Dog-strangling vine - *Cynanchum rossicum* (Kleopow) Borhidi

A review of distribution, ecology and control of this invasive exotic plant

February, 2008

Acknowledgements

This report was prepared and written by Gavin C. Miller and Vladimir Kricsfalusy with the assistance of Patricia Moleirinho, Sue Hayes and Rod Krick.

The study was supported by funding from Rouge Park.

The authors would like to thank the following people for their time and contribution:

- The curators of leading herbaria: Dr. Timothy Dickinson (Royal Ontario Museum) and Dr. Peter Ball (University of Toronto Mississauga) who have kindly made material available for our study.

- Dr. Stephen Darbyshire (Agri-Food and Agriculture Canada) for sharing his data from different herbaria in Canada and the United States, and his knowledge.

- Cara Webster, City of Toronto Urban Forestry, for providing documentation and data concerning control methods on dog-strangling vine.

- Dr. Naomi Cappuccino, Department of Biology, Carleton University (Ottawa) and Dr. Toni DiTommaso, Department of Crop and Soil Sciences, Cornell University (Ithaca NY) for contributing information on dog-strangling vine research.

- The following are thanked for their assistance with obtaining inaccessible scientific papers: Dr. Sergei Mochnacky (Kosice University, Slovakia), Dr. Gennadiy Budnikov (Uzhgorod University, Ukraine), and Dr. Viktor Kodobocz (Hortobagy National Park, Hungary).

- Ken Towle of the Ganaraska and Kawartha Conservation Authorities is thanked for his photo.

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1. INTRODUCTION

The invasive species dog-strangling vine (*Cynanchum rossicum* (Kleopow) Borhidi), is a twining perennial herb in the Asclepiadaceæ (milkweed family). It is one of three similar species introduced into Ontario and New York State. The other two are *C. nigrum* (syn. *C. louiseæ*, *Vincetoxicum nigrum* – black swallow-wort) and *C. vincetoxicum* (syn. *Vincetoxicum hirundinaria* – white or pale swallow-wort). *C. vincetoxicum* has not become established in North America, while *C. nigrum* is locally established and invasive in New England and a few places in Ontario (DiTommaso *et al*., 2005a).

C. rossicum was introduced over 100 years ago from Europe and naturalized in North America, particularly in the northeastern United States and southeastern Canada. A number of agencies note that the species appears to be currently expanding its range at an alarming rate, threatening mostly natural and semi-natural habitats, although no-till cropping systems are also at risk (DiTommaso *et al*., 2005a; Beevis, 2006; Weston *et al*., 2006). *C. rossicum* is considered the single most virulent invasive vascular plant species in Ontario, and it made the top twenty list of prioritized invasive plants in all of Canada (Catling and Mitrow, 2005).

There is relatively little known about *C. rossicum* and what information there is tends to be widely dispersed; therefore an analysis of scientific and research papers is essential to devising a strategy to control its impact. A literature review can also provide groundwork for further baseline research.

The main objectives of this project are as follows:

- Conduct review of scientific and research papers on *C. rossicum* in order to explore its taxonomy/history, ecology, behaviour, and colonization potential. Identify its modes of invasion.

- Examine available data from TRCA field work to provide further new baseline information on dog-strangling vine distribution and habitat in the Toronto area.

- Integrate both European and North American information sources, which have been largely isolated from each other.

- Gather information on the response of dog-strangling vine to mechanical disturbance, herbicides, pathogens, and insects in order to identify effective methods of control.

Results of this project can then be used to raise public awareness and lead to effective community involvement regarding prevention and control of dog-strangling vine based on state-of-the-art science. Information on the plant's ecology in its native range needs to be made available internationally. *C. rossicum* in its natural range in Ukraine and Russia doesn't show evidence of invasive strategy. It does not dominate ecosystems.

On the other hand, many native plant species from Canada and the United States do become severely invasive in eastern Europe[1] (Shevera and Kricsfalusy, 2002). This is why comparative analysis of dog-strangling literature from both introduced (North American) and native (Ukrainian) sources would help us to better understand and possibly explore the main causes of invasion, as well as why the species is so much less aggressive in its native range.

An additional consideration is an assessment of the current intensity of its invasion in the Toronto area and the types of habitats involved, based upon vegetation community inventory data amassed by the Toronto and Region Conservation Authority from the years 2000 – 2005. What proportion of regional natural and semi-natural habitat has been affected? Such information regarding the species' distribution patterns on a regional scale is very limited.

Thus, this report integrates three sources of information: European botanical literature, North American botanical literature focusing on the plant's invasive characteristics, and observational data provided by the Toronto and Region Conservation Authority and its partners, including the Ontario Ministry of Natural Resources (MNR).

This project was funded by Rouge Park, as they are concerned about the impact dog-strangling vine is having in the Park. This information should provide greater success in future habitat restoration in the Rouge Park and throughout southern Ontario due to improved understanding of dog-strangling vine and its control. This will help place the Rouge Park at the forefront of efforts to control dog-strangling vine and other invasive species; and hence, the restoration of native biodiversity.

2. MATERIALS AND METHODS

The taxonomic status and original native range of *C. rossicum* were evaluated by studying floras and manuals of Europe and North America as well as other literature sources.

To assess patterns of distribution of *C. rossicum* in the northeastern United States we used data published by Sheeley and Raynal (1996) who evaluated 198 specimens from 14 herbaria. Southeastern Canadian records are based on Pringle (1973) and DiTommaso *et al*. (2005a), including 207 specimens from 12 herbaria. In addition, a total of 65 herbarium records from the Toronto area spanning the years 1902-1996 were examined by V. Kricsfalusy at the University of Toronto herbaria (TRT and TRTE), and by S. Darbyshire at the CAN, DAO, HAM, KANU, MO, MT, MTMG, and WAT herbaria (see Appendix 2, includes list of abbreviations).

The current prevalence of dog-strangling vine infestation in the Toronto area was assessed using queries of Geographical Information Systems (GIS) ArcView data that had been collected by Toronto and Region Conservation Authority biologists over the period 2000 – 2005 with a few additional records dating back to 1996. This data covers about 60% of the natural cover in the TRCA jurisdiction. "Natural cover" is defined as land that is not under urban, agricultural, or otherwise actively managed use and consists of forest, wetland,

[1] For example, Canada goldenrod (*Solidago canadensis*), thin-leaved sunflower (*Helianthus decapetalus*), staghorn sumach (*Rhus typhina*), and wild cucumber (*Echinocystis lobata*). One wonders what might happen if riverbank grape (*Vitis riparia*), which is used as a hardy understock for some vineyards in Europe, escaped.

meadow, and successional habitats. The TRCA jurisdiction is defined by nine watersheds flowing into northwest Lake Ontario centred on Toronto. The furthest west watershed is Etobicoke Creek and the furthest east is Curruthers Creek. The area is approximately bounded by eastern Mississauga to the southwest, Mono Mills to the northwest, Glen Major (south of Uxbridge) to the northeast, and Ajax to the east. (The TRCA jurisdiction has approximately 25% natural cover. Therefore the vegetation surveys cover about 15% of the total land base in the 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 for use by TRCA (TRCA, 2005). Each vegetation community was divided into up to four different layers (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 infested land. This method identifies large, established populations, but small initial invasions where the species doesn't dominate any polygon layer are missed in this assessment. The majority of sites with *C. rossicum* present usually have abundant populations; thus, most of them would include *C. rossicum* as a dominant species within at least one polygon.

Local distribution patterns of *C. rossicum* populations were recorded using the UTM mapping grids (10x10 km squares) for the TRCA jurisdiction. This approach is similar to that used for the Central European Mapping Project (Niklfeld, 1971; 1994). However, due to the large size of these squares (which would yield too coarse a distribution pattern for this study), we further divided them into 2 x 2 km grids, providing a finer level of detail. This method has been developed and successfully applied in the study of rare and threatened plant species of the Carpathian flora (Kricsfalusy and Mezö-Kricsfalusy, 1994).

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 ELC information. Ecology in its native range was examined from European sources.

Information on germination, establishment, impacts of invasion, use by insects and other fauna, as well as control methods was gathered mostly from North American sources. Field observations of the above noted by TRCA biologists were also included.

3. TAXONOMIC STATUS

Dog-strangling vine has a long and confused taxonomic history. The lack of stable nomenclature both at the scientific and common name level has complicated efforts to understand and even correctly identify this plant. For a long time, it was assumed that Ontario plants, for example, were the closely-related black swallow-wort (*Cynanchum nigrum*). In fact the overwhelming majority of Ontario *Cynanchum* is *C. rossicum*. Even today, varying nomenclature is used. Some authors, on the basis of molecular phylogeny, have also reclassified the family Asclepiadaceæ (in which *Cynanchum* is found) as a subfamily of the Apocynaceæ (dogbane family)(Liede and Täuber, 2002; Dickinson *et al*., 2004). Hence, an overview of taxonomic history is provided here. Identifying the various species correctly is not difficult if one uses professional keys. DiTommaso *et al*. (2005a) provide an excellent description of and key to *Cynanchum* spp. and related genera found in eastern Canada.

3.1 Common name

C. rossicum is not named consistently. It has been called: swallow-wort, swallowwort, dog-strangling vine, pale swallow-wort, and European swallow-wort. According to DiTommaso *et al*. (2005a) the common name swallow-wort, and particularly pale swallow-wort is best restricted to *C. vincetoxicum* (L.) Pers. (*Vincetoxicum hirundinaria* Medik.) because of its pale cream-coloured flowers. That is why the common name dog-strangling vine is preferable.

C. rossicum is often not included in popular field guides and readers are directed to the black swallow-wort (*C. nigrum*) identification. *C. nigrum* is very rare in the Toronto region, mostly occurring in the western part of the city.

3.2 Scientific name

Due to intensive research accomplished in recent years, botanists have collected rich biological and ecological information on *C. rossicum* (Sheeley and Raynal, 1996; Cappuccino *et al*., 2002; DiTommaso *et al*., 2005a). However, nomenclatural ambiguity surrounding some genera, in which *C. rossicum* has been placed, complicates interpretation of available data.

There are several nomenclatural synonyms for the genus *Cynanchum* (L.) Pers., 1805: *Vincetoxicum* Wolf, 1776; *Vincetoxicum* Medik., 1790; *Cynanchum* (L.) R. Br., 1810; *Alexitoxicum* St. Lag., 1880; *Antitoxicum* Pobed., 1952.

DiTommaso *et al*. (2005a) noted that the application of the generic name *Vincetoxicum* has had a confusing history, being at one time applied to various native North American plants. Some authors recognize the distinctiveness of *Cynanchum* (Woodson, 1941; Kartesz, 1994), while others (Bullock, 1958; Markgraf, 1971; Liede and Tauber, 2002) lump it with *Vincetoxicum.*

Bullock's (1967) latest study has established that the name *Vincetoxicum* should be used for only the temperate Old World species. The present use of this name is widely followed in Europe, and prevailed in North America throughout until the last decades.

C. rossicum was described from Kharkov/Kharkiv oblast' ("circa Charkovia") of Ukraine at the beginning of the last century (Kleopow, 1929). The type specimen of *C. rossicum* Kleopow was deposited in the National Herbarium of Ukraine (KW) at the M.G. Kholodny Institute of Botany, National Academy of Sciences of Ukraine (Krytzka *et al*., 2000). This specimen appears to have been lost, but recently a new type specimen was chosen from the collection of Chernjaev at the same herbarium. This consists of two plants from Ekaterinoslav gubernija / Dnipropetrovsk oblast [province] collected in 1853 by Vojnov and Kolchigin (Fedoronchuk *et al*., 2006).

C. rossicum has been treated in the flora manuals from the territory of the former USSR also under the names *V. rossicum* (Kleop.) Barbar., *V. medium* Schmalh. p. p. non Decne., *V. schmalhauseni* (Kusn.) Stank. and *Antitoxicum rossicum* (Kleop.) Pobed. A full list of nomenclature for *Cynanchum rossicum* is provided in Appendix 1.

Specific epithets in North American literature have been used inconsistently (Table 1). Most authors have adopted European nomenclature, i.e. *V. rossicum* (Kleopow) Barbar., while others have included this species into *V. hirundinaria* Medik. (Gleason and Cronquist, 1991; Lauvanger and Borgen, 1998). Recently the name *C. rossicum* (Kleopow) Borhidi is being used more often, however some authors use both names simultaneously (DiTommaso *et al*., 2005a, b).

This study uses the name *C. rossicum* (Kleopow)Borhidi on the basis of priority as having been the first assigned name and one still in frequent usage.

4. DISTRIBUTION

As with other invasive species, dog-strangling vine has both an original native range, and an introduced range. As might be expected, information on its North American range and behaviour is more detailed, given that it is invasive in North America but relatively inconspicuous in its native habitat.

C. rossicum's native range is eastern Europe, specifically, eastern Ukraine and southwestern Russia. Its invasive range is eastern North America, centred on the lower Great Lakes in both Canada and the USA. There are also sporadic occurrences in northwestern Europe outside its native range.

4.1 Native Old World range

The first botanical description of the species was provided by Kleopow (1929). He considered *C. rossicum* as an endemic species to southeastern Ukraine and southwestern Russia. He suggested that *C. rossicum* originated in the Pliocene subxerophyllic oak woodlands in the Eastern part of the Mediterranean (Kleopow, 1990). The author, based on the Braun-Blanquet system of flora and vegetation classification, placed *C. rossicum* within the Crimea-Caucasian subelement of the Circum-Euxin geoelement of the Submediterranean type.

C. rossicum has been originally described from Kharkiv oblast in the Ukraine. It occurs in the lower parts of the Volga, Don and Dnieper/Dnipro River watersheds, in regions north of the Black Sea and the Caucasus (Pobedimova, 1952; 1978). *C. rossicum* is locally distributed in forest-steppe and steppe zones of southeastern Ukraine and southwestern Russia. Its range is approximately Kharkiv (Ukraine) to the north; Dnipropetrovs'k (Ukraine) to the west; Rostov-na-Donu (Russia) to the south, and Volgograd (Russia) to the east (**Figure 1**).

C. rossicum has rarely been recorded in other places of Europe. There are just a few reports of C. *rossicum* escaping cultivation in Germany (Markgraf, 1971) and in Norway, where it is considered potentially invasive (Lauvanger and Borgen, 1998).

Figure 1: Native range of *Cynanchum rossicum* in Europe (Ukraine and Russia)

4.2 Introduced North American Range

The history of introduction and spread of *C. rossicum* in North America is full of ambiguity because of taxonomical controversy in evaluation of species status as described in Section 3. Detailed historical information on the distribution of *C. rossicum* in the USA is given by Sheeley and Raynal (1996). According to these authors, first collections of this plant were under the name *C. louiseæ* from Monroe and Nassau counties (NY) in 1897. Modern distribution of *C. rossicum* plotted from US herbarium specimens covers Connecticut, Indiana, Massachusetts, Michigan, New Hampshire, New Jersey, New York, Pennsylvania (Sheeley and Raynal, 1996), Wisconsin (Lawlor, 2002) and Missouri (Kartesz, 1999). Distribution of C. *rossicum* in Canada, based on herbarium data (see Appendix 2), is shown on Figure 2.

Exactly how and why dog-strangling vine was introduced to North America remains unknown. The most likely scenario for *C. rossicum* (as well as *C. nigrum*) is that of multiple introductions in the northeastern U.S. and Ontario, e.g. the Experimental Farm in Ottawa (Pringle, 1973; Christensen, 1998a). A favoured theory, that the plant was introduced to the Ottawa farm as a rubber substitute during World War II, is undermined by the fact that dog-strangling vine had appeared there decades earlier, although cultivation for this purpose may have amplified the population[2]. Most likely, it was introduced as a horticultural curiosity or perhaps as an inadvertent weed.

