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Community ecology and invasion of natural vegetation by *Cynanchum rossicum* (Asclepiadaceae) in the Toronto region, Canada

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Abstract: Habitat preferences of the invasive alien species *Cynanchum rossicum* (KLEOPOW) BORHIDI in northeastern United States and southeastern Canada are characterized on the basis of data from both field studies and literature. *C. rossicum* behaves more as a habitat generalist in North America, compared to its native range in Europe, particularly with respect to shade tolerance and soil type. It is prevalent in forest habitats as well as open meadow and savannah or woodland; and occurs mainly on loam and sandy loam soils. The ecology and structure of vegetation communities affected by *C.rossicum* is analyzed in the Toronto region, Canada where the phytocoenological optimum of *C. rossicum* occurs in semi-open communities. *C. rossicum* tends to be the primary or secondary dominant species in infested vegetation community polygons (43% and 26%, respectively). The area infested by *C. rossicum* includes 1813.21 ha or 7.25% of surveyed natural cover in the Toronto region. Young-to-mid-aged forests and plantations as well as semi-open successional communities tend to have the most severe infestations. *C. rossicum* is a serious threat to rare plant communities such as alvars, tallgrass oak savannahs and woodlands and their associated species.

Keywords: conservation biology, habitat preferences, infestation, invasive species, vegetation cover.

Introduction

Invasive alien species are increasingly being recognized as one of the most important threats to biodiversity worldwide (VITOUSEK et al. 1996; ADAIR & GROVES 1998; PARKER et al. 1999; MACK et al. 2000). In the USA, invasive alien species are ranked as one of the top threats to endangered species (WILCOVE et al. 1998; SALA et al. 2000). The proportion of endangered species in Canada that is threatened by alien invasions has reached 22% (VENTER et al. 2006).

There has been much research on invasive alien plants' behaviour and control methods, but often relatively little detailed investigation of these species' community ecology. Only recently have researchers started to analyse possible relationships between invasive alien plant distribution, species traits (RICHARDSON, PYŠEK 2006; PYŠEK et al. 2009) and habitats (HEJDA et al. 2009) in native ranges and new invaded regions. Comparison of plant ecology in a species' home and introduced ranges may reveal both the plant's strategies of invasion and help to illuminate possible methods of control. This paper examines the ecology of one invasive species from eastern Europe that has affected parts of eastern North America: *Cynanchum rossicum* (KLEOPOW) BORHIDI (syn. *Vincetoxicum rossicum* (KLEOPOW) BARBARICH).

As concern about the invasiveness of *C. rossicum* in North America rises, an increasing amount of information is available on its ecology and biology. Recent comprehensive reviews of this species have been published (MILLER & KRICSFALUSY 2008; DOUGLASS et al. 2009). Nonetheless, significant gaps in knowledge remain, particularly regarding this species' habitats, community ecology and impact on natural vegetation.

Our previous study of *C. rossicum* was undertaken to assess its distribution patterns in southeastern Canada as well as estimate the rate of spread and colonization success of this alien species in the Toronto region given that *C. rossicum* is one of the most severe threats to natural heritage and biodiversity there (KRICSFALUSY & MILLER 2008).

The main goal of this paper is to provide additional data on *C. rossicum* that could help with development of effective methods for its control. This study attempts to analyze the species' geographic range parameters, habitat preferences, ecology and the structure of communities at a regional level. An additional goal was to assess the current intensity of infestation of vegetation cover in the Toronto region by *C. rossicum*.

Materials and methods

To compare conditions in native and introduced ranges of *C. rossicum* we gathered and analyzed available geographic and climatic data. Geographical coordinates of *C. rossicum* ranges in Europe and North America were estimated by the authors based on published literature data and herbarium records (KRICSFALUSY & MILLER 2008). Climate data (temperature, precipitation) were obtained from different sources on the Internet: WORLD CLIMATE (2009), WORLD CLIMATE INDEX (2009) and CANADIAN CLIMATE DATA (2009).

The current prevalence of *C. rossicum* infestation in the Toronto region was assessed using queries of Geographical Information System (GIS) data that had been collected by Toronto and Region Conservation Authority (TRCA) biologists over the period 2000-2005 with a few additional records dating back to 1996. This data covers about 40% of the total natural cover in the TRCA jurisdiction.

In these surveys, vegetation communities were delineated as polygons in ArcView GIS software and categorized according to the Ecological Land Classification (ELC) for southern Ontario (LEE et al. 1998). The ELC data collection protocols were adapted by TRCA and are regularly updated (TRCA 2010). Each vegetation community was divided into different layers (up to four layers depending on the complexity of the community: canopy, middle/subcanopy, lower/understorey, and ground). Dominant species (up to four) present in each layer were recorded. Those polygons that included *C. rossicum* on the list for any of the vegetation layer dominants were identified as being infested. This method identifies large, established populations, but does not capture small initial invasions where the species does not dominate in any polygon layer. The majority of sites that do have *C. rossicum* usually have abundant populations; thus, most of them would include *C. rossicum* as a dominant species within at least one polygon.

