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Assessing efficacy of treatment programs to control invasive Phragmites in highway corridors of southwestern Ontario

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Abstract	The invasive haplotype M of Phragmites australis originated in Europe and was introduced to the Atlantic coast in the 1800s. It eventually made its way to southwestern Ontario in the late 1940s. Since 2010, invasive Phragmites has greatly expanded into coastal and inland wetlands throughout all Great Lakes states and provinces, and has become firmly established in road corridors. Dense stands of Phragmites can be dangerous near roads as they create a fire hazard, block sight lines, and can compromise the structural integrity of roadways and infrastructure. The Ministry of Transportation of Ontario (MTO) developed a control strategy that involves use of glyphosate, a broad spectrum herbicide, to protect the infrastructure of MTO from this nuisance grass, and also to prevent further spread from highway corridors to adjacent natural heritage areas, watercourses and agricultural fields. Using the McMaster Invasive Phragmites Database (MIPD), we conducted a change-detection analysis between 2010 and 2015 GIS data to assess the effectiveness of the weed control program in roadway corridors that has been on-going since 2012. Except for the major expressway (i.e. 400-series highways), the extent of Phragmites on most of the treated roads decreased in areal cover by >95%; removal rates associated with the 400-series highways ranged

from 80-85%. It is important to note that the amount of new growth on Hwy 401 and 402 equaled or exceeded what had been removed, resulting in a net increase in Phragmites in 2016, despite the treatment program.

Keywords Invasive Phragmites, early detection, road maintenance, remote sensing

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Executive Summary

In this report, we present data from the McMaster Invasive Phragmites Database (MIPD; see Marcaccio and Chow-Fraser 2018) to show the overall response of Phragmites to glyphosate treatment in the southwestern region of the province. We conducted a change-detection analysis between 2010 and 2015 GIS data to assess the effectiveness of the weed control program in roadway corridors that has been on-going since 2012. Except for the major expressway (i.e. 400-series highways), most of the treated roads decreased in Phragmites areal cover by >95%; removal rates associated with the 400-series highways ranged from 80-85%. Some of the reasons for the difference in response are related to the timing of the treatment relative to the assessment; for example, highway segments in the southern region that had been treated three years earlier in 2012 were associated with lower efficacy than segments in the northern region, which had been treated in 2013 and 2014. To analyze the data at a smaller scale, we divided roads into 1-km segments and conducted a change-detection analysis to determine the effectiveness of treatment for each highway. There was considerable variation in how the road segments responded to treatment, but in general, if roads received minimal or no treatment or if treatment had been applied at least 2-3 years earlier (i.e in 2012 or 2013), we found a net increase in Phragmites; conversely, if roads had been treated in 2013 and 2014, they tended to have a net decrease in Phragmites. Based on these lines of evidence, we suggest that effectiveness of treatment will vary inversely with length of time since herbicide application; therefore, we support the recommended practice of applying follow-up treatments every 2 to 3 years to maintain a reduced presence of Phragmites until they are eradicated.

On the 400-series highways, Phragmites had a faster colonization rate compared with other road types, and this resulted in higher net gains of Phragmites over the study period, despite the high effectiveness of glyphosate. We also found that patch size of Phragmites had a significant influence on both efficacy of glyphosate treatment and the colonization rate, and that 400-series highways tended to have larger patch size than other road types. Phragmites along multi-lane divided freeways may be more difficult to control than on two-lane roads, and may require more frequent treatment. We therefore recommend development of different control strategies for each road type, and we warn against developing a single protocol to apply to all roads, sizes and geographic settings. In an appendix, we have also provided the Best Management Practices from jurisdictions throughout the Great Lakes basin, who are responsible for controlling and eradicating invasive Phragmites in roadway corridors. The McMaster Invasive Phragmites GIS Database, created specifically for MTO (i.e. Phragmites mapped in, 2006, 2010 and 2015 for the southwestern region of the province) has been provided to MTO.

Introduction

Phragmites australis (Cav.) Trin. ex Steudel (the common reed) is a perennial grass that grows in many habitat types throughout the world. There are 27 genetically distinct groups (haplotypes) worldwide, of which 11 have been found in North America (Saltonstall 2002). Over the past two decades, Haplotype M, which originated from Europe, invaded coastal and inland wetlands throughout southern Ontario, replacing native vegetation and generally reducing biodiversity (Meyerson et al. 2000; Markle and Chow-Fraser 2018). This invasive haplotype aggressively colonizes exposed mud flats sexually (through seeds), and then expand asexually (through rhizomes) to form dense monocultures. Its rapid spread has been attributed to it being a superior competitor against other emergent vegetation (Rickey and Anderson 2004; Uddin et al. 2014) and to being more tolerant of disturbances (e.g. road maintenance and changes in hydrologic regimes) and stress such as increased salinity due to road de-icing salts (McNabb & Batterson,1991; Marks et al.,1994; Chambers et al. 1999; Saltonstall 2002).

Past studies have shown that transportation corridors provide excellent invasion pathways for species such as invasive Phragmites. Linear ditches along roadsides or in the median can be readily colonized by invasive Phragmites (Lelong et al. 2007; Brisson et al. 2010), because they are able to tolerate high salinity from road salts and requires little moisture in comparison to other aquatic vegetation (Medeiros et al. 2013). Ministry of Transportation of Ontario (MTO) has acknowledged the destructiveness of Phragmites, both with respect to the road infrastructure, as well as to adjacent ecosystems, and has been developing a control strategy. Since 2012, MTO has sprayed highway corridors with glyphosate, a broad-spectrum herbicide used to control the growth of Phragmites and other weeds (**Figure 1**).

The primary goal of this project is to use the McMaster Invasive Phragmites Database (MIPD; see Marcaccio and Chow-Fraser 2018) to test hypotheses regarding the overall effectiveness of MTO's current treatment program. First, we wanted to document the degree of effectiveness of treatment (i.e. proportion of Phragmites removed between 2010 and 2015) on a road-by-road basis throughout West Region. Secondly, we wanted to know if degree of effectiveness varies with 1) the year that herbicide had been applied to highway segments, 2) type of road being treated (400-series highways vs all other highways), and 3) the amount (abundance and areal cover) of Phragmites present initially in 2010.