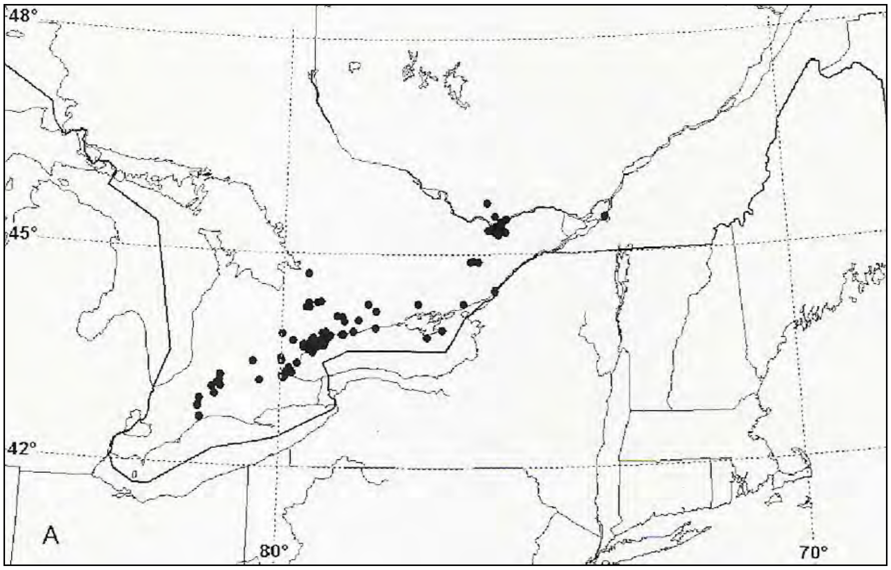

Figure 2: Distribution of *Cynanchum rossicum* in Ontario and Quebec (after DiTommaso *et al*., 2005a).

The earliest specimen of C. *rossicum* from Canada was collected under the name *C. medium* in 1885 in Victoria (BC), but the species has not persisted there. The first collection in Ontario was made by J.E. Moore in 1899 or 1889 near Toronto Junction (Dundas Street West and Keele Street area), however this specimen could not be located (Moore, 1959). Pringle (1973) considered an 1899 year of collection to be more likely. Later C. *rossicum* was found in many places mostly in southern Ontario, and recently at Montreal and in the Outaouais region of west Quebec (DiTommaso *et al*., 2005a)(Figure 2).

Over North America as a whole, the current distribution of *C. rossicum* extends interruptedly from the Outaouais region, Quebec, to the north; Berrien County, Michigan to the west; Green County, Pennsylvania to the south; and Rockingham, New Hampshire to the east. Some recent sources indicate that it has been found in Missouri (Kartesz, 1999) and Wisconsin (Lawlor, 2002; http://www.nps.gov/plants/alien/list/c.htm). This would extend its range westward to at least about 90^0 W.

[2] The sap is not particularly latex-like, much less so than milkweeds (*Asclepias* spp.)(Cappuccino, 2005).

4.3 Toronto area

The earliest two confirmed specimens of C. *rossicum* from Toronto region (at Toronto Junction) were collected under the name *V. medium* by J. White in 1902. Numerous additional collections (25 records) of this species were made within the Don River watershed in 1911-1980 (Appendix 2). During this phase the species occurred in a limited range of habitats mainly anthropogenic, notably along roadsides and settlements. The ornamental use of the plant, perhaps in conjunction with the nursery trade is the main means that enabled the escape, adaptation and establishment of the species during the initial period of invasion.

According to historical records, particularly Faull's (1913) notes, "*C. nigrum*" (misidentified, but almost certainly *C. rossicum*) was not only present in the Toronto region, but was "found in abundance in Don Valley" (*sic*). Thus large populations of the plant, at least locally, have been present for about a century. Alarm about its spread and invasiveness only began in the 1970's (Pringle, 1973) and 1980's (Kirk, 1985), becoming widespread in the local environmental community in the 1990s and attracting the attention of agencies mostly after 2000. This suggests that the initial phase of invasion is relatively slow, but then rapidly intensifying after a certain point (Cappuccino, 2004). The Charles Sauriol Reserve, centrally located on the East Don River just north of its confluence with the West Don, is now one of the densest centres of population of *C. rossicum* in the Toronto region.

It seems likely that the Don Valley populations (Charles Sauriol Reserve and Sunnybrook / Wilket Creek Parks) may be one of the original Toronto-area locations if they correspond to the Don Valley location noted in Faull (1913). Pringle (1973) noted repeated herbarium records for this area from 1902 – 1971. If so, this indicates the species' persistence in the landscape for a century after introduction. Similarly, populations have persisted at least 70 years at Great Gully Preserve, NY State (Lawlor, 2002). It would not then be a temporary invader, overwhelming the ecosystem for a time but then quickly diminishing. Rather, *C. rossicum* would likely remain dominant on a permanent basis.

Over the 103-year documented history (1902-2005) of *C. rossicum* in the Toronto region the total number of herbarium specimens is 65, with an additional 121 records from the Rouge Park collected by Varga *et al*. (1991)(Figure 3; Appendix 2). The number of infested ELC polygons is 1936, yielding a total of 2122 records. The finalized distribution data of *C. rossicum* is shown on Figures 4 and 5.

There are thus three types of record: herbarium specimens dating back to the late 19th century; MNR observations from the late 1980s and vegetation community information collected by TRCA from 2000-2005. One should note first that these records reflect the incomplete coverage of the TRCA jurisdiction; if there were 100% coverage, the number of infested polygons would be higher. Secondly, only populations that are large or noticeable enough to be captured in herbarium records or ELC polygon data are depicted in Figures 4 and 5. In the case of the ELC polygons, only polygons that included dog-strangling vine as one of the top four species in a vegetation layer are noted. Isolated patches or individual plants are not recorded in this protocol.

At present based on field biologist observations (2007), dog-strangling vine is found throughout the TRCA jurisdiction. Though it is most abundant in the southeast where more polygons show infestations, sporadic occurrences occur 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 TRCA jurisdiction northern edge (S. Varga, pers. comm.). There are still substantial patches of natural cover in the northern and western parts of the TRCA jurisdiction that are more-or-less free of dog-strangling vine, while other sites have a number of small infestations that do not appear in the ELC polygon data or herbarium records (for example, Bolton Resource Management Tract just northwest of Bolton in the Humber watershed, surveyed in 2007).

High levels of infestation in the southeast of the jurisdiction are very evident (Figure 4). Dog-strangling vine is established in almost every 2 x 2 km grid square of the Duffins, central and lower Rouge, and large parts of the Don watersheds (Figure 5). The Rouge Park is confirmed as one of the worst-infested areas, even with limited data available for the main section of the park south of Steeles[3] (Varga *et al*., 1991). The Rouge Park is part of the main eastern swath of dog-strangling vine infestation extending from the Don watershed in the Sunnybrook Park and Charles Sauriol Reserve areas east across the Scarborough Bluffs and Highland Creek through the Rouge Park into the Duffins Creek watershed, especially in the Seaton area (i.e. the vicinity of Brock and Taunton Roads)(Figures 4 and 5). The top end of the the Duffins watershed at Glen Major is also heavily affected. High levels of infestation are also apparent in the Humber watershed along the West Humber and main Humber near their confluence in the Thistletown area. The eastern populations from Highland Creek through the Rouge to Duffins Creek may correspond with earlier herbarium records from 1952 – 1953 in the White's Road area, Pickering, while the western Humber populations may be related to a 1957 record labeled "Mr. Myall's garden, Thistletown" (Pringle, 1973). In Toronto proper, the heaviest populations tend to be south of Lawrence Avenue, and decline in density northwards (Christensen and Strobl, 1999).

The data, together with numerous anecdotal reports, suggest that although it has been present for over a century, *C. rossicum* has in recent decades been spreading very rapidly across the Toronto area and increasing its dominance where it occurs, often to the extent of forming virtual monocultures (Beevis, 2006). However, there are no studies using a consistent monitoring methodology that can provide us with a quantitative estimate of the species' distribution and rate of spread. For example, we cannot infer an exponential growth scenario from the disparate types of data collected, even though observations suggest a slow establishment phase followed by explosive expansion. There are, nonetheless, recent ecological studies that focus on the plant's reproduction, growth and colonization strategies which help to back up this strong impression of its invasiveness.

[3] Many of the data points in this section of Rouge Park (where few TRCA ELC surveys from 2000 – 2005 exist) derive from MN records of the late 1980s.

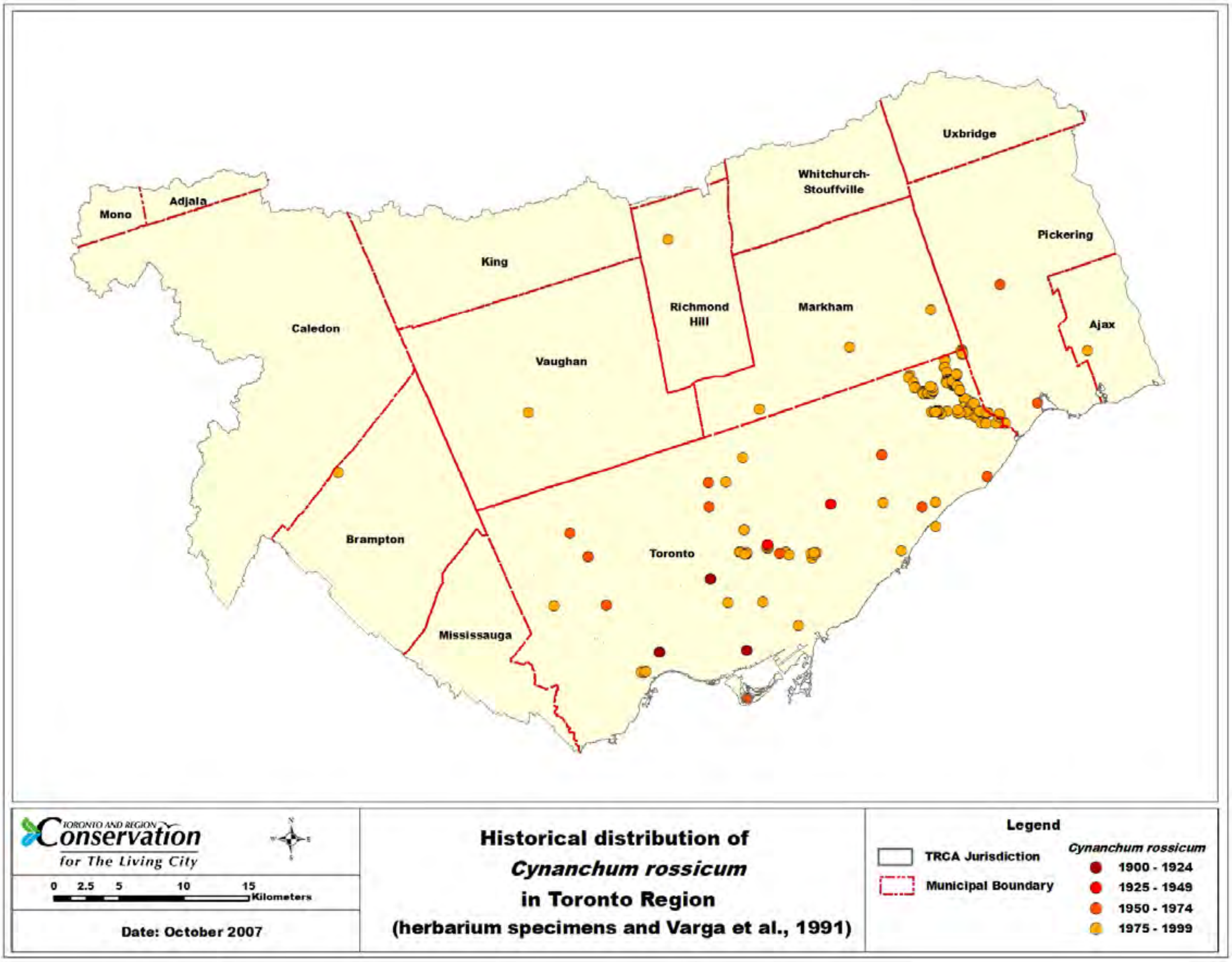

Figure 3: Historical records of *Cynanchum rossicum* in Toronto Region 1902-1999

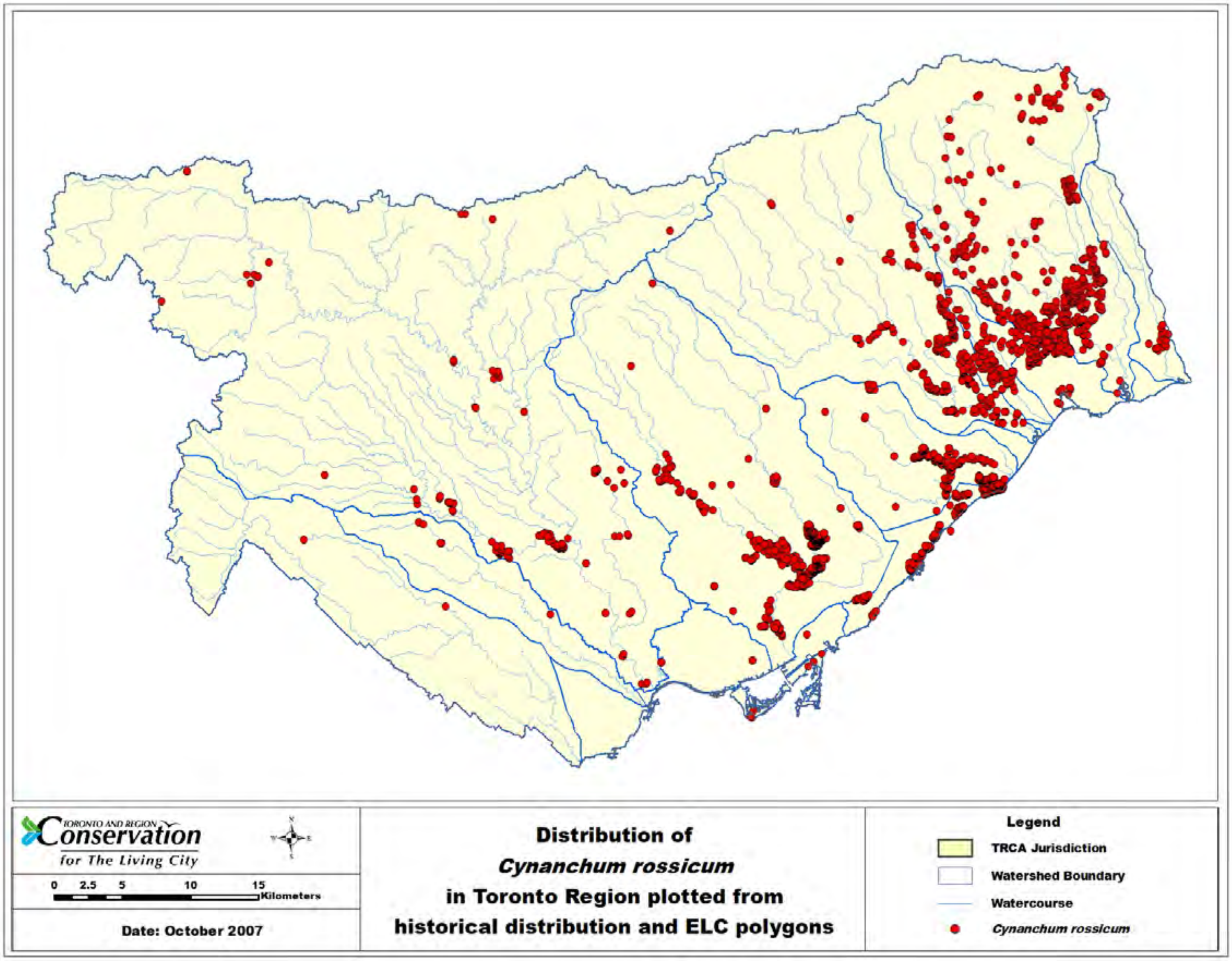

Figure 4: Distribution of *Cynanchum rossicum* in Toronto Region (historical + surveys 2000-2005)