To estimate the intensity of infestation of natural cover in the study area we analysed frequency of *C. rossicum* occurrence in the UTM (Universal Transverse Mercator) mapping grids (2 x 2 km). This method has recently been applied to assess distribution patterns of *C. rossicum* in the Toronto region (KRICSFALUSY & MILLER 2008).

The ecological requirements of *C. rossicum* in the Toronto region were inferred from the vegetation community data of infested polygons together with North American literature sources. Soils information for the Toronto region was provided by an overlay of Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA 1990) digital soil mapping onto TRCA information for the ELC polygons.

Results and discussion

Geographic range

The geographic range of *C. rossicum* lies within the temperate climate zones of Eurasia and North America (Table 1). The introduced range of *C. rossicum* is considerably larger than its native range in Europe (KRICSFALUSY & MILLER 2008). There are some differences in the latitudinal extent of the species' ranges. The native range of *C. rossicum* in Europe lies north of 47°, whereas in North America it is generally south of 45°. Its native range stretches across two latitudinal degrees (47°09’53.88”-49°58’16.38” N) while the introduced range extends through six latitudinal degrees (39^{0}49’35.95”-45°30’43.30” N). There is much more variation among the longitudinal extent of *C. rossicum*’s ranges. The distribution does not exceed ten longitudinal degrees in Europe (35°07’17.53”-

44°30’44.33” E), whereas in North America current range stretches across fifteen longitudinal degrees (71°02’30.82”-86°24’31.54” W). The differences in the geographic extent of the native and invaded ranges of *C. rossicum* are illustrated in Figure 1.

The recorded altitude ranges of *C. rossicum* in Europe and in North America are 66-107 m and 34-339 m respectively; thus, the species appears to attain slightly higher elevations in North America. The highest elevation of approximately 339 m is on the Oak Ridges Moraine about 30 km north of Toronto.

Climate conditions within the distribution *C. rossicum* in Europe are characterized by mean January temperatures from -4.6°C to -8.5°C; mean July temperatures from 20.3°C to 23.9°C; and mean annual precipitation from 373.2 mm to 595.1 mm (Table 1).

Tab. 1. Geographic and climatic data for range of *Cynanchum rossicum**

Area	Position	Latitude	Longitude	Mean t (°C) January	Mean t (°C) July	Annual rainfall (mm)	Elevation (m)
EUROPE							
Kharkiv/Kharkov (Ukraine)	N	49°58’16.38”	36°14’23.70”	-6.9	20.3	519	107
Dnipropetrovs’k/ Dniepropetrovsk (Ukraine)	W	48°24’05.78”	35°07’17.53”	-5.5	21.2	513	81
Rostov-na-Donu (Russian Federation)	S	47°09’53.88”	39°44’25.04”	-4.6	23.0	595.1	70
Volgograd (Russian Federation)	E	48°41’50.98”	44°30’44.33”	-8.5	23.9	373.2	72
Luhans’k/Lugansk (Ukraine)	Centre	48°34’17.99”	39°20’45.86”	-5.9	21.7	473	66
NORTH AMERICA							
Outaouais region (Quebec, Canada)	N	45°30’43.30”	75°47’14.77”	-11.5	20.7	987.1	116
Berrien county (Michigan, USA)	W	41°57’02.42”	86°24’31.54”	-4.6	21.7	940.8	205
Green county (Pennsylvania, USA)	S	39°49’35.95”	80°13’26.16”	-2.5	22.6	961.4	294
Rockingham (New Hampshire, USA)	E	42°57’37.40”	71°02’30.82”	-5.7	20.4	1164.1	34
Oak Ridges Moraine (Ontario, Canada)	Centre	43°58’44.25”	79°03’37.43”	-7.5	19.8	792.0	339

*Climatic data period used: nearest city means for 1980-2005 for Europe; 1971-2000 for North America

Climate conditions within the distribution of *C. rossicum* in North America are characterized by mean January temperatures of -2.5°C to -11.5°C; mean July temperatures from 19.8°C to 22.6°C; and mean annual precipitation from 792.0 mm to 1164.1 mm.

Overall, climate conditions in the parts of Canada and the USA where *C. rossicum* is found do not differ significantly in temperature to those of its native range in Ukraine and Russia. However, the climate in its North American range is much wetter, having up to twice the amount of average precipitation that falls in its European native range.