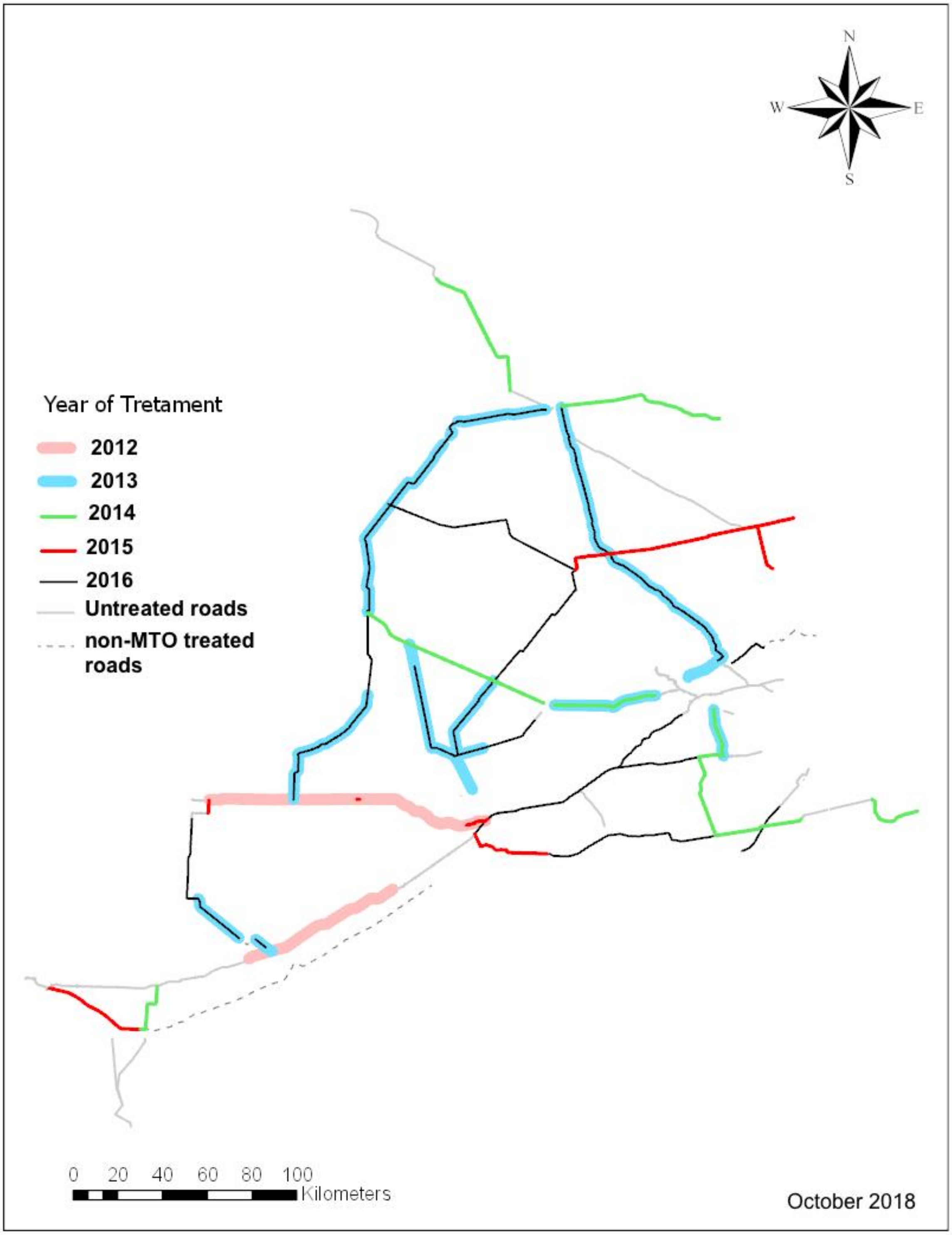


Figure 1: Roads in West Region that had been treated with glyphosate between 2012 to 2016. In this study, we included several roads that had been treated but which are not operated by MTO (dotted lines).

Methodology

McMaster Invasive Phragmites Database (MIPD)

The McMaster Invasive *Phragmites* Database (MIPD) is a GIS database that contains maps of the distribution of invasive *Phragmites* within the province of Ontario. It contains *Phragmites* maps of southwestern Ontario corresponding to spring of 2006, 2010 and 2015. These were created by automated classification with eCognition (2006 and 2010) or manual digitizations (2015) (Marcaccio and Chow-Fraser 2018). To determine potential discrepancies in results stemming from the two mapping protocols, we carried out a direct comparison for a subset of 2010 images. For the same stretch of road, we used the eCognition method to obtain 527 polygons of *Phragmites* totalling 0.6947 ha; when we manually digitized the same segment, we only obtained 249 polygons, but these totalled a much larger area of 3.0857 ha. In general, it appears that eCognition tends to produce many more smaller polygons (30% more for our subset), whereas manual digitization tended to produce fewer but larger polygons. The overall effect of this systematic bias is that 2010 maps tended to overestimate *Phragmites* distribution while 2015 maps tended to underestimate areal cover. With respect to assessing effectiveness of treatment, these errors would lead us towards a more conservative estimate of effectiveness, that is, we would be more likely to declare no or lower effectiveness. Given our overall goal, we deemed this to be an acceptable bias.

Assessing effectiveness of treatment

We completed a change-detection analysis in ArcGIS 10.3 to track the pattern of change in *Phragmites* between 2010 and 2015. By overlaying 2015 classified polygons on 2010 polygons, we produced a new layer with polygons identified as one of three effectiveness categories: 1) *Phragmites* that remained as *Phragmites* in 2015 (no change), 2) *Phragmites* that had turned into a non-*Phragmites* class in 2015 (decreased) and 3) non-*Phragmites* class that had turned into a *Phragmites* class in 2015 (increased). For example, if a hectare of grass in 2010 became converted to half grass and half *Phragmites* by 2015, then we would have 0.5 ha of a polygon identified as Category 3, indicating *Phragmites* had expanded by 0.5 ha. A new attribute was created for each polygon that identified the associated transformation from one habitat class into another.

To interpret results of the change detection, we have operationally defined roads that had been sprayed with glyphosate between 2012 and 2014 as being “treated” roads. This information had been conveyed to us by MTO and we did not have the actual areas sprayed by the contractors (see note in Recommendations). Therefore, any *Phragmites* patch that had been present in 2010 on a treated road, and that was no longer present in 2015 was interpreted as having been successfully killed by the herbicide (green=decreased; **Figure 2**). By comparison, presence of *Phragmites* on treated roads in both 2010 and 2015 images would indicate that the treatment had been ineffective (blue=unchanged; **Figure 2**). Finally, presence of any new *Phragmites* patch in 2015 would indicate that *Phragmites* had expanded (red=increased; **Figure 2**). In some instances, *Phragmites* may be regenerated within treated dead stands, and in that case, we would classify the entire stand as having been ineffectively treated (i.e. unchanged) since we were unable to distinguish between living and dead portions within mixed stands (see **Figure 3**).

To enable statistical analyses, we divided all roads into 1-km segments so that we had replicate segments by treatment type and highway name. The .dbf file associated with this GIS layer was then imported into JMP 13 (SAS, Cary NC) for further graphical and statistical analyses.

