Photo: Todd Ugine

Nine-spotted Lady Beetle

(Coccinella novemnotata) in Ontario

Ontario Recovery Strategy Series

2018

Natural. Valued. Protected.

Ministry of Natural Resources and Forestry

Ontario

About the Ontario Recovery Strategy Series

This series presents the collection of recovery strategies that are prepared or adopted as advice to the Province of Ontario on the recommended approach to recover species at risk. The Province ensures the preparation of recovery strategies to meet its commitments to recover species at risk under the *Endangered Species Act 2007* (ESA) and the Accord for the Protection of Species at Risk in Canada.

What is recovery?

Recovery of species at risk is the process by which the decline of an endangered, threatened, or extirpated species is arrested or reversed, and threats are removed or reduced to improve the likelihood of a species' persistence in the wild.

What is a recovery strategy?

Under the ESA a recovery strategy provides the best available scientific knowledge on what is required to achieve recovery of a species. A recovery strategy outlines the habitat needs and the threats to the survival and recovery of the species. It also makes recommendations on the objectives for protection and recovery, the approaches to achieve those objectives, and the area that should be considered in the development of a habitat regulation. Sections 11 to 15 of the ESA outline the required content and timelines for developing recovery strategies published in this series.

Recovery strategies are required to be prepared for endangered and threatened species within one or two years respectively of the species being added to the Species at Risk in Ontario list. Recovery strategies are required to be prepared for extirpated species only if reintroduction is considered feasible.

What's next?

Nine months after the completion of a recovery strategy a government response statement will be published which summarizes the actions that the Government of Ontario intends to take in response to the strategy. The implementation of recovery strategies depends on the continued cooperation and actions of government agencies, individuals, communities, land users, and conservationists.

For more information

To learn more about species at risk recovery in Ontario, please visit the Ministry of Natural Resources and Forestry Species at Risk webpage at: **www.ontario.ca/speciesatrisk**

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Cette publication hautement spécialisée « Recovery strategies prepared under the Endangered Species Act, 2007 », n'est disponible qu'en anglais en vertu du Règlement 411/97 qui en exempte l'application de la Loi sur les services en français. Pour obtenir de l'aide en français, veuillez communiquer avec recovery.planning@ontario.ca.

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Declaration

The recovery strategy for the Nine-spotted Lady Beetle was developed in accordance with the requirements of the *Endangered Species Act, 2007* (ESA). This recovery strategy has been prepared as advice to the Government of Ontario, other responsible jurisdictions and the many different constituencies that may be involved in recovering the species.

The recovery strategy does not necessarily represent the views of all of the individuals who provided advice or contributed to its preparation, or the official positions of the organizations with which the individuals are associated.

The goals, objectives and recovery approaches identified in the strategy are based on the best available knowledge and are subject to revision as new information becomes available. Implementation of this strategy is subject to appropriations, priorities and budgetary constraints of the participating jurisdictions and organizations.

Success in the recovery of this species depends on the commitment and cooperation of many different constituencies that will be involved in implementing the directions set out in this strategy.

Responsible jurisdictions

Ontario Ministry of Natural Resources and Forestry
Environment and Climate Change Canada – Canadian Wildlife Service, Ontario
Parks Canada Agency

Executive summary

The Nine-spotted Lady Beetle (*Coccinella novemnotata*) is a small (4.7 – 7.0 mm), pale orange-red, lady beetle species in the family Coccinellidae native to Ontario. As their name suggests, they generally have nine black spots on their wing covers but this varies among individuals. They also have a dark narrow line where their wing covers meet.

Prior to significant declines, the Nine-spotted Lady Beetle was one of the more common lady beetle species in Canada occurring in British Columbia, Alberta, Saskatchewan, Manitoba, Ontario and Quebec. It is geographically wide-ranging, occurring through most of southern Canada and the continental United States to the Mexican border. The Nine-spotted Lady Beetle now appears to be very rare or below detection thresholds in many parts of its range and has not been observed in Ontario since 1987.

The specific threats to the Nine-spotted Lady Beetle and the resulting causes of decline in their population are unknown. Possible threats to this species include negative interactions with non-native lady beetle species through competition, intraguild predation or indirect effects through the introduction of pathogens. Other possible threats include agricultural pesticide use to control their main prey species (aphids) and habitat loss due to changes in agricultural land uses.

The recommended long term recovery goal for the Nine-spotted Lady Beetle is to ensure the persistence of the species in Ontario. Since this species has not been observed in Ontario since 1987, the recommended short term recovery goal must be to determine if and where this species still occurs in the province. To facilitate realizing this goal, the following protection and recovery objectives have been recommended:

1. Determine the location, distribution, and abundance of any extant Nine-spotted Lady Beetle populations in Ontario.
2. Initiate research on knowledge gaps in Ontario.
3. Describe, enhance and/or create habitat, where feasible and determined to be appropriate based on research to increase habitat availability.
4. Where appropriate, augment existing populations, assist colonization to re-establish historical populations at suitable sites, and/or assist colonization in previously unoccupied, suitable habitats.

Approaches to achieving these protection and recovery objectives include inventory work, monitoring, protection and management, research, and education and outreach.

Currently there are no known locations where the Nine-spotted Lady Beetle occurs in Ontario, and it is unknown if through habitat loss, competition with non-native species, resource availability, or some other means it has become more specialized in its habitat selection which has contributed to its lack of detection. When (if) adults are found, it is recommended that research be carried out to determine the specific conditions at those

sites (e.g. resource availability, microhabitat conditions, local adaptations, absence of threats, etc.) which are contributing to the persistence of the species. Because potential habitat for the Nine-spotted Lady Beetle covers much of the province, it is recommended that the area prescribed as habitat in the habitat regulation be based on:

1) New documented occurrences of Nine-spotted Lady Beetle and naturalized habitats such as coniferous forests, deciduous forests, prairie grasslands, meadows, and riparian areas within 2 km of a new occurrence record. Agricultural areas, suburban gardens and suburban parks should not be included.
2) Overwintering sites that support aggregations of adults and a 5 m area around the overwintering site. These sites should be protected in all habitat types.

Understanding seasonal habitat use by the Nine-spotted Lady Beetle will be critical to recovery in Ontario and the habitat regulation should be flexible to incorporate this information as it becomes available. At this time it is not considered practical to include foraging habitat in the area prescribed in a habitat regulation.

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1.0 Background information

1.1 Species assessment and classification

Table 1. Species assessment and classification of the Nine-spotted Lady Beetle (*Coccinella novemnotata*). The glossary provides definitions for the abbreviations within, and for other technical terms in this document.

Assessment	Status
SARO List Classification	Endangered
SARO List History	Endangered (2017)
COSEWIC Assessment History	Endangered (2016)
SARA Schedule 1	No schedule, no status
Conservation Status Rankings	GRANK: G2 NRANK: NNR SRANK: SH

1.2 Species description and biology

Species description

The Nine-spotted Lady Beetle (*Coccinella novemnotata* Herbst 1793) was first described as a distinct species in 1793. No subspecies are recognized, and this description is still considered valid (COSEWIC 2016). In Canada, the genus *Coccinella* is represented by 13 lady beetle species, 11 of which are native, including the Nine-spotted Lady Beetle, and two non-native species (ITIS 2015).

The Nine-spotted Lady Beetle has four morphologically distinct developmental life stages: egg, larva, pupae and adult (Figure 1). Adults have elytra (wing covers) that are pale orange to red and adult beetles range in size from 4.7 – 7.0 mm (COSEWIC 2016). Most individuals have nine variably sized black spots, four on each elytra, with one central spot. The suture (where wing covers meet) has a dark narrow line which is diagnostic (COSEWIC 2016). The number and size of spots can vary across individuals and some lack spots entirely. The head is broad and black with a pale band between the eyes and the anterior margin of the pronotum is entirely pale and black posteriorly (Gordon 1985, Acorn 2007). Adults do not show sexual dimorphism (Stellwag and Losey 2014).

Figure 1. Adult Nine-spotted Lady Beetle (Photo: John Acorn)

Eggs are elongate, approximately one mm in length, yellow to orange in colour, and laid in tightly packed clusters (Hodek et al. 2012). The larvae are black with periodic orange/red markings at the sides and dorsal segments (terga), have mound-like projections bearing seta, or hair-like structures (Rees et al. 1994). The pupae are usually yellow to orange with black markings (Hodek et al. 2012).

Species biology

The Nine-spotted Lady Beetles can have two generations per year (McMullen 1967). Their life history however, depends on regional climatic conditions with individuals experiencing shortened lifespans with increasing temperature (Hodek et al. 2012). Development from egg to adult takes approximately 15 to 20 days depending on temperature (Ugine and Losey 2014). In other *Coccinella* species, male lady beetles locate females based on chemical and visual cues, and both sexes mate with multiple partners (Omkar and Srivastava 2002, Srivastava and Omkar 2004, Acorn 2007). During the oviposition period, which is approximately 31 days, females can lay upwards of 690 eggs (Ugine and Losey 2014). The eggs, laid in tightly packed clusters of approximately 18, stand upright (Acorn 2007). They are deposited on a wide range of plants that are likely to support aphids (Acorn 2007, Hodek et al. 2012). Many females also lay unfertilized eggs as another food source for young larvae (Acorn 2007). Larvae of the Nine-spotted Lady Beetle hatch from eggs after approximately three to four days (Ugine and Losey 2014), then undergo four instars over seven to nine days before pupating, metamorphosing and reaching adulthood (Losey et al. 2012). After

approximately five to six days as a pupa, adults emerge and their elytra harden (Ugine and Losey 2014). Mating begins shortly after adult emergence (Acorn 2007, Hodek et al. 2012).