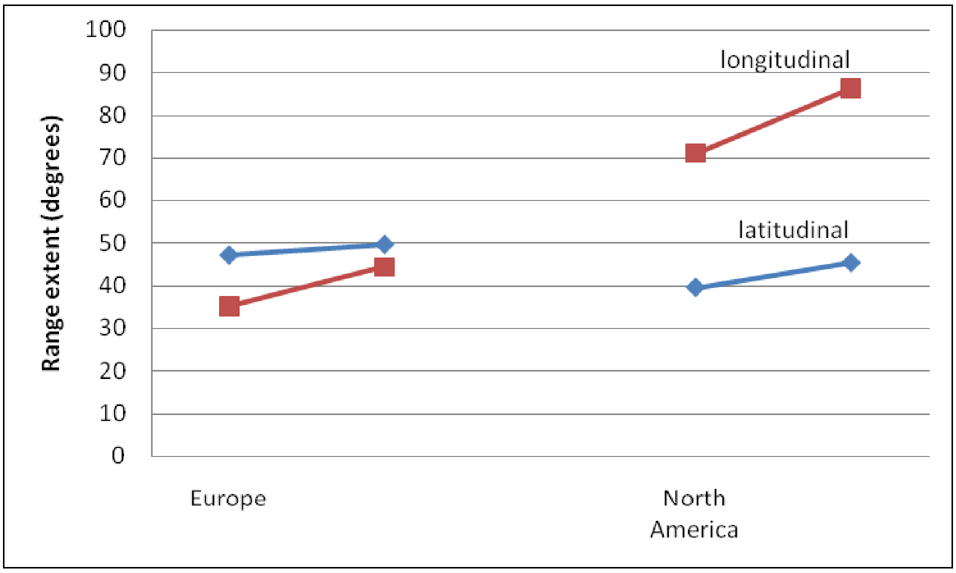

Fig. 1. The geographic extent of the native and introduced ranges of *C. rossicum*.

Habitat preferences

The native habitats of *C. rossicum* in southeastern Ukraine and southwestern Russia are located in forest-steppe and steppe zones on the slopes of ravines, sandy hills and scrub habitats (VISIULINA 1957; POBEDIMOVA 1978). KLEOPOW (1990) characterized the original habitat in which the plant probably evolved as subxerophyllic (i.e. fairly dry) oak woodland.

Comparative analysis of *C. rossicum* habitat preferences in its native range in Europe and introduced range in North America shows a remarkable similarity between them: semi-open scrub or woodland on calcareous, often light-textured soils. “Forest-steppe” and “steppe” in Europe are approximately equivalent to “woodland/savannah” and “prairie” (or grassland) in North America. These habitat preferences are consistent with the plant’s threat to limestone-based alvar ecosystems and oak savannah or woodland in the Great Lakes region.

One possible difference is that *C. rossicum* is more generalist in its habitat associations in North America, particularly with respect to shade tolerance and soil type. It is prevalent in more-or-less shaded forest habitats in the Toronto region as well as open meadow and savannah or woodland. It can occur on clay soils and occasionally even in moist-to-wet communities.

While there is similarity in the habitat of *C. rossicum* in Europe and North America, the plant's behaviour is radically different. It is not aggressive or invasive in its native range. In fact it is considered to be rare, or even endemic to southeastern Ukraine and southwestern Russia (KLEOPOW 1929). Because of its limited native range *C. rossicum* actually needs local protection in southeastern Ukraine (OSTAPKO 1995).

In North America *C. rossicum* is associated with disturbed and waste areas, such as transportation corridors, limestone quarries, abandoned pastures, hedgerows, pastures and old fields (DITOMMASO et al. 2005). According to ERNST & CAPPUCCINO (2005) it is abundant in sunny undisturbed old fields and along railways in the Ottawa region. It often grows along open rocky or gravelly shores. *C. rossicum* has been reported in Ontario by MOORE (1959) and KIRK (1985) from streambanks, edges of alluvial woods, woods (maple, beech, oak, ash), grassy slopes, as well as gardens, fencerows and railroad embankments.

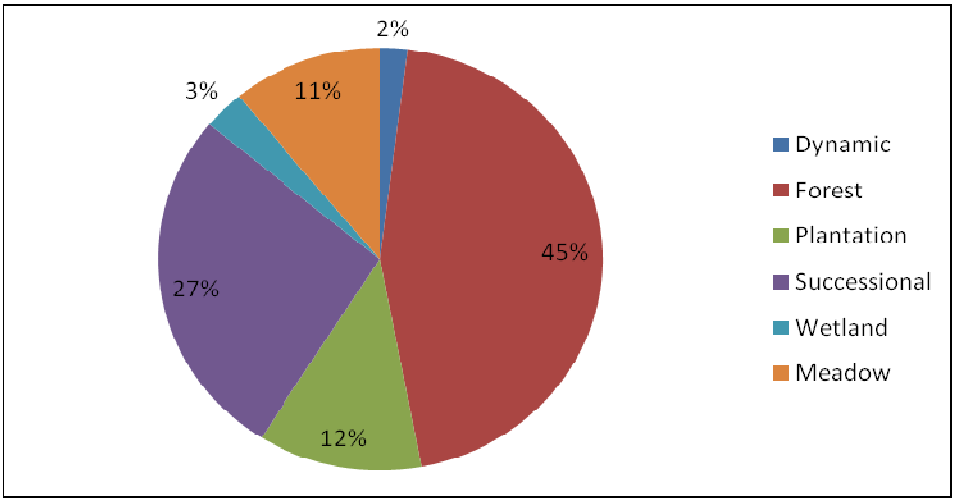

Fig. 2. Occurrence of *Cynanchum rossicum* in different habitat types in the Toronto region (ELC community classes as adapted by TRCA).