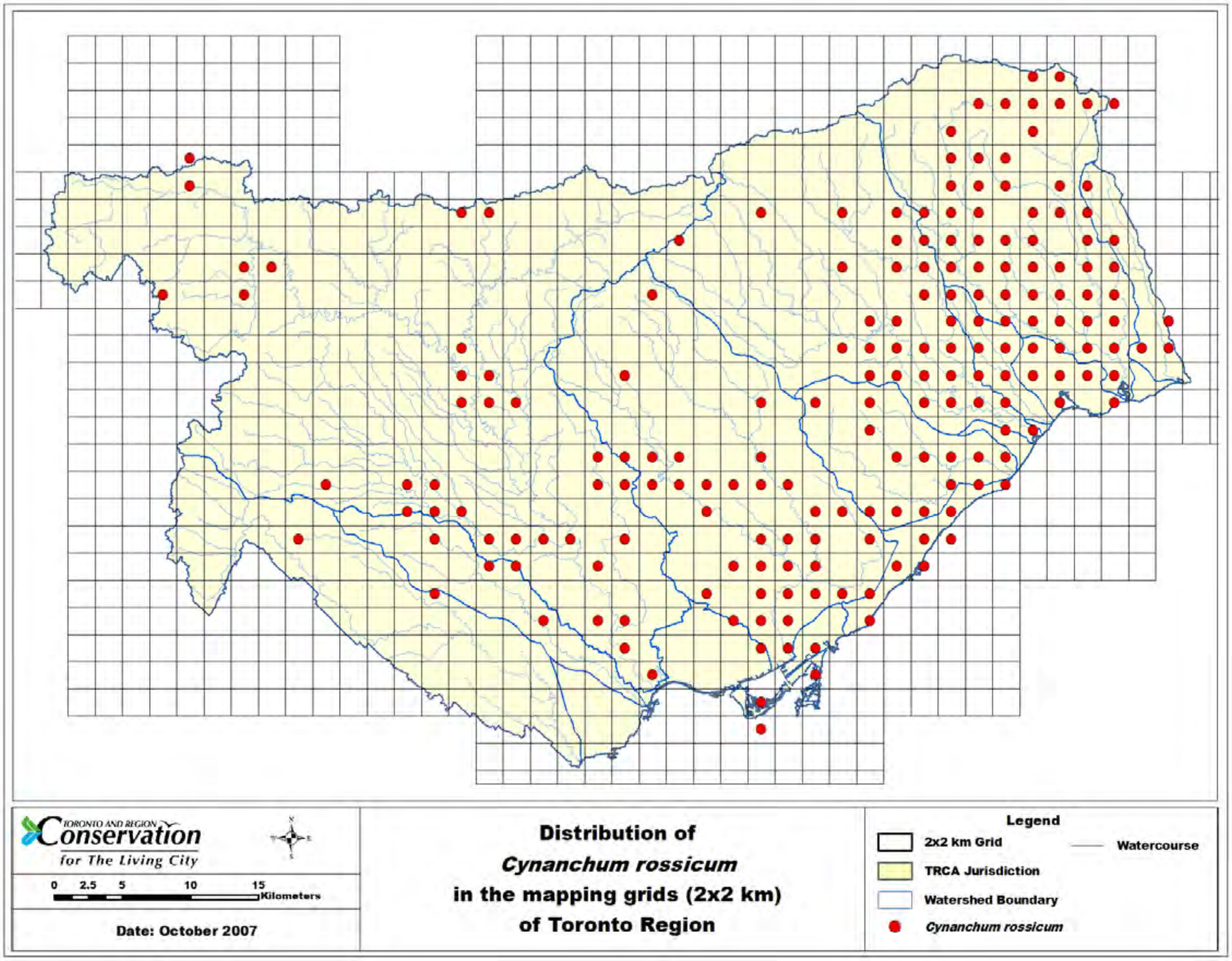

Figure 5: Distribution of *Cynanchum rossicum* by 2 km map grids in Toronto Region.

5. ECOLOGY

As concern about the invasiveness of *C. rossicum* rises, an increasing amount of information is available on its ecology and behaviour, although significant gaps remain, particularly regarding its behaviour in its native European range.

Ecological information, particularly regarding the plant's habitats, germination, establishment strategies, and use by fauna (particularly insects that might eat it), would be of critical importance in trying to identify weak points in its life cycle or possible biological controls.

5.1 Habitats

The native habitats of *C. rossicum* in the Ukraine and 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.

5.1.1 Vegetation Communities

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*., 2005a). According to Ernst and Cappuccino (2005) in the Ottawa region it is abundant in sunny undisturbed old fields and along railways. It often grows along open rocky or gravely 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.

In the Toronto region according to our analysis (Figure 6) dog-strangling vine has been recorded in forest (deciduous, mixed, coniferous), successional (thicket, hedgerow, savannah, cultural woodland), plantation (deciduous, mixed, coniferous), cultural meadow, wetland (swamp, meadow marsh, shallow marsh) and dynamic habitats (beach, sand dune, bluff, sand barren, tallgrass prairie, savannah and woodland). A full list of vegetation communities (ELC vegetation type) with reported *C. rossicum* infestations is found in Appendix 3.

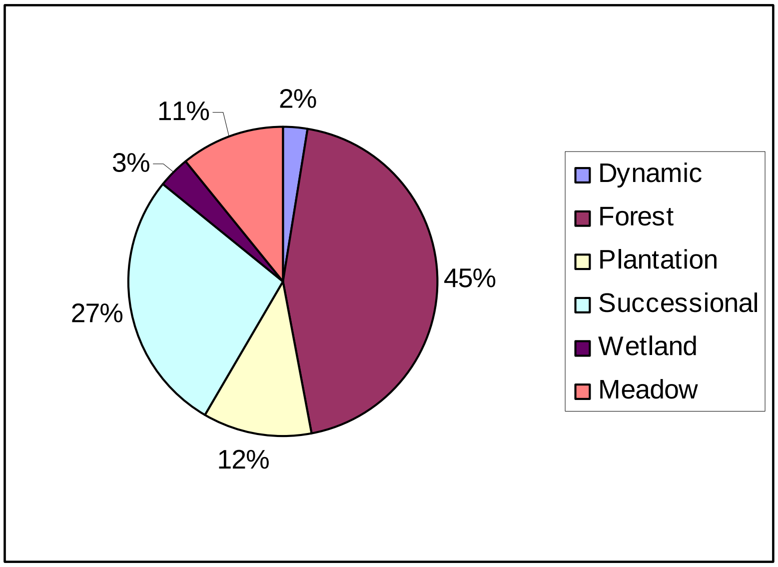

Figure 6: *Cynanchum rossicum* – infested polygons classified by habitat type (ELC community classes as adapted by TRCA).

Almost half (45%) of all recorded ELC polygons containing dog-strangling vine 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, both deciduous and coniferous. However plant density is usually lower in shaded forest habitats than in sunny locations. Overall *C. rossicum* shows a very high degree of plasticity and a generalist strategy in all types of habitat in Toronto region.

A wide range of plant species are found with *C. rossicum* (Christensen, 1998b; DiTommaso *et al*., 2005a). Forests in which it 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),* white spruce *(Picea glauca)* and Scots pine *(Pinus sylvestris).* In the TRCA's field work, poplar (*Populus* spp.) stands also often appeared to be infested with *C. rossicum*.

Most common understory shrub species are thicket creeper *(Parthenocissus quinquefolia),* poison ivy *(Rhus rydbergii),* European buckthorn *(Rhamnus cathartica)* (itself highly invasive), grey dogwood *(Cornus fœmina),* staghorn sumach *(Rhus typhina)* wild raspberry (*Rubus idæus*) 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).*

The age structure of treed vegetation communities 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

7). Open meadow to shrubby communities are by definition young and do not have age class recorded, so the prevalence of dog-strangling vine in earlier-successional communities may be greater than indicated in Figure 7. One can conclude that young-to-mid-aged forests as well as semi-open successional communities tend to have the most severe infestations.

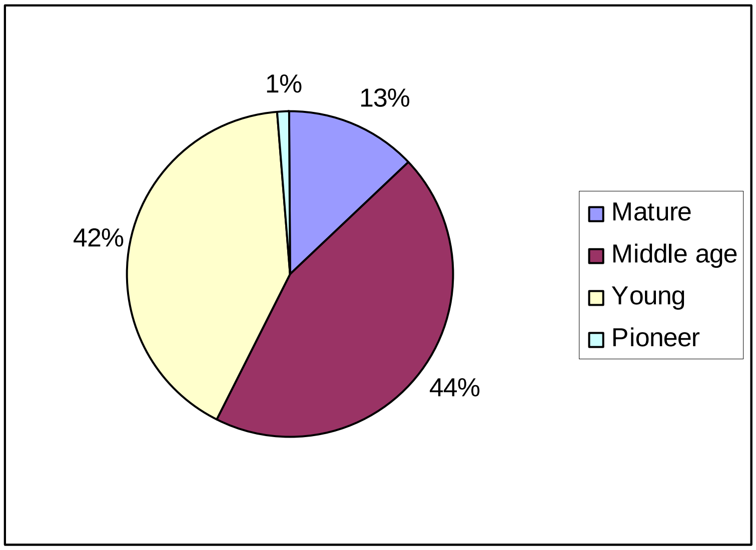

Figure 7: Age structure of treed vegetation communities with *Cynanchum rossicum* as dominant or subdominant in Toronto region.

5.1.2 Soils

C. rossicum is typically associated with calcareous soils. In its native range in Eastern Europe and Russia, the species grows on stony soils and open calcareous screes usually rich in calcium and carbonates (Visiulina ,1957; 1965). 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*., 2005a).

According to Christensen (1998b) populations of *C. rossicum* in Toronto region were found growing on sand loams and loamy sands overlying glacial till with carbonate deposites in the upper layers indicating a fluvial origin.

Analysis of TRCA polygon data show that (discounting the polygons that either have no soil layer data or which span more than one soil type), vegetation communities with *C. rossicum* in Toronto region tend to occupy loam and sandy loam soils (Figure 8). Almost half of all infested ELC polygons fall in these soil categories. Nonetheless, there are numerous populations on clay and clay loam as well.

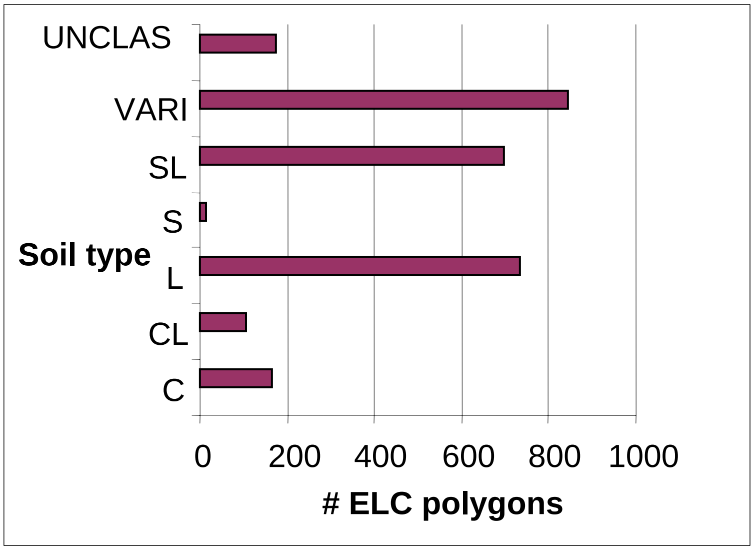

Figure 8: Soil types of vegetation polygons infested with *Cynanchum rossicum* in the Toronto region (TRCA field data; OMAFRA soils data): UNCLAS – no soil data; VARI – polygons spanning >1 soil type; SL – sandy loam; S – sand; L – loam; CL – clay loam; C – clay.

5.1.3 Comparison of European and North American habitats

The results show there is actually a remarkable similarity between *C. rossicum's* habitat preferences in its native range in Europe and its introduced range in North America: 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 North America, particularly with respect to shade tolerance and soil type. It is prevalent in more-or-less shaded forest habitats in the TRCA jurisdiction as well as open meadow and savannah or woodland; and can occur on clay soils and even occasionally in moist-to-wet communities.

While there is similarity in the habitat of dog-strangling vine 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 uncommon (DiTommaso *et al*., 2005a, Beevis, 2006).

Examination of *C. rossicum*'s life cycle, including germination and strategies of growth and establishment, can yield clues to its invasive behaviour and help in planning possible control measures.

5.2 Propagation

C. rossicum propagates mostly by seed. Rhizomes are short rather than creeping and clonal growth is not a significant strategy although it may occur to some extent with the related *C. nigrum* (DiTommaso *et al*., 2005a). The short, thick rootstalk enables individual plants to grow rapidly and produce many stems, but not to form a colony (Figure 9).

Figure 9: The rootstalk of *Cynanchum rossicum* (photo V. Kricsfalusy)

The fact that huge monocultures of this plant derive entirely from seed production implies a very effective seed dispersal and germination strategy, and that is what studies so far have found, at least in the plant's invasive North American range. A vast amount of viable seed can be deployed under varying conditions of pollination and ambient light. Information on pollination, seed production and dispersal in its native eastern European range is scarce. However, polyembryony was observed in C. rossicum in Ukraine (von Hausner, 1976).

5.2.1 Pollination

Dog-strangling vine is self-compatible, able to produce seed either by insect pollination or by self-pollination. In common with other members of the Asclepiadaceæ, pollen is aggregated into structures called pollinaria that are attached to insect visitors' legs or probosci. Christensen (1998a) observed a number of insect floral visitors, but St. Denis and Cappuccino (2004) noted that ants were the only daytime insects that were likely to transmit pollen. (See section 6.3 for a description of various insect users). They also noted that isolated plants tended to have more evidence of insect pollination (i.e. removed pollinaria) than those in dense populations.

Self-pollination seems to be almost as effective in producing viable seed as insect pollination, however (St. Denis and Cappuccino, 2004). While insect visitation of potted plants (as evidenced by pollinaria removal) increased fruit-set and polyembryony, human-mediated self-pollination was just as effective in fruit and seed/embryo production as induced cross-pollination. Spontaneous self-pollination has been observed in the greenhouse within a day of anthesis, with pollen tube initiation (St. Denis and Cappuccino, 2004). These results imply that dog-strangling vine can adapt to varying supplies of pollinators, enjoying the genetic benefits of out-crossing when pollinators are abundant, while still able to produce copious seed when pollinators are scarce.

5.2.2 Seed Production and Viability

C. rossicum produces a large quantity of wind-dispersed seed, much of which contains multiple embryos (polyembryony)(DiTommaso *et al*., 2005a, 2005b). Several studies have examined the rate of fruit, seed, and embryo production under varying light conditions. In New York State, plants in shaded conditions produced fewer fruit pods and seeds than those in a sunny location (Sheeley, 1992). There was an average of two pods per shaded plant each containing seven viable seeds, while open-grown plants averaged eight follicles with 10 seeds per pod. In more recent years and very heavily infested sites, seed production appears to be greater. Christensen and Leale (1997) found an average of 9.1 pods per plant on a shaded site in Toronto's Don Valley (as counted in late July, 1996), while there was an average of 16.9 pods in a sunny location. Smith *et al*. (2006) found an average of about 20 pods per stem in part-shade, 15 in full light, and 17 in shade. Where shade is very heavy, plants may produce little or no seed at all, but can persist for years, ready to exploit any canopy disturbance. Smith *et al*. (2006) indicate that around 30 000 seeds / m^2 could be produced in a dense population of dog-strangling vine in ideal conditions of partial sun. Reproductive biomass was slightly less in full sun and considerably less in shade but still substantial.

Seed viability is fairly high. Smith *et al*. (2006) noted that viability ranged from around 56% for shade-grown seed to 70% for sun-grown. Polyembryony is strongly evident; often the majority of seeds have more than one embryo, particularly when produced under high light conditions. Seedlings from polyembryonic seedlings were found to more likely establish themselves successfully (Ladd and Cappuccino, 2005). Apparently, the advantages conferred by polyembryony (i.e. "back-up" seedlings in case one failed, improved performance in groups over individuals "Allee effect") outweighed the disadvantage of intraspecific competition. Staggered seedling emergence in polyembryonic seeds can give each seed a "second chance" if drought or other factors kill the first emerging seedling; emergence can be separated by as much as 20 days (Ladd and Cappuccino, 2005).

High rates of germination of seed placed in existing old-field vegetation were observed by Ladd and Cappuccino (2005). Using naturally-stratified (overwintered) seed, a rate of 71% germination occurred over a 1.5 month period for seed buried 1cm and even 38% for seed left on the soil surface! A small portion germinated in subsequent years, raising the question of whether dog-strangling vine can create a durable seed bank.

The ability of an invasive exotic species to produce a durable seed bank has very important implications for control. If seed bank recruitment keeps occurring over many years after the first removal, efforts must continue until the seed bank is exhausted. For example, garlic mustard (*Alliaria petiolata*) requires 5 years of constant vigilance to exhaust the seed bank (Nuzzo, 2000; White *et al*., 1993)[4].

