# Hemlock woolly adelgid-induced losses in riparian corridors in New York State

*Produced by the Forest Ecosystem Monitoring Cooperative for the New York Invasive Species Research Institute and Cornell University, using funding provided by the U.S. Department of Agriculture, Forest Service, Northeastern Area - State & Private Forestry.*

Alexandra M. Kosiba[12], James A. Duncan[12] and Carrie Brown-Lima[3]
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[1] Forest Ecosystem Monitoring Cooperative, S. Burlington, VT
[2] University of Vermont, Burlington, VT
[3] New York Invasive Species Research Institute, Cornell University, Ithaca, NY

## Abstract

The loss of eastern hemlock (*Tsuga canadensis*) due to the invasive pest hemlock woolly adelgid (*Adelges tsugae*; HWA) could have profound impacts to riparian forest function and provisional services. Following a request by collaborators in New York State (NYS) to identify and prioritize riparian corridors at potential risk of future hemlock losses due to HWA (2013-2027, USFS 2012b, 2012c), we created risk maps using three riparian buffer widths (50-, 100-, and 200-ft) for NYS. We expressed projected basal area (BA) losses two ways: in $ft^2/ac$ and as a percentage of total stand BA. We found that the central and southern portions of the state are at risk of greater losses of hemlock in the riparian corridor, which could influence water quantity and quality adjacent to large population centers (e.g., New York City). Because of the large size of the pixels used to represent loss (240m x 240m, 14.23 ac), we found that the width of the riparian buffer (i.e., 50-, 100-, 200-ft) did not drastically influence the projected losses. As the density of streams in NYS is high, we recommend using our sub-catchment level maps for identifying watersheds with elevated potential BA losses, and then pinpointing stream corridors within the sub-catchment for research, monitoring, or future management and restoration efforts.

| Task | Products |
|---|---|
| **Task 1**<br>Quantify risk to stream corridors of hemlock loss to hemlock woolly adelgid | • Spatial data on projected losses of riparian hemlock basal area and total stand basal area near streams within 50-, 100- and 200-ft buffers.<br>• Spatial data summarizing losses in riparian hemlock basal area and total stand basal area at the sub-catchment scale for each buffer width.<br>• Spatial data quantifying stream flow patterns at all gaged streams.<br>• Description of major patterns and comparison with other products. |
| **Task 2**<br>Make information easy accessible to research and monitoring community | • Online maps to enable data exploration available at https://arcg.is/1D1LXe.<br>• Open archive of data and scripts used to generate the spatial products available through the data archive for this project. |

## Introduction

Hemlock woolly adelgid (*Adelges tsugae*) is a destructive pest of eastern hemlock (*Tsuga canadensis*) trees. Because the survival of this invasive pest – a native insect to parts of Asia – is limited by extreme cold temperatures (Paradis et al. 2008), its abundance in the northeastern United States (US) had remained low until recent years. Yet, where it has been able to reproduce and survive winter temperatures, the feeding of HWA on vascular tissues has left large stands of hemlock dead or dying (Orwig and Foster 1998). With warmer winter minimum temperatures projected for the northeastern US, we may continue to see HWA expand its range northward (Paradis et al. 2008). Therefore, forecasting the possible ecological repercussions of this invasion is critical for identifying high-risk areas and for prioritizing field research, monitoring, and management.

Hemlock -- a temperate, late successional conifer – maintains a unique ecological niche in the riparian forest of the northeastern US compared to co-occurring species, all of which are deciduous angiosperms. Unlike most other invasive pests of eastern trees (e.g., chestnut blight, Dutch elm disease), HWA affects hemlock of all crown classes, including seedlings and thus has the potential to extirpate hemlock from the landscape (Orwig and Foster 1998). Unfortunately, to date no one has demonstrated HWA resistance in eastern hemlocks, only what researchers deem “putative resistance” where a lone tree survives for unknown reasons (Caswell et al. 2008), or found naturally occurring enemies in the introduced range (Orwig and Foster 1998) in NYS. If hemlock dies and is replaced by other non-evergreen species, the nature and function of riparian forests may change dramatically.

To avoid these potentially affects to forests and the ecosystem services provided, hemlock trees can be treated with insecticides either preventatively or to retard existing HWA infestations. However, such treatments are expensive and have short-term effectiveness. Longer-term control efforts, such as the introduction of HWA predators as biological control agents, are currently being tested in some infestation areas. Although these management efforts have the potential to protect existing hemlocks, currently it is not feasible to treat all hemlocks in all locations in NYS; therefore, it is essential that we identify priority areas for HWA monitoring and management. Additionally, understanding the impacts of hemlock loss due to HWA on key resources, such as the watersheds that provide drinking water to NYS residents, is key to gaining stakeholder support for control programs and for making strategic decisions on where to invest limited resources for HWA control.

In NYS, where the majority of water comes from upstate forests, loss of hemlock and changes to riparian forest ecosystem function could pose a threat to the drinking supply by increasing water temperature, nitrate inputs, and turbidity (Jenkins et al. 1999, Kizlinski et al. 2002, Vose et al. 2013).