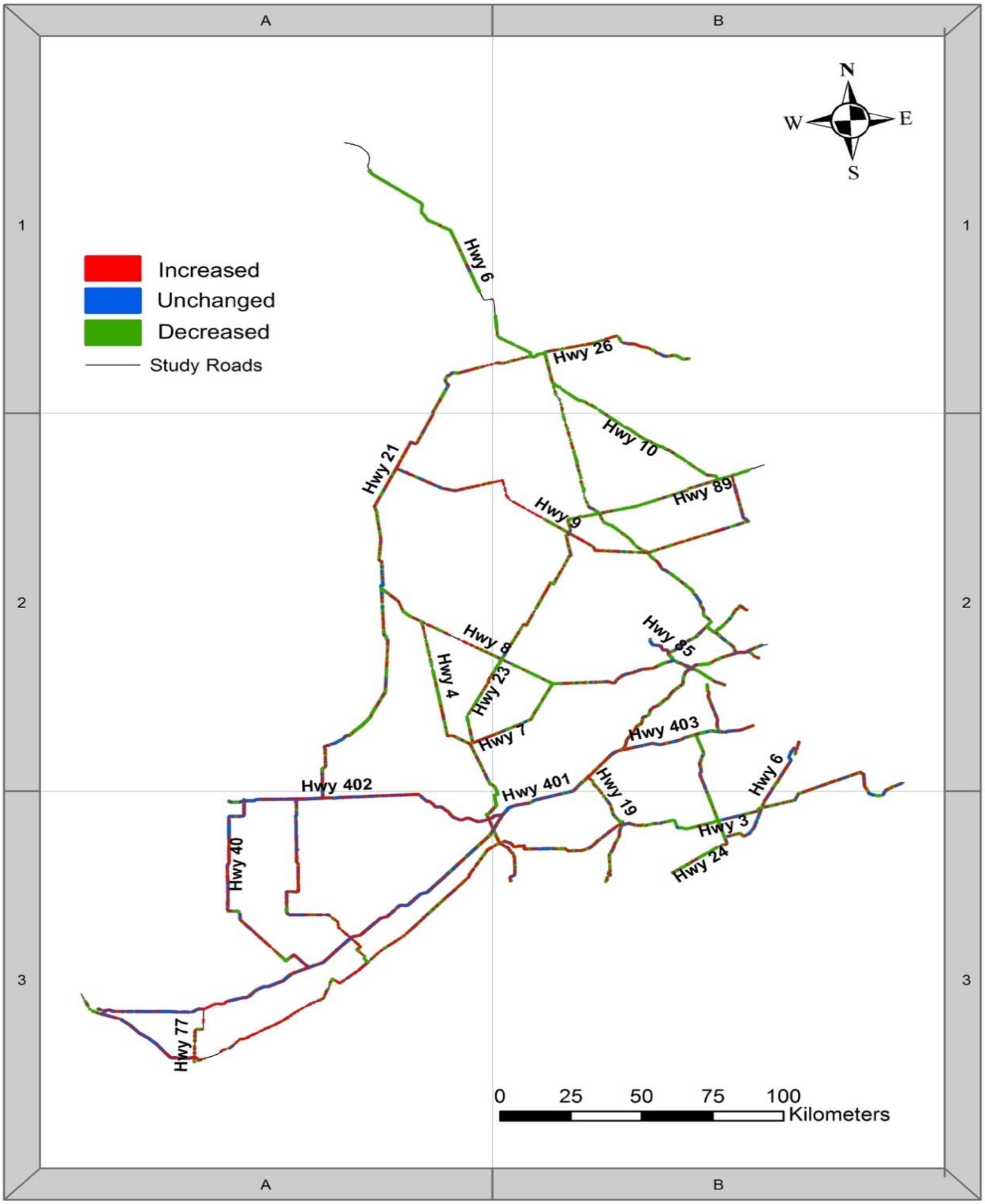


Figure 2: Results of a change detection of invasive Phragmites occuring in highway corridors of southwestern Ontario between 2010 and 2015, based on SWOOP image data only.

a) b)

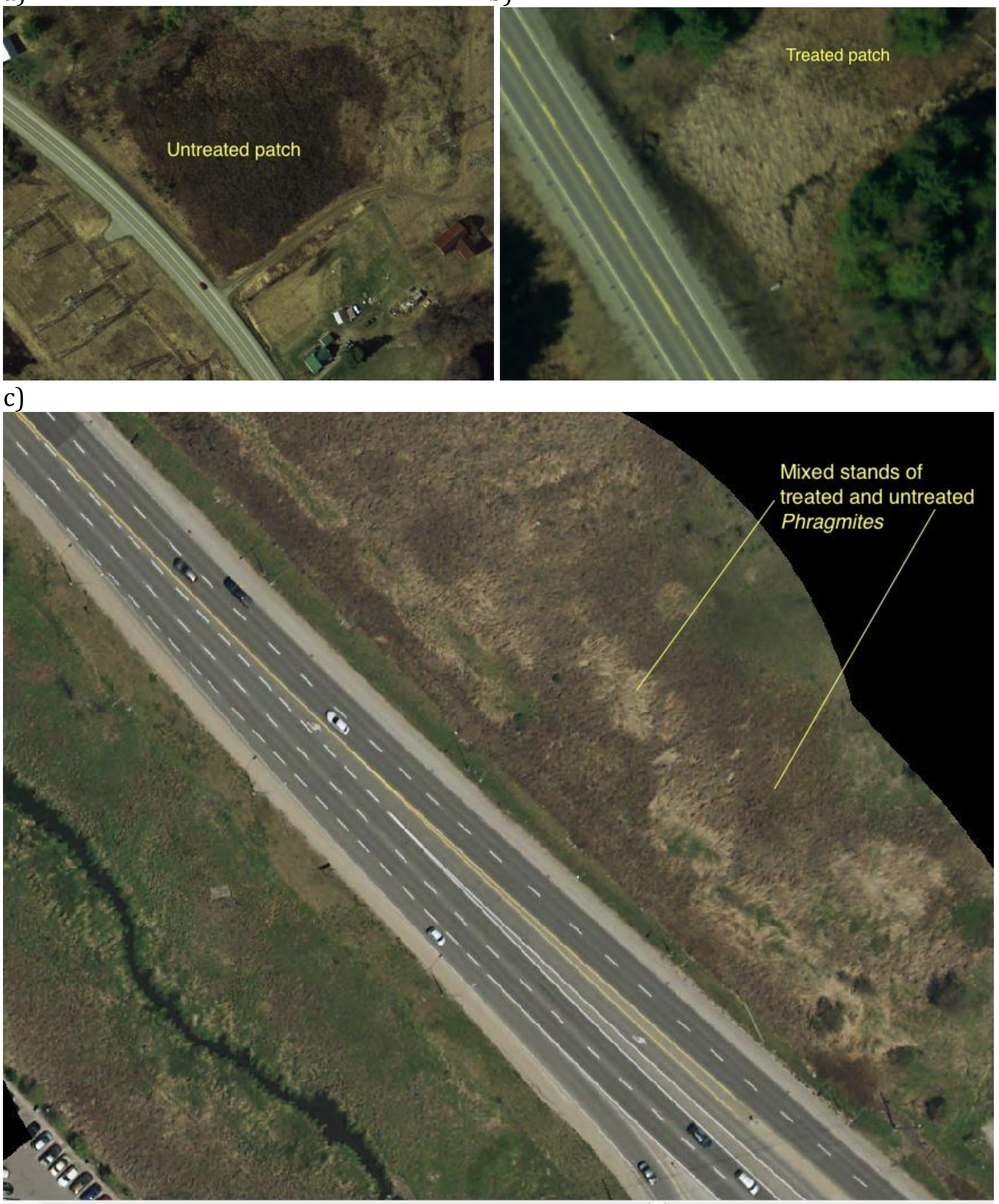


Figure 3: Images showing Phragmites in highway corridor that had: a) a dark mottled appearance characteristic of living stands, b) a light mottled appearance characteristic of dead stands (presumed to have died from glyphosate treatment). Panel c) shows a mixture of dead and living specimens side by side, which may have resulted from imperfect treatment or regrowth from rhizomes of treated individuals.

Results

Overall Trends

We used results of the change detection to determine the effectiveness of treatment for each road/highway. As explained in the methods, we have assessed effectiveness by measuring the proportion of *Phragmites* that had been removed from a treated road between 2010 and 2015. Each highway was converted into 1-km segments prior to change-detection; growth in 2010 that was no longer visible in 2015 was interpreted as having been successfully treated (i.e. removed) while those in 2010 that remained in 2015 was deemed to have been unsuccessfully treated. It is important to note that some highways are very long (e.g. Hwy 6, which runs north-south for 472 km through southwestern Ontario from the Bruce Peninsula to Port Dover, going through many towns and cities) while others are very short (e.g. Hwy 77 running north from Leamington for only 22.6 km). The 400-series highways such as 401, 402 and 403 have multiple lanes and are associated with much larger traffic volumes.

