Mapping the Purple Menace: Spatiotemporal Distribution of Purple Loosestrife (*Lythrum Salicaria*) Along Roadsides in Northern New York State

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Abstract

Purple loosestrife (*Lythrum salicaria* L.) is an invasive herbaceous plant, frequently found in wetlands and along roadsides throughout northern New York State. Its propensity to create monoculture stands in wetlands has resulted in intensive management in parts of its range, including central New York and Ontario and Quebec. The goal of this study was identifying the extent of infestations and to determine factors that promote the spread of purple loosestrife in order to determine best land use practices to reduce the spread of this highly invasive wetland plant." We attempted to answer several questions: What is the level of infestation along roadsides? Does mowing contribute to the spread? How do culverts under roadways influence the spread? Between mid-July and mid-August in 2017–2019, we mapped all infestations along 150 km (93 miles) of state highway north of the Adirondack Park and south of the St. Lawrence River using the Environmental Systems Research Institute (ESRI) Collector app. We mapped the size and locations of infestations, in addition to collecting information on the plants within 1 m, recording over 100 additional species. The results of our preliminary analysis revealed significant increase in the number of plants over the study time ($P < 0.001$), including several hundred more infestations than had previously been recorded. We did not find any evidence that mowing promotes the spread of loosestrife. There were many more individual infestations in ditches along highways, but much larger and denser infestations in wetlands ($P = 0.003$ in 2019). We observed that culverts, drainage conduits under roadways, frequently had purple loosestrife on both sides of the road. We also found that culverts appear to serve as corridors that promote the spread of purple loosestrife from one side of the road to the other. We recommend working with the local landowners and NYS Department of Transportation to contain the spread and continue to propagate and spread the biological control.

1.0 Introduction

Purple loosestrife (*Lythrum salicaria* L.), an invasive herbaceous plant of Eurasian origin [1], has been found in North America since the early 1800s [2]. It was sighted specifically in New York State, and was likely found throughout southern Ontario and northern New York prior to the 1940s. Since the early 1990s, this species has been well documented in central New York, specifically along the New York State Thruway [3, 4]. There have been similar recordings of infestations in Ontario and Quebec [5]. Great effort was put into studying purple loosestrife's natural history and control in central New York [1,6,7,8]; to evaluate some successful management [9] as well as in Ontario and Quebec, in Canada [5,10]. However, very little monitoring has been done in between these larger studied populations along the New York side of the St. Lawrence River and inland toward the Adirondack Park.

Purple loosestrife grows to 1–2 m tall, with 30–50 stems creating a candelabra effect from a single rootstock [1]. These stems can produce prodigious numbers of seeds, each plant capable of casting hundreds of thousands of seeds, creating a very strong seed bank [11]. Mature stands of 4–5 years can disperse seeds predominantly through water, with occasional, short distance (> 10 m) spread by wind with dense stands forming after 4–5 years [1].

There is some debate about short-term and long-term effects of an invasion of purple loosestrife creating monocultures of nonnative wetland plants and limiting biodiversity in wetlands [1, 12, 13], but the consensus is that purple loosestrife has limited value in the ecosystem as a source of nutrients or habitat for wildlife, disrupting a functional ecosystem [14]. The impact of purple loosestrife on soil nutrients has been well documented, though those implications over the long term are unclear [15]. Part of this could be the lack of information about the species' rate of spread. While its seed production and ability to germinate in a variety of environments presents clear advantages over native species [3], the rate of spread outside a controlled environment, even over a short time, has not been well studied. However, Thomas and Moloney [16] created a predictive model to understand invasion risk based on a disturbed landscape by examining how land use affected the invasion probability of wetlands.

The goal of this study was to document the infestation of purple loosestrife in an under-studied area between two larger infested areas in central New York and across the St. Lawrence River in Ontario. The lack of previous data describing the infestation has led to minimal management options by local environmental protection agencies and has potentially allowed an invasive plant to spread unchecked throughout a relatively naïve system. Once the initial mapping was completed, there were several questions that emerged about the annual spread and increase in the number of plants, methods for limiting the spread, and future management options. We wanted to understand if mowing by the state or county was contributing to the spread, or if the presence of culverts beneath the roads was contributing to the spread. Our hope was to find easily correctable sources of spread that could be the target of management controls.