Depending on conditions, adults of the spring generation can begin reproducing or undergo aestivation to avoid high summer temperatures (COSEWIC 2016). Adults of the autumn generation congregate over the winter and undergo diapause, only becoming active and reproducing when temperatures rise in the early spring (McMullen 1967, Hodek et al. 2012, Losey et al. 2012). The Nine-spotted Lady Beetles also occupy a wide ecological niche across a variety of temperature regimes in Canada, are cold-tolerant, and as adults are able to overwinter (COSEWIC 2016). Their adaptability enables them to exploit seasonal changes in prey availability across different habitats and vegetation types (Hodek et al. 2012).

Based on available (complete) collection records, adult Nine-spotted Lady Beetle are most commonly encountered between late June and August (68% of records), with peak activity in Ontario in July (38% of records). This implies that larvae would be most frequent from mid-July into September (a couple of weeks later than peak adult frequency).

Adults and larvae feed primarily on aphids (Acorn 2007, Obrycki and Kring 1998, Obrycki et al. 2009, Hodek et al. 2012), but most lady beetle species also feed opportunistically on other soft-bodied herbivorous arthropods (e.g. scale insects, psyllids, beetle larvae, mites), as well as other insects and eggs such as alfalfa weevils, leafhoppers, lepidopteran eggs, in addition to sap, nectar and pollen (Gordon 1985, Wheeler and Hoebeke 1995, Acorn 2007, Giorgi et al. 2009, Hesler et al. 2012, Losey et al. 2012).

There are approximately 50 different alkaloids that have been identified in lady beetles (Laurent et al. 2005), which are released from tibiofemoral joints when provoked as a defense mechanism (Hodek et al. 2012). It is presumed that the Nine-spotted Lady Beetle has the ability to exhibit this defensive behavior as do many other lady beetles (COSEWIC 2016).

Little is known on the natural dispersal rates specifically for the Nine-spotted Lady Beetle but, in general, lady beetles are very mobile (COSEWIC 2016). They do not exhibit high site fidelity and readily engage in short- and long-distance dispersal (van der Werf 2000, Acorn 2007, Hodek et al. 2012). Based on the potential dispersal ability of other lady beetle species, the Nine-spotted Lady Beetle could potentially fly from 18 km to up to 120 km in a single flight (Jeffries et al. 2013). The ability to disperse relatively long distances has resulted in high rates of gene flow between lady beetle subpopulations (Krafsur et al. 2005).

1.3 Distribution, abundance and population trends

Prior to significant declines, the Nine-spotted Lady Beetle was one of the more common lady beetle species in Canada occurring in British Columbia, Alberta, Saskatchewan, Manitoba, Ontario and Quebec (COSEWIC 2016). It is geographically wide-ranging, occurring through most of southern Canada and the continental United States to the Mexican border (Brown 1962, Gordon 1985) (Figure 2). The Nine-spotted Lady Beetle now appears to be very rare or below detection thresholds in many parts of its range (COSEWIC 2016). Continued declines in relative abundance and shrinking geographic range have been documented in numerous studies across Canada and the United States (Staines et al. 1990, Wheeler and Hoebeke 1995, Marshall 1999, Stephens 2002, Acorn 2007, Harmon et al. 2007, Hesler and Kieckhefer 2008, Fothergill and Tindall 2010, Skinner and Domaine 2010, Evans et al. 2011, Koch 2011, COSEWIC 2012).

Within the last ten years, there have only been thirteen records of the Nine-spotted Lady Beetle in Canada from two sites in British Columbia, six sites in Alberta, and one site in Quebec (COSEWIC 2016). Historical records of the Nine-spotted Lady Beetle record it throughout southern Ontario, occurring as far north as the eastern shores of Lake Superior (P. Grant. pers. comm. 2017). There is anecdotal evidence indicating that this was once one of the most commonly encountered lady beetle species in Ontario along with the Transverse Lady Beetle (*C. transversoguttata*) in agricultural areas (COSEWIC 2012, S. Marshall pers. comm. 2017). A very small number of observations were recorded in the 1980’s and there have been no records of this species in Ontario since 1987 [P. Grant pers. data 2017 (Royal Ontario Museum specimen)].

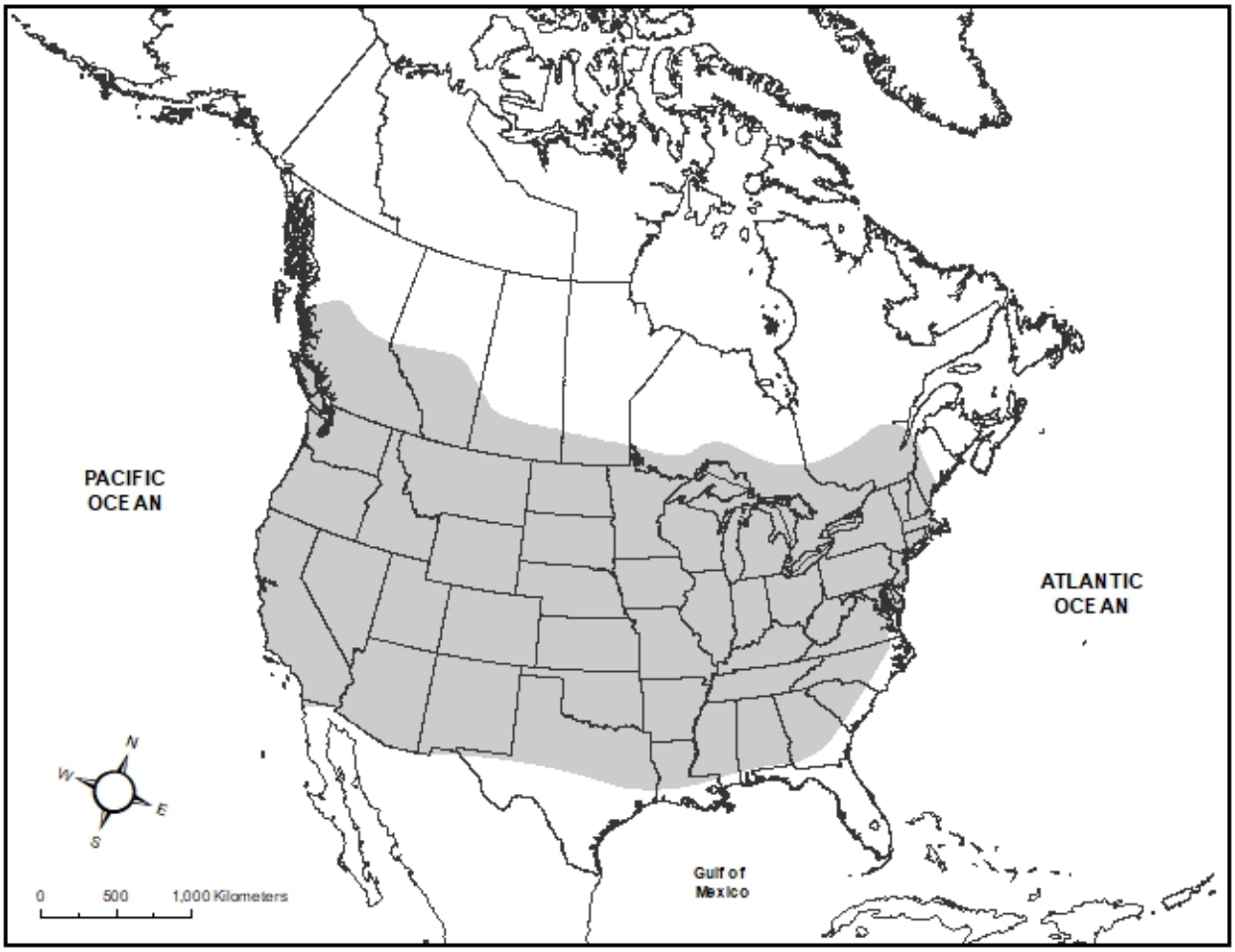

Figure 2. The geographic range of the Nine-spotted Lady Beetle. This range map is based on a historic range map by Gordon (1985)[i] and collection records (Grant pers. data 2017).

In the mid-1990's and 2014, directed efforts to find it produced no additional records (COSSARO 2016; COSEWIC 2016). This absence of recent records suggests that the Ontario population may now be extirpated, but individuals or small populations may have been overlooked in parts of its historically known range (COSSARO 2016). Recent records in Quebec and New York indicate that it is possible that the Nine-spotted Lady Beetle still occurs in parts of Ontario (COSSARO 2016). In Ontario after 1980, the estimated extent of occurrence for the species based on collection records (P. Grant pers. data[ii]) is 39,822 km^2 (COSSARO 2016).

