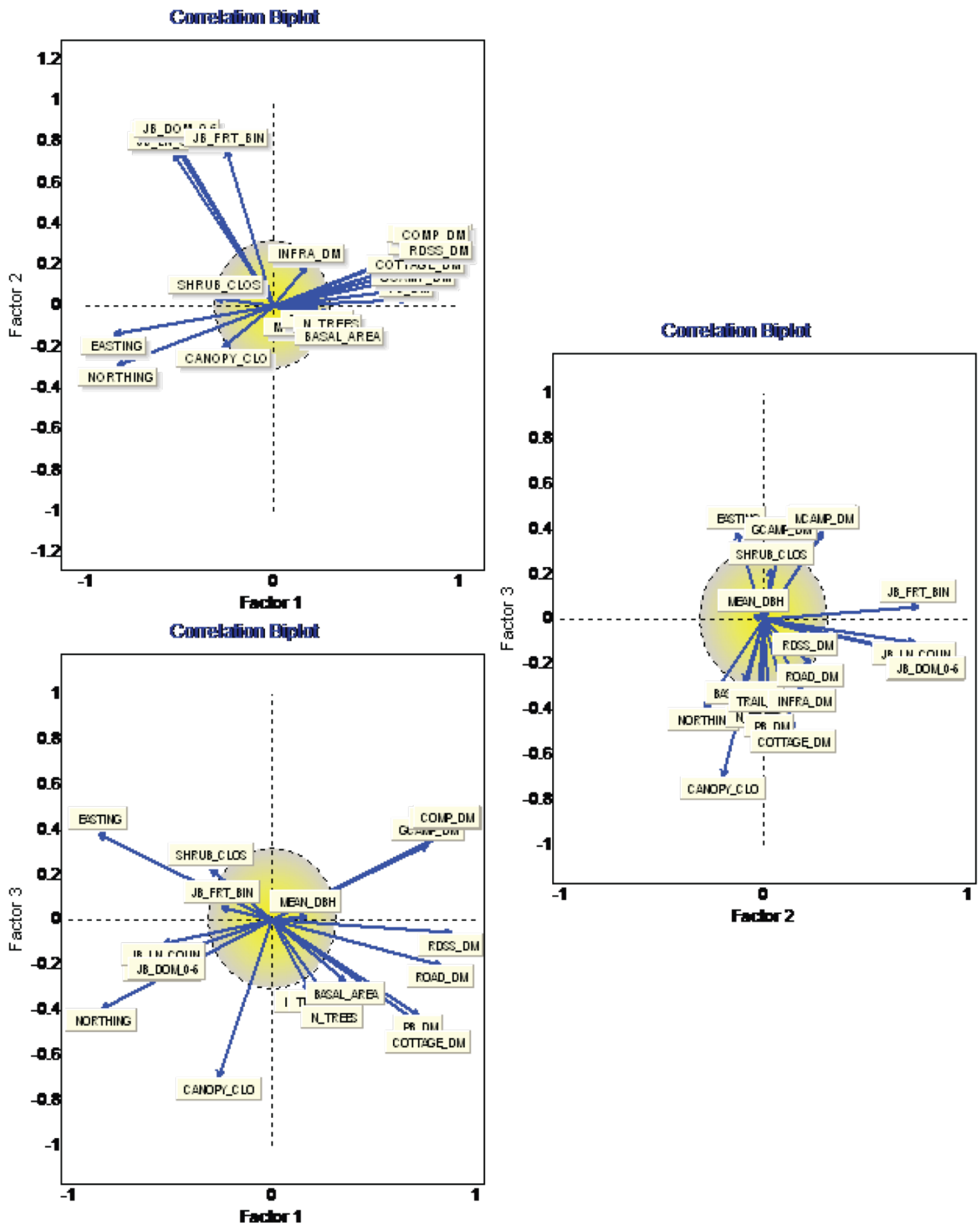

Figure 14. Principle Component Analysis biplots

Table 11. Principal component loadings; rose shading indicates high positive component loading, light gray indicates high negative component loading