2.0 Results

2.1 Overall Increase in Infestation and Density

After 3 years of data collection from 2017 to 2019, we found many more infestations than expected or had been previously documented. There were 663 individual infestations in 2017, with an average size of 42.5 m, with an average number of 73 plants (range 1-3100 plants). However, nearly 24% of infestations (n = 158) only had one plant. For 2018, there were 685 individual infestations, and the average size continued to be 42.5 m, but the average number of plants increased to 82 plants (range 1-3000 plants), but only 10% of infestations had a single plant. In 2019, the number of individual infestations was lowered to 537 infestations. The average size of an infestation increased to 67 m, and 158 plants (range 1-3500 plants), and only 8% of infestations had only a single plant (See Table 1).

Table 1
Descriptions of infestations across the study time frame

Year of data collection	2017	2018	2019
Number of infestations	663	685	537
Total number of plants	48901	56215	85152
Total length of route infested (km)	28.2 km	29.0 km	36.17 km
Average size of infestation (range)	42.53 m (1 m-1600 m)	42.54 m (140 ft) (1 m-595 m)	67 m (1 m-809 m)
Average number of plants (range)	73 plants (1-3100)	82 plants (1-3000)	158 plants (1-3500)
Infestations with a single plant	24%	10%	8%

We compared the summarized polygons across years to investigate the change in the size of infestations over time. The results show significant increases from 2018 to 2019 ($P = 0.002$) and over the entire time from 2017 to 2019 ($P < 0.001$). The change from 2017 to 2018 did not show a significant increase in the mean size of infestations and number of plants ($P = 0.12$). In total, there was a 14% increase in the number of plants from 2017 to 2018, and a 51% increase from 2018 to 2019.

2.2 Water type, Wetlands and Culverts

During data collection in 2017, we developed the definitions of water type categories and created consistency. Therefore, 2017 was not used for analysis of differences in infestation size by water type. In 2018, there was a significant difference between infestations sizes by water type ($P = 0.002$), and again in 2019 ($P < 0.001$). The largest infestations were found in wetlands, though wetlands only made up ~ 20% of the infestations, while ditches and standing water made up the predominant number of infestations. In 2018, with higher rainfall, there was more standing water than in 2019, but both ditches and standing water had more individual infestations than wetlands (Fig. 1).

The increase in number of plants and size of infestations was found predominantly in wetlands, compared to outside a wetland. A non-parametric Mann-Whitney U test demonstrated that in 2018 and 2019, there was a significantly higher number of plants in wetland infestations than outside wetlands ($P = 0.001$ and $P = 0.003$ respectively) (Fig. 2). There was no measurable trend in 2017 ($P = 0.077$).

Comparing culverts to random points demonstrated a strong influence of culverts on the presence and number of purple loosestrife plants. A two-samples chi-square analysis revealed significantly more purple loosestrife plants at culverts compared to random points ($P < 0.001$).

2.3 Directional Spread

We found no significance from our McNemar test ($P = 0.686$) that mowing is causing a directional infestation spread.

3.0 Discussion

Over the 3 years of the study the total number of plants increased, while the number of infestations decreased. Based on visual inspection of the detailed maps, the fewer infestations was due to previously smaller infestations connecting and becoming larger infestations in successive years. The downward trend in the number of infestations with a single plant supports this idea. The increase in the number of plants is consistent with the strong ability of purple loosestrife to produce thousands and thousands of seeds [1]. An increase in rainfall in August 2018 [17] could have contributed to the larger increase in number of plants from 2018 to 2019 as seeds would spread and be more likely to germinate with increased water availability [18, 19]. Yakimowski et al. [20] also found that the seed bank within invaded wetlands contained enormous numbers of purple loosestrife seeds (several hundred thousand/m²) and suggested that only environmental variations changed the emergence of seeds within an invaded wetland. Inconsistent weather patterns between years in our study is likely a factor of higher increases between 2018 and 2019, but is unlikely to be the main cause of increase in number of plants and size of invasions.

Infestations grew larger inside wetlands compared to outside wetlands along roadsides, particularly in the ditches along the roads, which is to be expected given the preference purple loosestrife has for germinating seeds in moist soil after being dispersed by water [1]. The ephemeral nature of water in ditches alongside the road has allowed the infestations to sustain themselves and grow larger in wetter years given their likely substantial seedbank [11]. The concern is the spread in small numbers along roadsides in ditches connecting wetlands will lead to invasions in all wetlands over time.