A visual comparison of the 2010 and 2015 distributions of *Phragmites* throughout southern Ontario confirms the efficacy of the treatment program from 2012 to 2014 (**Figure 4**). *Phragmites* had been almost eradicated in the Bruce Peninsula in the northern portion of the study area and had been greatly reduced in the central portion of southern Ontario. Overall, relatively high proportions of the original *Phragmites* present in our highways had been removed by 2015, indicating that the treatment program had been highly effective (**Figure 5**). The net proportion of *Phragmites* removed on Hwy 40, 401 and 402 were below 85% while most of the other roads were above 95%.

The lower efficacy associated with Hwy 401 and 402 may be because these roads had been treated only once in 2012, compared with other roads that had been treated in 2013, 2014 or in two consecutive years (**Figure 6a**). There is growing consensus that *Phragmites* will not be eradicated with a single treatment; in many studies, complete eradication was not achieved without repeated treatments for 2 or 3 years (Reimer 1976, Turner & Warren 2003, Derr 2008, Lombard et al. 2012, Warren et al. 2013). Irrespective of the timing of treatment, effectiveness tended to be lower on freeways (i.e. 400-series highways) than on smaller highways, collectors and arterial roads within highway networks. We therefore re-analyzed the data to determine the influence of road type on the colonization rate of *Phragmites* and found that % *Phragmites* removed from 400-series highways was significantly lower than those on other roads (t-test; $P<0.0001$) (**Figure 6b**). This may be due to the larger right-of-way of Hwy 401 and 402, with larger areas to colonize (**Figure** 7; middle panel). It may also be due to higher traffic volume on these freeways, redistributing seeds through traffic-generated wind patterns or attachment and transport by vehicle.

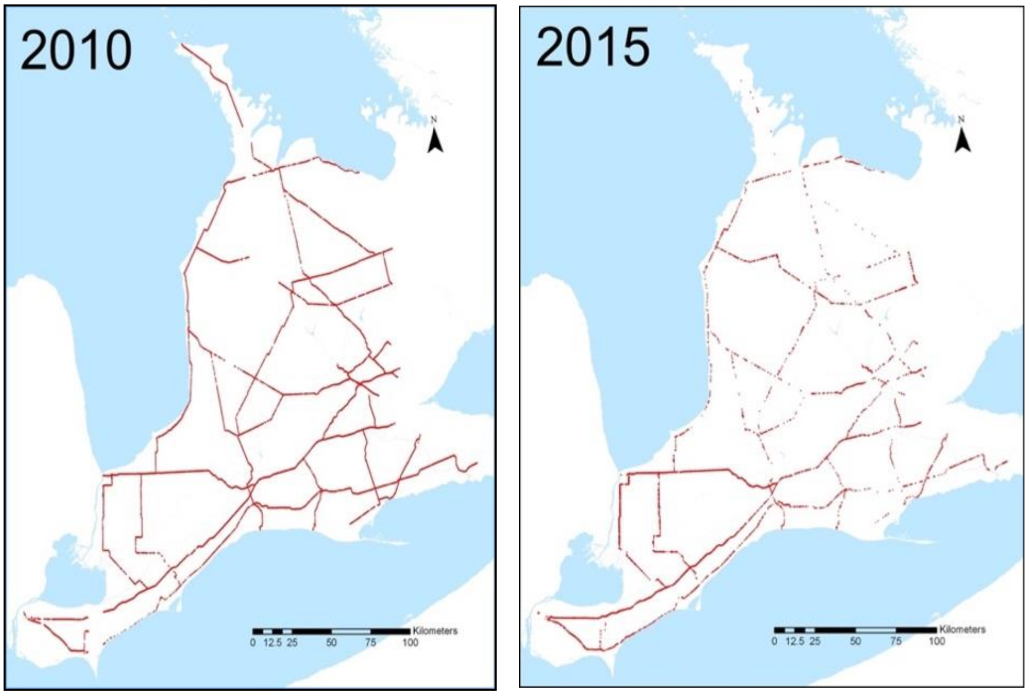


Figure 4: Phragmites distribution in MTO-managed roads in southwestern Ontario during 2006, 2010, and 2015. Distribution in 2010 was mapped by automated classification whereas that for 2015 was manually digitized.

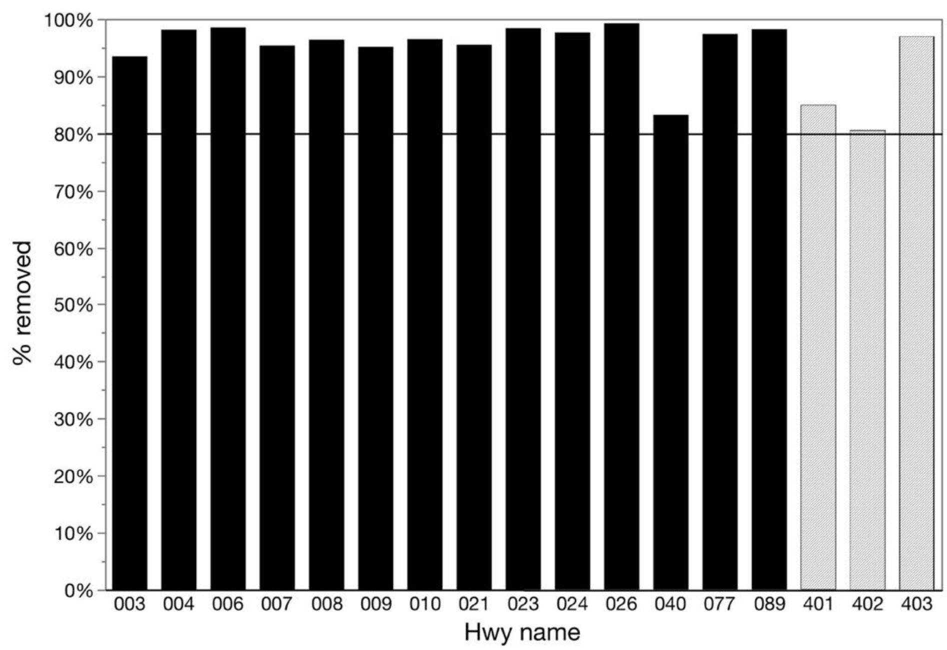


Figure 5: Percentage of Phragmites that had been removed shown seperately by highway. Removal is inferred from decrease in Phragmites in 2015 relative to 2010 (see Figure 2). The black line corresponds to 80% removed.

