# **The European Fire Ant, *Myrmica rubra* (Hymenoptera: Formicidae) in the Credit River Valley Watershed**


by

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## FOREWORD

In writing my Plan of Study, I wanted to focus on protected areas, and what can be done to improve them, as well as invasive species and how they interact with protected areas, as they pose a growing threat to biodiversity worldwide. This interest led to three components in my area of concentration – policy in conservation of at-risk species, managing invasive species, and protected areas. Many of my learning objectives within these components were completed through course work, investigating various case studies regarding policies regarding both invasive species and protected areas, as well as beginning research on the European fire ant, *Myrmica rubra*, the focal species of my major paper research. The remaining objectives were accomplished through the research presented in this paper.

The second component in my Plan of Study, managing invasive species, was the primary focus of this research project. The research, focusing on what environmental factors are associated with higher *M. rubra* abundance, allowed me to appreciate the negative impacts *M. rubra* has had on sites and other species in Ontario and Canada, and develop an expertise on *M. rubra* in the Credit River watershed and learn what factors make sites vulnerable to an *M. rubra* invasion, which aligns with my learning objectives for the managing invasive species component. Because of how difficult eradication of *M. rubra* from sites that have already been invaded has proven to be, knowing what uninvaded sites are vulnerable to invasion may be a key component to preventing further spread of the species and limiting its negative impacts on the area.

My final learning component, protected areas, was also touched on through my research. Because this research took place on lands managed by Credit Valley Conservation, I was able to see first-hand the impacts *M. rubra* have had on certain protected areas, in addition to investigating the impacts invasive species have had on protected areas elsewhere. Invasive species are emerging as one of the foremost threats to biodiversity, and I was able to see through my research how information gained through studies such as this one may be used to manage the impacts of invasive species on protected areas in the future.

## ABSTRACT

The European fire ant, *Myrmica rubra* (Linneaus) (Hymenoptera: Formicidae) is an ant species native to Europe that is invasive in the northern United States and Canada. *M. rubra* has proven very hard to control once it has invaded an area, and preventing the further spread of the species has become important for limiting its negative effects. Knowing what environmental factors are associated with high abundance of *M. rubra* can help to inform where efforts at limiting future spread should be aimed, but for most areas this information is lacking. In this study, pitfall traps were used to sample *M. rubra* abundance at ten sites managed by Credit Valley Conservation (CVC), in the Credit River watershed in southern Ontario. These data were combined with environmental data gathered by CVC and used to determine whether the surrounding urban cover of sites, the disturbance level of sites and the wetness of sites are associated with *M. rubra* abundance. The surrounding urban cover of a site emerged as the most important predictor variable of *M. rubra* abundance, with more surrounding urban cover having higher *M. rubra* abundance. Higher wetness and disturbance also both predicted higher *M. rubra* abundance in the Credit River watershed. This information can be used to help target prevention and management efforts at sites that may be particularly vulnerable to future *M. rubra* invasion.

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## INTRODUCTORY CHAPTER

Invasive alien species, defined by the IUCN as "a species that has been introduced to an environment where it is non-native, or alien, and whose introduction causes environmental or economic damage or harm to human health" (IUCN 2011), are a growing danger to global biodiversity**.** Invasive species are a significant cause of biodiversity decline and species extinction worldwide (Clavero & Garcia-Berthou 2005), being noted as a threat to 22% of the endangered species in Canada in an analysis by Venter et al. (2006). These introduced species often have negative effects on the ecological and economic systems of the areas they are moved to, as well as negatively affecting native biota (Epperson & Allen 2010). Economic impacts are incurred; every year, the agriculture and forest industries in Canada lose upwards of $7 billion due to IAS (Government of Ontario, 2015). These impacts are only expected to grow, due to strong links observed between invasive species and factors such as climate change and a growing, mobile human population (Genovesi & Monaco 2013, Simberloff et al. 2013, Spear et al. 2013).

Invasive species pose a growing threat to the world's protected areas, and increasingly, protected areas are being called on to help in the management of invasive species (Genovesi & Monaco 2013). Because protected areas focus on preserving key biological elements, the impacts of invasive species in these areas may be especially strong (Foxcroft et al. 2014). Limited resources and awareness about invasive species limit the current ability of protected areas to manage the threat of invasive species (De Poorter 2007, Pysek et al. 2014), though Genovesi & Monaco (2013)) indicate that protected areas could improve their management of invasive species through improving knowledge, having a response framework for invasive species and implementing monitoring and information exchange networks. Doing this could allow protected areas to help defend native species against invasive species, and knowledge from within protected areas could be used to inform invasive species management (Genovesi & Monaco 2013).