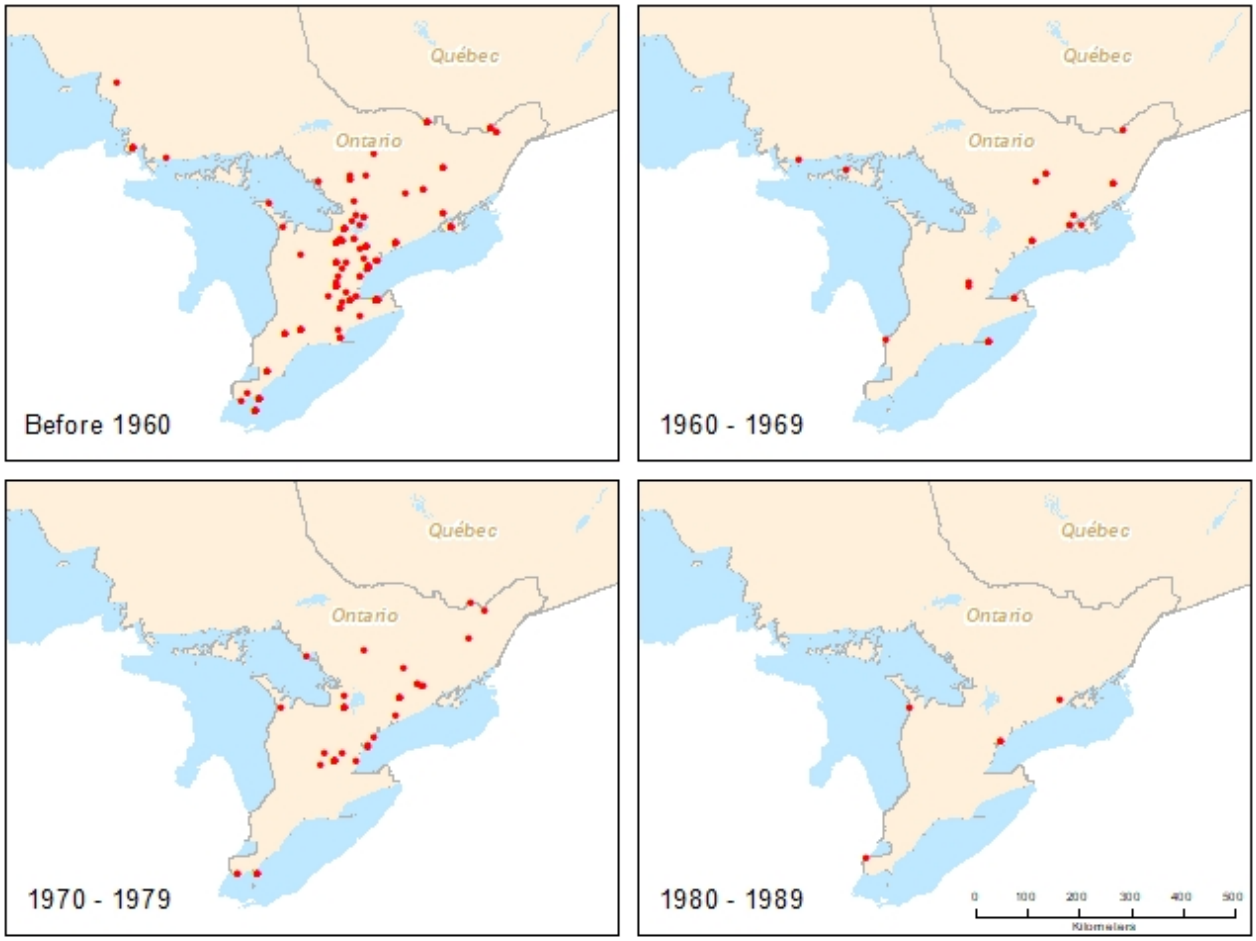

Figure 3. Distribution of the Nine-spotted Lady Beetle in Ontario from 1895 to 1960, and by decade from 1960 to 1989 (P. Grant pers. data[2]).

1.4 Habitat needs

The Nine-spotted Lady Beetle is a habitat generalist recorded within agricultural areas, suburban gardens, parks, coniferous forests, deciduous forests, prairie grasslands, meadows, riparian areas and other natural open areas (COSEWIC 2016). Most often it is associated with areas of shrubs or small trees interspersed with open grassy areas, but not continuous closed canopy forests (COSEWIC 2016, Gagne & Martin 1968). It is found in a wide variety of vegetation including birch, pine, spruce, maple, mountain ash, poplar, willow, sage, cherry, alder, thistles, grasslands, and scruff pea plants along the edge of sand dunes (Wheeler and Hoebeke 1995, Acorn 2007, Harmon et al. 2007, Losey et al. 2007). Historically, within agricultural crops it was one of the more dominant lady beetles found on alfalfa, potatoes, corn, soybean, and cotton (Wheeler and Hoebeke 1995, Harmon et al. 2007, Losey et al. 2007, Gardiner et al. 2011). It was also readily found on a wide variety of other crops in gardens and on grass, clover and

weeds (Wheeler and Hoebeke 1995, Harmon et al. 2007, Losey et al. 2007, Gardiner et al. 2011). In one Ontario-based study of coccinellids in red pine plantations, Nine-spotted Lady Beetle was found in early plantation establishment stages (i.e 6 years) but not before or after (Gagne and Martin 1968). The authors of this study speculate old field is the best habitat for this species.

Their distribution is driven to a large extent by prey availability rather than habitat type (Hagen 1962, Hodek and Honěk 1996, Sloggett and Majerus 2000, Hodek et al. 2012) and with increasing prey abundance, emigration decreases (Ives 1981, Ives et al. 1993, Elliott 2000, van der Werf 2000, Cardinale et al. 2006, Jeffries et al. 2013). Due to their close association with aphids, several studies have shown the density of adult lady beetles is positively correlated with aphid density (Turchin and Kareiva 1989, Hodek and Honěk 1996, Osawa 2000, Evans and Toler 2007).

A recent study indicates that in temperate zones, abundant populations of prey on crops and in orchards are a copious source of food for the breeding of coccinellids while non-crop habitats provide refugia in which coccinellids can survive for short periods when crops are not infested with prey (Honek et al. 2017). This suggests that a combination of habitats within a particular geographic area (i.e. home range) may be important to Nine-spotted Lady Beetle.

Overwintering adults aggregate in well ventilated microhabitats such as under stones, rock crevices, in grass tussocks, in leaf litter, or in tree bark (Hodek et al. 2012). Larvae are generally located in habitat with an abundance of prey, and pupate in the same habitat (COSEWIC 2016).

1.5 Threats to survival and recovery

The specific threats to the Nine-spotted Lady Beetle and the resulting causes of decline in their population are unknown. Possible threats to this species include negative interactions with non-native lady beetle species through competition, intraguild predation (i.e. feeding by non-native lady beetles on the larvae of native lady beetles), or indirect effects through the introduction of pathogens (COSEWIC 2016). Other possible threats include agricultural pesticide use to control their main prey species (aphids) and habitat loss due to changes in agricultural land use.

Exotic and Invasive Species

At least 179 non-native lady beetle species have been introduced in North America either through intentional release or through unintentional arrival (Gordon 1985). This has led to nine non-native species becoming well established in Canada. This includes the Seven-spotted Lady Beetle (*Coccinella septempunctata*) and the Multi-coloured Asian Lady Beetle (*Harmonia axyridis*) (COSEWIC 2012), non-native species which continue to be widely available and released for biocontrol (COSEWIC 2016).

There has been considerable speculation that the spread of these non-native lady beetles across Canada is related to the observed decline in some native species of lady beetle (Ducatti et al. 2017). Shortly after some non-native species began to be abundant and widely distributed in eastern Canada, reports began emerging that formerly common native species became increasingly difficult to find (Wheeler and Hoebeke 1995, Marshall 1999, Turnock et al. 2003). Although a direct causal link is not obvious, the timing and extent of the decline of the Nine-spotted Lady Beetle and the introduction and spread of non-native species, such as Fourteen-spotted Lady Beetle (*Propylea quatuordecimpunctata*), are coincidental (COSEWIC 2016). It has been established that locations where the Nine-spotted Lady Beetle were historically collected up to the early 1980's transitioned to collections of Seven-spotted Lady Beetle in the University of Guelph Insect Collection (Marshall 1999). Although Seven-spotted Lady Beetle replaced the Nine-spotted Lady Beetle across its known range, it became well established after the decline. It is therefore likely that the presence and abundance of Seven-spotted Lady Beetle did not contribute directly to the decline, but may have reduced or eliminated the potential for Nine-spotted Lady Beetle to recover from its decline by exploiting its niches. This conclusion is supported by long-term data analysis in other countries where direct causal links between the arrival of non-native species and the decline of native lady beetles cannot be made, although it is likely a contributing factor in addition to many other interacting factors contributing to the change in coccinellid community composition, particularly habitat modifications (Honek et al. 2016).

It is widely reported in the literature that significant declines in geographic range and abundance of native lady beetles are frequently due to changes in habitat or interactions with non-native species (New 1995, Cottrell and Shapiro-Ilan 2003, Evans 2004, Snyder and Evans 2006, Finlayson et al. 2008, Kenis et al. 2008, Kajita and Evans 2010, Crowder and Snyder 2010, Smith and Gardiner 2013, Ugine and Losey 2014, Tumminello et al. 2015) and the invasion of Seven-spotted Lady Beetle and Multi-coloured Asian Lady Beetle have been implicated in an overall reduction in the Nine-spotted Lady Beetle and other native lady beetle subpopulations (Wheeler and Hoebeke 1995, Elliott et al. 1996, Marshall 1999, Ellis et al. 1999, Brown 2003, Cottrell and Shapiro-Ilan 2003, Turnock et al. 2003, Hesler et al. 2004, Acorn 2007, Harmon et al. 2007, Hesler and Kieckhefer 2008, Fothergill and Tindall 2010, Skinner and Domaine 2010, Evans et al. 2011, Losey et al. 2012, Comont et al. 2014, Turnipseed et al. 2014, Ugine and Losey 2014, Tumminello et al. 2015). In the literature this correlation is most often focused on negative interactions through competition, intraguild predation or indirect effects such as the introduction of pathogens (Schaefer et al. 1987, Ehler 1990, Cottrell and Shapiro-Ilan 2003, Louda et al. 2003, Evans 2004, Lucas 2005, Snyder and Evans 2006, Lucas et al. 2007, Kenis et al. 2008, Riddick et al. 2009, Evans et al. 2011, Turnipseed et al. 2014, Ugine and Losey 2014, Tumminello et al. 2015, Ducatti et al. 2017). It is worth noting that considerable effort has been invested to find effective biological control agents for pest aphids (Brewer and Elliott 2004) therefore aphid densities could also be reduced by other aphid predators, parasitoids or parasites

(COSEWIC 2012). This makes the direct relationships between lady beetles and exotic species difficult to document.
Others have argued that the direct role of non-native species in declines of native species may be overstated (COSEWIC 2012). These studies have implicated changes in land use and pesticides (e.g. Wheeler and Hoebeke 1995, Harmon et al. 2007, Diepenbrock et al. 2016) and inconsistencies in collection records (Marshall 2008). Acorn (2007) pointed out that native lady beetle species are still present in Alberta, although there has been a change in the predominant (numerically dominant) species. It has been suggested that more recent collection efforts have focused on human-altered habitats vs. native habitats which may result in collection records emphasizing the absence of native lady beetles. Evans (2004) indicated that non-native species such as the Seven-spotted Lady Beetle tend to reduce aphid densities in human-altered habitats and therefore native species do not aggregate in such habitats. It is therefore possible that the Nine-spotted Lady Beetle is less likely to occur in the traditional human-altered habitats it once occupied because of direct or indirect competition with non-native species.