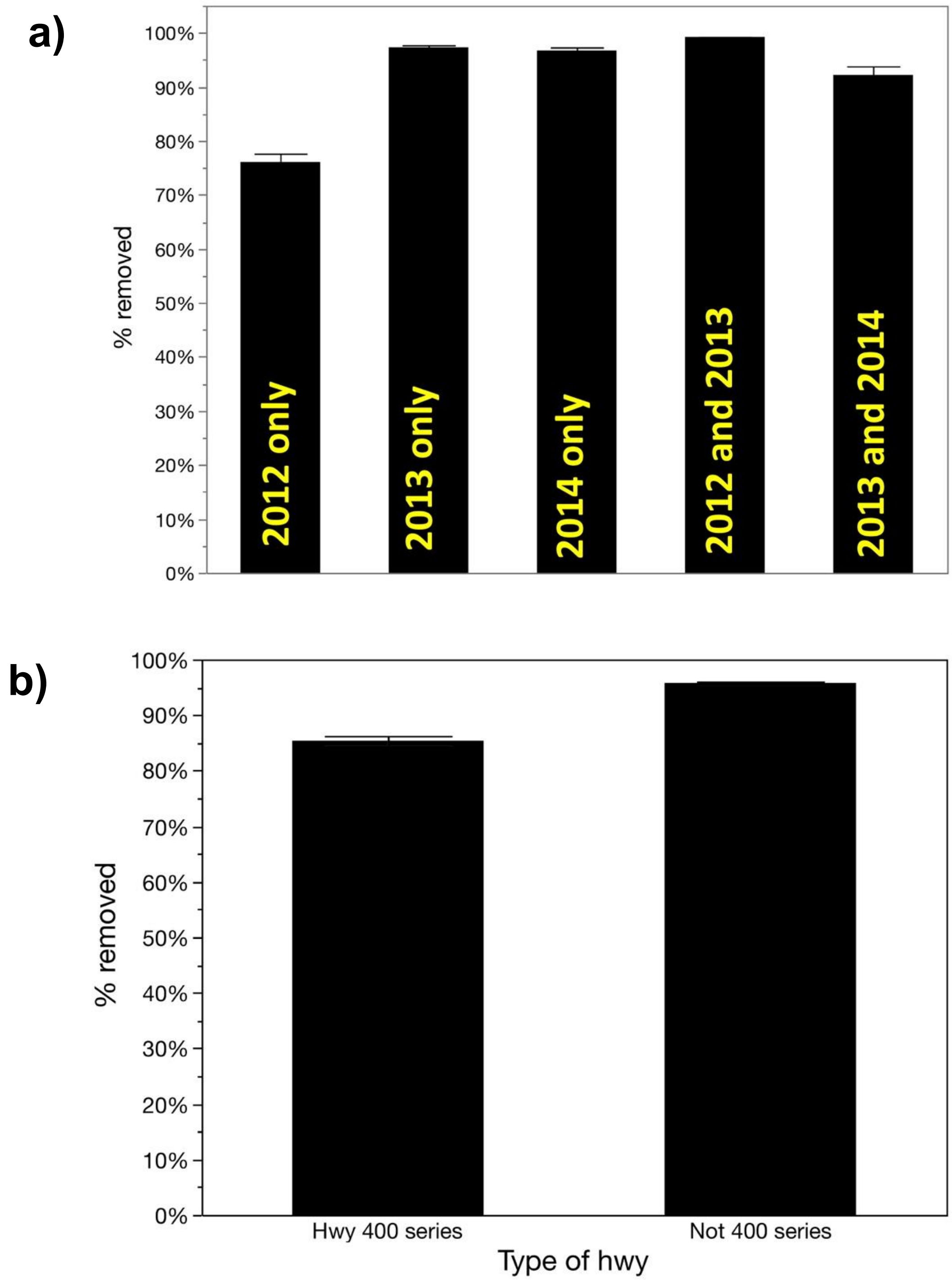


Figure 6: Percent Phragmites removed for a) roads grouped according to when they had been treated, and b) 400-series and non-400-series highways.

Repeat applications
Based on these results, we conclude that effectiveness of treatment will vary inversely with length of time since herbicide application; therefore, we support the recommended practice of applying follow-up treatments every 2 to 3 years to maintain a reduced presence of *Phragmites* until they are completely eradicated.

It is noteworthy that the efficacy of the treatment program did not necessarily reflect the amount of *Phragmites* present in 2010. For instance, Hwy 40 had less growth compared with Hwy 21 in 2010, but Hwy 40 had a lower rate of removal. There had been greater areal cover of *Phragmites* on Hwy 401 in 2010, and yet, removal rate was higher than that for Hwy 402 (see **Figure 7**). The change detection also revealed that all areas that had been sprayed had been effectively treated, and that the reason for the overall lower efficacy for Hwy 401 and 402 was the amount of "new" growth that had occurred—new stands of *Phragmites* that had colonized beside and around the treated stands (top panel; **Figure 7**). We verified that very little of the growth observed in 2015 had been re-growth in the treated stands, but were in fact new growth.

The degree of expansion in 2015 appears to be directly related to the amount that had been present in 2010, and this is consistent with observations that *Phragmites* expands clonally (**Figure 8a**). Once invasive *Phragmites* colonizes new habitat, it tends to send out rhizomes (Minchinton & Bertness 2003), and the linearity of the highway corridors facilitates easy expansion (rate varied from <1 to 27% in this study). Similarly, we also found degree of resistance to treatment (amount of *Phragmites* that remained unchanged following treatment) was directly related to the amount that had been present in 2010 (**Figure 8b**). The implication of this is that *Phragmites* can be more successfully eradicated when they are smaller and fewer in number and is a good reason for implementing an early detection program and treating the sparsely populated areas before they become dense.

Road-specific protocols and need for early detection
Based on the evidence thus far, we recommend developing different control strategies for each type of highway/road and we warn against developing a single protocol to be applied to all roads types, sizes and geographic settings.

Given that *Phragmites* stands are more effectively eradicated when they are small, implementation of early detection program may be the best way to prevent its expansion throughout the province.

Regional Analysis

The GIS database assembled was used for more in-depth regional analysis. By overlaying the 2010 and 2015 distribution of *Phragmites,* and accounting for the timing of treatment, we produced regional maps of different regions in southern Ontario for visual comparison and assessment.