The European fire ant, *Myrmica rubra*, is a species native to Eurasia that, since the early 20th century, has invaded certain regions of North America – primarily New England and the Pacific Northwest (Global Invasive Species Database 2009; Garnas 2004; Wetterer & Radchenko 2011; Naumann & Higgins 2015). The first report of the ant in North America was the description of a population in Massachusetts in 1908 (Wheeler, in Groden et al. 2005). Wetterer & Radchenko (2011) reported that the *M. rubra* is found in a large area of the Palearctic, with the native range stretching from Ireland and Portugal to central Asia and Siberia, and now invading five southeastern Canadian provinces, including Ontario, six states in the northeastern U.S., as well as Washington State and British Columbia (Higgins 2013, Naumann & Higgins 2015).

*Myrmica rubra* has a painful sting, making it a nuisance to humans, and is also known to dominate native species (Global Invasive Species Database 2009; Invasive Alien Species Working Group). Garnas (2004), in measuring native ant communities in Maine, found a total of twenty groups of native ants in territory not invaded by *M. rubra*, but only five groups in territory where *M. rubra* was present. A univariate assessment of pitfall traps used by Garnas (2004) to collect ants also revealed higher diversity in uninvaded sites.

McPhee et al. (2012) found that European fire ants have strong impacts on homopterans in Maine, with specific homopteran taxa having higher abundances in areas infested with *M. rubra*. In British Columbia, Naumann & Higgins (2015) also report lower ant diversity in areas *M. rubra* had invaded. At some sites *M. rubra* represented 99.99% of the total ant fauna trapped. They also found that in sites with *M. rubra* present, there was consistently lower arthropod biodiversity, with 17 of 20 non-ant arthropod species showing declines in capture numbers. European fire ants have also been found to have negative impacts on herring gull reproduction in Maine – DeFisher and Bronter (2013) found that birds incubating at nests where there was *M. rubra* activity engaged in more preening and other behaviours disrupting incubation than where there was no presence of *M. rubra*, and that chicks from nests without any *M. rubra* activity grew more quickly. While there have been no observations for *M. rubra*, other invasive ant species have also been noted to attack anurans. *Solenopsis invicta* was observed predating on Houston toad (*Bufo houstonensis)* toadlets (Freed & Nietman 1988 in Allen et al. 2004), and richness and abundance of amphibian species increased after the red imported fire ant was eradicated (Slater & Allen 2002, in Todd et al. 2008).

Management of *M. rubra* has proven very difficult. In Maine, bulletins have been posted for homeowners concerning the European fire ant, noting that prevention is the best strategy, and that for homeowners with *M. rubra* on their property, chemical treatments are the best way to suppress populations. However, populations have been known to resurge after insecticide treatments (University of Maine, 2015). The City of Markham in Ontario has noted that there are no known effective, long-term control methods for parkland, because treatments will likely kill too many beneficial insects in addition to the fire ants (City of Markham 2014). The same was indicated in Maine, with biologist Frank Drummond saying “They’ll never be able to eliminate them; it just isn’t possible. To totally eradicate them, you’d have to blanket the park with insecticides and do more harm than good” (Edgecomb 2002).

With the difficulty in managing and eradicating established *M. rubra* populations, prevention of the establishment of new populations becomes increasingly important. Ecological variables can predict the presence of invasive ant species. Groden et al. (2005) noted that in Maine, *M. rubra* were found primarily under and within downed woody debris, as well as in leaf litter. Groden et al. (2005) also noted that the ants are likely moved around into new habitats by humans, through the transport of plant material and soil into new areas. In Tommy Thompson Park and Rouge Park in Toronto, Rudmik (2011) found that soil type and soil moisture influence the abundance of *M. rubra*. Also working in sites in the Greater Toronto Area, Ito et al. (2014) found that soil moisture, soil surface temperature and altitude impact *M. rubra* presence and abundance.

Experimenting with another ant species, *Solenopsis invicta,* King & Tshinkel (2008) found that while disturbing a habitat tended to decrease native ant populations in a Florida forest habitat, the populations of the invasive *S. invicta* were favoured by disturbed habitats, and determined that human activity is the primary force behind *S. invicta* invasions. With this, it is expected that more disturbed areas will have higher populations of *M. rubra*, which is certainly the case of Tommy Thompson Park (see Rudmik 2011).