Despite documented declines in native species of lady beetles in Canada and the arrival and range expansion of non-native lady beetles in North America, the links between the non-native species and causes of the declines are not clear due to inconsistent collection efforts/records (COSEWIC 2012). COSEWIC (2012) assessed whether the data support a conclusion that declines of native species coincide with the arrival of non-natives, and reviewed potential threats to native lady beetles, with an emphasis on Canada and the northern United States. This report makes it clear, from the wide variety of museum and collector specimen considered, that some native lady beetle species have declined in abundance and geographical range in Canada and that some of the regional declines are coincident with the arrival of non-native lady beetle species.

Non-native lady beetle species may also affect native lady beetles indirectly through the introduction and transmission of exotic parasites and pathogens (Bjornson 2008). Generally, lady beetles are hosts to a variety of parasitoids, parasitic mites, nematodes, protozoans, fungal pathogens, microsporidia, and bacteria which can all negatively impact lady beetle fitness and reduce overwintering survivorship (Cali and Briggs 1967, Hurst et al. 1995, Ceryngier and Hodek 1996, Barron and Wilson 1998, Webberley and Hurst 2002, Cottrell and Shapiro-Ilan 2003, Webberley et al. 2004, Bjornson 2008, Roy and Cottrell 2008, Riddick et al. 2009, Bjornson et al. 2011).

Although it is uncertain what the effect of these natural enemies is on the Nine-spotted Lady Beetle, in general native species often have a greater susceptibility to exotic pathogens (Cottrell and Shapiro-Ilan 2003) and several studies have reported a greater susceptibility of native lady beetles to the braconid wasp parasitoid (Obrycki 1989) and at least one fungal pathogen (Cottrell and Shapiro-Ilan 2003) compared to non-native species.

Habitat Loss

It is not known to what extent habitat loss has impacted the Nine-spotted Lady Beetle, particularly given they are considered habitat generalists. It is anticipated that habitat loss, which reduces prey availability would have negative consequences for this species. Farmland abandonment across Canada may have resulted in habitat changes and reduced prey availability however there are no data to demonstrate causality between these changes and lady beetle densities (Elliott and Kieckheffer 1990, Elliott et al. 1998, Harmon et al. 2007). After an initial increase in open habitat associated with European settlement in eastern North America in the 1800's which facilitated the spread and increase in abundance of lady beetles, much marginal farmland was abandoned and reverted to forest, or planted in other types of crops (COSEWIC 2012). In southern Ontario, the conversion of marginally productive farmland to forest began in about 1900 and has continued (Fox and Macenko 1985, Bucknell and Pearson 2007). In Ontario traditional farming has also been largely replaced by more intensive agricultural practices. Sometimes hedgerows are removed to increase field size or accommodate larger equipment and fields are ploughed to their edges, eliminating grassy buffer strips (McGauley 2004). Traditionally wider and more structurally diverse hedgerows are anticipated to support higher levels of biodiversity. There is some evidence to support this is true for birds (Benoit et al. 2001) and plants (Boutin et al. 2002) and it is reasonable to assume for insects, including the Nine-spotted Lady Beetle. Fahrig et al. (2015) suggests that biodiversity in crop fields (including carabid beetles) depends more strongly on the presence of semi-natural field boundary habitats than on larger natural areas such as forest patches.

Habitat loss associated with the expansion of residential and commercial developments may be contributing to local declines of this species however, greenlands within these areas may also still provide habitat for the Nine-spotted Lady Beetle (COSEWIC 2016).

Agricultural Pesticides

In urban and agricultural landscapes, the Nine-spotted Lady Beetle may be threatened by a variety of pesticides. Depending on the location and type of agriculture this may include neonicotinoids, insect growth regulators and broad-spectrum pyrethroids, which tend to be more destructive to lady beetles than organophosphates (Kumar and Bhatt 2002, Moser and Obrycki 2009). Susceptibility to insecticides among lady beetles varies between species and the chemical composition, but can range from acute lethal effects to a reduction in fecundity (Theiling and Croft 1988). Insects commonly experience combined effects of exposure to more than one compound found in pesticides, even for compounds that were considered harmless when tested separately (Petersen 1993).

While very effective against plant pests, especially aphids, neonicotinoids have proven to be detrimental to insects at concentrations in the parts per billion (ppb) (Smith and Krischik 1999, Marletto et al. 2003). In one study, 72 percent of Multi-coloured Asian Lady Beetle larvae exposed to seedlings treated with neonicotinoids developed

neurotoxic symptoms (trembling, paralysis, and loss of coordination) from which only 7 percent recovered (Moser and Obrycki 2009).

1.6 Knowledge gaps

The current distribution of the Nine-spotted Lady Beetle in Ontario is unknown. There have been no documented occurrences of the Nine-spotted Lady Beetle in Ontario since 1987, but it is possible it has been overlooked (COSSARO 2016). Recent records in Quebec and New York, combined with the fact that it is likely able to disperse long distances, indicate that it possible that the Nine-spotted Lady Beetle still occurs in parts of Ontario (COSSARO 2016). The full historic range in Ontario has not been surveyed, allowing for the possibility that the Nine-spotted Lady Beetle still occurs in one or more discrete populations (COSSARO 2016).The majority of existing data is based on non-target specific collection records (i.e. lady beetles collected during general insect collecting) which have the potential to be biased by the abundance of non-native species (Marshall 2008) and the locations and types of habitat individuals are collecting in (Acorn 2007). Previously this species was known to occupy a range of habitats and was considered a habitat generalist, found anywhere from naturalized ecosystems, agricultural areas, to urban gardens. Non-native species now dominate human-altered environments in Ontario which reduces aphid densities therefore, this could account for why native lady beetles no longer occupy these habitats (Evans 2004). However, it is unknown if they still persist in other habitat types where survey and collection efforts are less common. In other parts of the species range, the Nine-spotted Lady Beetle is more confined presently to naturally open or shrub-dominated habitats (Acorn 2007). Therefore, areas such as alvars, early successional habitats, oak savannas, old fields, and regenerating areas such as old sand and gravel extraction areas may be the highest priority areas to check for extant populations.

Understanding of habitat use by the Nine-spotted Lady Beetle will be critical to recovery in Ontario, but this type of natural history information is generally lacking. The most useful information for conservation would be data on preferred habitats in the spring, how habitat use changes through the summer, and preferred overwintering sites (COSEWIC 2012). Differences in seasonal habitat choices of lady beetles can be linked to seasonal patterns in their food sources (COSEWIC 2012), since aphids vary in their feeding preferences and habitat use through the year (Dixon 1985; Moran 1992). Some species are plant-specific (i.e. monophagous) while others feed on a variety of plants (i.e. polyphagous) and some change the primary plants they feed on based on the time of year (COSEWIC 2012). This interaction of seasonal habitat use and plants that support aphids needs to be integrated in an understanding of the Nine-spotted Lady Beetle natural history. Therefore, factors that need to be considered when outlining habitat use by lady beetles include habitat use at different times of year and facultative responses to changing localities with high concentrations of aphids.

Because distribution data is unavailable, population trends in Ontario are unknown along with specific threats to any extant populations. It is possible that threats are site-specific (e.g. application of specific insecticides at specific locations).

The direct causes for the decline of the species are unknown. The arguments linking the decline of the Nine-spotted Lady Beetle with competition from non-native species are based mainly on the coincidence of one species declining as the other is increasing, and there is little or no evidence for direct interactions (COSEWIC 2012). Similarly, the arrival of non-native lady beetle species in Ontario has probably introduced new parasites and pathogens, though direct evidence for impacts does not exist (COSEWIC 2012).

Other potential factors for decline, such as habitat change, have also occurred coincidentally, but the cause and effect relationship is not understood (Harmon et al. 2007). Changes in land use clearly affect populations of native lady beetles, and this factor needs more study to assess links between land use and species declines, especially in concert with the arrival of non-native lady beetles (COSEWIC 2012) and the current distribution of the Nine-spotted Lady Beetle in Ontario.