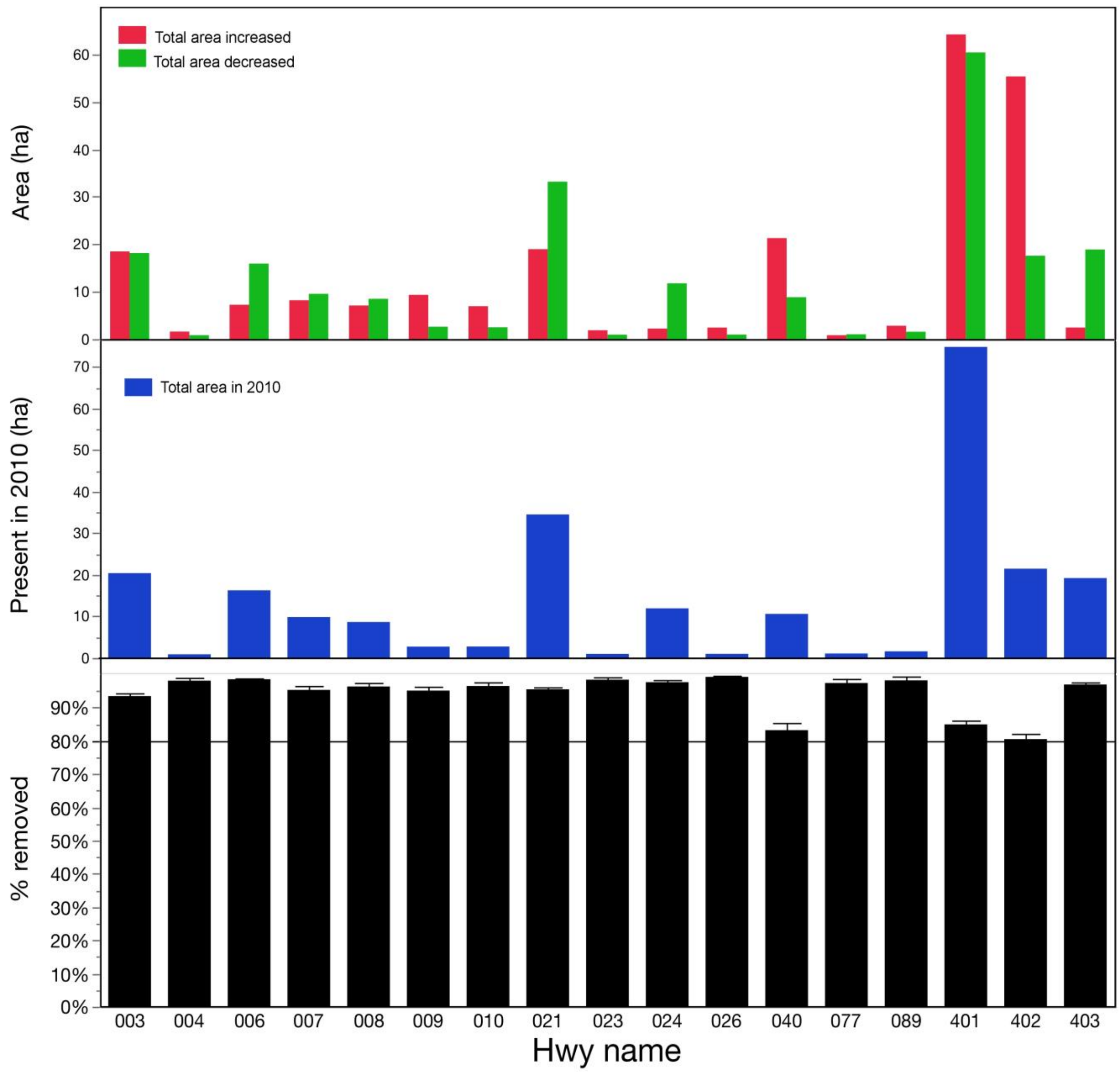
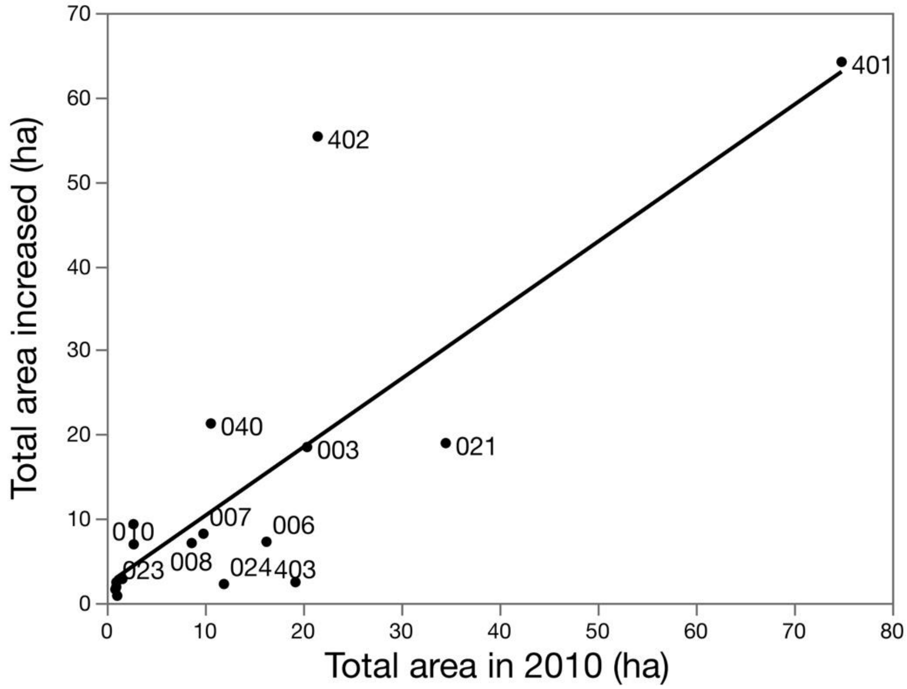


Figure 7: Results of a change detection showing amount of Phragmites that had decreased, remained unchanged, or increased between 2010 and 2015. Top Panel: Mean SE calculated for 1km-segments for each highway; Middle Panel: Total area present in 2010; Bottom panel: Percent Phragmites removed as of 2015.

a)



b)

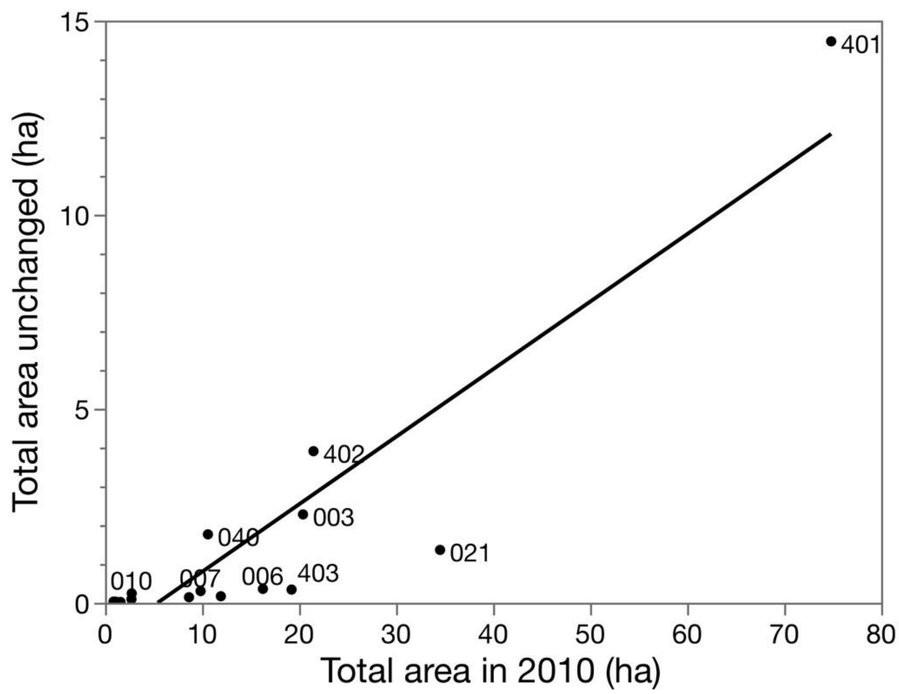


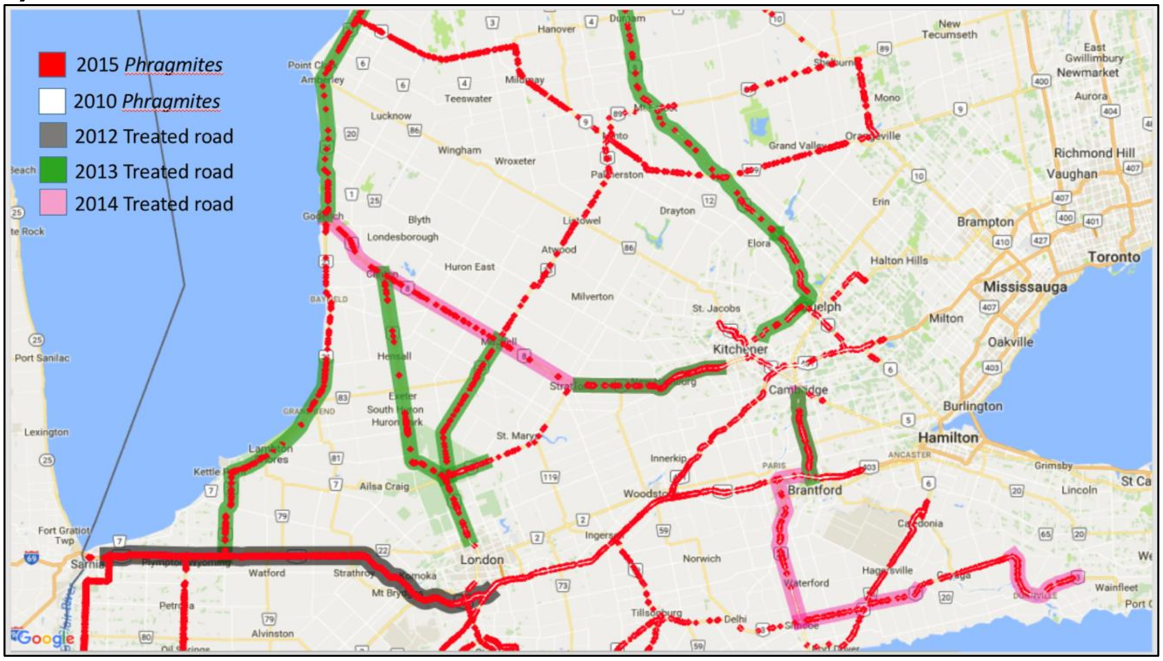
Figure 8: a) total area that had changed as a function of original area in 2010, and b) Total area that remained unchanged as a function of original area in 2010.