Further, the width of the road should be an impediment to the natural spread of purple loosestrife, as its seeds rarely spread independently beyond 10 m [1]. However, culverts that carry water under the road create another mechanism for spreading purple loosestrife between wetlands. We found that purple loosestrife infestations were found more frequently at culverts and more frequently on both sides of the road next to culverts compared to random sites along the route. This suggests that culverts are increasing the spread, potentially into new areas. Wilcox [4] also found that culverts under the New York State Thruway increased the spread of purple loosestrife along the highway, rather than from sites outside the road corridor.

The analysis of adjacent polygons failed to reveal a directional spread of purple loosestrife due to mowing, despite [4] demonstrating that adjacent polygons containing infestations increased the likelihood of infestation. Our original goal to determine if mowing along the highway was promoting the spread of purple loosestrife was inconclusive. This could be due to the relatively large size of the polygons in the analysis compared to very small infestations. It was not practical to examine individual infestations and examine spread from year to year to capture individual population spread, as infestations merged, or possibly spread naturally in both directions. It is likely that water availability and proximity to wetlands more strongly affected the spread of purple loosestrife. As wetlands were spaced throughout the study area (71 of 186 polygons contained wetlands), each was providing a source for

infestations to increase in density and likely to spread out from that location based on movements of water (e.g., culverts or ditches) rather than solely by being mowed. In addition, the local NYS DOT office (James Ayers, personal communication Mar 2021) described the patterns of mowing as twice each summer spread throughout the region, so each area gets mowed at slightly different times of the summer. For example, it is possible that regions with high infestations have previously been mowed when the seeds were ready to spread, while in other parts of the study, mowing might have been done prior to seed being set. We recommend that avoiding any increase in the spread to uninvaded wetlands should be the goal of any management because substantial seeds throughout infested wetlands were reported, even in parts of the wetland without obvious plant growth [17].

Thomas and Moloney [16] predicted invasions of wetlands based on local landcover variation. While their study was predominantly in an urban area centered around St. Paul/Minneapolis, the variations of land use have implications for our study. The mixture of lawns and state-mowed roadsides creates a variation where the spread of purple loosestrife is stopped by unsuitable habitat (lawns). Finer scale analysis and the inclusion of individual lawns as possible breaks in spread could reveal the connection between mowing and spread of purple loosestrife.

While controlling spread through mowing is one strategy, controlling the overall infestation with other management strategies, including biological controls, has had some success and has been well studied [10, 21, 22]. We did track the presence of herbivory across the study area and found some clusters of likely areas with beetles, though no beetles were seen in the first 2 years of the study (beetles emerge and generally complete their life cycle prior to the emergence of inflorescence). In 2018 we began to release *Galerucella* sp. beetles at one of the wetlands and have been monitoring these sites biannually since. In 2019, we propagated several thousand *Galerucella calimerensis* L. beetles at SUNY Potsdam according to methods by Rowell [23]. We intend to continue monitoring any released beetles at the largest infestations.

4.0 Conclusion

Our study area in northern New York is at as much risk of purple loosestrife invasion as more studied areas due to a highly connected series of wetlands in the 4 major drainage basins from the Adirondacks into the St. Lawrence River. We succeeded in documenting the presence and increase of purple loosestrife throughout the area, focusing on state highways due to high traffic and disturbance, over a 3-year period. We have shown that in our area along roadsides in relatively disturbed habitat, wetlands are primarily where purple loosestrife is spreading; and that culverts are enabling infestations to spread across roads which would normally be a natural barrier to purple loosestrife. Left unmanaged, purple loosestrife will continue to infest the wetlands of northern New York.

Our next steps turn towards investigating appropriate management options for the study area in order to seek to control the spread of purple loosestrife. Despite being unable to demonstrate any effect of directional spread via mowing, we will work carefully with the NYS Department of Transportation in our

region to coordinate timing of mowing to avoid coinciding with seed set in the largest infested areas. Given their strong willingness to work with us, it would be helpful to understand in more detail how these kinds of high-volume mowers spread purple loosestrife. Much of the land is privately owned, necessitating working with individual landowners to limit the spread of purple loosestrife. After our first field season, we sent letters to make landowners aware of infestations on their property but had a minimal response. Reaching out to those landowners, particularly between wetlands, to stop the spread in smaller infestations, based on our findings, could have a big impact on minimizing the spread between wetlands.