Information on the seed dormancy / seed bank dynamics of *Cynanchum rossicum* is scanty. The observations of Ladd and Cappuccino (2005) suggest that the vast majority of the seed will germinate after one overwintering in the lower Great Lakes climate if it is slightly buried. Only 0.4% germinated in years 2 and 3 respectively. However, of the seed that remained on the soil surface, 8.9% germinated in year 2 and 3.1% in year 3.

Some seed, particularly that which ripens early (i.e. in August), is non-dormant and will germinate without stratification – a proportion that can approach 50% (DiTommaso *et al*., 2005a, 2005b). The same authors' findings suggest that dormancy is induced by shade and cold temperatures. Seed collected late in the season or from shaded plants is more likely to be dormant. Larger seed may also have more dormancy.

Sites from which *C. rossicum* has been cleared could theoretically provide information on seed bank, as new plants could be recruited from it. Christensen (1998b) did report seedlings or small plants appearing the year after herbicide treatments but did not differentiate between shoots from surviving root crowns, seed blown in from nearby, or seed from a long-term seed bank.

The findings suggest overall that the majority of seed will germinate after a single cold-stratification, but that there is flexibility built into the pattern. Seed that is exposed to unfavourable conditions such as cold, low light, or dryness (e.g. sitting on the soil surface) is likely to enter a deeper dormancy and may persist as viable for several years, awaiting an opportune time.

While the majority of seed is likely to germinate within a year, even small amounts of seed that last longer could be problematic because of the huge numbers of seed produced.

5.2.3 Seed Dispersal

The seed of *C. rossicum*, like most other Asclepiadaceæ, has a fluffy pappus and is dispersed by wind. Dispersal occurs over an extended period of time as pods ripen and open. Christensen and Leale (1997) observed dispersal from the end of August through to November. St. Denis and Cappuccino (2004) observed fruit opening in the Ottawa Region as early as 10 August 2001 after a significant heat wave.

The vast majority of seed falls close to the parent plant, in spite of the fluffy pappus on the seed. One study indicated that 83% of the seed dropped immediately beneath the source population over a 2-month dispersal season (Ladd and Cappuccino, 2005). Nonetheless, some seed was collected at 60 m from the source population. In a one-day dispersal trial, 50% of the seed fell within 2.5 m of a 1.5 m – high release point, and some traveled up to 18 m (Cappuccino *et al*., 2002).

[4] And in fact, possibly longer based on informal comments from Toronto area restorationists.

Lighter seed might be expected to travel further than heavier seed but have lower viability or produce weaker seedlings (Cappuccino *et al*., 2002). When this was investigated, however, the relationships between seed weight, dispersal distance, and viability were small enough to suggest that even large seeds can be competent dispersers and small seeds are capable of producing established seedlings (Ladd and Cappuccino, 2005). The trade-off between seed viability and dispersibility does not present a serious obstacle to the spread of *C. rossicum*.

Pathways of spread appear to correspond to ease of wind dispersal. Infestations follow valley and stream corridors (DiTommaso *et al*., 2005a). It is often abundant along railway lines and highway corridors such as the lakeshore CNR line near the mouth of the Rouge River and the Don Valley Parkway in Toronto (Kirk, 1985; Christensen and Strobl, 1999). Transportation corridors provide both open habitat along which seed can disperse and air currents caused by the slipstream of passing trains and vehicles.

Any long-term strategy to control dog-strangling vine must address seed production and quality.

5.3 Establishment Strategies

Dog-strangling vine is exceptionally good at establishing itself, even in the presence of shade or competition. Seeds sown into trays with pre-existing young grass experienced no significant decrease in germination (although seedlings were smaller) compared to those without (Cappuccino *et al*., 2002). Ladd and Cappuccino (2005) found high seedling emergence with seeds planted into existing old-field vegetation: 71% with seed buried 1 cm and 51% with seed left on the soil surface. They noted that this success rate was considerably higher than results with other aggressive old-field plants such as reed canary grass (*Phalaris arundinacea*) or tall goldenrod (*Solidago altissima*).

Survivorship of germinated seedlings is also exceptionally high: 71-100% of seedlings survive one year in old-field vegetation, while the figures for 3-year survival are 60-82% (Ladd and Cappuccino, 2005)[5]. Larger and polyembryonic seeds have some advantage. Three-year plants averaged 12 – 16 cm in height. This ability to invade intact, already-occupied plant communities such as old fields in addition to disturbed sites is characteristic of dog-strangling vine.

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 dog-strangling vine, while preliminary research suggests that it makes use of mycorrhizæ to facilitate its growth and performance. A high level of phenotypic plasticity allows the plant to adapt to varying environments, especially differing light regimes.

[5] This would be considered an enviable survival rate for tree plantings even with excellent site preparation, maintenance, and watering, let alone seeding into unmaintained old-field vegetation.

5.3.1 Chemical Strategies

The Asclepiadaceæ are known for their chemical defences. Poisonous hæmolytic glycosides are found in the closely-related *Cynanchum vincetoxicum* and grazing mammals tend to avoid plants in this genus. A very limited amount of grazing by cattle or browsing by deer has been noted, but toxicity to mammals (e.g. a tested goat) is also evident (DiTommaso *et al*., 2005a).

New research focusing specifically on *C. rossicum* has uncovered phytochemicals that protect it against bacteria, fungi, and insects (Mogg *et al*., 2007). Pathogen damage to *C. rossicum* is rarely observed in North America. The main antibiotic agent in *C. rossicum* was found to be a phenanthroindolazidine alkaloid: (-)-antofine. This compound appears to interfere with DNA synthesis. Extracts from dog-strangling vine strongly inhibited a broad spectrum of fungi, including human pathogens. Bacteria were also affected, and phenanthroindolazidine alkaloids also have anti-cancer effects (DiTommaso *et al*., 2005a; Mogg *et al*., 2007).

The chemistry of dog-strangling vine is apparently not restricted to the above. Extracts of the plant applied to rose leaflets reduced feeding by rose sawfly larvæ, while the same extract not only inhibited feeding of masked birch caterpillars, but also killed them within one day (Mogg *et al*., 2007). The authors found that the agent in this case was not (-)-antofine, but some other component or components, as yet unidentified.

In light of the known phytochemistry of *C. rossicum* and its ability to dominate vegetation communities, allelopathy must also be strongly suspected. Conclusive research is not yet available regarding *C. rossicum*'s effect on other plants; however, experiments have shown that root extracts will inhibit germination of radish (*Raphanus sativa*) seedlings (Cappuccino, unpubl.).

5.3.2 Mychorrhizal Status

Mycorrhizal fungi are an important part of the soil community and form mutualistic symbioses with the majority of flowering plant species. In general, healthy native plant communities such as eastern North American forests (Sauer, 1998) or tallgrass prairie (Miller, 1997) have an abundant, diverse array of mycorrhizæ that support native flora and fauna diversity, while degraded habitats tend to lack mycorrhizæ. Ruderal and often invasive species are often less dependent on mycorrhizæ, such as cool-season grasses or members of the mustard (Brassicaceæ) or chenopod families (Chenopodiaceæ). Restoration ecologists frequently attempt to inoculate degraded sites with mycorrhizæ.

Invasive species such as garlic mustard (*Alliaria petiolata*) may actually suppress mycorrhizæ as part of their growth strategy (Roberts, 1997). Given the behaviour and anti-fungal chemistry of dog-strangling vine, one might expect the same. However, that is not the case.

Investigation of the relationship between mycorrhizæ and dog-strangling vine and two other notorious invasive exotic species: kudzu (*Pueraria lobata*) and Chinese privet (*Ligustrum sinense*) revealed that these plants do form symbiotic associations with native mycorrhizal populations (Greipsson and DiTommaso, 2006). Furthermore, in the case of *C. rossicum*, mycorrhizal spore density was actually higher in soil from invaded areas than from nearby non-invaded areas. The species of mycorrhizæ involved are not known; however, the results suggest that dog-strangling vine can take advantage of native mycorrhizal communities and perhaps alter their composition and density. This is a very different pattern from that of garlic mustard and again suggests that dog-strangling vine is not particularly dependent on disturbed soils but can invade intact sites.

5.3.3 Phenotypic Plasticity

Dog-strangling vine is able to adapt its growth and morphology to different environments, in spite of the fact that it probably originated from a limited number of introductions and so might be expected to lack genetic diversity.

C. rossicum typically emerges between late April and mid-May at sites in the Toronto area and upstate New York (Sheeley, 1992; Christensen and Leale, 1997). Shoot elongation occurs rapidly until mid-June, and then tapers off. Flowering occurs from mid-June to mid-August, and pods start forming immediately. Seed ripens and is dispersed starting in August as described above (section 5.2). Plants senesce and go dormant relatively early in the fall: between early August and early October (Christensen and Leale, 1997).

On shaded sites, dog-strangling vine has significantly longer stems than in sunny places: >130 cm versus 65-80 cm (Sheeley, 1992; Christensen and Leale, 1997). Plants in very high-density populations in open areas were also taller than those in lower-density populations (Christensen and Leale, 1997). Stems are able to gain height by twining around woody stems of saplings or shrubs, overtopping the competition while gaining more light and an increased height for seed launching. Shade also delays flower/seed production and senescence (Christensen and Leale, 1997).

C. rossicum also shows some evidence of drought and fire tolerance. Plants in open, dry sites often show drooping leaves during drought, but this doesn't seem to have serious deleterious effects. The climate of its native range is somewhat drier than that found in the lower Great Lakes although otherwise similar. It is possible that while precipitation is higher in the Toronto area and New York State, evapotranspiration is also higher, given the further south latitude and increased solar radiation received in the North American range. Sheeley (1992) observed relatively low xylem water tensions, indicating good drought tolerance.

The root crown of *C. rossicum* is at least a centimeter below the soil surface, which provides ample protection from fires. Rapid recovery after fire was noted at the Montezuma National Wildlife Refuge (New York State) in late spring 1999 (Lawlor, 2002). In fact, burned plots at Toronto's High Park showed earlier emergence by up to two weeks of dog-strangling vine as compared to unburned plots (Webster, 2007). Thus, it behaves similarly to North American tallgrass savannah and woodland species and may actually benefit from fire.

5.3.4 Allee Effect

Positive feedback between population size and growth rate is a recognized phenomenon in both plants and animals, and may result in a lag between the introduction of an invasive species and its subsequent takeover of ecosystems. This is known as the **Allee effect**, and has been observed in *C. rossicum*.

Media reports and casual observations may give the impression that dog-strangling vine is spreading like wildfire as if it were a sudden new phenomenon (Mathias, 1999). In fact this plant has been present in southern Ontario and upstate New York for many decades (over a century in the Toronto area). However it is only relatively recently that it has become invasive to a degree that has raised alarm (Pringle, 1973; Beevis, 2006). Such observations suggest that the species has an initial slow increase of population but then expands rapidly, even explosively, after reaching a kind of critical threshold or 'tipping point' on a site.

Cappuccino (2004) found a significant increase in vigour (as measured by plant biomass) and pod production in *C. rossicum* plantings as patch size increased from 1 to 9 to 81. There was some evidence that more isolated plants put more energy into root production, with higher root / shoot ratios. The Allee effect in dog-strangling vine appears to be likely due to its ability to suppress background vegetation when growing in larger patches, and there may be a threshold population size between 9 and 81 plants per patch according to her study.

6. IMPACTS

Direct quantitative measures of loss of native vegetation and biodiversity due to the invasion of a site by dog-strangling vine are lacking, i.e. "before" and "after" observations (Christensen and Strobl, 1999; Lawlor, 2002). Neither has any study demonstrated the extirpation of particular population of a rare or sensitive species specifically because of invasion. However, observations of its invasion of natural areas are abundant, and threats to the flora and fauna in such areas are virtually certain. Some comparisons of fauna biodiversity in infested and non-infested areas also exist. Therefore, the following sections examine the condition of areas invaded by dog-strangling vine.

6.1 Native Flora

Large, monospecific 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, 2000; 2002).

C. rossicum invades gardens, hedgerows, shrubby thickets, and a variety of forest types in southern Ontario (Figure 6; Appendix 1) and the northeastern United States. Christmas tree growers in New York State report increased pressure by *C. rossicum* in plantations (DiTommaso *et al*., 2005a; Weston *et al*., 2006). At restoration plantings, small trees may be so tangled by the vines that they are pulled to the ground (Christensen, 1998a). *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. The wide range of habitats that can be affected has been described in section 5.1.1.

Large colonies can occupy hundreds of hectares, as at Grenadier Island (eastern Lake Ontario) in New York State (Lawlor, 2002; Beevis, 2006).

Perhaps even more importantly, *C. rossicum* occupies a high level of dominance on the sites that it occupies, once it has established itself and the Allee effect sets in. Study plots in New York State (Lawlor, 2000) and the Toronto region (Christensen and Leale, 1997; Christensen and Strobl, 1999) show that cover values over 90% are commonly encountered in open or semi-open habitats. Christensen and Strobl (1999) note that the density of dog-strangling vine and its invasiveness are reduced in mature forests with closed canopy (see also above: Figure 7, section 5.1.1). However, even with somewhat reduced vigour and reproductive potential, we have observed severe ground cover dominance in closed-canopy forests (Figure 16). At Great Gully Preserve, New York State, which has had dog-strangling vine for at least 70 years, it was dominant in the ground layer of a mature mixed forest with 70% cover and 117 shoots/m^2 (DiTommaso *et al*., 2005b).

TRCA ELC polygon data shows the extent and intensity of invasion in the Toronto Region. Of the area surveyed in recent years, 1,936 of 24,857 vegetation polygons include *C. rossicum* as a dominant or subdominant species (Figure 10). 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 surveyed from 2000 - 2005. Eight percent of this large sample of TRCA natural cover has dog-strangling vine that has apparently already passed the Allee effect threshold, with smaller satellite populations not counted[6]. Furthermore, it tends to be the primary or secondary dominant in infested polygons (43% and 26% respectively of the 1,936 polygons that record dog-strangling vine) (Figure 11). It is less likely to "accept" a subdominant position (3rd or 4th 18% and 13% respectively).

[6] An informal count by TRCA biologists of such small satellite populations in the north section of Bolton Resource Management Tract (one site about 150 ha in the upper Humber where *C. rossicum* is in early stages of invasion) yielded 31 locations in the summer of 2007.