In the Toronto region according to our analysis *C. rossicum* thrives in forest (deciduous, mixed, coniferous), successional (thicket, hedgerow, savannah, cultural woodland), plantation (deciduous, mixed, coniferous), cultural meadow, and dynamic (beach, sand dune, bluff, sand barren, tallgrass prairie, savannah, woodland) habitats (Figure 2). It is even occasionally present in wetlands (swamp, meadow marsh, shallow marsh) usually along edges where conditions are less saturated.

Almost half (45%) of all recorded ELC polygons containing *C. rossicum* were forest communities that, together with plantations (12%), account for 57% of the total (another 27% are successional). From this we can assume that the essential ecological requirements of *C. rossicum* are being met in different forest stands. However plant density is usually lower in shaded forest habitats than in sunny locations (CHRISTENSEN & STROBL 1999), or even may be considerably less according to DITOMMASO et al. (2005). Overall, *C. rossicum* shows a very high degree of plasticity and a ruderal strategy in all types of habitat in the Toronto region.

C. rossicum is typically associated with calcareous soils. In its native range in southeastern Ukraine, the species grows on stony soils in steppes, on open calcareous screes usually rich in calcium and carbonates (VISIULINA 1957, 1965; OSTAPKO, pers. comm.). In Canada *C. rossicum* occurs primarily on shallow soils over limestone bedrock, silty and sandy loams, glacial till, deep loams of upland woods, rocky or clay loam based ravines (DITOMMASO et al. 2005).

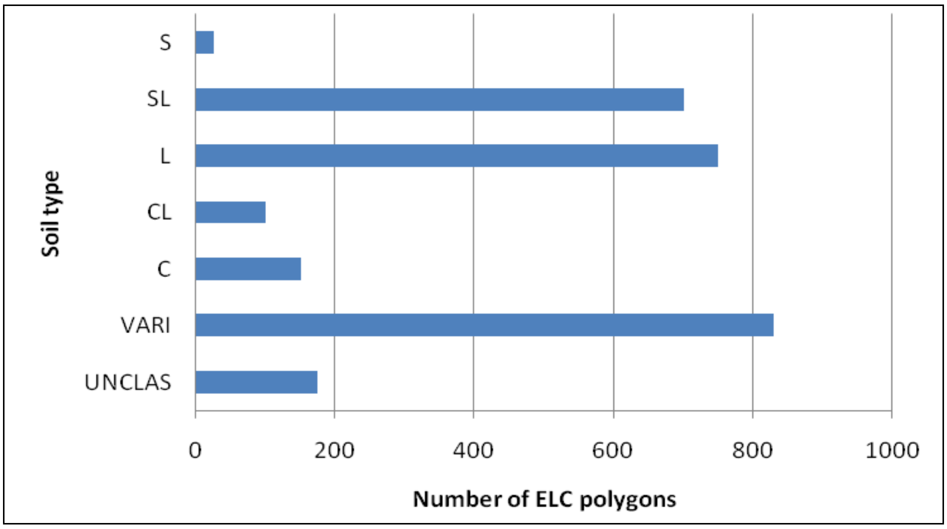

Fig. 3. Soil types of vegetation polygons with *Cynanchum rossicum* in the Toronto region: S – sand; SL – sandy loam; L – loam; CL – clay loam; C – clay; VARI – polygons spanning >1 soil type; UNCLAS – no soil data.

Analysis of TRCA vegetation polygon and OMAFRA soil data show that vegetation communities with *C. rossicum* in the Toronto region tend to occupy loam and sandy loam soils (discounting the polygons that either have no soil layer data or which span more than one soil type) (Figure 3). Almost half of all infested ELC polygons fall in these soil categories. Nonetheless, there are numerous populations on clay and clay loam as well. According to CHRISTENSEN (1998) populations of *C. rossicum* in the Toronto region were found growing on sand loams and loamy sands overlying glacial till with carbonate deposits in the upper layers indicating a fluvial origin.

Community structure

A wide range of vegetation communities with numerous plant species are found with *C. rossicum* in North America. Our observations, in conjunction with the literature (CHRISTENSEN 1998; DITOMMASO 2005) show that forests in which this species grows include such trees as red cedar (*Juniperus virginiana),* white cedar *(Thuja occidentalis),* white ash *(Fraxinus americana),* ironwood *(Ostrya virginiana),* Manitoba maple (*Acer negundo*), sugar maple *(Acer saccharum),* basswood *(Tilia americana),* as well as plantations of white spruce *(Picea glauca)* and Scots pine *(Pinus sylvestris).* In the Toronto region poplar (*Populus* spp.) stands also often appeared to be infested with *C. rossicum*.