1.7 Recovery actions completed or underway

The Lost Ladybug Project is an initiative founded and directed by Dr. John Losey, associate professor in the entomology department at Cornell University. The project is citizen-science based and allows people to send in sightings of lady beetles, including photographs, which are submitted online, and identifications are confirmed by experts. To date tens of thousands of photos have been submitted to the project resulting in the development of distribution mapping of North America's lady beetles. The project has resulted in major successes such as the documentation of a the Nine-spotted Lady Beetle on Long Island in 2011, which was the first documented sighting of the species in New York in 29 years. To date limited targeted promotion of this initiative has occurred in Ontario.

A proposal to establish an International Union for Conservation of Nature (IUCN) specialist group on coccinellids is currently under review (J. Losey pers. comm. 2017). If implemented, it will be the first international effort to conserve Coccinellids.

There has been no formal or coordinated survey effort in Ontario to document the Nine-spotted Lady Beetle but staff of the Ontario Ministry of Natural Resources and Forestry (MNRF) and several entomologists look for the species while conducting field work (C. Jones pers. comm. 2017).

2.0 Recovery

2.1 Recommended recovery goal

The recommended long term recovery goal for the Nine-spotted Lady Beetle is to ensure the persistence of the species in Ontario. Since this species has not been observed in Ontario since 1987, the recommended short term recovery goal must be to determine if and where this species still occurs in the province.

2.2 Recommended protection and recovery objectives

Table 2. Recommended protection and recovery objectives.

Number	Protection or recovery objective
1	Determine the location, distribution, and abundance of any extant Nine-spotted Lady Beetle populations in Ontario.
2	Initiate research on knowledge gaps in Ontario.
3	Describe, enhance and/or create habitat, where feasible and determined to be appropriate based on research to increase habitat availability.
4	Where appropriate, augment existing populations, assist colonization to re-establish historical populations at suitable sites, and/or assist colonization in previously unoccupied, suitable habitats.

2.3 Recommended approaches to recovery

Table 3. Recommended approaches to recovery of the Nine-spotted Lady Beetle in Ontario.

Objective 1: Determine the location, distribution, and abundance of any extant Nine-spotted Lady Beetle populations in Ontario.

Relative priority	Relative timeframe	Recovery theme	Approach to recovery	Threats or knowledge gaps addressed
Critical	Short-term	Inventory, Monitoring and Assessment	**1.1** Develop a standardized survey protocol for the Nine-spotted Lady Beetle[iii]. • The protocol should include a consistent method for documenting both positive and negative search effort, presence/absence survey methods, a standardized monitoring protocol, and direction on submission of results to the Natural Heritage Information Centre. • The protocol should target documentation of all lady beetle species with specific emphasis on also documenting Seven Spotted Lady Beetle, Multi-coloured Asian Lady Beetle. • The protocol should identify specific priority habitats/areas to target surveys such as alvars, early successional habitats, oak savannas, old fields, and regenerating areas. • The protocol should also include the most effective detection methods for identifying overwintering congregations.	Knowledge gaps: • Current distribution & population trends
Critical	Short-term	Inventory, Monitoring and Assessment	**1.2** Carry out an inventory program. • Identify specific threats to extant populations. • Develop and carry out a monitoring program for extant populations.	Threats: • All Knowledge gaps: • Current distribution & population trends

Relative priority	Relative timeframe	Recovery theme	Approach to recovery	Threats or knowledge gaps addressed
Critical	Short-term	Inventory, Monitoring and Research	**1.3** At extant sites, determine specific habitat characteristics supporting the persistence of the Nine-spotted Lady Beetle. • Determine any population-specific adaptations supporting persistence of population(s).	Threats: • All Knowledge gaps: • Current distribution & population trends
Beneficial	Ongoing	Education and Outreach	**1.4** Encourage citizen science participation in the inventory program. • Distribute an identification guide. • Promote participation in the Lost Lady Bug Project and record submission to repositories such as iNaturalist. • Engage public in inventory program and public survey events.	Threats: • N/A Knowledge gaps: • Current distribution & population trends

Objective 2: Initiate research on knowledge gaps in Ontario.

Relative priority	Relative timeframe	Recovery theme	Approach to recovery	Threats or knowledge gaps addressed
Critical	Ongoing	Research	**2.1** Clearly define habitat parameters based on extant sites identified through inventory program or best available knowledge on the species in other locations. • Conduct research to determine which, and to what extent, specific habitat parameters are limiting to Nine-spotted Lady Beetle.	Knowledge gaps: Current distribution & population trends

Relative priority	Relative timeframe	Recovery theme	Approach to recovery	Threats or knowledge gaps addressed
Critical	Ongoing	Research	**2.2** If feasible, determine the specific direct and indirect impacts of non-native lady beetles on extant population(s). • Conduct research on the potential for introduced pathogens. • Conduct research on site-specific interactions and prey availability. • If the Nine-spotted Lady Beetle is determined to be extirpated in Ontario, support research efforts in other provinces.	Threats: • Exotic and invasive species Knowledge gaps: Specific threat of non-native species
Necessary	Long-term	Research	**2.3** For all research activities, collaborate with United States of America (USA) based researchers actively working on the Nine-spotted Lady Beetle recovery.	Threats: • All Knowledge gaps: • All
Necessary	Long-term	Research	**2.4** Conduct a Population Viability Analysis (PVA) on extant population(s) identified through the inventory program. • Determine annual population growth and recruitment rates. • Estimate their sensitivity to specific threats and identify appropriate recovery efforts. • If extant population(s) are identified through the inventory program, determine if there is a relationship between invasive lady species density and Nine-spotted Lady Beetle density. • If the Nine-spotted Lady Beetle is determined to be extirpated in Ontario, support PVAs in other provinces to inform feasibility assessments of reintroduction.	Threats: • All Knowledge gaps: • Current distribution

Relative priority	Relative timeframe	Recovery theme	Approach to recovery	Threats or knowledge gaps addressed
Necessary	Ongoing	Research	**2.5** Determine what/if any insecticide applications are affecting Ontario Nine-spotted Lady Beetle populations. • If applicable, determine specific chemical threats at extant sites and identify potential mitigation techniques (e.g. timing of application, alternative insecticides, etc.).	Threats: • Pesticides Knowledge gaps: • Impacts of specific agricultural chemicals in Ontario

Objective 3: Describe, enhance and/or create habitat, where feasible and determined to be appropriate based on research to increase habitat availability.

Relative priority	Relative timeframe	Recovery theme	Approach to recovery	Threats or knowledge gaps addressed
Necessary	Short-term	Protection & Management	**3.1** Develop a habitat regulation to define the area protected as habitat for the Nine-spotted Lady Beetle in Ontario, to be applied once adults are found.	Threats: • All threats Knowledge gaps: • Current distribution
Beneficial	Long-term	Management	**3.2** Identify habitat restoration and/or enhancement opportunities to increase/improve habitat availability in Ontario. • Identify existing or ongoing programs which may be mutually beneficial (e.g. pollinator habitat restoration projects)	Threats: • Habitat loss Knowledge gaps: • N/A

Objective 4: Where appropriate, augment existing populations, assist colonization to re-establish historical populations at suitable sites, and/or assist colonization in previously unoccupied, suitable habitats.

Relative priority	Relative timeframe	Recovery theme	Approach to recovery	Threats or knowledge gaps addressed
Necessary	Long-term	Protection, Management & Research	**4.1** Once key threats or causes of decline are identified, assess if they have been (or could be) sufficiently reversed or mitigated in order to enable effective and feasible population augmentation or reintroductions.	Threats: • All threats. Knowledge gaps: • All knowledge gaps.
Necessary	Long-term	Protection, Management & Research	**4.2** Determine the feasibility (and need for) a captive breeding program. • Identify success and failure rates of USA captive breeding programs. • Identify potential source population(s).	Threats: • All threats. Knowledge gaps: • N/A
Necessary	Long-term	Protection, Management & Research	**4.3** Consider augmenting existing populations OR reintroducing populations at suitable sites where feasible and appropriate based on a population viability analysis and identification of key threats. • Collaborate with researchers who have undertaken similar program in the USA. • Monitor the success of the program.	Threats: • All threats. Knowledge gaps: • N/A

2.4 Area for consideration in developing a habitat regulation

Under the ESA, a recovery strategy must include a recommendation to the Minister of Natural Resources and Forestry on the area that should be considered in developing a habitat regulation. A habitat regulation is a legal instrument that prescribes an area that will be protected as the habitat of the species. The recommendation provided below by the author will be one of many sources considered by the Minister when developing the habitat regulation for this species.

Existing information available indicates that the Nine-spotted Lady Beetle is a habitat generalist. Currently there are no known locations where it occurs in Ontario, and it is unknown if through habitat loss, competition with non-native species, resource availability, or some other means it has become more specialized in its habitat selection which has contributed to its lack of detection. However, the Nine-spotted Lady Beetle is not known to demonstrate site fidelity at this time.

Because potential habitat for the Nine-spotted Lady Beetle covers much of the province, it is recommended that the area prescribed as habitat in the habitat regulation be based on:

1) New documented occurrences of Nine-spotted Lady Beetle and naturalized habitats such as coniferous forests, deciduous forests, prairie grasslands, meadows, and riparian areas within 2 km of a new occurrence record. Agricultural areas, suburban gardens and suburban parks should not be included.
2) Overwintering sites that support aggregations of adults and a 5 m area around the overwintering site. These sites should be protected in all habitat types.