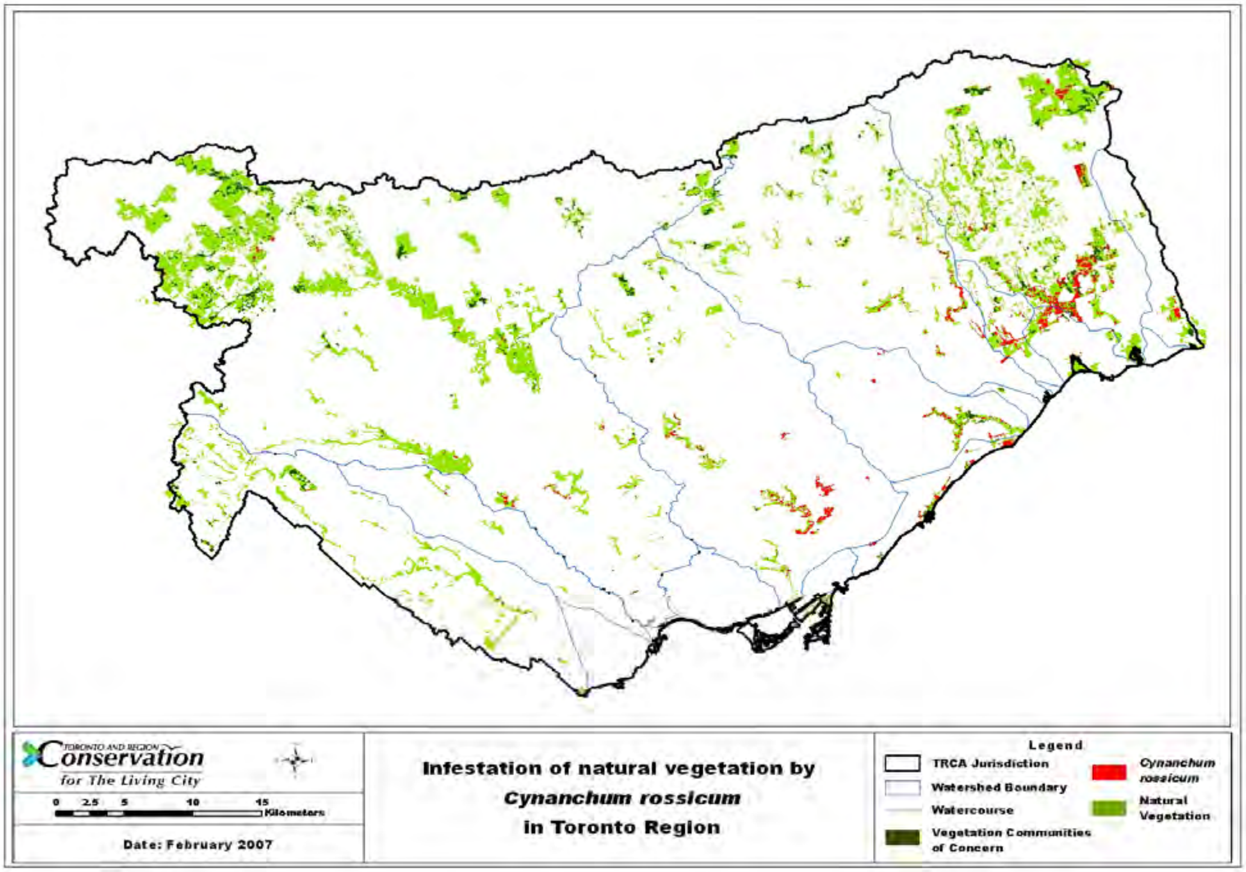

Figure 10: TRCA-surveyed vegetation polygons with *Cynanchum rossicum* infestations in the Toronto region

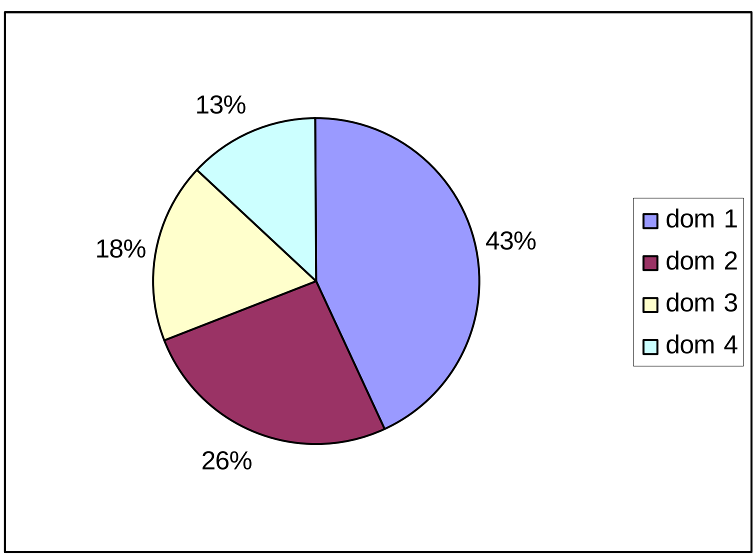

Figure 11. *Cynanchum rossicum* dominance in structure of vegetation communities in the Toronto region: 1-4 – order of dominance in vegetation types/polygons.

This data indicates the propensity of this species to massively dominate and form monocultures rather than merely form a large but secondary part of the community structure. We have observed such situations across the Toronto region (Figures 12-16).

Figure 12: *Cynanchum rossicum* understorey in conifer plantation Orono Crown Forest (photo K. Towle).

Figure 13: *Cynanchum rossicum* (foreground) in successional thicket near West Duffins Creek (photo V. Kricsfalusy).

Figure 14: *Cynanchum rossicum* understorey in black locust plantation Rouge Park (photo V. Kricsfalusy)**.**

Figure 15: *Cynanchum rossicum* dominant in meadow adjacent to Rouge Park (photo V. Kricsfalusy).

Figure 16: *C. rossicum* ground layer in mid-aged sugar maple stand, Rouge Park (photo V. Kricsfalusy).

C. rossicum is also 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*., 2005a), 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 both species of dog-strangling vine (*C. nigrum* is present in addition to *C. rossicum*)(Webster, 2003).

Other habitats of particular rare or sensitive plants have been invaded: for example, hart's tongue fern (*Phyllitis scolopendrium* var. *americanum*) in Onondaga County, NY (Weston *et al*., 2006), and Jessop's milkvetch (*Astragalus robbinsii*) in Vermont (due to *C. nigrum*)(Lawlor, 2002).

In the Rouge Park, Toronto, an attempt was made in 2005 by TRCA to re-locate the rare and sensitive flora documented by Varga *et al*. (1991) for the high-quality valley and tablelands between Twyn Rivers Drive and Kingston Road. 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 (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 dog-strangling vine is a prime suspect, along with severe deer browsing and shading-out of habitats by common woody species in the absence of fire[7].

6.2 Native Fauna

There are preliminary data about *C. rossicum* impact on fauna species, particularly birds and animals. According to information supplied by G. Smith to DiTommaso *et al*. (2005a), dense populations of this species discourage grassland birds from nesting in summer months. Other unpublished data from The Nature Conservancy also showed a significant negative correlation between *C. rossicum* cover and number of breeding grassland birds (savannah sparrow, bobolink, and eastern meadowlark) in Jefferson County, NY. They were absent from pure stands of dog-strangling vine. Impressions by TRCA biologists also suggest that ground-nesting songbirds such as ovenbird will suffer from the consequences of dog-strangling vine invasion. Such birds require available forest floor with leaf litter and sight lines for visibility. Inundation of the forest floor by dog-strangling vine would impair these habitat requirements.

On the other hand, according to a preliminary study conducted by Hanrahan (2006) some native species of wildlife have adapted to *C. rossicum* and occasionally appear to have benefited. She analyzed nests of seven bird species from the Fletcher Wildlife Garden (Ottawa) and found very interesting results.

Ten of the eleven nests of yellow warbler used at least some dog-strangling vine in their construction, and some were made only from this plant. A Baltimore oriole nest was made entirely of stem fibre and lined primarily with fluff from dog-strangling vine. Only one nest of warbling vireo was obtained and it too was constructed largely of *C. rossicum* stem fibre. Red-eyed vireo, house sparrow, song sparrow and red-winged blackbird nests all contained varying amounts of *C. rossicum* stem fibre and/or fluff. Only the American goldfinch nest did not contain any plant parts. However, only one nest of this bird was investigated.

The same author found that two large winter nests of meadow voles were made of approximately 90% dog-strangling vine stem fibre, fluff and seed pods, and 10% grass. At the bottom of each nest was an exceptionally thick pile of *C. rossicum* fluff which could have been lining, or a seed stash, although very few seeds were found. However, these findings largely represent opportunistic use of available fibre sources.

Small mammals may be protected from raptor predation in winter by the dense tangles of *C. rossicum* stems (DiTommaso *et al*., 2005a).

Hoofed browsers such as deer tend to avoid the plant, as might be expected given its formidable array of phytochemicals (Lawlor, 2002). A complication of this that must be considered for the Rouge Park and other places with heavy deer pressure is that high populations of deer may exacerbate dog-strangling vine infestations by eating palatable native competition. Deer have already altered

[7] A number of the extirpated or almost-extirpated species were found in clearings where dog-strangling vine was abundant in 2005. For example, wide-leaved panic grass (*Panicum latifolium*), fan-leaved hawthorn (*Cratægus flabellata*), silver-rod (*Solidago bicolor*), sharp-leaved goldenrod (*S. arguta*), and the northern of the two Rouge Valley records of bashful bulrush (*Trichophorum planifolium*)(seen in the 1970s). The bashful bulrush is a nationally-endangered species whose only extant location in Canada now is Hamilton Royal Botanic Gardens.

extensive areas of forest in the northeastern United States by selectively browsing palatable plants (Sauer, 1998). The two problems facing native flora may reinforce each other.

6.3 Insect Observations

North American insects have evolved in the absence of Eurasian *Cynanchum* species and their phytochemical constituents. Dog-strangling vine thus enjoys a large degree of immunity from insect herbivory and conversely, populations of this species do not support rich insect communities because they are poisonous to them and our insects have not adapted to eat dog-strangling vine.

Ernst and Cappuccino (2005) surveyed arthropod populations on *C. rossicum*, *Asclepias syriaca*, *Solidago altissima*, and mixed graminoids. Stands of dog-strangling vine supported the lowest abundance of both stem- and ground-dwellers, as well as the lowest number of arthropods in most herbivorous guilds. Gall-makers and leaf-miners were completely absent.

Ernst and Cappuccino (2005) also noted very few pollinators on dog-strangling vine flowers in the Ottawa area, repeating the findings of St. Denis and Cappuccino (2004) who found only ants as likely daytime pollinators. On the other hand, numerous pollinators have been observed in Toronto, including flies from several families, bees and wasps, ants, and beetles, though bumblebees avoided the flowers (Christensen, 1998a). A similar array of pollinators has been found in New York State populations (DiTommaso *et al*., 2005a).

Dog-strangling vine invasions are thus likely to reduce arthropod biodiversity, with the possible exception of some pollinators. The decline in herbivorous insects could also have a cascading effect on predatory species (including birds and mammals) that depend on them for food.

C. rossicum may attract insects that normally feed on related milkweeds (*Asclepias* spp.). The transfer from one species to another may succeed, or fail due to the different phytochemistry of *Cyanchum*. Dog-strangling vine may have a negative impact on monarch butterfly populations because of displaced oviposition and larval mortality (DiTommaso *et al*. 2005a). In one study, monarch butterflies from Ithaca, New York did not oviposit on *Cynanchum rossicum* or *C. nigrum*, but fewer than half the larvæ placed on dog-strangling vine leaves survived after 48 hours (DiTommaso and Losey, 2003). Larvæ placed on *C. rossicum* had significantly higher survival than those placed on *C. nigrum* but still did poorly. Another study in Rhode Island did show monarch butterflies ovipositing up to 24.5% of their eggs on *C. nigrum* plants; these larvæ did not survive (Casagrande and Dacey, 2007). This intrusion into the obligate relationship of monarch reproduction on *Asclepias* species is of concern, especially as *C. rossicum* (and *C. nigrum*) increases its range, because it may lead to declines in numbers of monarchs.

Casual observations of herbivorous insects include other Asclepiadaceæ-herbivore species transferring to dog-strangling vine. Ernst and Cappuccino (2005) record observations of milkweed longhorn beetle (*Tetraopes tetraopthalmus*) nibbling on a plant and feeding on cut leaves in the lab, while the small milkweed bug (*Lygæus kalmii*) was observed feeding on seed pods.

The large milkweed bug (cf. *Oncopeltus fasciatus*) was observed by the authors on dog-strangling vine in the summer of 2006 (Figure 17). This is a North American native that specializes in eating the seeds of milkweeds.

Figure 17: Milkweed bug (cf. *Oncopeltus fasciatus*) on *Cynanchum rossicum* seed pod, Taylor Creek Park (photo G. Miller).

Oleander aphids (*Aphis nerii*) normally live on *Asclepias* spp. in Ontario (Figure 18). Some were placed on dog-strangling vine invading a native plant nursery in Toronto in the late 1990s (G. Miller, pers. obs.). The aphids survived and asexually reproduced while the stem of *C. rossicum* became stunted. However, no scientific study or follow-up was done. The rate of reproduction of the aphids appeared to be considerably lower than that on its regular host of *Asclepias* spp. (milkweeds). *C. rossicum* is thus a potential, but definitely not a preferred host.

Figure 18: *Aphis nerii* on *Asclepias incarnata*, Rowntree Mills Park (photo G. Miller).

No research to date has suggested that any of the above insects successfully thrive on *C. rossicum*, nor are there indications that they have a significant impact on dog-strangling vine vigour or reproduction. Generally, no significant insect damage has been observed in North American populations of dog-strangling vine (Lawlor, 2002).

One possible exception was noted in the summer of 2007 by V. Kricsfalusy and G. Miller (pers. obs.). Simultaneously and independently, several instances of Colorado potato beetle (*Leptinotarsa decemlineata*) attacking *C. rossicum* were noted. The beetles left a noticeable "shotgun" pattern of leaf damage, along with some leaf curl on the dog-strangling vine (Figure 19).

Figure 19. Colorado potato beetle (*Leptinotarsa decemlineata*) on *Cynanchum rossicum*, Highland Creek (photo G. Miller).

This insect is a serious agricultural pest that originated on a few native Solanaceæ (not Asclepiadaceæ) species in the Rocky Mountain region of the United States, quickly adapting to potato and spreading throughout the world. The insects observed feeding on dog-strangling vine appear to have transferred from bittersweet nightshade (*Solanum dulcamara*) that was growing in the immediate vicinity.

7. CONTROLS

As it is only relatively recently that resource managers have realized the extent of problems that dog-strangling vine is causing, assessment of potential control measures has lagged. Many areas now have huge infestations, which makes finding effective controls that much more urgent.

7.1 Mechanical

Mechanical methods of control include mowing (or otherwise removing stems and fruit), digging, and mulching.

In Toronto, repeated mowing reduced average stem height, but did not significantly reduce cover (Christensen, 1998a). Plants on a mowed site successfully flowered and set viable seed the following year (Christensen, 1998b). However, mowing properly timed, or the similar activity of pulling and cutting stems, can prevent seed set and thus limit population expansion (DiTommaso *et al*., 2005a). The key is to ensure all pods are removed through to the end of the growing season. Thus, if pods are present at the time of mowing, the clippings must be removed.

Land managers at The Nature Conservancy's Great Gully Preserve reported that digging up *C. rossicum* root crowns was more effective than hand pulling alone (Lawlor, 2002). Digging can be very effective and might be the method of choice for very small populations, particularly if the associated soil disturbance is not considered too serious a side effect. If the root crown is pulled up, it must be removed from the site and/or destroyed because broken root crowns tossed on the ground have been observed to re-grow. This suggests that disk harrowing may not be a successful control method, and may actually contribute to increases in patch size.

According to Lawlor (2002), fruits of *C. rossicum* can be manually removed and destroyed to prevent seed dispersal, but this practice is time-consuming and must be continued until no more pods are produced and the plants senesce at the end of the growing season. It is more effective to remove the entire plant by mowing or pulling as it takes the plants a long time to recover and they often cannot do so in time to produce more seeds that season.

Grazing is of limited use in controlling *C. rossicum*; the plant is at least potentially toxic to livestock, and grazing and trampling can stimulate resprouting (DiTommaso *et al*., 2005a). Cattle will suppress the species temporarily but it will rebound once the pasture is abandoned, while horses and sheep shun it (Lawlor, 2002). Some horse farmers have even abandoned their horse pastures because of dog-strangling vine (Weston *et al*., 2006).

Mulching is potentially effective, if one uses black plastic or some other material that excludes light; however, animals repeatedly tore it open in one trial (Christensen, 1998a, b). Gaps in unprotected cover mulch quickly fill in again with dog-strangling vine (Webster, unpubl.; Figure 20). Results with a barrier mulch might be improved if the plastic is covered with wood chips. Once the dog-strangling vine is killed, trees may be planted in holes in the plastic if desired.

Figure 20: Black plastic laid down in 1998 with *Cynanchum rossicum* coming through gaps in 2006, Rouge Park (photo C. Webster).

Cowbrough (2006a, b) summarized data on manual and mechanical control methods that have been tested by N. Cappuccino at Carlton University (Table 1).

Table 1: Non-chemical control strategies for managing of *Cynanchum rossicum* (after Cowbrough 2006a, b).

Method	Strategy	Notes
Periodic mowing or cutting	Stops the plants from flowering and thereby reduces seed production	Doesn't kill the plants as new ones will sprout up from the buds at the base of the stem
Digging up roots	Remove the entire root of individual plant	Effective, but time consuming; disturbs the soil; practical only for small areas
Mowing and mulching	Mow the plants to stop seed production then cover area with a competitive mulch to stop sprouting of new plants from rhizome	Effective, but unsightly; mulch needs to exclude light and endure until dog-strangling vine propagules (root crown and seed) are eliminated.