	Component number and loadings			
Variable	1	2	3	4
Easting coordinates	-0.85	-0.137	0.377	-0.237
Northing coordinates	-0.835	-0.291	-0.395	0.081
Canopy closure	-0.262	-0.2	-0.699	-0.126
Basal area (m2)	0.354	-0.097	-0.277	-0.806
Mean dbh (cm)	0.168	-0.048	0.01	-0.589
Number of trees	0.296	-0.035	-0.382	-0.498
Shrub_closure	-0.306	0.034	0.216	0.3
Log of barberry stem count	-0.53	0.736	-0.105	-0.068
Barberry Dominance (7 Class)	-0.517	0.797	-0.164	-0.064
Barberry Dominance (5 Class)	-0.535	0.788	-0.172	-0.083
Fruiting	-0.25	0.751	0.053	-0.014
Distance to road	0.821	0.228	-0.201	-0.004
Distance to park Infrastructure	0.182	0.187	-0.313	0.023
Distance to trail	0.242	-0.014	-0.313	0.359
Distance to cottage lot	0.764	0.138	-0.49	0.261
Distance to main campground	0.845	0.289	0.381	-0.074
Distance to group campground	0.758	0.078	0.327	-0.138
Distance to cottage lot with barberry observed	0.878	0.203	-0.062	0.1
DIstance to prescribed burn boundary	0.718	0.025	-0.425	0.27
Distance to compost area	0.848	0.284	0.385	-0.075
Proportion of variance accounted for	0.368	0.142	0.109	0.087
Cumulative proportion of variance	0.368	0.51	0.619	0.706

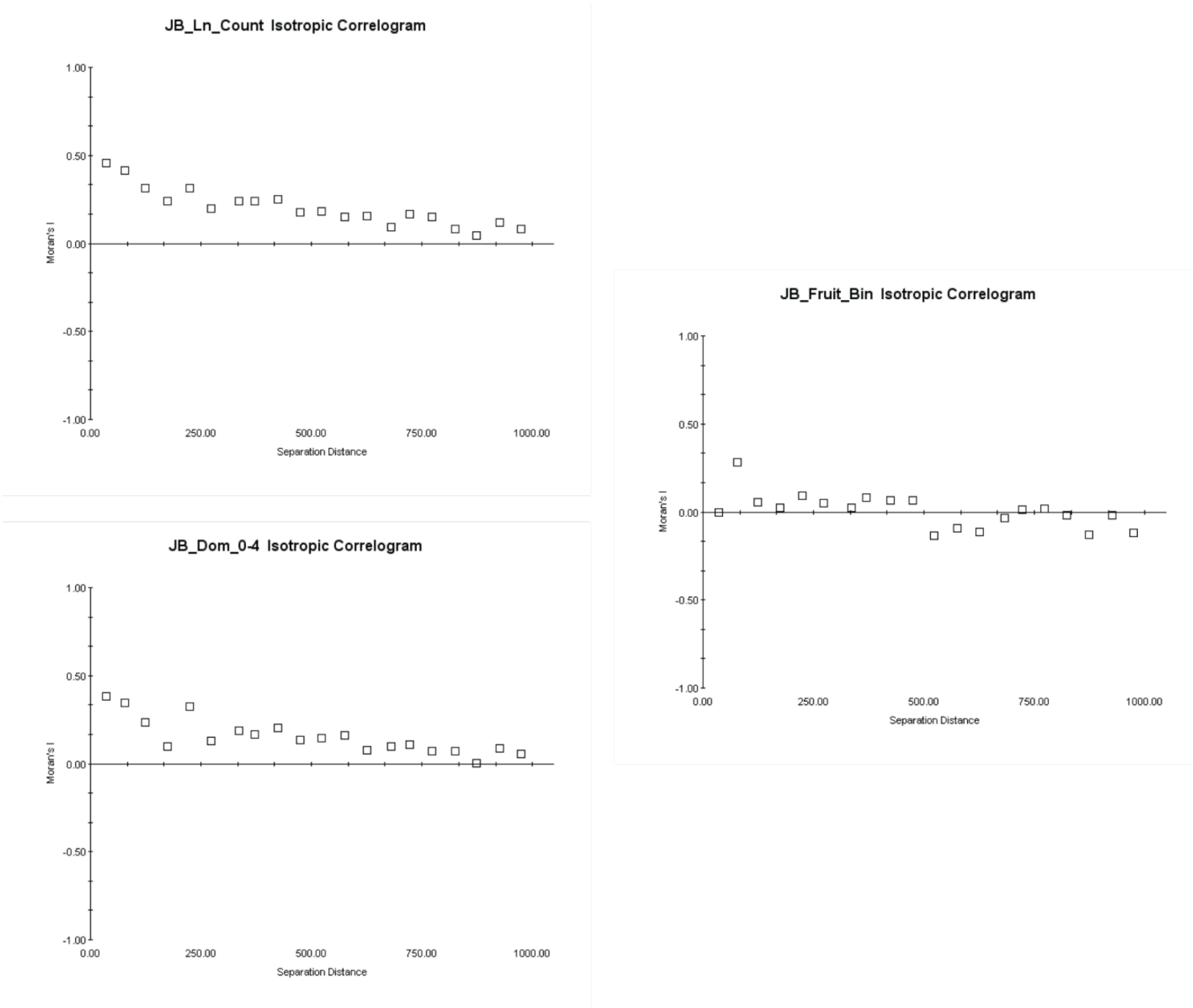

Figure 15. Correlograms of Response variables