Their distribution is driven to a large extent by prey availability rather than habitat type and based on the potential dispersal ability of other lady beetle species, the Nine-spotted Lady Beetle could potentially fly from 18 km to up to 120 km in a single flight (Jeffries et al. 2013). Therefore, understanding seasonal habitat use by the Nine-spotted Lady Beetle will be critical to recovery in Ontario and the habitat regulation should be flexible to incorporate this information as it becomes available. Given the broad area of the landscape potentially used by the Nine-spotted Lady Beetle and the seasonality of habitat use, it is not practical to include foraging habitat in the area prescribed in a habitat regulation. Including 2 km around new documented occurrences is suggested for consideration in the habitat regulation based on the inferred minimum extent of habitat use distance used to document element occurrences of other beetle species[iv] by NatureServe. Five meters around a defined overwintering site is considered sufficient to protect the microhabitat characteristics of the feature.

Comprehensive inventory work is recommended. When (if) adults are found, it is recommended that research be carried out to determine the specific conditions at those sites (e.g. resource availability, microhabitat conditions, local adaptations, absence of threats, etc.) which are contributing to the persistence of the species. This important information will assist in refining the habitat which should be protected for Nine-spotted

Lady Beetle. Therefore, the habitat regulation should be re-evaluated as new information becomes available and knowledge gaps are filled.

Glossary

Aestivation: prolonged torpor or dormancy of an animal during a hot or dry period.

Alkaloid: any of a class of naturally occurring organic nitrogen-containing bases. Alkaloids have diverse and important physiological effects on humans and other animals.

Anterior: nearer the front, especially situated in the front of the body or nearer to the head.

Committee on the Status of Endangered Wildlife in Canada (COSEWIC): the committee established under section 14 of the Species at Risk Act that is responsible for assessing and classifying species at risk in Canada.

Committee on the Status of Species at Risk in Ontario (COSSARO): the committee established under section 3 of the Endangered Species Act, 2007 that is responsible for assessing and classifying species at risk in Ontario.

Conservation status rank: a rank assigned to a species or ecological community that primarily conveys the degree of rarity of the species or community at the global (G), national (N) or subnational (S) level. These ranks, termed G-rank, N-rank and S-rank, are not legal designations. Ranks are determined by NatureServe and, in the case of Ontario's S-rank, by Ontario's Natural Heritage Information Centre. The conservation status of a species or ecosystem is designated by a number from 1 to 5, preceded by the letter G, N or S reflecting the appropriate geographic scale of the assessment. The numbers mean the following:

1 = critically imperiled
2 = imperiled
3 = vulnerable
4 = apparently secure
5 = secure
NR = not yet ranked

Diapause: a period of suspended development in an insect, other invertebrate, or mammal embryo, especially during unfavorable environmental conditions.

Elytra: modified, hardened forewings of several insect orders including beetles (Coleoptera) and a few 'true bugs' (Hemiptera).

Endangered Species Act, 2007 (ESA): the provincial legislation that provides protection to species at risk in Ontario.

Extant: currently or actually existing.

Extirpated: a species is considered to be extirpated from a region when it is no longer found in that region, but still survives elsewhere in the world.

Fecundity: the actual reproductive rate of an organism or population, measured by the number of gametes (eggs) or the natural capability to produce offspring.

Inferred Extent Distance: the distance (in kilometers) that the underlying mapped component(s) (i.e., Source Feature[s]) of an element occurrence may be buffered in order to create a separate inferred extent feature that might better represent the area likely utilized by the Element at that location, which may be useful for conservation planning purposes. The inferred extent distance is essentially an approximate spatial requirement for certain species, typically based on the average home range (Natureserve 2017).

Instar: a phase between two periods of molting in the development of an insect larva or other invertebrate animal.

Intraguild predation: the killing and eating of potential competitors. This interaction represents a combination of predation and competition, because both species rely on the same prey resources and also benefit from preying upon one another.

Larva(e): the immature, wingless, and often wormlike form that hatches from the egg of many insects, alters chiefly in size while passing through several molts, and is finally transformed into a pupa or chrysalis from which the adult emerges.

Neonicotinoids: nicotine-based class of insecticides.

Organophosphates: general name for esters of phosphoric acid. Organophosphates are the basis of many insecticides, herbicides, and nerve agents.

Oviposition: to deposit or lay eggs.

Parasitoid: an insect whose larvae live as parasites that eventually kill their hosts (typically other insects).

Posterior: further back in position, of or nearer the rear or hind end, especially of the body or a part of it.

Pronotum: a prominent plate-like structure that covers all or part of the dorsal surface of the thorax of some insects.

Psyllids: jumping plant lice in the family Psyllidae.

Pupa(e): an intermediate stage of a metamorphic insect (such as a bee, moth, or beetle) that occurs between the larva and the adult, is usually enclosed in a

cocoon or protective covering, and undergoes internal changes by which larval structures are replaced by those typical of the adult.

Pyrethroids: a class of insecticides that constitute the majority of commercial household insecticides.

Sexual dimorphism: the differences in appearance between males and females of the same species, such as in colour, shape, size, and structure, that are caused by the inheritance of one or the other sexual pattern in the genetic material.

Species at Risk Act (SARA): the federal legislation that provides protection to species at risk in Canada. This act establishes Schedule 1 as the legal list of wildlife species at risk. Schedules 2 and 3 contain lists of species that at the time the Act came into force needed to be reassessed. After species on Schedule 2 and 3 are reassessed and found to be at risk, they undergo the SARA listing process to be included in Schedule 1.

Species at Risk in Ontario (SARO) List: the regulation made under section 7 of the Endangered Species Act, 2007 that provides the official status classification of species at risk in Ontario.

Tibiofemoral: refers to the joint between the between the femur and tibia

References

Acorn, J. 2007. Ladybugs of Alberta: Finding the Spots and Connecting the Dots. The University of Alberta Press, Edmonton, Alberta.

Barron, A., and K. Wilson. 1998. Overwintering Survival in the Seven Spot Ladybird, *Coccinella septempunctata* (Coleoptera: Coccinellidae). European Journal of Entomology 95: 639-642.

Benoit, J., L. Choinière, and L. Bélanger. 2001. Bird use of three types of field margins in relation to intensive agriculture in Québec, Canada Agriculture, Ecosystems & Environment 84: 131-143.

Bjornson, S. 2008. Natural Enemies of the Convergent Lady Beetle, *Hippodamia convergens* Guérin-Méneville: their Inadvertent Importation and Potential Significance for Augmentative Biological Control. Biological Control 44:305-311.

Bjornson, S., J. Le, T. Saito, and H. Wang. 2011. Ultrastructure and Molecular Characterization of a Microsporidium, Tubulinosema hippodamiae, from the Convergent Lady Beetle, Hippodamia convergens Guérin-Méneville. Journal of Invertebrate Pathology 106:280-288.

Brewer, M.J., and N.C. Elliott. 2004. Biological Control of Cereal Aphids in North America and Mediating Effects of Host Plant and Habitat Manipulations. Annual Review of Entomology 49:219-42.

Brown, M.W. 2003. Intraguild Responses of Aphid Predators on Apple to the Invasion of an Exotic Species, *Harmonia axyridis*. BioControl 48:141-153.

Brown, W.J. 1962. A Revision of the Forms of *Coccinella* L., Occurring in America North of Mexico (Coleoptera: Coccinellidae). The Canadian Entomologist 94:785-808.

Boutin, C., B. Jobin, L. Bélanger, and L. Choiniere. 2002. Plant Diversity in Three Types of Hedgerows Adjacent to Cropfields. Biodiversity and Conservation 1: 1–25.

Bucknell, D., and C.J. Pearson. 2007. A Spatial Analysis of Land-use Change and Agriculture in Eastern Canada. International Journal of Agricultural Sustainability 4:22-38.

Cali, A., and J.D. Briggs. 1967. The Biology and Life History of *Nosema tracheophila* sp. n. (Protozoa: Cnidospora: Microsporidea) Found in *Coccinella septempunctata* Linnaeus (Coleoptera: Coccinellidae). Journal of Invertebrate Pathology 9:515-522.

Cardinale, B.J., J.J. Weis, A.E. Forbes, K.J. Tilmon, and A.R. Ives. 2006. Biodiversity as Both a Cause and Consequence of Resource Availability: a Study of Reciprocal Causality in a Predator-prey System. Journal of Animal Ecology 75:497-505.

Ceryngier, P., and I. Hodek. 1996. Enemies of the Coccinellidae. Pp. 319-350. In: Hodek, I., and A. Honěk. (eds). Ecology of Coccinellidae. Kluwer Academic, Dordecht.

Comont, R.F., H.E. Roy, R. Harrington, C.R. Shortall, and B.V. Purse. 2014. Ecological Correlates of Local Extinction and Colonisation in the British Ladybird Beetles (Coleoptera: Coccinellidae). Biological Invasions 16:1805-1817.

COSEWIC. 2016. COSEWIC Assessment and Status Report on the Nine-spotted Lady Beetle *Coccinella novemnotata* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. x + 57 pp.

COSEWIC. 2012. COSEWIC Special Report on the Changes in the Status and Geographic ranges on the Canadian Lady Beetles Coleoptera: Coccinellidae: Coccinellinae and the selection of Candidate Species for Risk, in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. 60 pp. (http://www.cosewic.gc.ca)

COSSARO. 2016. Ontario Species at Risk Evaluation Report for Nine-spotted Lady Beetle (*Coccinella novemnotata*). Committee on the Status of Species at risk in Ontario. Toronto. x + 14 pp.

Cottrell, T.E., and D.I. Shapiro-Ilan. 2003. Susceptibility of a Native and an Exotic Lady Beetle (Coleoptera: Coccinellidae) to *Beauveria bassiana*. Journal of Invertebrate Pathology 84:137-144.

Crowder, D.W., and W.E. Snyder. 2010. Eating Their Way to the Top? Mechanisms underlying the Success of Invasive Insect Generalist Predators. Biological Invasions 12:2857-2876.