In all three maps that follow (**Figures 9a & b and Figure 10**), red represents areal cover of *Phragmites* in 2015, which is essentially the growth at the end of 2014 since the orthophotos had been acquired in spring of 2015. White represents areal cover of *Phragmites* in 2010. Roads treated in 2012 are coloured grey, those treated in 2013 are coloured green and those in 2014 are coloured pink. In the first map (**Figure 9a**), Hwy 402 (west of the city of London) appears to be solid red, while Hwy 6 and 8, running north and west of the city of Kitchener had intermittent patches of *Phragmites* in 2015. All roads that had been treated in 2013 appear to have intermittent patches. The second map (**Figure 9b**) shows how the 2013 treated road had intermittent patches of *Phragmites* in 2015, while Hwy 401 appeared to have dense *Phragmites* stands throughout. Finally, the third map (**Figure 10**) shows that portions of Hwy 24 and 403 that had been treated in 2014 had very few patches of *Phragmites* in 2015, while the eastern segment of 403 (not yet been treated as of 2015) had much more *Phragmites* in 2015.

Conclusions

This is the first time that high-resolution remotely sensed image data have been used to scientifically assess the effectiveness of the most commonly used methods to control invasive *Phragmites* in highway corridors throughout southern Ontario. We found that regrowth of treated stands varied from <1 to 27% and that increase in distribution of *Phragmites* in 2015 was primarily from new growth.
Regrowth and new growth was more prolific on 400-series highways. Our data suggest that freeways may be more difficult to treat than other road types, but we urge that further studies be carried out in which timing of treatment and traffic volume are standardized to allow for direct comparisons. There was considerable variation in how the road segments responded to treatment, but in general, if roads received minimal or no treatment or if treatment had been applied at least 2-3 years earlier (i.e in 2012 or 2013), we found a net increase in *Phragmites*; conversely, if roads had been treated in 2013 and 2014, they tended to have a net decrease in *Phragmites*. We also found that the 400-series highways had lower proportions of *Phragmites* removed overall because there were higher colonization rates, resulting in higher net gains of *Phragmites* compared to other road types. This is likely the reason why *Phragmites* is more difficult to control along multi-lane divided freeways. We also found that patch size of *Phragmites* had a significant influence on both efficacy of glyphosate treatment and the colonization rate, and that the freeways tended to have larger patch size than other road types.

a)



b)

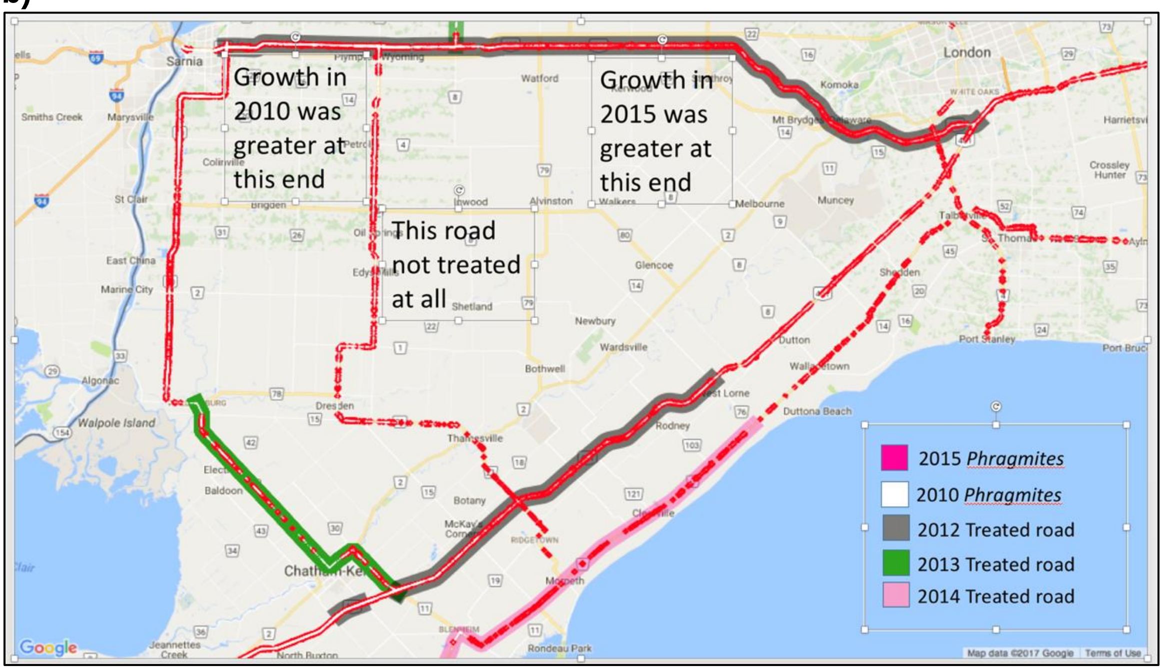


Figure 9: a) Map of Phragmites in 2015 (red) and in 2010 (white) superimposed on roads in southwestern Ontario. b) Comparing areal cover of Phragmites in highways located between London and Sarnia. Growth of Phragmites in 2010 had been greater at the western end of Hwy 402 (near Sarnia) whereas growth in 2015 had been greater in the eastern end (near London).