However, there has been relatively little research looking at the direct effects of hemlock loss on riparian systems across a range of spatial and environmental conditions in the Northeast. Complicating the matter is that there have been conflicting conclusions about the flora that may dominate hemlock stands following HWA infestation (see Jenkins et al. 1999, Kizlinski et al. 2002, Vose et al. 2013) – a critical component that may determine outcomes in riparian ecosystems. As of 2016, NYS had approximately 535,106,968 hemlock trees >1" diameter (DBH) on forestland (USFS 2012a), which equates to roughly 15.3 trees/ac in the state.

In light of these uncertainties, we evaluated the risk of HWA-induced hemlock losses to riparian corridors in NYS. By identifying the riparian corridors at risk of the largest hemlock losses due to HWA, our results will assist partners in (1) guiding the selection of research locations to study the impact of hemlock loss on water quality and quantity and (2) identifying priority areas for land managers to monitor, and potentially manage, HWA infestations. This study did not evaluate the severity of a possible HWA infestation, but the magnitude of potential losses to hemlock and total stand basal area should HWA become established. Research has shown that actual hemlock mortality can be variable, both within and between stands (Orwig and Foster 1998), and may depend on ancillary site and stand factors that we did not consider here.

# Materials and Methods

*Data inputs*

We utilized pre-existing spatial data projecting losses of hemlock due to HWA developed by the USDA Forest Service Forest Health Protection program (USFS 2012b, 2012c). Table 1 outlines the spatial inputs used in this effort. All spatial inputs were clipped to the sub-catchment watersheds (i.e., HUC12) draining into NYS (Figure 1). Specifically, we selected projected BA losses ($ft^2$/ac) and projected BA losses as a percentage of total stand BA (%) due to HWA per 240-meter pixel (Figure 2). These projections were modeled for 2013-2027. We also utilized pre-existing riparian buffers in widths of 50, 100, and 200 feet from the stream centerline (SHEDS 2017) that had been derived from the derived from National Hydrology Dataset (USGS 2017) (Figure 2). While 50 ft buffers typically are used for delineating riparian corridors, because the impact of hemlock losses to water quality may depend on the slope of the land in the riparian buffer, we also included 100 and 200 ft riparian buffers for comparison.

**Table 1. List of spatial inputs for this project. Note: BA = basal area, HWA = hemlock woolly adelgid.**

| Description | Resolution | Source |
|---|---|---|
| 50 ft riparian buffers derived from National Hydrology Dataset | Varies | SHEDS 2017 |
| 100 ft riparian buffers derived from National Hydrology Dataset | Varies | SHEDS 2017 |
| 200 ft riparian buffers derived from National Hydrology Dataset | Varies | SHEDS 2017 |
| Projected loss (%) to total stand BA due to HWA 2013-2027 | 240 x 240 m | USFS 2012b |
| Projected BA loss (sq ft/ac) due to HWA 2013-2027 | 240 x 240 m | USFS 2012b |
| Sub-catchment boundaries (HUC12) | Varies | USGS 2018 |
| Flow characteristics at stream gages in the conterminous US | Varies | Wolack 2003 |
| Watershed summaries of losses by HWA | Varies | USFS 2012c |