Diepenbrock,M.L., K.Fothergill, K. V. Tindall, J. E. Losey, R. R. Smyth, and D. L. Finke. The Influence of Exotic Lady Beetle (Coleoptera: Coccinellidae) Establishment on the Species Composition of the Native Lady Beetle Community in Missouri. Environmental Entomology 45: 855-864.

Ducatti, R.D.B., T.A. Ugine, and J. Losey. 2017. Interactions of the Asian Lady Beetle, *Harmonia axyridis* (Coleoptera: Coccinellidae), and the North American Native Lady Beetle, *Coccinella novemnotata* (Coleoptera: Coccinellidae): Prospects for Recovery Post-Decline. Environmental Entomology 0: 1-9.

Ehler, L.E. 1990. Introduction Strategies in Biological Control of Insects. Pp 111-134. In Mackauer, M., L.E. Ehler, and J. Roland. (eds) Critical Issues in Biological Control. Intercept Ltd, Andover.

Elliott, N. 2000. Adult Coccinellid Activity and Predation on Aphids in Spring Cereals. Biological Control 17:218-226.

Elliott, N.C., and R.W. Kieckheffer. 1990. A Thirteen-year Survey of the Aphidophagous Insects of Alfalfa. Prairie Naturalist 22:87-96.

Elliott, N.C., R.W. Kieckhefer, J.H. Lee, and B.W. French. 1998. Influence of Within-field and Landscape Factors on Aphid Predator Populations in Wheat. Landscape Ecology 14:239-252.

Elliott, N.C., R.W. Kieckhefer, and W.C. Kauffman. 1996. Effects of an Invading Coccinellid on Native Coccinellids in an Agricultural Landscape. *Oecologia* 105:537-544.

Ellis, D.R., D.E. Prokrym, and R.G. Adams. 1999. Exotic Lady Beetle Survey in Northeastern United States: *Hippodamia variegata* and *Propylea quatuordecimpunctata* (Coleoptera: Coccinellidae). Entomological News 111:73-84.

Evans, E.W. 2004. Habitat Displacement of North American Ladybirds by an Introduced Species. Ecology 85:637-647.

Evans, E.W., and T.R. Toler. 2007. Aggregation of Polyphagous Predators in Response to Multiple Prey: Ladybirds (Coleoptera: Coccinellidae) Foraging in Alfalfa. Population Ecology 49:29-36.

Evans, E.W., A.O. Soares, and H. Yasuda. 2011. Invasions by Ladybugs, Ladybirds, and Other Predatory Beetles. BioControl 56:597-611.

Fahrig, L. J. Girard, D. Duro, J. Pasher, A. Smith, S. Javorek, D. King, K. F. Lindsay, S. Mitchell, and L. Tischendorf. 2015. Farmlands with smaller crop fields have higher within-field biodiversity. Agriculture, Ecosystems and Environment 200: 219-234.

Finlayson, C.J., K.M. Landry, and A.V. Alyokhin. 2008. Abundance of Native and Non-native Lady Beetles (Coleoptera: Coccinellidae) in Different Habitats in Maine. Annals of the Entomological Society of America 101:1078-1087.

Fothergill, K., and K.V. Tindall. 2010. Lady Beetle (Coleoptera: Coccinellidae: Coccinellinae) Occurrences in Southeastern Missouri Agricultural Systems: Differences Between 1966 and Present. *The Coleopterists Bulletin* 64:379-382.

Fox, M.F. and Macenko, S.L. 1985. The Agriculture-forest Interface: an Overview of Land Use Change. Working Paper, Lands Directorate, Environment Canada. No. 38. pp. ix + 132pp.

Gagne, W.C. and J.L. Martin. 1968. The insect ecology of red pine plantations in central Ontario. Canadian Entomologist 100: 835-846.

Gardiner, M.M., M.E. O'Neal, and D.A. Landis. 2011. Intraguild Predation and Native Lady Beetle Decline. PloS ONE 6:e23576.

Giorgi, J. A., Vandenberg, N. J., McHugh, J.V., Forrester, J.A., Slipinski, A., Miller, K.B. Shapiro, L.R. and Whiting, M.F. 2009. The Evolution of Food Preferences in Coccinellidae. Biological Control 51: 215-231.

Gordon, R.D. 1985. The Coccinellidae (Coleoptera) of America North of Mexico. Journal of New York Entomological Society 95:1-912.

Grant, P. 2017. *Email correspondence to J. Linton* including personal database of records. June 30, 2017. Species at Risk Act Science Coordinator, Department of Fisheries and Oceans, Victoria, British Columbia.

Hagen, K.S. 1962. Biology and Ecology of Predaceous Coccinellidae. Annual Review of Entomology 7:289-326. 46

Harmon, J.P., E. Stephens, and J. Losey. 2007. The Decline of Native Coccinellids (Coleoptera: Coccinellidae) in the United States and Canada. Journal of Insect Conservation 11:85-94.

Hesler, L.S., and R.W. Kieckhefer. 2008. Status of Exotic and Previously Common Native Coccinellids (Coleoptera) in South Dakota Landscapes. Journal of the Kansas Entomological Society 81:29-49.

Hesler, L.S., G. McNickle, M. Catangui, J. Losey, E. Beckendorf, L. Stellwag, D. Brandt, and P. Bartlett. 2012. Method for Continuously Rearing Coccinella Lady Beetles (Coleoptera: Coccinellidae). The Open Entomology Journal 6:42-48.

Hodek, I., and A. Honěk. 1996. Ecology of Coccinellidae. Kluwer Academic Publishers, Boston.

Hodek I, H.F. van Emden, and A. Honěk. 2012. Ecology and Behaviour of the Ladybird Beetles (Coccinellidae). Wiley-Blackwell. Kindle Edition.

Honek, A., A. F. G. Dixon, A. O. Soares, J. Skuhrovec, and Z. Martinkova. 2017. Spatial and temporal changes in the abundance and compostion of ladybird (Coleoptera: Coccinellidae) communities. Current Opinion in Insect Science 14: 61–67

Honek, A., Z. Martinkova, A. F. G. Dixon, H.E. Roy, and S. Pek. 2016. Long-term changes in communities of native coccinellids: population fluctuations and the effect of competition from an invasive non-native species. Insect Conservation and Diversity 9: 202–209.

Hurst, G.D.D., R.G. Sharpe, A.H. Broomfield. *et al.* 1995. Sexually Transmitted Disease in a Promiscuous Insect, *Adalia bipunctata*. Ecological Entomology 20:230-236.

ITIS (Integrated Taxonomic Information System). 2015. Retrieved [November 2015], from the on-line database (Integrated Taxonomic Information System).

Ives, A.R., P. Kareiva, and R. Perry. 1993. Response of a Predator to Variation in Prey Density at Three Hierarchical Scales Lady Beetles Feeding on Aphids. Ecology 74:1929- 1938.

Ives, P.M. 1981. Estimation of Coccinellid Numbers and Movement in the Field. The Canadian Entomologist 113:981-997.

Jeffries, D.L., J. Chapman, H.E. Roy, S. Humphries, R. Harrington, P.M.J. Brown, and L.J. Handley. 2013. Characteristics and Drivers of High-altitude Ladybird Flight: Insights from Vertical-looking Entomological Radar. *PloS ONE* 8:e82278.

Jones, C. 2017. *Email correspondence to J. Linton*. July 13, 2017. Provincial Arthropod Zoologist, Ministry of Natural Resources and Forestry, Peterborough, Ontario.

Kajita, Y., and E.W. Evans. 2010. Alfalfa Fields Promote High Reproductive Rate of an Invasive Predatory Lady Beetle. Biological Invasions 12:2293-2302.

Kenis, M., M.A. Auger-Rozenberg, A. Roques, L. Timms, C. Pere, M.J.W. Cock, J. Settele, S. Augustin, and C. Lopez-Vaamonde. 2008. Ecological Effects of Invasive Alien Insects. Biological Invasions 11:21-45.

Koch, R.L. 2011. Recent Detections of a Rare Native Lady Beetle, *Coccinella novemnotata* (Coleoptera: Coccinellidae), in Minnesota. Great Lakes Entomologist 44:196-199.

Krafsur, E.S., J.J. Obrycki, and J.D. Harwood. 2005. Comparative Genetic Studies of Native and Introduced Coccinellidae in North America. European Journal of Entomology 102:469-474.

Kumar, S., and R.I. Bhatt. 2002. Pyrethroid-induced Resurgence of Sucking Pests in the Mango Ecosystem. Journal of Applied Zoological Research 13:107-111.

Laurent, P., J.C. Braekman, and D. Daloze. 2005. Insect Chemical Defense. Topics in Current Chemistry 240:167-229.

Losey, J., J. Perlman, and E.R. Hoebeke. 2007. Citizen Scientist Rediscovers Rare Nine-spotted Lady Beetle, *Coccinella novemnotata*, in Eastern North America. Journal of Insect Conservation 11:415-417.

Losey, J., J. Perlman, J. Kopco, S. Ramsey, L. Hesler, E. Evans, L. Allee, and R. Smyth. 2012. Potential Causes and Consequences of Decreased Body Size in Field Populations of *Coccinella novemnotata.* Biological Control 61:98-103.

Louda, S.M., R.W. Pemberton, M.T. Johnson, and P.A. Follett. 2003. Non-target Effects- the Achilles' Heel of Biological Control? Retrospective Analyses to Reduce Risk Associated with Biocontrol Introductions. Annual Review of Entomology 48:365-396.

Lucas, E. 2005. Intraguild Predation Among Aphidophagous Predators. European Journal of Entomology 102:351-364.