Elsewhere, soil moisture has emerged as an important predictor of ant presence. *Linepithema humile*, the invasive Argentine ant, was found more frequently and in higher abundance in moist sites in Southern California than in drier sites (Sodeman 2014). Krushelnycky et al. (2005) noted that soil temperature and moisture accounted for most of the variation in foraging activity of *L. humile* in Hawaii, and that rainfall patterns had a significant influence on the patterns of spread of the species. In New Zealand, Lester (2005) found that established invasive ant species are more likely to be found in cooler sites that are moister and have higher rainfall. Looking at ant communities in San Francisco parks, Clarke et al. (2008) found that soil moisture is positively related to ant species richness.

The surroundings of a site, and how urban a setting it is in, can also influence populations of *M. rubra* and other ant species. Clarke et al. (2008) examined ants in urban park areas in San Francisco.  Urban areas were found to reduce overall ant richness and abundance, and the invasive *L. humile* had little to no effect on native ants in these areas, thought to be because of structural differences between urban forests and natural forests. Testing ant dominance in urban areas, Stringer et al. (2009) found that the number of ant species trapped in an area was dependent on habitat type and adjacent landscapes likely influencing the ant populations and species diversity within urban habitat patches. In a park outside of Montreal, Lessard and Buddle (2005) found that more urban assemblages tended to be characterized by one or several dominant species, including invasive species. Other invasive ant species, such as *S. invicta* and *L. humile* have shown an affinity to urban environments (Forys et al. 2002, Carpintero et al. 2004). *L. humile* was found to decline in abundance from urban edges towards the interior of coast habitat scrub in California, with the high abundance at edges likely due to spillover from urban sources into the habitat (Bolger 2007). Thus, surrounding landscapes may have a significant impact on whether *M. rubra* will be present at or near a site and whether that site is likely to be invaded.

For this project, I investigated what ecological factors are important in predicting where *M. rubra* infest in the Credit River watershed. Credit Valley Conservation (CVC) is a conservation authority in southern Ontario that operates in wetland, forest, and riparian sites in the Credit River watershed (Credit Valley Conservation 2017). Focusing on wetland sites, I used CVC habitat data to examine what ecological factors influence *M. rubra* presence and abundance in these areas. In regions that have not yet been invaded by the *M. rubra,* a model using ecological variables to predict what habitats are most vulnerable to become infested with *M. rubra* could be an important management tool, as it would allow monitoring efforts to be focused on these areas. Knowing what makes certain areas more favourable for infestation by *M. rubra* is an important step in preventing new invasions before they occur.

What follows is a stand-alone paper in the form of a manuscript, which presents the outcome of this research using the formatting of the *Canadian Entomologist* Journal. Laura Timms from the CVC and Gail Fraser both contributed to this research and will be co-authors on the paper.

# The European Fire Ant, *Myrmica rubra* (Hymenoptera: Formicidae) in the Credit River Valley Watershed

## INTRODUCTION

The European fire ant, *Myrmica rubra* (Linneaus), is invasive in North America found across the northeastern United States and southeastern Canada, as well as in Washington State and British Columbia (Wetterer and Radchenko 2011, Higgins 2013, Naumann & Higgins 2015). In North America the species was found to have a negative impact on other arthropod biodiversity (Garnas 2004, Naumann & Higgins 2015) and is a concern for park managers and municipalities where it has established (e.g., Groden et al. 2005, City of Markham 2014).

Successful invasions are linked to a variety of factors, but the local conditions support the ecological success of invasive ant species (see Holoway 2002 for a review). In some cases, anthropogenic disturbance can influence ant community assemblages (Lessard and Buddle 2005) and in its native range *M. rubra* used human made wastes in their nests (Michlewicz and Tryjanowski 2017). In Maine, *M. rubra*, was found primarily under and within downed woody debris, as well as in leaf litter (Groden et al. 2005) and in southern Ontario their abundance appeared influenced by soil characteristics (moisture, temperature in particular) (Rudmik 2011 and Ito 2014). Little information is available about how *M. rubra* presence or abundance is linked to anthropogenic disturbance (Ito 2014). Given the paucity of information on *M. rubra* in southern Ontario, its apparent preference for moist soil (Krushelnycky et al. 2005, Lester 2005, Clarke 2008, Sodeman

2014), and perhaps an association with disturbed areas (see Ito 2014), we focused on sampling wetlands in a watershed that has variation in urban land cover. It was predicted that both soil moisture and habitat disturbance would be strong predictors of *M. rubra* abundance. Wetlands represent areas of high biological importance (Gibbs 1993; Gibbs 2000; Junk et al. 2006) and *M. rubra* present a threat to that biodiversity (Garnas 2004; McPhee et al. 2012; Naumann and Higgins 2015).