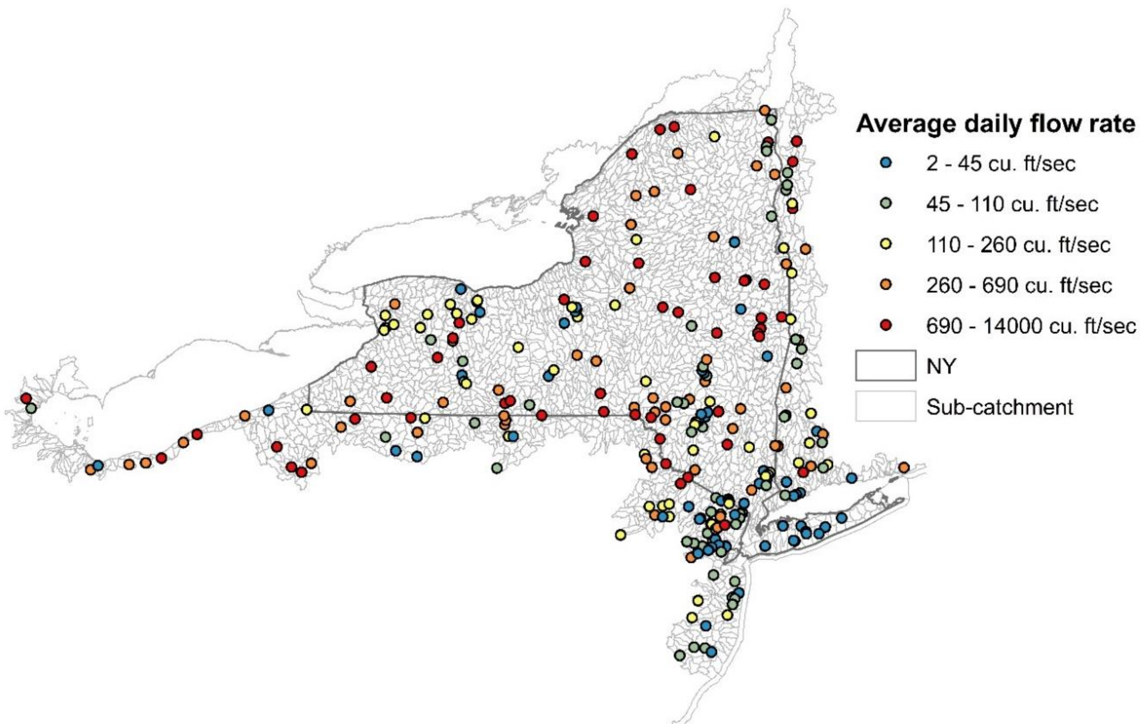


**Figure 1. State of New York with sub-catchments (HUC12 watersheds) draining into the state and locations of stream gages with at least 15 years of data. Different colors for gage locations depict mean daily flow rate (ft$^3$/sec; Wolock 2003).**

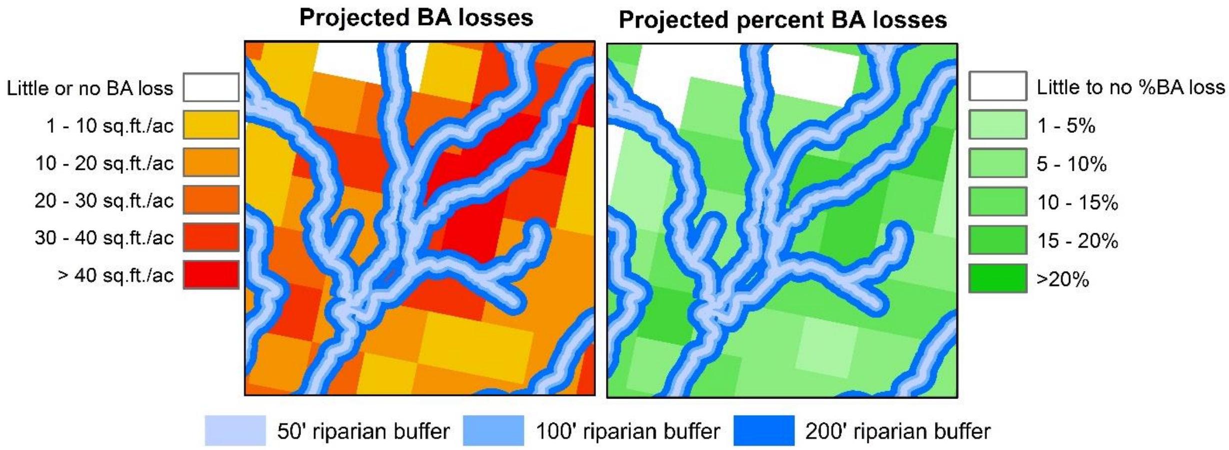


**Figure 2. Example of the three riparian buffer widths (50, 100, and 200 ft) overlaid on projections of BA losses due to HWA, displayed both as BA loss in ft$^2$/ac (left) and as a percentage (%) of total stand BA (right).**

*Stream corridor risk mapping*

We computed the (1) projected BA loss (expressed as hemlock BA losses due to HWA per pixel) and (2) projected percent BA loss (expressed as a percentage of total stand BA losses due to HWA per pixel). We converted these projected loss raster images to polygons, and then computed the spatial intersection with the three riparian buffers (50, 100, and 200 ft buffer widths). From this, we computed the relative BA loss or percent BA loss per stream buffer section depending on the amount of buffer intersecting each pixel in order to compute the proportional value for BA loss or percent BA loss for each stream section. Stream sections were defined by the National Hydrology Dataset (USGS 2017).

Because the stream network in NYS is dense, visualizing the projected losses by riparian buffer was difficult (Figure 3). Thus, we summarized findings (three buffer widths and two data inputs) by sub-catchment. Sub-catchments then can be displayed by mean, standard deviation, and maximum BA loss or percent BA loss, each for the 50, 100, and 200 ft riparian buffers. We also included average stream flow rates for select USGS stream gages (Wolock 2003) to help identify high flow streams for potential monitoring (Figure 1). Gages were included if they had at least 15 years of recent data. We included average daily flow rate (ft$^3$/sec), and percentile statistics on daily stream flow over the period of record.