The most common shrub species associated with *C. rossicum* are thicket creeper *(Parthenocissus quinquefolia),* poison ivy *(Rhus rydbergii),* European buckthorn *(Rhamnus cathartica),* itself highly invasive, grey dogwood *(Cornus foemina),* staghorn sumach *(Rhus typhina)*, wild raspberry (*Rubus idæus* ssp. *melanolasius*) and riverbank grape *(Vitis riparia).*

Associated herbaceous layer species include European cool-season grasses (*Agrostis, Bromus, Phleum* spp.), tufted vetch (*Vicia cracca*), herb Robert *(Geranium robertianum*), the invasive garlic mustard *(Alliaria petiolata),* Jack-in-the-pulpit *(Arisæma triphyllum),* May-apple *(Podophyllum peltatum)* and goldenrod *(Solidago altissima, S. canadensis* and *S. gigantea).*

In examining the structure of ELC vegetation units recorded for *C. rossicum* in the Toronto region the spectrum includes 26 community classes, 43 community series, 165 ecosites and 1936 vegetation types (ELC polygons). From the Toronto area data we might assume that meadow communities, followed by successional, have a relatively low structural diversity as attested by the fact that a large number of its vegetation types fit in a low number of higher-level community classes (Figure 4). The opposite is true of the dynamic and wetland communities whose wide range of structure is reflected in their greater division at the community class and series levels.

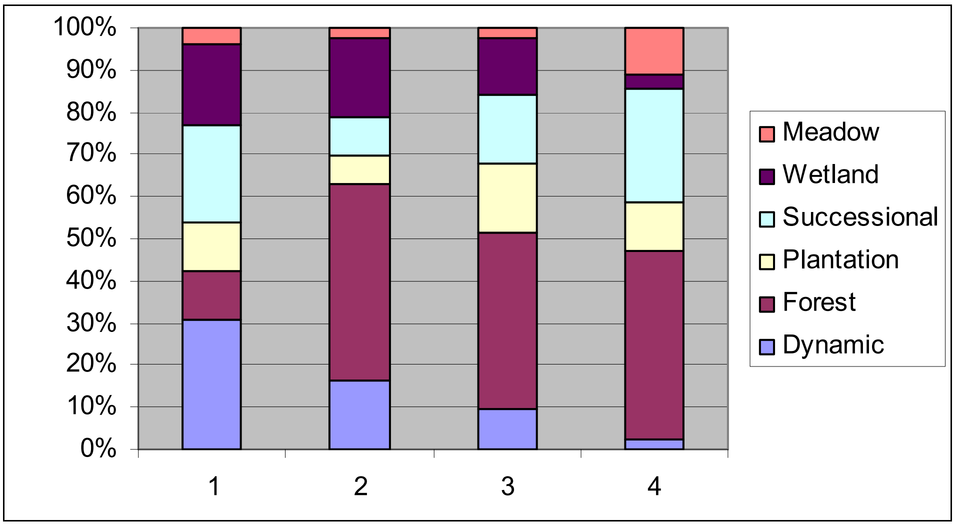

Fig. 4. Proportion of ELC vegetation units recorded for *Cynanchum rossicum* in the Toronto region: 1 – community class; 2 – community series; 3 – ecosite; 4 – vegetation type.

The number of surveyed ELC polygons in the Toronto region at the time of analysis is 24857, and *C. rossicum* as a dominant (first in order of dominance) or subdominant (2nd to 4th) species was recorded in 1936 polygons (7.79%). Where it occurs, the species plays an important role in the structure of vegetation communities. It is either the first or second dominant in more than ⅔ of all recorded ELC polygons.

The age structure of treed vegetation communities (forest, plantations and more open treed communities such as savannahs) with *C. rossicum* varies from pioneer to mature. However most communities (86%) belong to middle and young age groups, indicating that it has somewhat successional affinities and that mature forests may be more resistant to invasion (Figure 5). This supports the hypothesis about the high resistance of closed-canopy forests to invasion proposed by REJMÁNEK (1989) and RICHARDSON & PYŠEK (2006). Despite this view, we suspect that some other mechanisms may be in place during colonization of forest communities by *C. rossicum.* In particular, we observed that invasion of mature forests occurs more slowly compared to middle and young age stands. In most cases *C. rossicum* initially exploits gaps and other small-scale disturbances in forests, such as hiking trails. From there, this species has the capacity to invade deeply shaded forest understory, sometimes even old-growth stands. Thus, it seems that disturbance is not an obligatory condition; rather, it is an effective mechanism to accelerate invasion. However, the mechanism is poorly understood and more robust studies need to be done.