**Study Site**

*M. rubra* were sampled in the Credit River watershed. In Ontario, conservation authorities are delineated by watersheds, and they manage large protected areas along these watersheds. The Credit Valley Conservation (CVC) Authority monitors wetlands in their jurisdiction. Measures of habitat wetness, habitat disturbance, and surrounding urban cover were used in this analysis (see below).

Ten wetlands were sampled in the CVC watershed (Figure 1). The sites were selected based on their accessibility, available habitat data, anecdotal fire ant observations (ranging from none to infested) and spatial coverage that represents a wide range of land cover. The sites sampled represent two types of wetlands – swamps and marshes - as classified by the Canadian Wetlands Classification System. Swamps wetlands are dominated by trees or tall shrubs with the water table below a major area of the ground surface, while marshes are wetter, with shallow levels of standing or slow-moving water, with vegetation primarily composed of aquatic macrophytes (National Wetlands Working Group 1997).

## METHODS

### Sampling

In June 2016 ants were sampled using pitfall traps (e.g., Garnas 2004, Andersen 1991, Golden & Crist 2000, Naumann & Higgins 2015). Traps (650 g containers filled half way with water, dish soap and propylene glycol) were placed every 10 m along two 40m transects for a total of 10 traps at each site (see below; Fig. 1). The traps, flush with the ground had a roof to prevent the trap filling with water in the event of rain, and a fence, constructed out of chicken wire, surrounded each trap to prevent the accidental trapping of larger species. Traps were deployed for 7 days, and contents were stored in alcohol prior to processing.

### Ant Identification and Counting

Ants in samples with a low or intermediate amount of ants were identified and counted individually by hand. Ants were identified using Ellison et al. (2012). Distinguishing *M. rubra* features are a scape pointing gently upward, small, thin frontal lobes pointing upward; and a propodeum level with the pronotum (Ellison et al. 2012). Non-*M. rubra* ants were separated and identified separately using the same key.

Samples with large numbers of ants, generally >1000 *M. rubra* were dried, scanned for ants of other species, and the approximate total number of *M. rubra* was identified by weight. A selection of ants from these larger samples were identified by hand so as to ensure that the sample was comprised overall of *M. rubra*. Samples were dried in a drying oven at 65$^{o}$C for 24 hours. A random sample of 20 ants was removed 5 times from each sample and weighed to determine the average ant biomass. This average did not differ between samples and was used to determine the total number of ants in each sample. The samples were then weighed using the 100G/0.001G B1003T Electronic Balance Laboratory scale to determine the total ant biomass, and the average ant biomass was used to determine the ant abundance in each sample.

**Ecological Data: Moisture, Disturbance, and Urban Cover**

Ants were sampled in coordination with CVC, who maintains an annual monitoring program of a variety of environmental variables, two of which are relevant to this study (disturbance and moisture). CVC monitoring plots consist of a 50m-x10m plot, with posts every 10 m along the 50 m transect that straddles the hydrological gradient of the wetland (Figure 2), where all of the vascular plants were identified to the species level (Credit Valley Conservation 2013).

**Moisture & Disturbance**

For both moisture and disturbance, the plant species present at the site were used to establish ecological values. Plant type was used as a metric for moisture of each subplot. Direct moisture measures were not possible because soil moisture was not available for the study year. Each plant species observed at a site was assigned a "wetness" value depending on its habitat wetness needs, using the Floristic Quality Assessment System for Southern Ontario - the value is between -5 and +5, with -5 being an obligate wetland species and +5 an obligate upland species. (Oldahm et al. 1995; O'Reilly et al. 2010). A mean value for all of the plants present provides a representative value for the wetness of the habitat at the site, with lower (more negative) numbers representing wetter sites. Habitat disturbance within a wetland was inferred using a measure of native to non-native vascular plant species; the higher the proportion of non-native species present at a site, the more disturbed the site was presumed to be.

Through a rotating panel design, some sites are sampled every year, while others were sampled every two years (Credit Valley Conservation 2013). For this analysis, data from the last two sample years at each site were used for habitat wetness and habitat disturbance; thus the values come from years 2013-2016, depending on the most recent years the sites were sampled, with the average value over the two years taken as the data point for each site.