Future management of purple loosestrife must include biological control of purple loosestrife. We have begun releasing *Galerucella* sp. beetles, first from captured beetles the NYS DEC provided from central New York, and then propagating our own in 2019, to increase their presence in the area. This study was done before beetles were widely released throughout the area and no beetles were seen in our initial field seasons, though evidence of some herbivory was noted. Comparisons of these infestations to post-beetle release monitoring are crucial to understand when we have reached the threshold of ecosystem equilibrium. Several more years of beetle release and monitoring is necessary to understand its use in this ecosystem.

5.0 Methods

5.1 Study Site

The study area in Northern New York was chosen because initial informal surveys clearly indicated far greater numbers of infestations than the New York State Department of Environmental Conservation (NYS DEC) indicated on their website [24]. We contained our research to state highways in St. Lawrence and Jefferson Counties in northern New York (Fig. 3 and [25] for detailed description of the study area). State highways were chosen as they represented the largest traffic density spreading through the area from the Adirondack Park to the St. Lawrence River. New York State Department of Transportation manages all of the roads we used and permission was granted to allow us to walk along roadsides and collect data in their right of way, any area maintained as a clear zone along the highway [26]. There are no interstate highways in St. Lawrence County, and our data collection connected the major interstate highway to the west in Jefferson County, along the St. Lawrence River to the Adirondack Park. Management inside the Park is handled by specific state agencies and prioritizes environmental protection rarely seen outside a protected area.

5.2 Data Collection

Data were collected over 3 successive summer seasons from 2017 to 2019 using the Collector app from ESRI on mobile devices. A survey template was created with predetermined fields to limit variation from person to person and year to year. Undergraduate student research assistants were trained each summer in the identification of purple loosestrife and other herbaceous plants known to exist within the region. The first day of training involved practice with the Collector app and identifying plants, using plant

identification books as well as plant identification apps (e.g., Picture This!). All infestations under 25 plants were counted individually. Above 25 plants, estimates were performed using a 1 m² quadrat to practice estimating the number of purple loosestrife plants by putting it into different densities of infestations and counting all the stems within the quadrat. All researchers practiced estimations until they could estimate infestations to a similar degree.

The data collected for each infestation included the date, time, Global Positioning System (GPS) location, collector's name, distance from the highway (< 5 meters), the length of the invasion along the road (m), the estimated number of plants, average height of the plants (m), whether herbivory was present (indicated by holes in the leaves/petals or presence of insects), type of water it grew in (from 5 described categories), other species present, and what type of mowing was being done (e.g., a lawn mown by landowners to the road, or the 2.5-5 m of mowing done by the Department of Transportation (DOT) or no mowing at all). Water types included wetlands (flooded areas containing other plants species known to inhabit wetlands), ditches (depressions with risen sides with ephemeral water), standing water (flooded areas with no clear wetland characteristics), culverts (passages under roadways that did not connect to a wetland), or none (no evidence of any water pooling). A minimum of one photo was taken at each location of purple loosestrife and was georeferenced by the software [25]. Individual infestations were distinguished if they occurred more than 6 m apart, and the infestation had to include at least one flowering plant to confirm plant identification. Location data accuracy was at least 5 m based on the internal GPS units on our mobile devices. Beginning in 2018, we added a Bad Elf Global Navigation Satellite System (GNSS) Surveyor, connected by bluetooth to increase data accuracy, generally to less than 2 m (6 ft), but distinguishing infestations at 6 m (20 ft) was maintained despite increased accuracy.

Beginning in the third week of July as the plants began to bloom, researchers walked along the highway following the direction of traffic, mapping each infestation. In 2017, data was collected as a point in the field and converted to a line parallel to the highway in ArcGIS Online. In 2018 and 2019 data was collected in the field as line data. Researchers walked for several hours in one direction noting infestations, then crossed the highway and returned to the point they started. Data collection lasted until the entire 150 km highway was mapped, until mid-August. The final 2 days of research each year involved driving the entire route slowly to confirm all data points and ensure any later blooming infestations were included.

Culvert information was collected manually. The NYS Department of Transportation had a GIS layer of culverts, but it contained many fewer than anecdotal knowledge suggested. Culvert points were collected both during purple loosestrife collection and independently as a separate layer. A culvert point was collected at any location that had a roadside marker with a small yellow reflective rectangle, confirmed with a pipe or tunnel under the highway where water could pass through. While the size of the culvert, from 1 m to more than 5 m for larger bridge-sized passages was collected, we did not distinguish by size in the analysis as water could pass through all culverts given the proper conditions (e.g., sufficient rainfall). Wetland data was obtained from the National Wetlands Inventory for New York State and clipped to the study region [27].