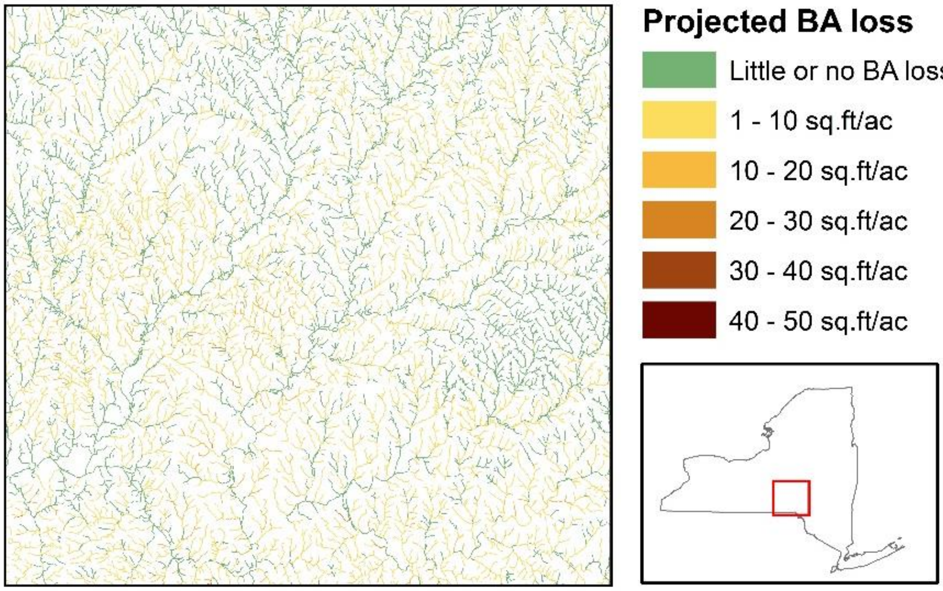


**Figure 3. Example of the spatial density of streams in NYS. Here streams depicted as 200-ft riparian buffers for easier visualization. To more easily view the state in entirety, we summarized by sub-catchment.**

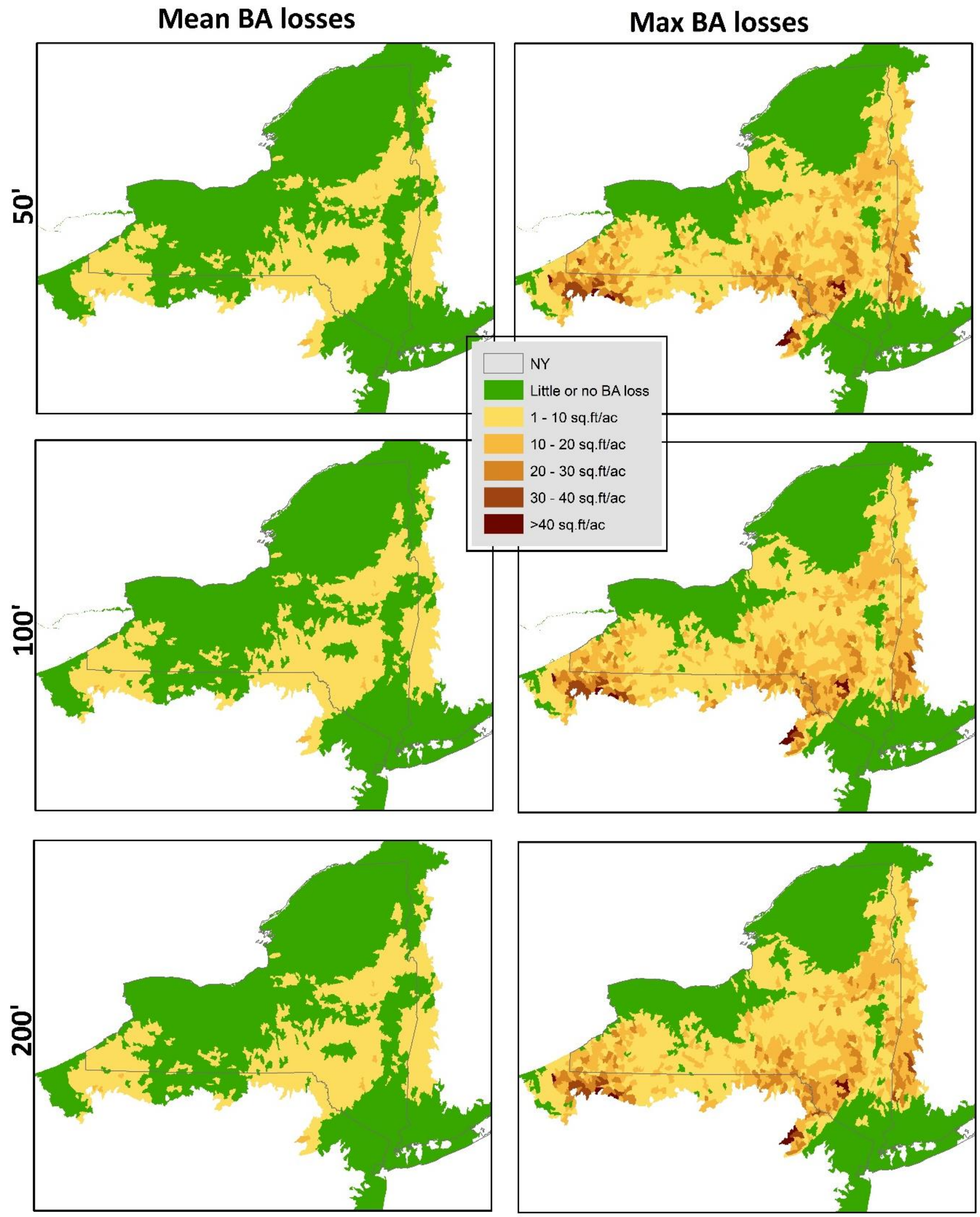


**Figure 4. Sub-catchment scale statistics of HWA impacts displayed by mean and maximum values of projected hemlock BA losses (ft$^2$/ac) computed for the three riparian corridors: 50, 100, and 200 ft buffer widths.**