**Surrounding Urban Cover**

The amount of land surrounding a site with urban uses can provide an indication of how much urban and human activity occurs in and around the site. I used CVC data for this measure. The methods are as follows. Using ArcGIS on aerial photographs percent of urban cover 2016 data (not agricultural or natural uses categorized as active aggregate, inactive aggregate, commercial, construction, transportation and urban residential) was measured. A 30m buffer was created around the centre of each site, and the amount of natural, urban, and agricultural land use was calculated in the 2km surrounding this buffer for each site (Roy & Paudel 2013). The total area of land with urban use in the 2km surrounding each site was summed and divided by the total land area to determine the percentage of urban land cover surrounding each site.

**Statistical Analysis**

Ant abundance data were log-transformed to account for the large differences in *M. rubra* abundance between sites (Princeton University Library Data and Statistical Services 2008; Warner 2012). The total number of *M. rubra* was calculated for each site, and standardized to 10 traps. Abundance was chosen as a response variable over presence/absence, because it better captured the differences in *M. rubra* distribution between sites.

R version 3.1.2 was used for model selection. Model selection using Akaike's Information Criterion (AIC)(Akaike 1974), with log(*M. rubra* abundance + 1) as the dependent variable, was used to determine which parameters (habitat disturbance, habitat wetness, and percent surrounding urban cover) should be included in the model and which model had the best fit for the data. The response variable in the models was log-transformed abundance data, with 1 being added to each *M. rubra* abundance value to account for zeroes.

## RESULTS

Eight out of the ten sites sampled had *M. rubra*: three were infested (> 30,000 ants collected), one had a relatively moderate presence (> 500) and the remaining four sites had very low (<50) presence (Table 1). Notably, three of the sites with *M. rubra* infestations (Rattray Marsh, Cawthra, and Credit River) were geographically very close together, while one (Hungry Hollow) was more isolated from the other sites (see Fig. 2).

There was a narrow range of habitat wetness across sites (from -3.795 to -0.205, SD ± 1.106). Habitat disturbance showed a wider range (30.8 to 5.8%, SD ± 9.4%) as did surrounding urban cover ranged (6.67 to 79.8%, SD ± 25.5%).

The model with the lowest AIC included surrounding urban cover and habitat wetness as parameters (where log(*M. rubra* abundance +1) = (6.88760 * % urban cover) - (0.7714 *habitat wetness) - 2.6912 (adjusted $R^2$ = 0.5179, p =0.03228; Table 2). A summary of the model shows only % surrounding urban cover as being a significant predictor (p=0.0112), with wetness having a p-value of 0.1403. However, a model with only surrounding urban cover as a predictor variable has a lower adjusted $R^2$ (0.4115 compared to 0.5179) as well as a lower AIC, so a model with both surrounding urban cover and habitat wetness as parameters was selected. A model with all three parameters retained as predictor variables has a slightly higher adjusted $R^2$ of 0.5319, but has a higher AIC, and so disturbance was dropped from the model.

## DISCUSSION

In this study, we aimed to determine which ecological variables were most important in predicting *M. rubra* abundance and to determine which wetlands were infested in the Credit River Valley. While it was found that urban cover and habitat wetness were both identified as predictor variables in the model, the amount of urban cover surrounding sites emerged as the most important predictor of *M. rubra* abundance at CVC sites. Habitat wetness was secondarily important in predicting *M. rubra* abundance.

The importance of urban cover as a predictor variable for abundance corresponds with previous studies on other invasive ant species, where urban settings are often associated with higher populations of invasive ant species as well as dominance of these species (see (Forys et al. 2002, Carpintero et al. 2004, Thompson & McLachlan 2006, Bolger 2007). However, most studies focusing on urban cover are set within urban areas, and there are few studies examining the influence of land cover on ant abundance. Lessard & Buddle (2005) found that urban areas around the Molson Reserve (Quebec) were characterized by several dominant species, one of which was invasive. They argued that urbanized areas, with fewer predators, permit the establishment of invasive species more easily. This mechanism may be the case for *M. rubra* as it dominates invaded habitats, leading to lower ant and arthropod diversity (Garnas 2004; Naumann & Higgins 2015).

As predicted, habitat wetness, a measure of soil moisture, positively influenced *M. rubra* abundance. Ito (2014) also found soil moisture to be an important variable for the presence of *M. rubra* and this abiotic variable appears to be important for the invasive *L. humile* (Krushelnycky et al. 2005; Sodemann 2014)**.** While soil moisture was inferred from a plant wetness index, this substitute appears to be suitable for sites that are too wet for direct soil moisture readings. The statistical relationship may have been more pronounced if soil moisture was directly measured. A more significant effect of habitat moisture may also be observed if wetlands with a wider moisture range were sampled, or if both forest and wetland sites were included in the study.