Lucas, E., C. Vincent, G. Labrie, G. Chouinard, F. Fournier, F. Pelletier, N.J. Bostanian, D. Coderre, M.P. Mignault, and P. Lafountaine. 2007. The Multicolored Asian Ladybeetle *Harmonia axyridis* (Coleoptera: Coccinellidae) in Québec Agroecosystems Ten Years After its Arrival. European Journal of Entomology 104:737-743.

Marletto, F., A. Patetta, and A. Manino 2003. Laboratory Assessment of Pesticide Toxicity to Bumble Bees. Bulletin of Insectology 56:155-158.

Marshall, S. 2008. Lady Beetles of Ontario. Retrieved December, 2008, from University of Guelph - Lady Beetles of Ontario.

Marshall, S. 1999. Alien Invasions, Ontario's Ever Changing Bug Landscape. Seasons. Spring 1999:26-29.

McGauley, E. 2004. Bird on the Farm: A Stewardship Guide. Edited by Gregor G. Beck and Anne Bell. Ontario Nature. Available online: Ontario Nature - Birds on the Farm Guide Online

McMullen, R.D. 1967. The Effects of Photoperiod, Temperature and Food Supply on Rate of Development and Diapause in Coccinella novemnotata. The Canadian Entomologist 99:578-586.

Moser, S.E., and J.J. Obrycki. 2009. Non-target Effects of Neonicotinoid Seed Treatments, Mortality of Coccinellid Larvae Related to Zoophytophagy. Biological Control 51:487-492.

Natureserve. 2017. Glossary. http://explorer.natureserve.org/glossary/gloss_i.htm (Accessed March 16, 2018).

New, T.R. 1995. Introduction to Invertebrate Conservation Biology. Oxford University Press, New York. 194 pp.

Obrycki, J.J. 1989. Parasitization of Native and Exotic Coccinellids by *Dinocampus Coccinellae* (Schrank) (Hymenoptera: Braconidae). Journal of Kansas Entomological Society 62:211-218.

Obrycki, J.J., Harwood, J.D., Kring, T.J. and O'Neil, R.J. 2009. Aphidophagy by Coccinellidae: Application of Biological Control in Agroecosystems. Biological Control 51: SI244-SI254.

Obrycki, J.J. and Kring, T.J. 1998. Predaceous Coccinellidae in Biological Control. Annual Review of Entomology 43: 295-321.

Omkar, and S. Srivastava, 2002. The Reproductive Behaviour of an Aphidophagous Ladybeetle, *Coccinella septempunctata* (Coleoptera: Coccinellidae). European Journal of Entomology 99:465-470.

Osawa, N. 2000. Population Field Studies on the Aphidophagous Ladybird Beetle *Harmonia axyridis* (Coleoptera:Coccinellidae): Resource Tracking and Population Characteristics. Population Ecology 42:115-127.

Petersen, L.S. 1993. Effects of 45 Insecticides, Acaricides and Molluscicides on the Rove Beetle *Aleochara bilineata* (Col.: Staphylinidae) in the Laboratory. Entomophaga 38:371-382.

Rees, B.E., D.M. Anderson, R.D. Gordon, and D. Bouk. 1994. Larval Key to Genera and Selected Species of North American Coccinellidae (Coleoptera). Proceedings of the Entomological Society of Washington 96:387-412.

Riddick, E.W., T.E. Cottrell, and K.A. Kidd. 2009. Natural Enemies of the Coccinellidae: Parasites, Pathogens, and Parasitoids. Biological Control 51:306-312.

Roy, H.E., and T. Cottrell. 2008. Forgotten Natural Enemies: Interactions Between Coccinellids and Insect-parasitic Fungi. European Journal of Entomology 105:391-398.

Schaefer, P.W., R.J. Dysart, and H.B. Specht. 1987. North American Distribution of *Coccinella septempunctata* (Coleoptera: Coccinellidae) and Its Mass Appearance in Coastal Delaware. Environmental Entomology 16(2): 368-373.

Skinner, B., and E. Domaine. 2010. Rapport sur la Situation de la Cocinnelle à Neuf Points (*Coccinella novemnotata*) au Québec. Ministère des Ressources Naturelles et de la Faune du Québec. Faune Québec. 37 pp.

Sloggett, J.J., and M.E.N. Majerus. 2000. Habitat Preferences and Diet in the Predatory Coccinellidae (Coleoptera): An Evolutionary Perspective. Biological Journal of the Linnean Society 70:63-88.

Smith, C.A., and M.M. Gardiner. 2013. Biodiversity Loss Following the Introduction of Exotic Competitors: Does Intraguild Predation Explain the Decline of Native Lady Beetles? PLoS ONE 8:e84448.

Smith, S.F., and V.A. Krischik. 1999. Effects of Systemic Imidacloprid on *Coleomegilla maculata* (Coleoptera, Coccinellidae). Environmental Entomology 28:1189-1195.

Snyder, W.E., and E.W. Evans. 2006. Ecological Effects of Invasive Arthropod Generalist Predators. Annual Review of Ecology, Evolution and Systematics 37:95-122.

Srivastava, S., and Omkar. 2004. Age-specific Mating and Reproductive Senescence in the Seven-spotted Ladybird, *Coccinella septempunctata*. Journal of Applied Entomology 128:452-458.

Staines, C.L., M.J. Rothchild, and R.B. Trumble. 1990. A Survey of the Coccinellidae (Coleoptera) Associated with Nursery Stock in Maryland. Proceedings of the Entomological Society of Washington 92:310-313.

Stellwag, L., and E. Losey. 2014. Sexual Dimorphism in North American Coccinellids: Sexing Methods for Species of *Coccinella* L. (Coleoptera: Coccinellidae) and Implications for Conservation Research. The Coleopterists Bulletin 68:271-281.

Stephens, E.J. 2002. Apparent Extirpation of *Coccinella novemnotata* in New York State: Optimizing Sampling Methods and Evaluating Explanations for Decline. MSc Thesis. Cornell University, Ithaca NY USA.

Theiling, K.M., and B.A. Croft. 1988. Pesticide Side Effects on Arthropod Natural Enemies: a Database Summary. Agriculture, Ecosystems and Environment 21:191-218.

Tumminello, G., T.A. Ugine, and J.E. Losey. 2015. Intraguild Interactions of Native and Introduced Coccinellids: The Decline of a Flagship Species. Environmental Entomology 44:64-72.

Turchin, P., and P. Kareiva. 1989. Aggregation in *Aphis varians* - an Effective Strategy for Reducing Predation Risk. Ecology 70:1008-1016.

Turnipseed, R.K., T.A. Ugine, and J.E. Losey. 2014. Effect of Prey Limitation on Competitive Interactions Between a Native Lady Beetle, *Coccinella novemnotata* , and an Invasive Lady Beetle, *Coccinella septempunctata* (Coleoptera: Coccinellidae). Environmental Entomology 43:969-976.

Turnock, W.J., I.L. Wise, and F.O. Matheson. 2003. Abundance of Some Native Coccinellines (Coleoptera: Coccinellidae) Before and After the Appearance of *Coccinella septempunctata*. The Canadian Entomologist 135:391-404.

Ugine, T.A., and J.E. Losey. 2014. Development Times and Age-specific Life Table Parameters of the Native Lady Beetle Species *Coccinella novemnotata* (Coleoptera: Coccinellidae) and its Invasive Congener *Coccinella septempunctata* (Coleoptera: Coccinellidae). Physiological Ecology 43:1067-1075.

van der Werf, W., E.W. Evans, and J. Powell. 2000. Measuring and Modelling the Dispersal of *Coccinella septempunctata* (Coleoptera: Coccinellidae) in Alfalfa Fields. European Journal of Entomology 97:487-493.

Webberley, K.M., G.D.D. Hurst, R.W. Husband, J. Hinrich, G.V.D. Schulenburg, J.J. Sloggett, V. Isham, J. Buszko, and M.E.N. Majerus. 2004. Host Reproduction and a Sexually Transmitted Disease: Causes and Consequences of *Coccipolipus hippodamiae* Distribution on Coccinellid beetles. Journal of Animal Ecology 73:1-10.

Webberley, K. M., and G.D.D. Hurst. 2002. The Effect of Aggregative Overwintering on an Insect Sexually Transmitted Parasite System. Journal of Parasitology 88:707-712.

Wheeler, A.G., and E.R. Hoebeke. 1995. *Coccinella novemnotata* in Northeastern North America: Historical Occurrence and Current Status (Coleoptera: Coccinellidae). Proceedings of the Entomological Society of Washington 97:701-716.

List of abbreviations

COSEWIC: Committee on the Status of Endangered Wildlife in Canada
COSSARO: Committee on the Status of Species at Risk in Ontario
CWS: Canadian Wildlife Service
ESA: Ontario's *Endangered Species Act, 2007*
ISBN: International Standard Book Number
MNRF: Ontario Ministry of Natural Resources and Forestry
SARA: Canada's Species at Risk Act
SARO: Species at Risk in Ontario

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[i] The range map for the Nine-spotted Lady Beetle in Gordon (1985) contains one record from Great Slave Lake in the Northwest Territories. This record is considered a rare vagrant from its known range as no other records north of Edmonton have been documented in Canada.
[ii] Based largely on the curation efforts of Dr. Steve Marshall at the University of Guelph Insect Collection and data basing efforts of Meghan Marriott.
[iii] See COSEWIC 2012 for baseline recommendations on developing a lady beetle monitoring protocol
[iv] Currently there are no element occurrence specifications for lady beetles specifically but there are for tiger beetles (subfamily: Cicindelinae)