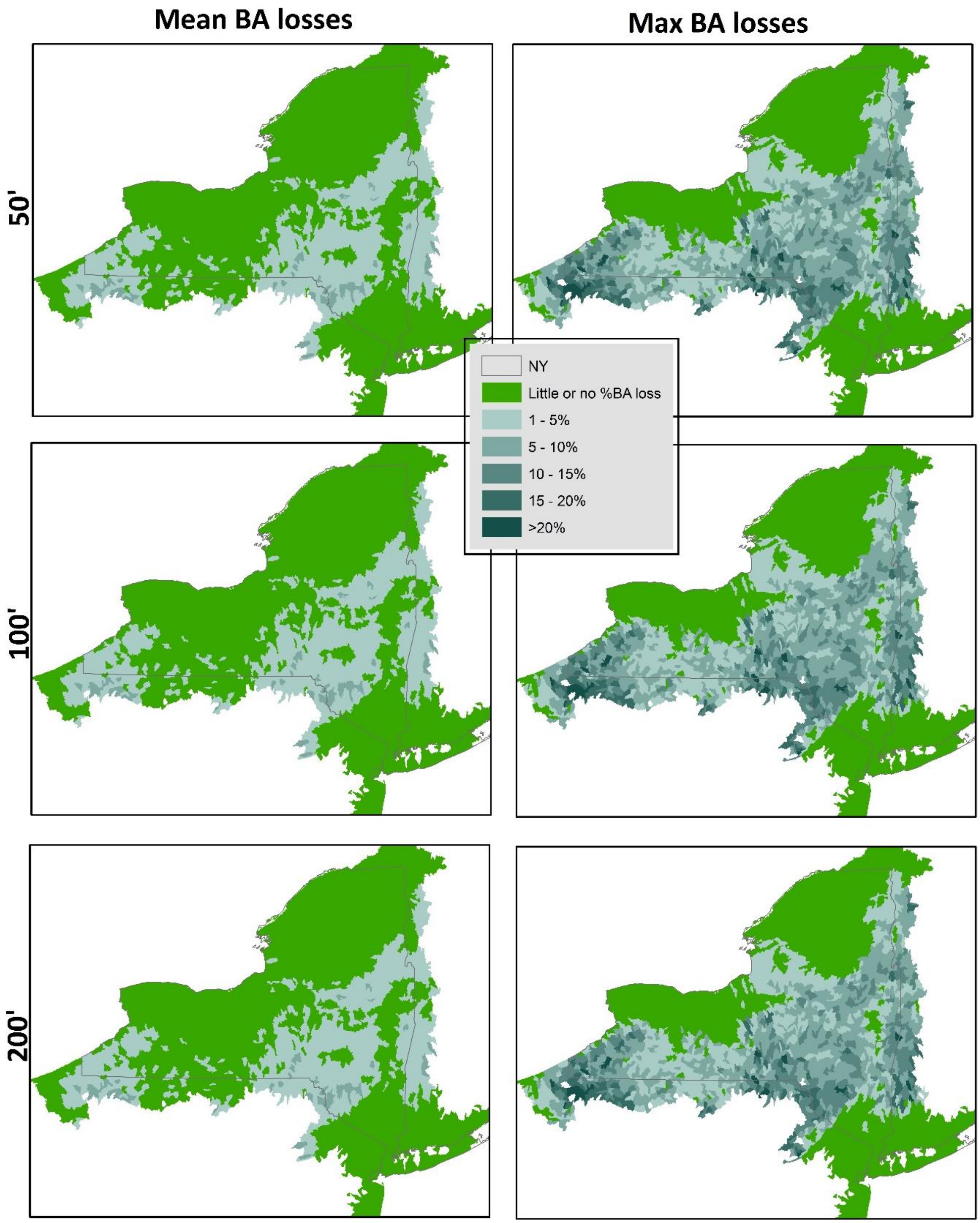


**Figure 5. Sub-catchment scale statistics of HWA impacts displayed by mean and maximum values of projected percent losses of total stand BA (%) computed for the three riparian corridors: 50, 100, and 200 ft buffer widths.**