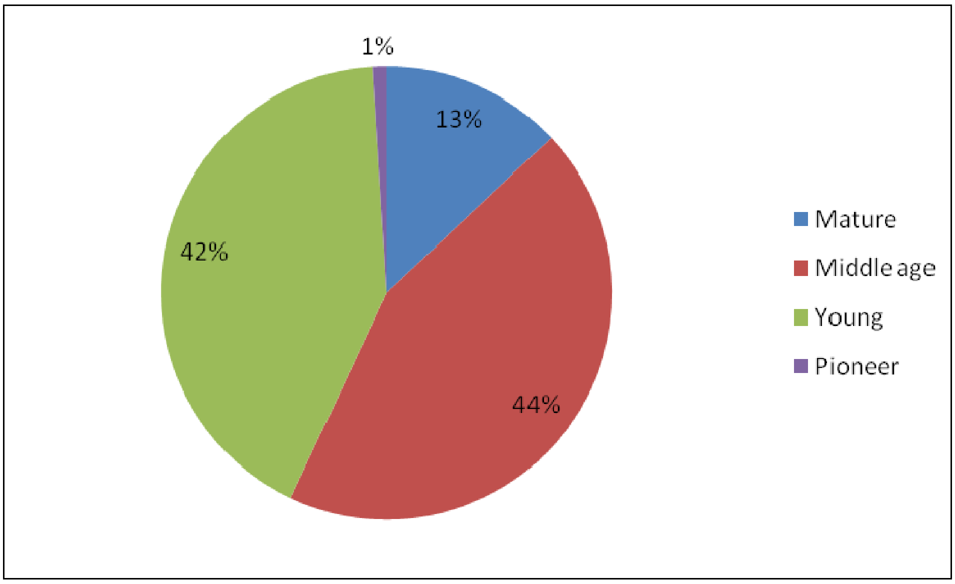

Fig. 5. Age spectrum of treed vegetation communities with *Cynanchum rossicum* as dominant or subdominant species in the Toronto region.

Open meadow to shrubby communities are by definition young and do not have age class recorded, so the prevalence of *C. rossicum* in earlier-successional communities may be greater than indicated in Figure 2.

One can conclude that young to-mid-aged forests and plantations as well as semi-open successional communities tend to have the most severe infestations. *C. rossicum* apparently reaches its phytocoenological optimum in such communities.

Intensity of infestation

C. rossicum is exceptionally good at establishing itself, even in the presence of shade or competition (LADD & CAPPUCCINO 2005). Such high performance indicates that *C. rossicum* likely manipulates its environment to facilitate its spread, as well as adapting its growth strategy to varying environments. Various chemical strategies to deter herbivory, disease, and other plants (allelopathy) are known or suspected for *C. rossicum* (DITOMMASO et al. 2005; MOGG et al. 2007), while preliminary research suggests that it makes use of mycorrhizæ (GREIPSSON & DITOMMASO 2006) to facilitate its growth and performance. A high level of phenotypic plasticity allows the plant to adapt to varying environments, especially differing light regimes (SMITH et al. 2006; HOTCHKISS et al. 2008; MILBRATH 2008).

Direct quantitative measures of loss of native vegetation and biodiversity due to the invasion of a site by *C. rossicum* are lacking (CHRISTENSEN & STROBL 1999; LAWLOR 2002). Such a study should involve comparison of the same site pre- and post-invasion. A good example of the kind of data that would fill this gap would be a standardized monitoring program for herbaceous vegetation (EMAN) as propounded by Environment Canada (ROBERTS-PICHETTE & GILLESPIE, 1999). TRCA (2009) has initiated a long-term monitoring program based on that of Environment Canada that may capture changes in vegetation composition and biodiversity due to invasive species along with other environmental changes. Neither has any study demonstrated the extirpation of particular populations of a rare or sensitive species specifically because of invasion. However, there are numerous observations of its invasion of natural areas, and threats to the flora and fauna in such areas are virtually certain.

Large, almost exclusive stands of this species suggest it can suppress other plants via competition for soil moisture and nutrients, light, other environmental factors, and likely allelopathy (LAWLOR 2002). *C. rossicum* invades gardens, hedgerows, shrubby thickets and a variety of forest types in southern Ontario and the northeastern United States. *C. rossicum* can occupy a wide range of habitats, including forests where it inhibits tree regeneration. Plants can even be found in old-growth stands, although successional stands are the worst affected. In more than ¾ of all invaded habitats intensity of community infestation by *C. rossicum* is very high – from moderate to severe (Figure 6).

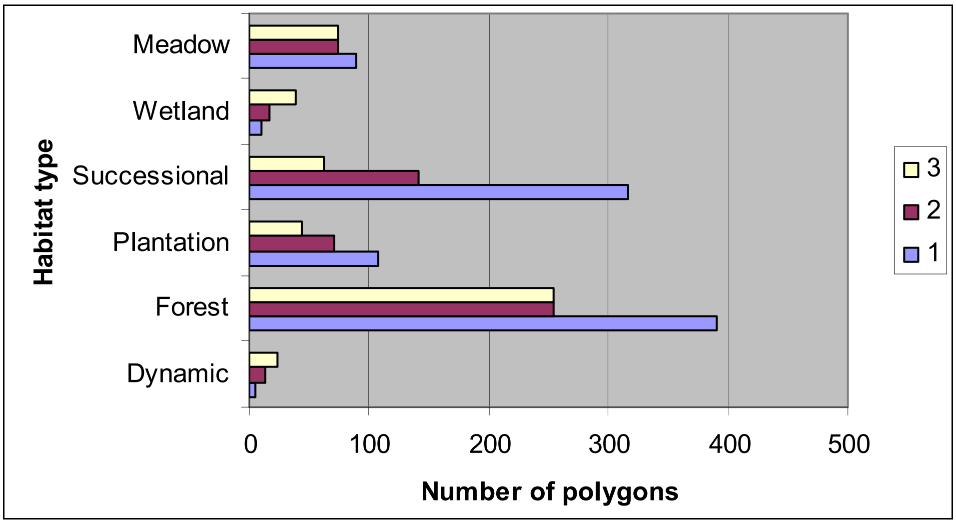

Fig. 6. Habitat infestation by *Cynanchum rossicum* in the Toronto region: 1 – severe; 2 – moderate; 3 – light.