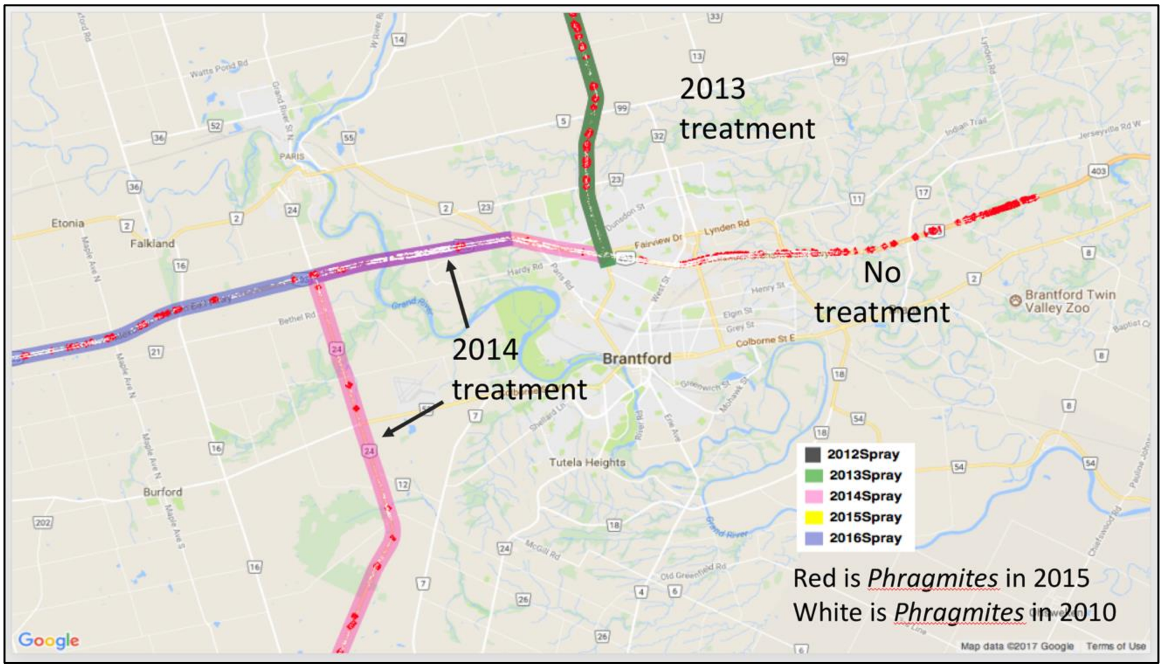


Figure 10: Growth of Phragmites in 2015 (red) on a segment of Hwy 403 that had not been treated (shown on the right), compared with few patches of Phragmites in segments of Hwy 24 and Hwy 403 that had been treated in 2015 (shown towards the left). Also shown are Phragmites in 2010 (white) that are no longer evident on these segments.

Recommendations

For a geographic area as large as that of southwestern Ontario, the only cost-effective approach to map the distribution of Phragmites over time and space is to use some sort of automated classification system such as eCognition. SWOOP images were the only ones with the required resolution and geographic coverage for this type of large-scale mapping. It is unfortunate, however, that the orthophotos acquired in 2015 could not be used in automated classification with eCognition, and we therefore hope that future acquisitions will rectify this limitation.

The recent pilot study by Rupasinghe & Chow-Fraser (2018) indicated that Sentinel 2 image data may be suitable for regular benchmarking purposes, and that Worldview 3 satellite image data may be used for early detection of sparsely distributed Phragmites stands. Using these medium- and high-resolution satellites could circumvent the reliance on Ontario orthophotography datasets, and has the added convenience of faster acquisition times (average revisit times 5 days to <1 day for Sentinel 2 and Worldview 3, respectively). Sentinel 2 can be used to assist in management and determining the initial areal cover of Phragmites on roadsides. Very high resolution Worldview 3 data can be used post-treatment to monitor small stands and regrowth in the following years.

Many management agencies within the Great Lakes watershed have produced Best Management Practices (BMP), some specifically targeting roads and others for general wet habitat (Appendix). While effectiveness is rarely documented quantitatively, post-treatment monitoring is conducted to determine the quantity of glyphosate that should occur for complete eradication of Phragmites. It is noted in most BMPs that repeat spraying is required to control the population.

We have shown that effectiveness of treatment will vary inversely with length of time since herbicide application; therefore, we support the recommended practice of applying follow-up treatments every 2 to 3 years to maintain a reduced presence of Phragmites until they are eradicated. Our evidence thus far leads us to recommend development of different control strategies for each road type, and we warn against developing a single protocol to apply to all roads, sizes and geographic settings. The larger right-of-way present on 400-series highways, the additional complexity associated with intersection, and the added cost of managing high-traffic roads present unique challenges and should be addressed uniquely, especially when compared to smaller, less trafficked roads.

Knowing the time sensitive nature of treatment efficacy, we recommend that MTO immediately start Phragmites treatment in the northern and eastern portions of the province where current Phragmites density is still very low. Given the most recent estimates in Marcaccio & Chow-Fraser 2018, areal cover of Phragmites in the southwestern and central portion of the province could expand to over 6,000 hectares of Phragmites by 2020 if left untreated. Such high densities would prolong eradication efforts and increase the cost of management dramatically. If control programs are started immediately while presence of Phragmites is still limited, treatment would be more successful and less costly overall to MTO.

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Appendices

Survey Results

Results from a survey conducted by McMaster University to summarize current practices to control invasive *Phragmites* in roadways and wetlands throughout N. America

Authors/ Agencies	Type of Habitat	Herbicide Used/ Options	Mechanical Treatment Used or Recommended	All Treatments Used	Recommendation for spraying in consecutive years	Disposal Methods	Post Treatment Monitoring	Results of Effectiveness after 1 year	Results of Effectiveness after year >2
BMPs from Canada									
Kincardine (2013)	Wetlands and Shoreline	Glysophate 4-5% (Weathermax)	Burning	ATV spraying, backpack spraying, hand-wicking, prescribed burns	Yes	Rolling/ Burning	Yes	Speaks of U.S. combining Glysophate and Imazapyr for 80-100% kill	N/A
Ontario Ministry of Natural Resources and Forestry (2011)	Generic habitats	Glysophate	Cutting, tarping, solarization, drowning, rolling	Spraying, cutting, tarping, solarization, drowning, rolling	Yes	Bagged in thick plastic, then dried out in the sun. Once dry can be burned or disposed of	Yes	N/A	N/A
Ontario Phragmites Working Group (2015)	Roadways	Glysophate 4-5%	Rolling, cutting	Spraying, wicking, wet blade, rolling, cutting, burning	Yes	Burying, covering (3m deep), covering with heavy plastic, burning, or dispose in an open agricultural field where emerging plants can be treated	Yes	70-95%	For most cells, complete control can be expected after two treatments
BMPs from USA									
Brigham City, Utah (2007)	Wetlands	Glysophate 2%	N/A	Spraying and burning	Yes	Burning	Yes	N/A	N/A
King County (2010)	Roadways and generic habitats	Glysophate (Rodeo and Aquamaster) and Imazapyr (Habitat)	Spading young plants, repeated cutting before tasseling	Spading, cutting, wick wiping, herbicide spraying, burning	Yes	Place roots, rhyzomes, and seed heads in sturdy plastic bags and dispose. Stems left on site for compost or burning	Yes	N/A	N/A
Michigan State and Partners n.d	Roadways and generic habitats	Glysophate (6 pints per acre), Imazapyr (six pints per acre), or even mix	Hand tools, weed whips, small mower	Spraying, burning, flooding, mechanical treatments	Annual Maintenance	N/A	Yes	N/A	Annual spot treatment of pioneer colonies 100%
New york State DOT Adirondack Park (2014)	Roadways	No Mention	Spading young plants, pulling, digging	Spraying, cutting, pulling, digging	Yes	Drying/liquefying, Brush Piles, Burying, Herbicide	Yes	N/A*	N/A*
PowerPoint Presentation									
Janice Gilbert for Lake Huron Centre for Coastal Conservation (2016)	Roadways and generic habitats	Glysophate	Covering, smothering, rolling, drowning, cutting, spading	Spraying, hand wicking, burning, mechanical control	Yes	N/A	Yes	N/A	N/A

N/A = not available

*Webinar in October 2017: found that probability of eradicating (no growth after 3yrs) decreased drastically with treatment area; 83% for 0.36 sq.m vs 1% for >3000sq.m

Also noted that one year after treatment, 60% will return; if treated for 2 consecutive years, minimum 20% will return, and if treated for 3 consecutive years <5% will return.