**Table 2. List of spatial layers produced. Note: BA = basal area.**

| Name | Description | Fields for display |
|---|---|---|
| RB_50 | Polygon delineations of 50-foot riparian buffers and metrics of projected HWA impacts | • BA_peAc: BA losses ($ft^2$) per acre of buffer<br>• Pct_BA: percent (%) loss of total stand BA in buffer |
| RB_100 | Polygon delineations of 100-foot riparian buffers and metrics of projected HWA impacts | • BA_peAc: BA losses ($ft^2$) per acre of buffer<br>• Pct_BA: percent (%) loss of total stand BA in buffer |
| RB_200 | Polygon delineations of 200-foot riparian buffers and metrics of projected HWA impacts | • BA_peAc: BA losses ($ft^2$) per acre of buffer<br>• Pct_BA: percent (%) loss of total stand BA in buffer |
| WBDHU12 | Polygon delineations of sub-catchment watersheds (HUC12) with associated statistics (mean, sd, and max) for BA losses and percent BA losses due to HWA for the stream buffer widths (50-, 100-, and 200-ft). | • MEANba_50: mean BA losses ($ft^2$/ac) in 50-ft buffers within the catchment<br>• STDba_50: standard deviation of mean BA losses ($ft^2$/ac) in 50-ft buffers within the catchment<br>• MAXba_50: maximum BA losses ($ft^2$/ac) in 50-ft buffers within the catchment<br>• MEANba_100: mean BA losses ($ft^2$/ac) in 100-ft buffers within the catchment<br>• STDba_100: standard deviation of mean BA losses ($ft^2$/ac) in 100-ft buffers within the catchment<br>• MAXba_100: maximum BA losses ($ft^2$/ac) in 100-ft buffers within the catchment<br>• MEANba_200: mean BA losses ($ft^2$/ac) in 200-ft buffers within the catchment<br>• STDba_200: standard deviation of mean BA losses ($ft^2$/ac) in 200-ft buffers within the catchment<br>• MAXba_200: maximum BA losses ($ft^2$/ac) in 200-ft buffers within the catchment<br>• MEANpcba_50: mean stand BA losses (%) in 50-ft buffers within the catchment<br>• STDpcba_50: standard deviation of mean stand BA losses (%) in 50-ft buffers within the catchment<br>• MAXpcba_50: maximum stand BA losses (%) in 50-ft buffers within the catchment |

| | | |
|---|---|---|
| | | • MEANpcba_100: mean stand BA losses (%) in 100-ft buffers within the catchment<br>• STDpcba_100: standard deviation of mean stand BA losses (%) in 100-ft buffers within the catchment<br>• MAXpcba_100: maximum stand BA losses (%) in 100-ft buffers within the catchment<br>• MEANpcba_200: mean stand BA losses (%) in 200-ft buffers within the catchment<br>• STDpcba_200: standard deviation of mean stand BA losses (%) in 200-ft buffers within the catchment<br>• MAXpcba_200: maximum stand BA losses (%) in 200-ft buffers within the catchment |
| Gages_act15yrs_flowrate | Active USGS stream gages with at least 15 years of record | • AVE: average daily flow rate ($ft^3$/sec) for the period of record<br>• P50: $50^{th}$ percentile of daily flow ($ft^3$/sec) rate for the period of record<br>• P99: $99^{th}$ percentile of daily flow ($ft^3$/sec) rate for the period of record<br>• Other percentiles are included, too. |

## Results and Discussion

We produced five spatial layers each with multiple fields for identification of potential risk of water quality issues due to hemlock mortality from HWA. Specifically, we created riparian risk maps for three buffer widths (50, 100, and 200 ft) and using two different projected loss inputs (hemlock BA losses and percent of total stand BA losses). We also summarized these findings by sub-catchment for easier visualization (see Figures 3, 4, 5). Table 2 lists the five spatial products and for each, a description of the product and the fields that can be used for visualization and/or analysis.

Overall, approximately half of the state's sub-catchment area (29.3 Mac) contains streams that are projected to experience hemlock losses (Figure 5). When visualized by sub-catchment, there were no discernable differences between the three buffer widths in the projected losses (Figures 4, 5), likely driven by the small difference in the buffer area compared to the extent of the projected loss data (Figure 2). The two types of projected BA losses due to HWA, expressed as hemlock BA loss in $ft^2$/ac and as percent (%) of total stand BA, display similar spatial patterns (Figures 4, 5), but the maps can be used to identify different types of forests. For example, in a very dense forest stand there may be projected BA losses of 30 $ft^2$/ac, but it may only equate to <10% of the total stand BA due to a large number of tree of other species. In other forest stands, a loss of 30 $ft^2$/ac could equate to more than 50% of the total BA and result in more serious ecological impacts. In general, the locations most at risk for potential riparian buffer degradation occurred throughout the central and southern portions of the state (Figures 4, 5). In some of these sub-catchments, stream corridors may experience hemlock BA losses of >40 $ft^2$/ac and >20% of the total BA. This area of the state is in close proximity to population centers, and contains the highest density of active stream gages (Figure 1) that could be used to target locations for further research.

We found that for the 50, 100, and 200 ft stream buffer widths, the total area covered was 1.72, 3.41, and 6.66 Mac, respectively. Of this total acreage, 0.72 (42% of the riparian buffer area), 1.45 (42%), and 2.9 (44%) Mac, respectively, had projected losses of hemlock due HWA greater than zero – which is similar to the results when displayed by sub-catchment. When we examined the extent of stream buffers with projected hemlock losses ≥15% of the total BA, we found that between 3,886 and 6,901.8 ac (225-227 stream sections) were at potential risk depending on the riparian buffer width selected. In general, the 200 ft riparian buffer had the highest projected losses, but the differences were minimal. Thus, using these layers to target the streams at the highest potential risk of loss of hemlock will help focus research, monitoring, and restoration efforts.