Habitat disturbance, as measured by invasive plant species, was not retained in the final model, but did influence abundance in the expected direction – more disturbed sites have higher *M. rubra* abundance. It is possible that a more direct measure of human-inflicted disturbance on habitats may have resulted in a stronger relationship between habitat disturbance and *M. rubra* abundance, rather than a plant-related measure of disturbance. Much of the research relating disturbance to *M. rubra* movement is related to humans - Groden et al. (2005) noted that the ants are likely moved around into new habitats by humans, through the transport of plant material and soil into new areas. Additionally, Michlewicz & Tryjanowski (2017) found higher *M. rubra* colony and nest density in areas with anthropogenic waste products, suggesting that human activity is creating more potential nest sites for the species.

The *M. rubra* abundance found in this study is comparable to that found in other studies of *M. rubra* in its invasive range. We collected a total of approximately 199,710 ants in 96 pitfall traps over ten sites, for an average of 3,229 ants per trap. Naumann & Higgins (2015) found a total of 147,071 *M. rubra* over ~60 traps, for an average of approximately 2,451 ants per trap. In Maine, Garnas (2004) found a lower number of *M. rubra,* having collected a total of 27,363 *M. rubra* in 48 pitfall traps over four sites for an average of 570 ants per trap. However, this study occurred over 10 years ago, and it is likely that the number of *M. rubra* at those sites has increased in the interim.

Knowledge of *M. rubra* distribution permits mitigation and possible prevention of their spread (Edgecomb 2002; City of Markham 2014; University of Maine 2015**)**. Further, with the sites sampled, *M. rubra* abundance can be linked to other biotic wetland monitoring programs such as the CVC's anuran monitoring (Credit Valley Conservation 2010), permitting an analysis of their potential impact on amphibian biodiversity. Knowing that wetter sites in urban settings are more likely to have high *M. rubra* abundances can help land managers know where to focus monitoring and prevention efforts in areas that have not yet been invaded, as disturbed and urban sites may be the most vulnerable to potential invasions. More research is needed to paint a complete picture of what habitats are the most suitable for *M. rubra* and thus the most important to focus management efforts on, and the hope is this research is just the start of *M. rubra* research in Ontario.

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## TABLES AND FIGURES

**Table 1:** Abundance and ecological data from 10 Credit Valley Conservation sites.

| Site No. | Site | Traps Sampled[a] | Abundance | Wetness[b] | Disturbance[c] | Years Sampled (Wetness & Disturbance) | Surrounding Urban Cover |
|---|---|---|---|---|---|---|---|
| W-04 | Rattray Marsh | 10 | 56962 | -3.485 | 0.292 | 2015, 2016 | 0.448 |
| W-02 | Credit River | 8 | 30812 | -2.410 | 0.308 | 2014, 2016 | 0.680 |
| W-06 | Hungry Hollow | 10 | 103615 | -3.387 | 0.212 | 2013, 2015 | 0.555 |
| W-09 | Ken Whillans | 9 | 0 | -2.238 | 0.290 | 2015, 2016 | 0.131 |
| W-11 | Erin Pine Estates | 10 | 13 | -3.607 | 0.058 | 2014, 2016 | 0.321 |
| W-16 | Starr | 9 | 0 | -3.599 | 0.100 | 2015, 2016 | 0.067 |
| W-19 | Melville | 10 | 47 | -3.795 | 0.182 | 2013, 2015 | 0.455 |
| W-31 | Alton | 10 | 5 | -2.614 | 0.066 | 2014, 2016 | 0.072 |
| W-37 | Cawthra | 10 | 517 | -0.205 | 0.125 | 2015, 2016 | 0.797 |
| W-43 | Meadowvale South | 10 | 25 | -1.892 | 0.186 | 2014, 2016 | 0.549 |
| **Variance** | | | | 1.224 | 0.009 | | 0.065 |
| **Standard** | **Deviation** | | | 1.106 | 0.094 | | 0.255 |

a: Some sites had fewer than 10 sample traps. At Starr and Credit River, not all traps could be placed as this would have resulted in traps being placed under water. At Ken Whillans, one of the traps had been overturned and had no contents when the traps were recollected.

b: Wetness, an indication of moisture, was inferred by plant type, with each species being assigned a value between -5 (obligate wetland) and +5 (obligate upland) according to the Floristic Quality Assessment System for Southern Ontario (Oldham et al. 1995).

c: Disturbance was calculated as the proportion of plant species present at a site that were non-native at each site.