5.3 Analysis

All spatial analysis was done in ArcGIS Pro v2.7.2 and statistical analysis was done in IBM SPSS Statistics v25. To capture changes to infestations, polygons were created along the entire route, each appropriately 1 mile in length and 12 m from the center highway line. This created 93 polygons on each side of the road (186 total). Polygons were numbered beginning at the southwest end of the route in Alexandria Bay with Polygon 1, increasing to polygon 38 in Ogdensburg on Route 37. The route turned east to Route 68 and polygon 39, continuing to South Colton on Route 56, ending with polygon 75. Because there was extension of Route 37 to Waddington, the polygons continued numbering at 76, ending in Waddington with polygon 93. This meant that polygon 38 connected to both polygon 39, and polygon 76 (Fig. 4). This was noted for any analysis that examined spread.

The total size of infestations and the total number of plants within each polygon was summarized using the Summarize Within tool in ArcGIS Pro. To examine the connection between wetlands and infestations of purple loosestrife, the National Wetlands Inventory dataset was clipped to the study region and all wetlands within 5 m of a roadside polygon were included in the analysis examining the connection between the size of infestations and proximity to wetlands.

Each culvert point was manually examined and assigned to one of three categories: purple loosestrife on both sides, on only one side, or no purple loosestrife present. Random points were generated along the entire route using the Create Random Points tool in ArcGIS Pro. The random points were also assigned to one of the same 3 categories above. The culvert data and random data points were compared using a chi-squared statistical analysis to determine if culverts had a significant influence on increasing infestations.

We looked at each polygon and its neighbors (those numbered one less and one greater than each target polygon) to understand whether a directional spread could be detected. We assumed that the lower number polygon would have a greater influence on whether the target polygon had received its infestation as a result of directional infestation (mowing) compared to the higher number polygon. We assumed the prior polygon would have a greater influence because state and county roadside mowers always move in the direction of traffic, as did our numbering. If mowing caused directional infestation spread, we would expect the target polygon to be populated and have an equal to or smaller infestation than the polygon immediately prior to it. In addition, we would expect the target polygon to be less influenced by the polygon immediately following it. We ran a McNemar test, following methods for looking at spread of infestations [4].

Declarations

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Authors' contributions

Dr. Jessica Rogers conceived and designed the research protocols, and did the majority of the analysis and manuscript writing. Dr. Kamal Humagain greatly contributed to the analysis, creation of figures, and editing of the manuscript. Dr. Adam Pearson contributed to the analysis framework, interpretation of results, and editing.

Conflicts of interest/Competing interests (include appropriate disclosures)

The authors have no relevant financial or non-financial interests to disclose.

References

1. Thompson, D. Q., Stuckey, R. L. & Thompson, E. B. *Spread, impact, and control of purple loosestrife (Lythrum salicaria) in North American wetlands*. U. S. Fish and Wildlife Service, 1987). at <http://stoppinginvasives.com/dotAsset/670d2f92-cd0c-41ab-9955-7204f1a9a192.pdf>
2. U. S. Fish and Wildlife Service. National Wetlands Inventory. <http://www.fws.gov/wetlands/> (2020).
3. Blossey, B., Skinner, L. C. & Taylor, J. Impact and management of purple loosestrife (*Lythrum salicaria*) in North America. *Biodivers. & Conserv.* **10**(10), 1787– 1807 (2001).
4. Wilcox, D. A. Migration and control of purple loosestrife (*Lythrum salicaria* L.) along highway corridors. *Environ. Manag.* **13**(3), 365–370 (1989).
5. St. Louis, E., Stastny, M. & Sargent, R. D. The impacts of biological control on the performance of *Lythrum salicaria* 20 years post-release. *Biol. Control.* **140**,104–123 (2020).
6. Blossey, B., Schroeder, D., Hight, S. D. & Malecki, R. A. Host specificity and environmental impact of two leaf beetles (*Galerucella californiensis* and *G. pusilla*) for biological control of purple loosestrife (*Lythrum salicaria*). *Weed Sci.* **42**, 134–140 (1994).
7. Blossey, B. Before, during and after: the need for long-term monitoring in invasive plant species management. *Biol. Invasions* **1**, 301–311 (1999).
8. Blossey, B. & Hunt, T. R. Mass rearing methods for *Galerucella californiensis* and *G. pusilla* (Coleoptera: Chrysomelidae), biological control agents of *Lythrum salicaria* (Lythraceae). *J. Econ.*