Overall, we did not find large differences in the projected losses among the three buffer widths (Figure 6), likely due to the large size of the projection data relative to the buffer widths (Figure 2). The maximum value of projected BA losses across all three riparian buffers were quite similar: 44.8, 45.2, and 45.2 $ft^2$/ac for 50, 100, and 200 ft buffers, respectively. Displayed by percent of total stand BA losses, the maximum percentages for the three riparian buffers were also similar at 30.0%, 30.0%, and 28.7%, respectively. Therefore, users of these maps may utilize any of the three buffer widths for locating 'at risk' stream corridors. We suggest first using the sub-catchment level maps to identify areas of high projected losses due to HWA and then the stream buffer map to pinpoint precise stream sections.

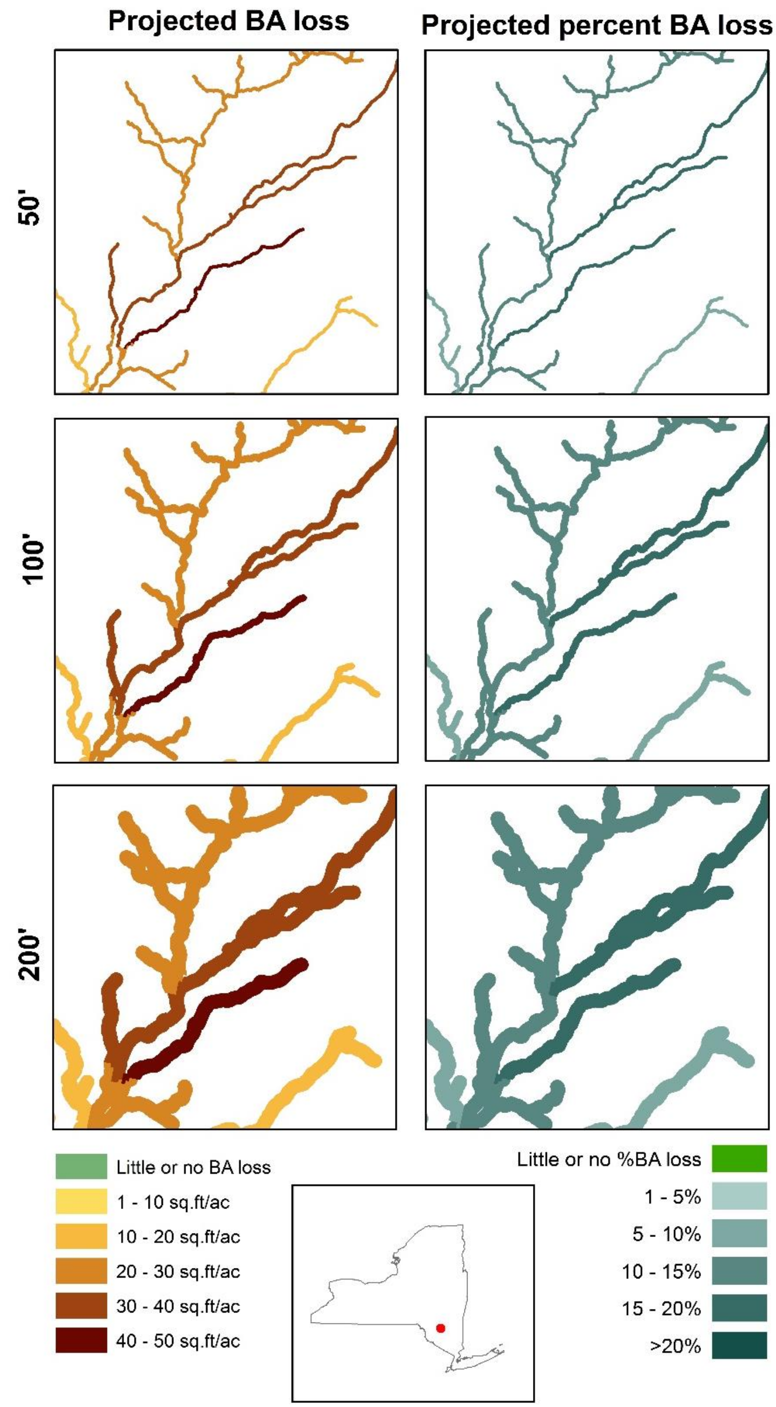


**Figure 6. Example of mean BA losses (left) and percent of total BA losses (right) projected with HWA infestation and displayed for the three riparian buffers: 50, 100, and 200 ft riparian buffer widths.**

*Comparisons with other products*

Along with the pixel-based projected losses used here, USFS also produces sub-catchment watershed (HUC12) summaries of tree loss risk (USFS 2012c). These watershed-level summaries do not account for riparian corridors, but the resultant maps are very similar to ours (Figure 7). That said, there are some important differences between our maps that were first summarized by stream buffer and those summarized by watershed. Our methods (Figure 7, left panel) have detected risk of hemlock losses in the riparian corridor in some sub-catchments that the USFS watershed-level summary maps classify as having little or no loss (right panel); for example, in the south central portion of the state. This finding suggests that there are more projected hemlock losses near streams compared to upland areas. Conversely, some of the sub-catchment summaries (right panel) depict higher projected percent BA losses compared to our product (left panel), which would indicate that more of the hemlock losses in these sub-catchments are projected to occur in uplands rather than adjacent to streams. As we have assessed projected losses in the stream corridor, the maps we have produced will allow for easier identification of potential streams at risk of ecological damage compared to the watershed-level summaries. In addition, we have also included BA losses along with percent of total BA losses.