7.2 Chemical

Herbicides are probably the current treatment of choice for small-to-moderate dog-strangling vine populations. Mechanical methods (particularly digging) may be effective for very small populations, but rapidly become extremely costly as the size of area to be treated increases. Some, such as mowing, may prevent seed set and population spread indefinitely, but only as long as the treatment continues.

Herbicide usage can be successful, depending on the type of herbicide, its concentration, its method of delivery, and especially the timing. Glyphosate and triclopyr are both be effective as foliar sprays, with cut-stem treatments being less effective (Lawlor, 2000; Lawlor and Raynal, 2002; DiTommaso *et al*., 2005). Glyphosate (RoundupPro) was effective as a foliar spray at concentrations of 2-5%, while triclopyr ester (Garlon 4) was effective at 1%. Only glyphosate, in high concentrations ($\geq$50%), was effective on cut-stem applications.

Glyphosate is a broad-spectrum herbicide; in some situations, triclopyr may be preferred if dog-strangling vine is mixed with valuable graminoids (Lawlor, 2002). Foliar sprays generally have the disadvantage of affecting all the vegetation in the vicinity rather than just the target species.

Timing of herbicide application is very important so as to both prevent seed set and to ensure translocation to the roots. Plants are generally more vulnerable at flowering and early fruit-ripening time when energy is being invested in reproduction; while maximum translocation down to the roots occurs late in the growing season as they prepare for winter dormancy. Christensen (1998b) reported the best results with glyphosate with three sprayings at 5% concentration (June – flowering time, early August – fruit maturing and root translocation beginning, and early September – translocation to roots). Reducing the number of sprayings to two (June and early August) was almost as effective, with over 90% reduction in percentage cover. The early August application appears to be the most critical one. Webster (2007) reported that 2% concentration was just as effective as 4% for backpack spraying.

At High Park in Toronto, intensive efforts since 2001 have had success in reducing the populations of both *Cynanchum rossicum* and *C. nigrum* (Webster, 2003). Because this is an unusual success story, it will be described in some detail. To reduce environmental impacts such as spray drift onto native oak savannah vegetation, glyphosate is applied directly using a car wash mitt to wick the plants. A Roundup formulation called WeatherMax - 22% for wicking is used (before 2006 it was a 33% solution of the Roundup-Transorb formulation)(Webster, pers. comm.). Application is done twice a year between early June and early September, approximating the regime recommended by Christensen (1998b). Testing of the wick treatment resulted in a 95% success rate two months after application (Webster, 2000). Large monocultural stands of dog-strangling vine are sprayed with 1.34% WeatherMax glyphosate solution twice during the growing season.

After the initial treatment, some follow up is necessary to remove survivors recruited from the seed bank or intact root crown fragments. On high-quality sites, native species will recover, but often the post-*Cynanchum* regeneration includes other invasive exotics or very weedy natives such as ragweed (*Ambrosia artemisiifolia*), which is a serious allergen. White sweet clover (*Melilotus alba*) appears to be particularly prolific; Christensen (1998b) noted that total cover for this species ranged from 22 – 71% (with one plot reaching 87%) a year after treatment. Other exotic species that appear in the exposed soil include bull thistle (*Cirsium vulgare*), common mullein (*Verbascum thapsus*), curled dock (*Rumex crispus*), charlock (*Sinapis kaber*), bedstraw (*Galium* sp.) and St. Johnswort (*Hypericum perforatum*). These are all ruderal species specific to newly-disturbed areas, troublesome over the short term, but much less serious than dog-strangling vine (although white sweet clover can be a significant problem in natural areas). They produce very long-lived seed banks and appear suddenly after disturbance.

Re-planting of areas where dog-strangling vine colonies have been removed at High Park was pursued where necessary (Figure 21).

It often takes two or three years of treatment before a dense infestation is ready for re-planting (Webster, pers. comm.). Sunflowers (*Helianthus* spp. especially *H. strumosus*), Canada wild rye (*Elymus canadensis*), bush honeysuckle (*Diervilla lonicera*) and raspberry (*Rubus* spp.) were successful at reclaiming the areas. The species list for re-planting should vary according to the target vegetation community, emphasizing natives that can colonize quickly.

Figure 21: Re-planted site after wick treatment, High Park, 2006 (from Webster, 2007).

Approximately five 1000 m^2 sites have been reclaimed by planting after herbicide control. A number of other sites, particularly those with isolated stems given the “wick” treatment just recover and fill in with native species already present. The successful experience of High Park can be attributed to the following factors:

- It is a high-profile, well-known site with a famous oak savannah community and rare / sensitive flora;
- The site is very accessible;
- There is high public awareness and support with an active stewardship community;
- A multi-year commitment (including financing) has been adhered to by agencies and the public;
- High Park, although it is large and has some big colonies of dog-strangling vine, is also relatively isolated from outside seed sources and dispersal corridors by the urban matrix. For example, residential areas and manicured parks separate it from the Humber Valley and its dog-strangling vine populations. Dispersal and re-invasion from these areas would be slow.

Treatment is relatively labour-intensive and costly; in 2004, the cost estimate was about $360 / ha / year (varying according to infestation intensity)(Webster, pers. comm.).

Further work on chemical control of *C. rossicum* continues. John Bowen from Hydro One has commenced trials at a couple of sites in the Rouge Park with Vantage (another formulation of glyphosate) and aminopyralid (Milestone), a recently-developed chemical (Webster, pers. comm.)[8].

Herbicide treatment becomes impractical in larger, linked corridors with severe infestations, such as many of the Toronto area valley lands and large upstate New York populations. Containment of such populations to prevent further expansion becomes the urgent priority here.

Herbicides, like all pesticides, are controversial because of their toxicity and impacts on non-target species. Glyphosate is relatively non-toxic to fauna and breaks down fairly quickly, but perhaps less than its manufacturers claim (Christensen, 1998a, b). It may persist in damaging levels in soil for several weeks. Direct wick application as used in High Park keeps it restricted to the target species and limits the total amount of herbicide actually used.

In the long term, biological control of dog-strangling vine provides the most promise.

7.3 Biological

Biological control usually involves the introduction of agents from an invasive species' original range that will eat the invader. Invasive exotic species are often invasive because they are free from natural enemies in their new territory. If these enemies (often specialist herbivorous insects) are imported, then the invasive species should decline to levels that are much less harmful to native biodiversity. The process has risks in that the insects may attack native plants and hence a lengthy series of trials must be undertaken to ensure that they will restrict themselves to the target invasive species. Purple loosestrife (*Lythrum salicaria*) is currently being controlled by several imported insects (Blossey *et al*., 2001). The TRCA has been involved in disseminating these insects and TRCA biologists have noticed a significant decline in purple loosestrife infestation since 2000.

Because of the risks involved, including the possibility that imported specialist insects may evolve to include native species in their future menu (over a longer time frame than trials allow), a modification of this approach could involve using native or naturalized insects that show initial signs of adapting to the invasive species. Captive breeding of these insects could induce or speed up the process of adaptation. Spontaneous adaptation by a North American weevil has enabled it to control the invasive Eurasian water-milfoil (*Myriophyllum spicatum*)(Sheldon and Creed, 1995).

Another biological approach would be to plant competing vegetation that can restrain the invasive species through shading or other means such as allelopathy.

Since *Cynanchum vincetoxicum* (white swallow-wort) is the most common of the European members of the genus, most insects studied have been reported for this species (DiTommaso *et al*., 2005a). There are several potential biological control agents associated with *C. vincetoxicum* in Europe (Tewksbury *et al* 2002). In western and central Europe, two chrysomelids, *Chrysochus asclepiadeus* Pallas and *Chrysomela aurichalcea* ssp. *bohemica* Mann, are reported as specialists on this plant (Mohr, 1966; Dobler *et al.*, 1998). Anecdotal Russian literature indicates that there are several other

[8] Webster also reports that work is being started at a site near the Finch meander (Sewell's Road and Finch Ave.) in the Rouge Park.

species of chrysomelid beetles that feed on *Cynanchum* species in Russia and central Asia[9]. The weevil *Otiorhynchus pinastri* and three flies (*Euphranta connexa*, *Contarinia vincetoxici*, and *C. asclepiadis*) feed on reproductive plant parts of *C. vincetoxicum*, e.g. immature seeds still in the pod (DiTommaso *et al*., 2005a).

Assessment of the insect fauna of *C. rossicum* in Eastern Europe and in Russia is confounded by the complicated plant synonymy at both the specific and generic level. The potential for finding herbivores seems great given the number of species recorded from that area.

In addition to these European insects, one fungal pathogen has been identified in the literature for *Cyanchum* spp.: a rust, *Cronartium flaccidum*. However, pines (*Pinus* spp.) are its alternate host and therefore it should not be considered as a possible biological control.

As for existing native or naturalized North American insects that may utilize *C. rossicum*, those that have been observed are described in Section 6.3 above. There is no evidence that the milkweed longhorn beetles, small or large milkweed bugs, or oleander aphids have any significant impact. The fact that the milkweed bugs are seed predators (and hence could reduce seed set and reproduction if sufficient predation occurs) might stand in their favour. Colorado potato beetle is complicated by the fact that it is a serious agricultural pest; however, it may be adapting spontaneously to *C. rossicum* without human help. All of these insects deserve further research and perhaps captive breeding trials to determine if they do indeed have potential as controls.

Several species of *Cynanchum* (or closely-related genera depending on the taxonomy used) are native to North America, with a range south of the Great Lakes and not yet overlapping with the invasive *C. rossicum*. The most prominent is honey-vine (*C. læve)*. The North American species are mildly weedy but not catastrophically invasive. It is almost certain that there are insects that utilize the North American *Cynanchum* species. It is possible that these insects could attack *C. rossicum* either spontaneously upon contact, or be induced to do so by adaptation. This is another possible avenue of exploration, and one that is arguably lower-risk than introducing European insects.

The planting of competing vegetation, especially plants that exhibit vigourous early-season growth or that cast dense shade, might help in some instances to control dog-strangling vine. Christensen and Strobl (1999) observed that the plant is less common and less vigourous under mature forest canopy. Tree cover also reduces seed production and dispersal and could slow it down. Plantings could be designed to set up barriers to dispersal along major corridors. However, dog-strangling vine is so competitive itself that there appear to be few plants that can take it on. Tree saplings and sometimes mature conifer plantations are readily swamped. It will even outcompete other invasive exotics. Furthermore, *C. rossicum* can persist indefinitely even in mature forests, suppressing ground layer vegetation and readily released by canopy disturbance. Tree planting in combination with a secure barrier mulch should be helpful, however.

Another avenue of biological control that could be promising is the planting of trees and shrubs that exhibit allelopathic inhibition of *Cynanchum rossicum*. While there is no literature on this subject, black walnut (*Juglans nigra*) is well-known for its allelopathic effects (secretion of juglone). In fact, we observed situations where black walnut did appear to inhibit dog-strangling vine within its drip-line

[9] The Colorado potato beetle, which has been observed on dog-strangling vine, is itself a chrysomelid (http://www.itis.gov/servlet/SingleRpt/SingleRpt?search_topic=TSN&search_value=720110).

(Figure 22). Black walnut inhibits many plant species; however, most native North American plants of the deciduous forest co-evolved with it, and many spring ephemerals, for example, are tolerant of juglone (Bade, 2006; Dana and Lerner, 2006). Other native plants, such as white pine, paper birch, and columbine are sensitive.

Figure 22: Inhibition of *Cynanchum rossicum* growth by *Juglans nigra* near West Duffins Creek (photo V. Kricsfalusy).

Somewhat less expected was a similar effect observed under planted specimens of Colorado spruce (*Picea pungens*) (Figure 23). While *C. rossicum* often vigorously invades conifer plantations (at least those with even moderate light penetration through the canopy – see Figure 12, p. 29), its growth was inhibited under specimens of this particular conifer species, even with more than adequate light. No literature concerning the specific allelopathic properties of Colorado spruce was located, yet all other commonly planted conifers do not appear to significantly inhibit *C. rossicum*, including other species of spruce as noted by TRCA and other biologists. Although not native, Colorado spruce has shown no signs of invasiveness in southern Ontario, in spite of being a frequently-planted ornamental.

Figure 23: Inhibition of *Cynanchum rossicum* growth by Colorado spruce *Picea pungens*, Humber River near Rowntree Mills Park (photo V. Kricsfalusy).

The decision to use black walnut or other competitive species should take into consideration the existing or desired target vegetation community.

8. RECOMMENDATIONS

C. rossicum, from all indications, appears to have a severe impact on natural habitats and native flora and fauna. Although specific information on its displacement of native species through comparison of pre- and post-invasion site conditions is lacking, there are enough observations of infested habitats and the plant's behaviour and ecology to make the case compelling.

The main pathway by which *C. rossicum* invades is by extremely efficient and successful seed production. Seed production is heavy, especially in conditions of light shade or sun; viability and germination are exceptionally high, and all this occurs with flexible strategies including the options of self- or out-pollination, polyembryony, and seed dormancy induced by less-than-favourable conditions. *Therefore the reduction or elimination of seed production and germination would be essential to a successful control programme for dog-strangling vine.*

Once present on a site, dog-strangling vine is subject to Allee effects whereby isolated plants are less vigourous and competitive than established patches. It also is able to exploit and probably alter existing soil mycorrhizal biota. The ecology of this plant seems to indicate that it is not especially dependent on disturbance. Rather, although it can exploit disturbance and colonize corridors, it tends to stealthily appear first in small numbers, then rapidly expand in population and overwhelm the ecosystem. *Thus, early detection is important. At the same time, large populations produce much more seed and so containing them will have a greater impact on preventing the establishment of new satellite populations* (Cappuccino, 2004).

8.1 Prevention

Prevention of further spread of dog-strangling vine is of the utmost importance. There are still natural areas in the Toronto region where it has not yet appeared, and establishment may still be avoided. The following steps may help in prevention:

a. Educate public agencies, non-governmental organizations, and private landowners (including urban ravine property owners) to recognize the plant and know the danger it presents to natural habitats. This will help ensure that new satellite populations are identified and removed as soon as they appear.
b. Notify nurseries and garden centres (aside from those specializing in native plants) about dog-strangling vine and other invasive species to prevent inadvertent propagation and dispersal (even today they frequently misidentify them).
c. Target infrastructure and transportation (utilities, railways, highways) regarding awareness of dog-strangling vine and possible control methods. The open to semi-open habitat, low-to-moderate periodic disturbance regime, connectivity, and wind movement along infrastructure corridors provide ideal opportunities for dog-strangling vine establishment and dispersal. Fortunately, Hydro One is already involved in *C. rossicum* control trials near the Rouge River.
d. Monitoring of conservation lands and transportation and utility corridors for *C. rossicum* and other invasive plants should be accepted practice. Some of the corridors can provide positive ecological benefits as well as risks; for example, hydro corridors can support native flora of concern that require periodic disturbance; and railway lines may have prairie plants along them. Ecological restoration and stewardship should be integral to utility corridor land management. Partnerships can be formed between agencies and others involved in restoration.
e. Plant preventive wind-breaks across infested corridors to slow down seed dispersal and spread. Even if such barrier vegetation has dog-strangling vine in the ground layer, the shaded plants produce less seed and the seed is less likely to travel far. Trees that cast dense shade and/or exhibit allelopathic potential should be considered.
f. Consider mowing some of the worst infested corridors on a regular basis to prevent seed set and dispersal. In this case, one would need to ensure that species of conservation concern are absent before starting a mowing regime.