- Entomol.* **92**(2), 325–334 (1999).
9. Grevstad, F. S. Ten-year impacts of the biological control agents *Galerucella pusilla* and *G. californiensis* (Coleoptera: Chrysomelidae) on purple loosestrife (*Lythrum salicaria*) in Central New York State. *Biol. Control* **39**(1), 1–8 (2006).
 10. Boag, A. E. & Eckert, C. G. The effect of host abundance on the distribution and impact of biocontrol agents on purple loosestrife (*Lythrum salicaria*, Lythraceae). *Écoscience* **20**(1), 90–99 (2013).
 11. Welling, C. H. & Becker, R. L. Seed bank dynamics of *Lythrum salicaria* L.: implications for control of this species in North America. *Aquat. Bot.* **38**, 303–309 (1990).
 12. Farnsworth, E. J. & Ellis, D. R. Is purple loosestrife (*Lythrum salicaria*) an invasive threat to freshwater wetlands? Conflicting evidence from several ecological metrics. *Wetlands* **21**(2), 199–209 (2001).
 13. Mahaney, W. M., Smemo, K. A. & Yavitt, J. B. Impacts of *Lythrum salicaria* invasion on plant community and soil properties in two wetlands in central New York, USA. *Botany* **84**(3), 477–484 (2006).
 14. Lavoie, C. Should we care about purple loosestrife? The history of an invasive plant in North America. *Biol. Invasions* **12**(7), 1967–1999 (2010).
 15. Fickbohm, S. S. & Zhu, W. X. Exotic purple loosestrife invasion of native cattail freshwater wetlands: effects on organic matter distribution and soil nitrogen cycling. *Appl. Soil. Ecol.* **32**(1), 123–131 (2006).
 16. Thomas, S. M. & Moloney, K. A. Combining the effects of surrounding land-use and propagule pressure to predict the distribution of an invasive plant. *Biol. Invasions* **17**, 477–495 (2015).
 17. Cornell University. Network for Environment and Weather Applications (NEWA). <http://newa.cornell.edu/>. (2021).
 18. Balogh, G. R. Distribution and seedling ecology of purple loosestrife in Ohio's Lake Erie marshes. *Ohio J. Sci.* **86**(2), 51–51 (1989).
 19. Keddy, P. A. & Constabel, P. Germination of ten shoreline plants in relation to seed size, soil particle size and water level: an experimental study. *J. Ecol.* **74**, 133–141 (1986).
 20. Yakimowski, S. B., Hager, H. A. & Eckert, C. G. Limits and effects of invasion by the nonindigenous wetland plant *Lythrum salicaria* (purple loosestrife): A seed bank analysis. *Biol. Invasions* **7**, 687–698 (2005).
 21. Barbier, E. B. Knowler, D., Gwatipedza, J., Reichard, S. H. & Hodges, A. R. Implementing policies to control invasive plant species. *BioScience* **63**(2), 132–38 (2013).
 22. Blossey, B. Measuring and evaluating ecological outcomes of biological control introductions. in *Integrating Biological Control into Conservation Practice* (eds. Van Driesche, R. *et al.*) 161–188 (John Wiley & Sons, 2016).
 23. Rowell, N. *Warren County Purple Loosestrife Management Program Final Report*. (2015). at <https://www.warrenswcd.org/reports.html>

24. New York Invasive Species Information (NYISI). Purple Loosestrife. (2019). at <
http://nyis.info/invasive_species/purple-loosestrife>.

25. Rogers, J. Controlling purple loosestrife (*Lythrum Salicaria*) along roadsides in St. Lawrence County: monitoring and biological controls. *Adirondack J. of Environ. Studies* **23**(1), 5 (2019).

26. New York State Department of Transportation. Clear Zones. (2021). at <
<https://www.dot.ny.gov/divisions/engineering/environmental-analysis/landscape/trees/rs-lsf-plant-photos>>

27. U. S. Fish and Wildlife Service. National Wetlands Inventory. <http://www.fws.gov/wetlands/> (2020).

Figures

Figure 1

Size of infestations by water type.

Figure 2

Annual changes in number of plants inside wetland areas and outside wetland areas.

Figure 3

Map of the study site. The study route followed State Route 56 from the Adirondack Park boundary, to State Route 68 in Colton to Ogdensburg, north along State Route 37 to Waddington, and south along State Route 37 to State Route 12 to Alexandria Bay.

Figure 4

Map of polygons, inset of the junction of Routes 37 and 68.