Large colonies of *C. rossicum* can occupy hundreds of hectares, as at Grenadier Island (eastern Lake Ontario) in New York State (LAWLOR 2002). Perhaps even more importantly, *C. rossicum* reaches a high level of dominance on the sites that it occupies, once it has established itself. There appears to be a positive feedback between population size and rate of increase; resulting in an apparent explosive growth after a certain density threshold is reached (CAPPUCCINO 2004). This is known as the Allee effect. Study plots in New York State (LAWLOR 2002) and the Toronto region (CHRISTENSEN & STROBL 1999) show that cover values over 90% are commonly encountered in open or semi-open habitats. CHRISTENSEN & STROBL (1999) note that the density of *C. rossicum* and its invasiveness are reduced in mature forests with closed canopy. However, even with somewhat reduced vigour and reproductive potential, we have observed situations where it strongly dominates the ground cover in closed-canopy forests.

At present *C. rossicum* is found throughout the most of the Toronto region (KRICSFALUSY & MILLER 2008). Although it is most abundant in the southeast where more polygons show infestations, sporadic occurrences have been recorded almost everywhere, including the northwest. It is now present at most natural areas on the Oak Ridges Moraine, the southwestern part of which overlaps with the northern edge of the TRCA jurisdiction (VARGA, pers. comm.). There are still substantial patches of natural cover in the northern and western parts of the Toronto region that are more-or-less free of *C. rossicum*, while other sites have a number of small infestations that do not appear in the ELC polygon data or herbarium records (e.g., Bolton Resource Management Tract just northwest of Bolton in the Humber watershed, where over 30 small populations were observed in 2007).

Fig. 7. ***Cynanchum rossicum*** **severe infestation of black locust plantation at Rouge Park, Toronto (photo V. KRICSFALUSY).**

Fig. 8. ***Cynanchum rossicum*** **severe infestation of meadow near Rouge Park, Toronto (photo V. KRICSFALUSY).**

As shown above, 1936 vegetation polygons recorded in the Toronto region include *C. rossicum* as a dominant or subdominant species. This means that the plant is included in one of the top four species in at least one vegetation layer in 7.79% of the polygons. It means that eight percent of this large sample of TRCA natural cover has *C. rossicum* that has apparently already passed the Allee effect threshold, with smaller satellite populations not counted. Furthermore, it tends to be the primary or secondary dominant in infested polygons (43% and 26% respectively) and it is less likely to "accept" a subdominant position (3rd or 4th 18% and 13% respectively).

This data indicates the propensity of *C. rossicum* to massively dominate communities rather than merely form a large but secondary part of the community structure. We have observed such severe infestations across the Toronto region (Figures 7 & 8).

According to our analysis from approximately 25000 ha of natural cover in the TRCA jurisdiction, the area infested by *C. rossicum* includes 1813.21 ha or 7.25% of surveyed natural cover. The analysis of UTM mapping grids (2 x 2 km) of the Toronto region shows evident concentrations of *C. rossicum* in the southeastern part of the Toronto region (Figure 9). The location of these areas does not reflect any correlation with the impact from human activities; however it corresponds to the *C. rossicum* colonization patterns described in the Toronto region earlier (KRICSFALUSY & MILLER 2008).

C. rossicum is a serious threat to rare plant communities such as alvars and tallgrass oak savannahs and their associated species. It is beginning to take over alvar systems in eastern New York State and eastern Ontario (DITOMMASO et al. 2005), and is now present on the Carden Plain alvars near Orillia, Ontario (JOVAN, pers. comm.). The globally-rare tallgrass oak savannah and woodland in Toronto's High Park has also been under threat from *C. rossicum* (WEBSTER 2003).

In Rouge Park, Toronto, where there are significant populations of *C. rossicum*, an attempt was made in 2005 by TRCA to re-locate the rare and sensitive flora documented here by VARGA et al. (1991). This area includes various types of forest and successional habitats, and even some small patches of tallgrass savannah and sand barren. Of the 47 species documented earlier, 21 were not found in 2005 during field surveys conducted by authors (TRCA, unpublished data). A number of others had populations of only one to a handful of plants, which clearly have no future without active recovery efforts. A number of factors are probably involved in this decline in native biodiversity, and no study was undertaken to clarify the sequence of events involved, but *C. rossicum* is a prime suspect, along with severe deer browsing and shading-out of habitats by common woody species in the absence of fire.