**Table 2**: Model Selection

| MODEL | STEP | AIC |
|---|---|---|
| Urban + Disturbance + Wetness | start | 8.53 |
| Urban + Wetness (final model) | remove disturbance | 8.3663 |
| Urban | remove wetness | 9.5793 |
| Intercept | remove urban | 15.0039 |

From the model selection, the best model retains urban and wetness as predictor variables, as this model has the lowest AIC value. The adjusted $R^2$ value of this model is 0.5179, and the p-value is 0.03228.

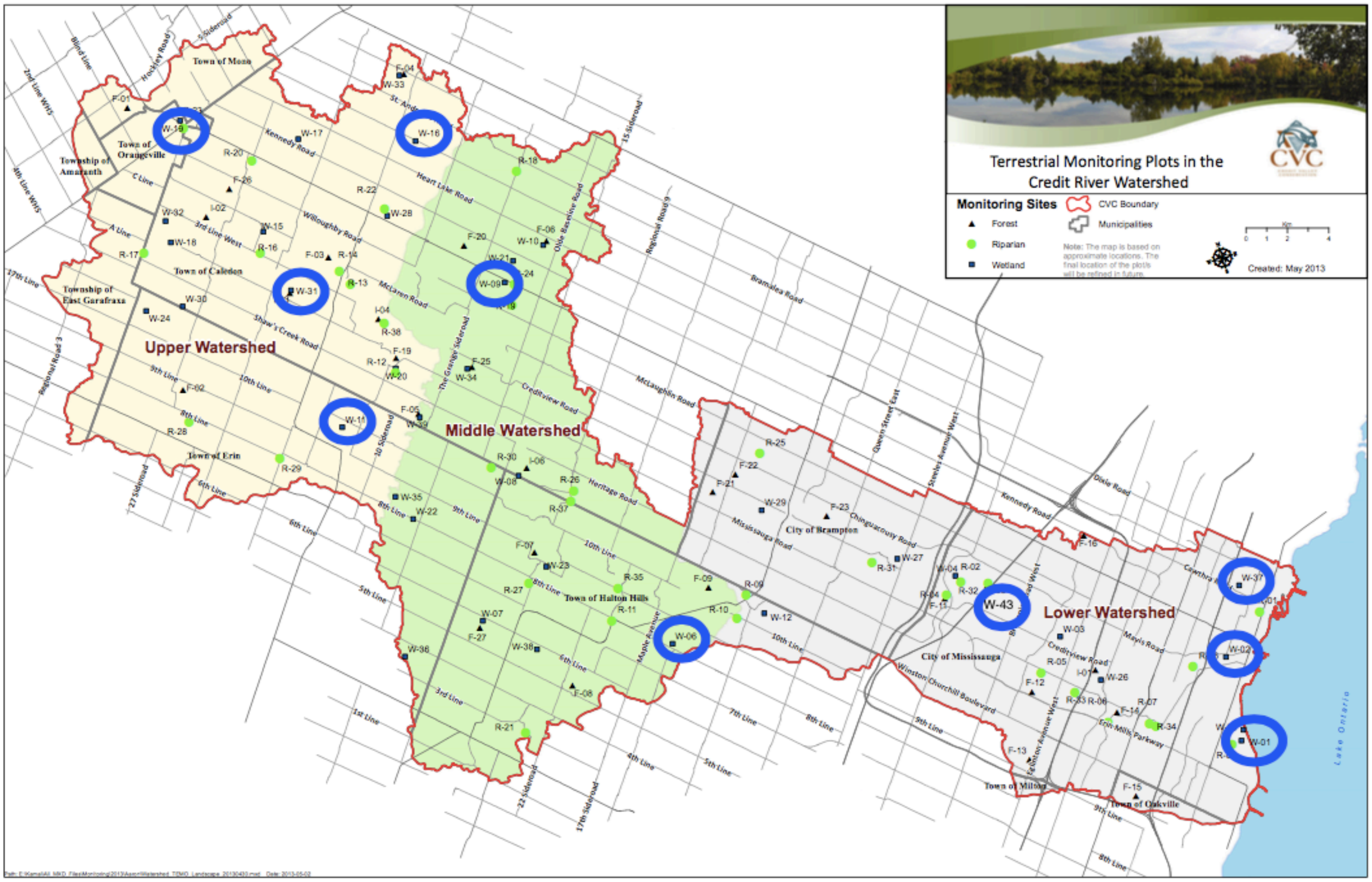


**Figure 1.** Map of sample sites. (Credit Valley Conservation). Circled sites are those that were sampled. See Table 1 for corresponding sampled site names.