8.2 Control

Given the severity of *C. rossicum* over large areas of the lower Great Lakes, and the expense and labour involved in mechanical and chemical control methods, long-term control will ultimately require biological agents. Purple loosestrife had presented a similar problem and biological controls have been successful. However, there are no known biological controls at present, aside from some possible competition provided by allelopathic trees. In many cases, threatened native ecosystem remnants may not have time to wait for a suitable biological control, and immediate action is warranted. A combination of mechanical, chemical, and barrier planting methods, depending on the site conditions, is recommended as outlined below:

a. Where infestations of dog-strangling vine are very small and isolated, digging the whole plant including the root crown is effective. The root crown must be removed and allowed to dry out to prevent possible re-establishment.
b. Light infestations, or those where native plants are intermingled with dog-strangling vine, should be given the wick treatment twice during the growing season with a moderately high concentration of glyphosate or similar herbicide as described in section 7.2.
c. To protect plants of special conservation concern that are in danger of being overwhelmed by heavy dog-strangling vine infestations, use the same wick application approach. A small "zone of protection" would be provided. This would be a temporary measure to preserve the native plant populations until more effective means (probably biological control) can be found. Examples of this situation might be prairie plants at East Point Park, Toronto or a few savannah / glade sites in the southern part of Rouge Park.
d. Heavy but isolated populations that are more-or-less monotypic should be sprayed with 2% glyphosate or equivalent twice per growing season (in June and August) as described in section 7.2. This should be done for three years. The site should then be planted with appropriate natives and monitored to prevent reinvasion by dog-strangling vine or other invasives.
e. Heavy infestations in linked corridors cannot feasibly be eliminated with methods currently available. The priority should be containment through planting wind breaks, mowing to stop seed set, or otherwise separating the dog-strangling vine population from its surroundings.
f. If forest cover on a heavily-infested site is the desired outcome, tree planting into a barrier mulch might work. Mow the site, covering it with a durable barrier mulch such as black plastic, followed by tree planting through small holes in the plastic, and then cover the plastic with sufficient wood chips or other organic mulch to protect it from animals or other puncturing agents. After complete canopy closure is achieved, the plastic should be removed and the ground layer planted with forest floor species.
g. Trees that appear to exhibit allelopathic inhibition of *C. rossicum*, such as black walnut and Colorado spruce, should be tried with or without barrier mulch. The choice of tree should depend on the desired target community and species suited to the site. Where species such as white pine that are susceptible to juglone are present or desired, Colorado spruce might be a better companion tree even though it isn't native. On the other hand, most spring ephemerals and other plants associated with rich deciduous forest are tolerant of juglone and so black walnut may be a good companion or nurse tree for establishing such communities.
h. Tree planting is not advisable in situations where species of conservation concern that require open habitat are mixed with dog-strangling vine (or where the presence of utilities prevents it). The wick treatment, followed by biological control as it becomes available, is to be preferred; or spraying / mowing where no native species are present.
i. Where remnant populations of plants of conservation concern are immediately threatened by dog-strangling vine, and successful control is not likely, seed from these native plants should be collected and propagated off-site to rescue them.

8.3 Further Research

While more information regarding *Cynanchum rossicum* has been appearing in recent years, there are still significant gaps that provide opportunities for research. These include research on specific impacts on native flora and fauna; potential biological controls, and even possible ways of making use of the plant and its phytochemical properties in beneficial ways. A summary of potential avenues of research is as follows:

a. Long-term monitoring for direct impacts of dog-strangling vine is needed, as site-specific information 'before' and 'after' invasion is missing. These impacts are inferred through observation of the plant's behaviour and by comparison of infested and non-infested sites. *The kind of research that is needed here is a set of monitoring plots across a gradient of infestation where in-situ changes in ecology, structure, and biodiversity can be observed during the process of invasion*.
b. Trials of allelopathic or potentially allelopathic trees such as black walnut and Colorado spruce to assess their ability to inhibit dog-strangling vine should be undertaken. Restoration efforts that make use of these trees should be monitored quantitatively.
c. Research into herbivorous insects (or pathogens) that could be potential biological controls should be a top priority, for this is the most likely long-term solution. Some specific directions for insect research might include:

    I. Because seed production and germination are so essential to the invasiveness of dog-strangling vine, *insects that show evidence of pod or immature seed predation should be given attention*.
    II. *Native (or already introduced) insects should be included for research due to their potential for spontaneous or induced adaptation and to reduce risk to native flora from further insect introductions* (see sections 6.3 and 7.3).
    III. Insects associated with North American *Cyanchum* (or related twining asclepiad genera) should also be investigated for their potential for adaptation. The introduction of insects from a few hundred kilometers away rather than transoceanic distances might be successful and lower-risk.
    IV. European insects associated with *Cynanchum* spp. such as chrysomelid beetles and tephretid flies should be subject to evaluation and trials as has been done successfully with purple loosestrife. It must be established that such insects will not attack native milkweeds or related species.

d. Possible interactions between troublesome plant pathogens and dog-strangling vine could be investigated. For example, butternut (*Juglans cinerea*), dog-strangling vine, and butternut canker should be researched. Butternut is endangered because of butternut canker, a fungal disease that is killing a large proportion of the trees. It is also a moderate producer of juglone and may suppress dog-strangling vine to some extent. On the other hand, the phytochemicals of dog-strangling vine are potent fungicides. Possible questions include: How much canker is evident on butternut trees and saplings growing amid dog-strangling vine? And how vigorous is dog-strangling vine growing under a butternut canopy?

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Appendix 1. Published nomenclature of *Cynanchum rossicum*

Name	Synonym	Author
Europe		
Cynanchum rossicum Kleop.	**-**	Kleopow 1929
Vincetoxicum medium Schmalh. p. p. non Decne.	*V. schmalhauseni* (Kusn.) Stank.	Stankov and Taliev 1949
Vincetoxicum rossicum (Kleop.) Barbar.	*V. medium* Schmalh. p. p. non Decne.	Barbarich 1950; Visiulina 1957
Antitoxicum rossicum (Kleop.) Pobed.	*V. rossicum* (Kleop.) Barbar., *V. medium* Schmalh. p. p. non Decne., *C. rossicum* Kleop.	Pobedimova 1952
Vincetoxicum rossicum Kleop.	*V. medium* Schmalh. p. p. non Decne., *A. rossicum* Pobed.	Visiulina 1965
Cynanchum rossicum (Kleopow) Borhidi	*V. medium* Schmalh. p. p. non Decne., *A. rossicum* Pobed.	Borhidi and Priszter 1966
Vincetoxicum rossicum (Kleop.) Barbar.	*C. rossicum* Kleop., *A. rossicum* (Kleop.) Pobed.	Pobedimova 1978
Vincetoxicum rossicum (Kleop.) Barbar.	*V. medium* Schmalh. p. p. non Decne., *A. rossicum* (Kleop.) Pobed.	Glagoleva 1987
Vincetoxicum rossicum (Kleopow) Barbarich	*A. rossicum* (Kleop.) Pobed.	Markgraf 1972
North America		
Vincetoxicum medium (R. Br.) Decne.	-	Pringle 1973
Vincetoxicum hirundinaria Medik.*	-	Gleason and Cronquist 1991
Vincetoxicum rossicum (Kleopow) Barbar.	-	Scoggan 1979; Voss 1996
Vincetoxicum rossicum (Kleo.) Barbar.	*C. rossicum* Kleo., *C. rossicum* (Kleo.) Borhidi, *A. rossicum* (Kleo.) Pobed.	Sheeley and Raynal 1996
Vincetoxicum rossicum (Kleopow) Barbar.	*C. rossicum* (Kleopow) Barbar.	Cappuccino *et al*. 2002; DiTommaso *et al*. 2005b
Cynanchum rossicum (Kleopow) Borhidi	*V. rossicum* (Kleopow) Barbar., *V. medium* not (R. Br.) Decne., *C. medium* not R. Br.	Morton and Venn 1990; Kartesz 1994; Newmaster *et al*. 1998; Darbyshire *et al*. 2000; DiTommaso *et al*. 2005a

**V. rossicum* (Kleopow) Barbar. is included by Gleason and Cronquist (1991) and Lauvanger and Borgen (1998) in this species.

Appendix 2: Herbarium records of Cynanchum rossicum (Toronto Region)

COLLECTOR'S NAME	LOCATION	DATE	HERBARIA (* full name below)
MAKKAY K.	TORONTO: WILLOWDALE: BANK OF DON RIVER	6/28/1992	WAT
CAZA C.	TORONTO: BAYVIEW AVE. EXTENSION	9/30/1978	TRT
OLDHAM M.	SCARBOROUGH: LOWER ROUGE VALLEY	6/3/1980	TRT
WHITING R.	BOROUGH OF YORK, HUMBER RIVER FLATS	6/24/1973	TRT
KIRKBY B. and D. TIGHE	BOROUGH OF YORK, LOT 3, CONC. III	?/?/1976	TRT
HUNG A.	SCARBOROUGH: BRIMWOOD FOREST	9/18/1996	TRTE
SMITH M.	SCARBOROUGH: BLUFFS	9/27/1981	TRT
SOPER J.H.	TORONTO: NORTH YORK TP, DON RIVER	10/26/1950	TRT
SCOTT W.M.	TORONTO: DON VALLEY	9/22/1911	DAO
SCOTT W.M.	TORONTO: DON VALLEY	9/22/1911	TRT
BROWN H.	TORONTO: DON VALLEY	6/6/1930	MT
BROWN H.	TORONTO: DON VALLEY	6/6/1930	TRT
DORE W.G.	TORONTO: DON VALLEY	7/16/1944	MO
CATLING P., J. KAISER and S.McKAY	TORONTO: DON VALLEY	9/28/1976	TRT
BRUNTON D.F.	TORONTO: DON VALLEY	7/13/1980	CAN
BARNES M.R.	TORONTO: DON VALLEY, E.R. WOOD ESTATE	1/1/1950	TRT
WALKER M.R. and S.J. HIBBINS	TORONTO: DON VALLEY WEST RAVINE	9/24/1977	TRT
BROWN H.H.	TORONTO: DONLANDS	6/15/1934	TRT
MORTON B.	TORONTO: DONLANDS	6/26/1911	TRT
BROOKS R.E.	DURHAM REGION: PICKERING VILLAGE	8/6/1989	KANU
CATLING P.M. and S. McKAY	TORONTO ISLAND: GIBRALTAR POINT	8/13/1972	TRT
CRUISE J., J. GREAR and P. CATLING	TORONTO: HIGH PARK	1/1/1970	TRT
WHITING R.E.	TORONTO: HUMBER R. FLATS	6/24/1973	HAM
REDHEAD S.	TORONTO: HUMBER RIVER	7/21/1974	TRT
LAUDENBACH J.	TORONTO: HUMBER RIVER VALLEY	6/2/1973	TRTE
LAUDENBACH J.	TORONTO: HUMBER RIVER VALLEY	8/15/1973	TRTE
SCHWARTZEL E.	TORONTO: BAYVIEW VILLAGE ON E. DON RIVER	6/22/1981	TRT
SCHWARTZEL E.	TORONTO: BAYVIEW VILLAGE ON E. DON RIVER	10/4/1981	TRT
GLENN S.	SCARBOROUGH: KINGSTON RD and GUILDWOOD	9/26/1980	TRT
CHAMPOUX S.	PICKERING: LITTLE ROUGE CREEK	7/24/1973	TRT
CRINS W.J. and P.	SCARBOROUGH: BELLAMY RAVINE	7/4/1985	TRTE

Appendix 2: Herbarium records of Cynanchum rossicum (Toronto Region)

COLLECTOR'S NAME	LOCATION	DATE	HERBARIA (* full name below)
WILLSTEAD			
HUNG A.	SCARBOROUGH: MORNINGSIDE, ROUGE RIVER	9/23/1966	TRTE
THOMPSON S. L.	TORONTO: DONLANDS	6/24/1922	TRT
VORONA D.	NORTH YORK: LAURALEAF PARK	10/19/1995	TRTE
BROWN H.	SCARBOROUGH: WEXFORD	10/6/1929	CAN
SHUMOVICH W.M.	PICKERING TP.: DUNBARTON	6/27/1953	DAO
SOMERS P.	TORONTO: ROSEDALE GOLF COURSE	6/23/1986	WAT
KUJA A.L. and S. MCKAY	SCARBOROUGH: BLUFFS	6/17/1981	TRT
LANCASTER, JANICE	SCARBOROUGH COLLEGE, HIGHLAND CREEK	8/5/1980	TRT
CATLING, P.M. ET AL.	SCARBOROUGH: WEST HILL	7/20/1973	TRT
PRINGLE J.S.	TORONTO: SERENA GUNDY PARK	10/6/1971	HAM
OWENS L.T.	TORONTO: SHERWOOD PARK	6/26/1955	TRT
BAHR P.	TORONTO: SUNNYBROOK HOSPITAL	7/16/1968	HAM
SIMON J.A.	TORONTO: SUNNYBROOK PARK	6/27/1939	TRT
SIMON J.A.	TORONTO: SUNNYBROOK PARK	8/15/1939	TRT
PRINGLE J.S.	TORONTO: SUNNYBROOK PARK	10/6/1971	HAM
KAYE D.	SCARBOROUGH: THOMSON PARK	1/1/1966	TRT
POKORNY A.	TORONTO, WILKET CREEK PARK	8/6/1968	MTMG
GARAY L.A.	UNIVERSITY OF TORONTO BOTANICAL GARDEN	6/3/1952	TRT
GARAY L.A.	UNIVERSITY OF TORONTO BOTANICAL GARDEN	6/3/1952	TRT
WALKER M.R.	TORONTO: WEST DON RIVER	7/22/1977	DAO
WALKER M.R.	TORONTO: WEST DON RIVER RAVINE	7/22/1977	TRT
BROWN H.	TORONTO: WEXFORD	10/6/1929	TRT
MARK G.C.	TORONTO: WILKET CREEK	9/30/1964	DAO
OWENS L.T.	TORONTO: YORK MILLS	8/5/1953	TRT
WHITE J.	TORONTO JUNCTION	8/29/1902	DAO
WHITE J.	TORONTO JUNCTION	11/1/1902	DAO
BROWN H.H.	SCARBOROUGH: WEXFORD	10/6/1929	DAO
McCCREADY S.B.	TORONTO	7/27/1945	DAO
GREVATT J.G.	ETOBICOKE: THISTLETOWN	1/1/1957	TRT
HEATON R.F.	TORONTO	6/20/1966	WAT
RICHARDSON L.	SCARBOROUGH: BLUFFS	10/4/1981	TRT
GODDARD A.W.	PICKERING: LOCUST HILL AND WHITEVALE	8/10/1988	DAO
KUBIW H. and A. DULHANTY	VAUGHAN: BOYD CONSERVATION AREA	6/9/1981	TRT
KRICSFALUSY V. and R. KRICK	RICHMOND HILL, ORMCP	?/?/1996	ANON.

* HERBARIA CITED IN THIS STUDY

KW – National Herbarium of Ukraine / M.G. Kholodny Institute of Botany, Kiev, Ukraine
CAN – Canadian Museum of Nature, Ottawa,ON
DAO – Agriculture and Agri-Food Canada, Ottawa, ON
HAM – Hamilton Royal Botanical Gardens, QU
MT – University of Montreal, Montreal, QU
MTMG – McGill University, Montreal, QU
TRT – University of Toronto / Royal Ontario Museum, Toronto, ON
TRTE – University of Toronto at Mississauga (Erindale Campus), Mississauga, ON
WAT – University of Waterloo, Waterloo, ON
KANU – University of Kansas, Lawrence, KS
MO – Missouri Botanical Garden, St. Louis, MO

Appendix 3: List of TRCA Vegetation Communities with records of polygons having Cynanchum rossicum infestation (i.e. dominant or co-dominant (1st-4th) in at least one layer).

ELC code	Vegetation Type	Local distribution	Local rank
	Forest		
FOC1	Dry-Fresh White Pine - Red Pine Coniferous Forest Ecosite	4	L1
FOC1-2	Dry-Fresh White Pine (- Red Pine) Coniferous Forest	4	L1
FOC1-a	Dry-Fresh Scots Pine Coniferous Forest	4	L+
FOC2	Dry-Fresh Cedar Coniferous Forest Ecosite	2	L4
FOC2-2	Dry-Fresh White Cedar Coniferous Forest	2	L4
FOC3	Fresh-Moist Hemlock Coniferous Forest Ecosite	2	L4
FOC3-1	Fresh-Moist Hemlock Coniferous Forest	2	L4
FOC3-A	Fresh-Moist Hemlock - White Pine Coniferous Forest	3	L3
FOC4	Fresh-Moist White Cedar Coniferous Forest Ecosite	2	L4
FOC4-1	Fresh-Moist White Cedar Coniferous Forest	2	L4
FOC4-2	Fresh-Moist White Cedar - Hemlock Coniferous Forest	2	L4
FOC4-A	Fresh-Moist White Cedar - White Pine Coniferous Forest	4	L3
FOM2	Dry-Fresh White Pine - Maple - Oak Mixed Forest Ecosite	2	L5
FOM2-1	Dry-Fresh White Pine - Oak Mixed Forest	4	L2
FOM2-2	Dry-Fresh White Pine - Sugar Maple Mixed Forest	2	L5
FOM2-A	Dry-Fresh White Pine - Hardwood Mixed Forest	3	L4
FOM3	Dry-Fresh Hardwood - Hemlock Mixed Forest Ecosite	2	L4
FOM3-1	Dry-Fresh Hardwood Hemlock Mixed Forest	5	L2
FOM3-2	Dry-Fresh Hemlock - Sugar Maple Mixed Forest	2	L4
FOM4	Dry-Fresh White Cedar Mixed Forest Ecosite	2	L5
FOM4-1	Dry-Fresh White Cedar - Paper Birch Mixed Forest	3	L4
FOM4-2	Dry-Fresh White Cedar - Poplar Mixed Forest	3	L4
FOM4-A	Dry-Fresh White Cedar - Hardwood Mixed Forest	3	L4
FOM6	Fresh-Moist Hemlock Mixed Forest Ecosite	2	L4
FOM6-1	Fresh-Moist Sugar Maple - Hemlock Mixed Forest	2	L4
FOM6-2	Fresh-Moist Hemlock - Hardwood Mixed Forest	3	L3

Appendix 3: List of TRCA Vegetation Communities with records of polygons having Cynanchum rossicum infestation (i.e. dominant or co-dominant (1st-4th) in at least one layer).