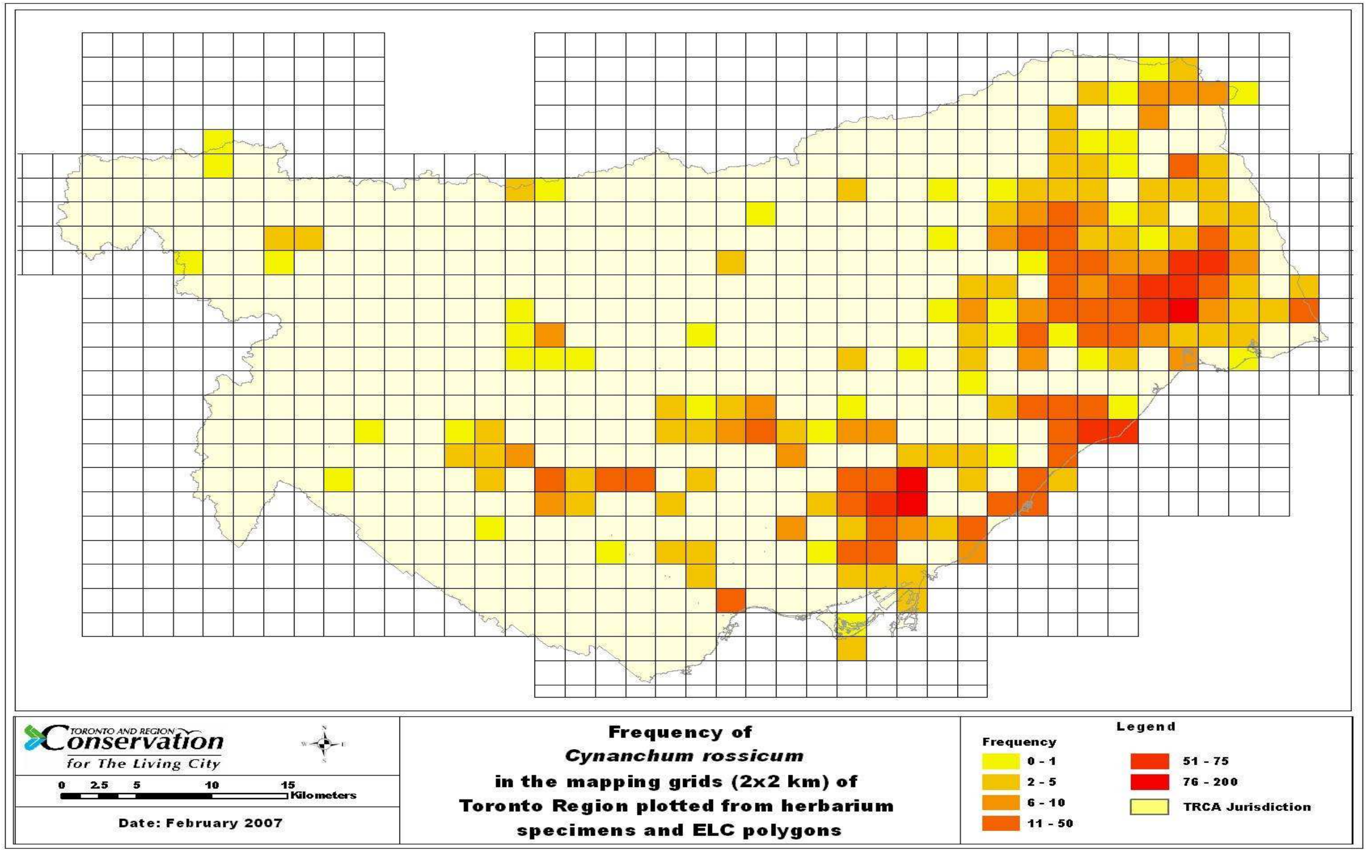

Fig. 9. Intensity of infestation by *Cynanchum rossicum* of natural cover in the Toronto region.

High Park and Rouge Park are two major local hot spots of biodiversity in the Toronto region. The remnants of tallgrass savannah systems with high plant species richness that occur there are at risk from land-use change, fragmentation, fire suppression, and invasive alien plant species, particularly *C. rossicum*. The dominant theories suggest that exotic species tend to invade and eventually dominate areas of low diversity (ELTON 1958; MACARTHUR & WILSON 1967) and that species-rich areas are less prone to invasion (REJMÁNEK 1989). However, it has been proven recently by experimental evidence (STOHLGREN et al. 1999) that hot spots of plant diversity are invasible in many landscapes. STOHLGREN et al. (1999) suggested that these patterns of invasibility depend on many factors, e.g. vegetation type, resource availability, species-specific responses to disturbances, etc. Our observations of *C. rossicum*'s success in invading the local hot spots of native plant diversity in the Toronto region more closely follow this hypothesis. To understand any impacts of this invasion on tallgrass savannah systems, closer investigation of the underlying mechanisms is needed.

These observations may have very important implications for park managers and conservation biologists since *C. rossicum* can accelerate the rapid loss of native plant species in tallgrass savannah. Because invasion of natural vegetation by *C. rossicum* has already occurred in Toronto parks, chemical control treatments may need to be applied on a regular basis in those infested areas that are hot spots of native plant diversity. Careful spot-application of glyphosate-based herbicides is labour-intensive, but has shown some promise in protecting high-quality natural areas that have been invaded by *C. rossicum* (CHRISTENSEN 1998; WEBSTER 2003; MILLER & KRICSFALUSY 2008). In the longer term, the best prospects for controlling *C. rossicum* involve research into biological control using insects from the plant's native range (MILBRATH 2010; WEED & CASAGRANDE, 2010).

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