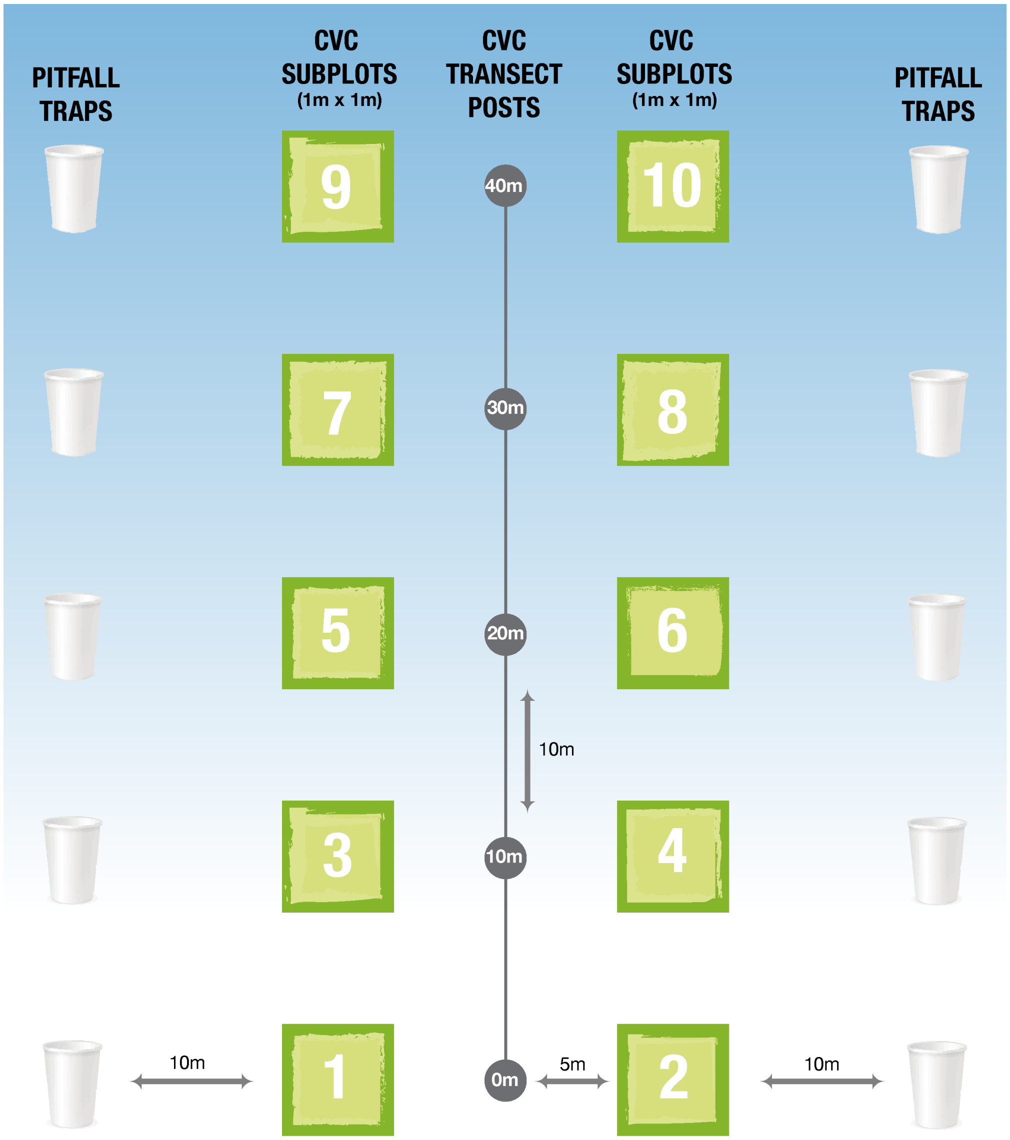


**Figure 2.** CVC sampling transect set-up. Subplots were 5m on each side of the centre transect, perpendicular to the centre transect. At each subplot was a 1m by 1m ground vegetation subplot. Pitfall traps were placed 10 m to the outside of subplots so as to avoid disturbing CVC sampling.

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