ELC code	Vegetation Type	Local distribution	Local rank
FOM7	Fresh-Moist White Cedar - Hardwood Mixed Forest Ecosite	2	L4
FOM7-1	Fresh-Moist White Cedar - Sugar Maple Mixed Forest	2	L4
FOM7-2	Fresh-Moist White Cedar - Hardwood Mixed Forest	2	L4
FOM8	Fresh-Moist Poplar - Paper Birch Mixed Forest Ecosite	4	L3
FOM8-1	Fresh-Moist Poplar Mixed Forest	5	L2
FOM8-2	Fresh-Moist Paper Birch Mixed Forest	5	L2
FOMA	Fresh-Moist White Pine Mixed Forest Ecosite	5	L3
FOMA-A	Fresh-Moist White Pine - Sugar Maple Mixed Forest	5	L3
FOD1	Dry-Fresh Oak Deciduous Forest Ecosite	4	L2
FOD1-1	Dry-Fresh Red Oak Deciduous Forest	4	L2
FOD1-4	Dry-Fresh Mixed Oak Deciduous Forest	4	L2
FOD2	Dry-Fresh Oak – Maple -Hickory Deciduous Forest Ecosite	3	L4
FOD2-2	Dry-Fresh Oak - Hickory Deciduous Forest	5	L3
FOD2-3	Dry-Fresh Hickory Deciduous Forest	5	L3
FOD2-4	Dry-Fresh Oak - Hardwood Deciduous Forest	3	L4
FOD3	Dry-Fresh Poplar - Paper Birch Deciduous Forest Ecosite	2	L5
FOD3-1	Dry-Fresh Poplar Deciduous Forest	2	L5
FOD3-2	Dry-Fresh Paper Birch Deciduous Forest	2	L4
FOD4	Dry-Fresh Anomalous Deciduous Forest Ecosite	n/a	n/a
FOD4-1	Dry-Fresh Beech Deciduous Forest	5	L3
FOD4-2	Dry-Fresh White Ash Deciduous Forest	2	L5
FOD4-A	Dry-Fresh Ironwood Deciduous Forest	5	L3
FOD4-c	Dry-Fresh Black Locust Deciduous Forest		
FOD4-d	Dry-Fresh Norway Maple Deciduous Forest	4	L+
FOD4-e	Dry-Fresh Exotic Deciduous Forest	5	L+
FOD5	Dry-Fresh Sugar Maple Deciduous Forest Ecosite	1	L5
FOD5-1	Dry-Fresh Sugar Maple Deciduous Forest	1	L5
FOD5-2	Dry-Fresh Sugar Maple - Beech Deciduous Forest	1	L5
FOD5-3	Dry-Fresh Sugar Maple - Oak Deciduous Forest	2	L4
FOD5-4	Dry-Fresh Sugar Maple - Ironwood Deciduous Forest	2	L5
FOD5-6	Dry-Fresh Sugar Maple - Basswood Deciduous Forest	4	L4

Appendix 3: List of TRCA Vegetation Communities with records of polygons having Cynanchum rossicum infestation (i.e. dominant or co-dominant (1st-4th) in at least one layer).

ELC code	Vegetation Type	Local distribution	Local rank
FOD5-7	Dry-Fresh Sugar Maple - Black Cherry Deciduous Forest	3	L4
FOD5-8	Dry-Fresh Sugar Maple - White Ash Deciduous Forest	2	L5
FOD5-10	Dry-Fresh Sugar Maple- Paper Birch-Poplar Deciduous Forest	2	L4
FOD5-A	Dry-Fresh Sugar Maple - Hawthorn Deciduous Forest	3	L4
FOD6	Fresh-Moist Sugar Maple Deciduous Forest Ecosite	2	L5
FOD6-1	Fresh-Moist Sugar Maple - Ash Deciduous Forest	2	L5
FOD6-2	Fresh-Moist Sugar Maple - Black Maple Deciduous Forest	3	L4
FOD6-3	Fresh-Moist Sugar Maple - Yellow Birch Deciduous Forest	4	L3
FOD6-4	Fresh-Moist Sugar Maple - White Elm Deciduous Forest	2	L5
FOD6-5	Fresh-Moist Sugar Maple - Hardwood Deciduous Forest	2	L5
FOD7	Fresh-Moist Lowland Deciduous Forest Ecosite	n/a	n/a
FOD7-1	Fresh-Moist White Elm Lowland Deciduous Forest	2	L5
FOD7-2	Fresh-Moist Ash Lowland Deciduous Forest	2	L5
FOD7-3	Fresh-Moist Willow Lowland Deciduous Forest	1	L5
FOD7-4	Fresh-Moist Black Walnut Lowland Deciduous Forest	5	L3
FOD7-5	Fresh-Moist Black Maple Lowland Deciduous Forest	3	L4
FOD7-a	Fresh-Moist Manitoba Maple Lowland Deciduous Forest	2	L5
FOD7-b	Fresh-Moist Norway Maple Lowland Deciduous Forest	4	L+
FOD7-c	Fresh-Moist Exotic Lowland Deciduous Forest	5	L+
FOD7-E	Fresh-Moist Hawthorn - Apple Lowland Deciduous Forest	2	L5
FOD7-F	Fresh-Moist Basswood Lowland Deciduous Forest	4	L4
FOD8	Fresh-Moist Poplar - Sassafras Deciduous Forest Ecosite	2	L5
FOD8-1	Fresh-Moist Poplar Deciduous Forest	2	L5
FOD8-A	Fresh-Moist Cottonwood Coastal Deciduous Forest	5	L2
FOD8-B	Fresh-Moist Paper Birch Deciduous Forest	3	L4

Appendix 3: List of TRCA Vegetation Communities with records of polygons having Cynanchum rossicum infestation (i.e. dominant or co-dominant (1st-4th) in at least one layer).

ELC code	Vegetation Type	Local distribution	Local rank
FOD9	Fresh-Moist Oak -Maple-Hickory Deciduous Forest Ecosite	2	L5
FOD9-1	Fresh-Moist Oak - Sugar Maple Deciduous Forest	3	L3
FOD9-5	Fresh-Moist Bitternut Hickory Deciduous Forest	5	L3
CUP1	Deciduous Plantation Ecosite	2	L5
CUP1-1	Sugar Maple Deciduous Plantation	4	L5
CUP1-4	Hybrid Poplar Deciduous Plantation	2	L+
CUP1-5	Silver Maple Deciduous Plantation	2	L5
CUP1-7	Red (Green) Ash Deciduous Plantation	2	L5
CUP1-A	Restoration Deciduous Plantation	2	L5
CUP1-c	Black Locust Deciduous Plantation	3	L+
CUP1-f	Siberian Elm Deciduous Plantation	5	L+
CUP2	Mixed Plantation Ecosite	3	L5
CUP2-A	Restoration Mixed Plantation	3	L5
CUP2-b	Black Locust - Conifer Mixed Plantation	3	L+
CUP2-c	Norway Maple - Conifer Mixed Plantation	2	L+
CUP2-D	Apple - Conifer Mixed Plantation	3	L5
CUP2-E	Silver Maple - Conifer Mixed Plantation	3	L5
CUP2-f	Hybrid Poplar - Conifer Mixed Plantation	3	L+
CUP2-h	Horticultural Mixed Plantation	3	L+
CUP3	Coniferous Plantation Ecosite	1	L5
CUP3-1	Red Pine Coniferous Plantation	2	L5
CUP3-2	White Pine Coniferous Plantation	2	L5
CUP3-3	Scotch Pine Coniferous Plantation	1	L+
CUP3-4	Jack Pine Coniferous Plantation	4	L5
CUP3-6	European Larch Coniferous Plantation	3	L+
CUP3-9	Norway Spruce - European Larch Coniferous Plantation	2	L+
CUP3-A	Restoration Coniferous Plantation	5	L5
CUP3-b	Austrian Pine Coniferous Plantation	2	L+
CUP3-C	White Spruce Coniferous Plantation	2	L5
CUP3-e	Norway Spruce Coniferous Plantation	2	L+
CUP3-G	White Cedar Coniferous Plantation	3	L5
CUP3-H	Mixed Conifer Coniferous Plantation	2	L5
	Successional		
CUT1	Mineral Cultural Thicket Ecosite	1	L5
CUT1-1	Sumac Cultural Thicket	1	L5
CUT1-2	Serviceberry Cultural Thicket	4	L3
CUT1-3	Chokecherry Cultural Thicket	3	L4
CUT1-5	Raspberry Cultural Thicket	2	L5
CUT1-A	Native Sapling Cultural Thicket	1	L5

Appendix 3: List of TRCA Vegetation Communities with records of polygons having Cynanchum rossicum infestation (i.e. dominant or co-dominant (1st-4th) in at least one layer).

ELC code	Vegetation Type	Local distribution	Local rank
CUT1-A1	Native Deciduous Sapling Cultural Thicket	1	L5
CUT1-A2	Native Mixed Sapling Cultural Thicket	2	L5
CUT1-A3	Coniferous Sapling Cultural Thicket	2	L4
CUT1-b	Buckthorn Cultural Thicket	3	L+
CUT1-c	Exotic Cultural Thicket	4	L+
CUT1-D	Round-leaved Dogwood Cultural Thicket	4	L3
CUT1-E	Red Osier Dogwood Cultural Thicket	4	L4
CUH1	Hedgerow Ecosite	1	L5
CUH1-A	Treed Hedgerow	1	L5
CUH1-B	Native Shrub - Sapling Hedgerow	2	L5
CUH1-c	Buckthorn Hedgerow	2	L+
CUS1	Mineral Cultural Savannah Ecosite	2	L5
CUS1-1	Hawthorn Cultural Savannah	2	L5
CUS1-2A	White Cedar Cultural Savannah	3	L4
CUS1-A	Native Cultural Savannah	2	L5
CUS1-A1	Native Deciduous Cultural Savannah	2	L5
CUS1-A2	White Pine Cultural Savannah	4	L3
CUS1-b	Exotic Cultural Savannah	2	L+
CUW1	Mineral Cultural Woodland Ecosite	2	L5
CUW1-A	Native Cultural Woodland	2	L5
CUW1-A1	White Cedar Cultural Woodland	3	L4
CUW1-A2	White Pine Cultural Woodland	4	L3
CUW1-A3	Native Deciduous Cultural Woodland	2	L5
CUW1-b	Exotic Cultural Woodland	2	L+
CUW1-D	Hawthorn Cultural Woodland	2	L5
	Wetland		
SWM1	White Cedar Mineral Mixed Swamp Ecosite	2	L4
SWM1-1	White Cedar - Hardwood Mineral Mixed Swamp	2	L4
SWD2	Ash Mineral Deciduous Swamp Ecosite	2	L4
SWD2-2	Red (Green) Ash Mineral Deciduous Swamp	3	L4
SWD3	Maple Mineral Deciduous Swamp Ecosite	2	L4
SWD3-2	Silver Maple Mineral Deciduous Swamp	3	L3
SWD3-3	Swamp Maple Mineral Deciduous Swamp	3	L4
SWD3-4	Manitoba Maple Mineral Deciduous Swamp	3	L4
SWD4	Successional Mineral Deciduous Swamp Ecosite	n/a	n/a
SWD4-1	Willow Mineral Deciduous Swamp	1	L5
SWD4-2	White Elm Mineral Deciduous Swamp	2	L4
SWD4-3	Paper Birch - Poplar Mineral Deciduous Swamp	2	L4
SWT2	Mineral Thicket Swamp Ecosite	n/a	n/a
SWT2-1	Alder Mineral Thicket Swamp	2	L4

Appendix 3: List of TRCA Vegetation Communities with records of polygons having Cynanchum rossicum infestation (i.e. dominant or co-dominant (1st-4th) in at least one layer).

ELC code	Vegetation Type	Local distribution	Local rank
SWT2-2	Willow Mineral Thicket Swamp	1	L5
SWT2-3	Mountain Maple Mineral Thicket Swamp	3	L3
SWT2-5	Red-osier Mineral Thicket Swamp	2	L5
MAM2	Mineral Meadow Marsh Ecosite	n/a	n/a
MAM2-2	Reed Canary Grass Mineral Meadow Marsh	2	L5
MAM2-6	Broad-leaved Sedge Mineral Meadow Marsh	3	L4
MAM2-7	Horsetail Mineral Meadow Marsh	3	L3
MAM2-10	Forb Mineral Meadow Marsh	2	L4
MAS2	Mineral Shallow Marsh Ecosite	n/a	n/a
MAS2-1	Cattail Mineral Shallow Marsh (type of cattail not identified)	1	L5
MAS2-C	Horsetail Mineral Shallow Marsh	2	L4
MAS3	Organic Shallow Marsh Ecosite	2	L3
MAS3-1	Cattail Organic Shallow Marsh (type of cattail not identified)	3	L3
MAS3-4	Broad-leaved Sedge Organic Shallow Marsh	4	L2
MAS3-10	Forb Organic Shallow Marsh	4	L2
Dynamic (Beach, Bluff, Barren, Prairie, Savannah)			
BBO1	Mineral Open Beach / Bar	4	L3
BBO1-1	Sea Rocket Sand Open Beach	4	L2
BBS1	Mineral Shrub Beach / Bar Ecosite	4	L2
BBS1-2	Willow Shrub Beach	4	L2
BBT1	Mineral Treed Beach / Bar	5	L2
SDT1	Treed Sand Dune Ecosite	5	L2
SDT1-1	Cottonwood Treed Sand Dune	5	L2
BLO1	Mineral Open Bluff	2	L4
BLS1	Mineral Shrub Bluff Ecosite	3	L3
BLS1-A	Sumac - Willow Shrub Bluff	3	L3
BLS1-B	Serviceberry - Buffaloberry Shrub Bluff	5	L2
BLS1-c	Exotic Shrub Bluff	1	L+
BLT1	Mineral Treed Bluff Ecosite	2	L4
BLT1-A	White Cedar Treed Bluff	4	L2
BLT1-B	Deciduous Treed Bluff	3	L3
BLT1-c	Exotic Treed Bluff	4	L+
SBT1	Treed Sand Barren	5	L1
TPO1	Dry Tallgrass Prairie Ecosite	5	L1
TPO1-1	Dry Tallgrass Prairie Type	5	L1
TPO2	Fresh-Moist Tallgrass Prairie Ecosite	5	L1
TPO2-1	Fresh-Moist Tallgrass Prairie Type	5	L1
CUS1-3	Red Oak Cultural Savannah	4	L3
CUS1-3A	White Oak Cultural Savannah	5	L2
CUW1-2	Red Oak Cultural Woodland	4	L3

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ELC code	**Vegetation Type**	**Local distribution**	**Local rank**
	Meadow		
CUM1	Mineral Cultural Meadow Ecosite	1	L5
CUM1-1	Dry-Moist Old Field Meadow	1	L5
CUM1-A	Native Forb Old Field Meadow	1	L5
CUM1-b	Exotic Cool-season Grass Old Field Meadow	1	L+
CUM1-c	Exotic Forb Old Field Meadow	1	L+