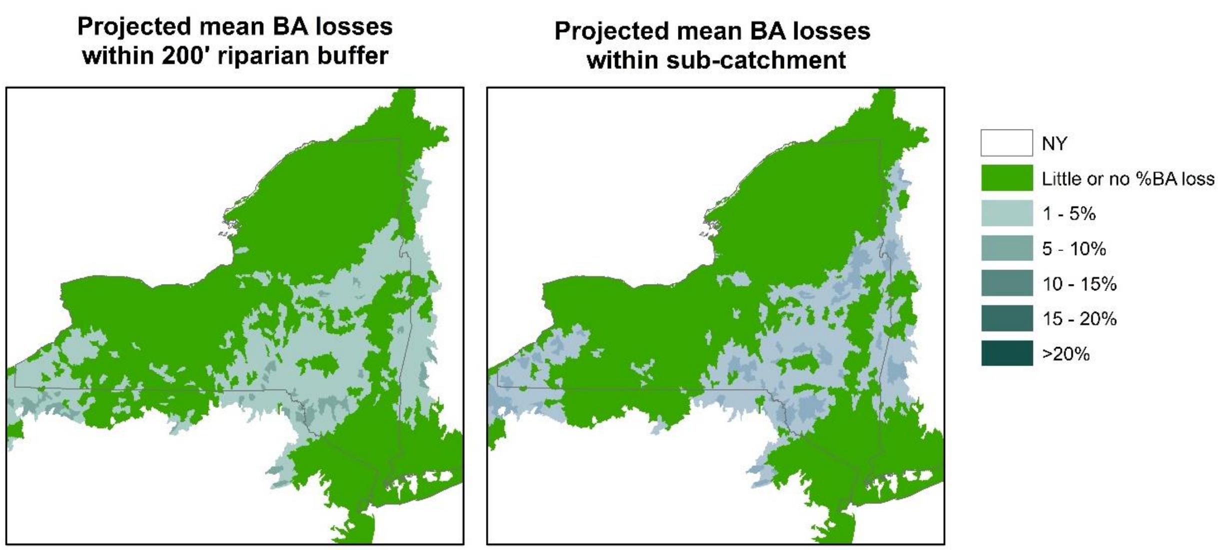


**Figure 7. Comparison of riparian buffer risk maps (left) to watershed summary risk maps produced by USFS (2012c; right). Both images depict projected percentage losses to total BA.**

*Caveats and limitations*

The biggest limitation we encountered for identifying riparian corridors in NYS at risk due to hemlock losses were the input data utilized. The projected losses to hemlock have been computed at a relatively coarse scale (e.g., 240 m resolution that is equivalent to 14.23 ac) (Table 1, Figure 2). Considering the current affinity of hemlock to exist in hollows, ravines, and steep areas, this large extent likely does not capture the spatial heterogeneity of hemlock distribution in the forests of NYS. Because of this limitation, we cannot pinpoint where in the 14.23 ac pixel the hemlock trees are located. However, these maps do help direct research and monitoring efforts to those areas with the most concentration of hemlock in the state. An additional caveat is that the USFS risk maps do not indicate the likelihood of HWA invading an area, which research suggests is contingent on a number of site and environmental factors (Orwig and Foster 1998). Follow-up field surveys would be needed to confirm the presence or absence of HWA at various locations.

## Conclusions

Our riparian corridor maps that depict projected BA losses due to HWA will help inform future research and monitoring for our NY partners, and could be a model for identifying and prioritizing impacts from HWA elsewhere in the region. As the impacts of hemlock mortality on water quality and quantity have yet to be fully understood in the northeastern US, pinpointing locations with high hemlock density adjacent to streams will allow for targeted efforts to address those gaps. Further, the maps produced here would be easily created for other states where HWA has only just begun to infiltrate, and can be easily updated when new projections are developed.

This work will be important for agencies concerned with losses of hemlock due to HWA in NYS, such as the NYS Department of Environmental Conservation and the NYC Department of Environmental Protection, which are responsible for protecting the forests and waters in NYS. The Partnerships for Regional Invasive Species Management (PRISMs), a group tasked with the detection and management of high impact invasive species such as HWA will also benefit from the availability of these maps in order to prioritize and target their efforts. Additionally, researchers from universities across the state including Cornell University’s Water Resources Institute and NYS Hemlock Initiative are conducting research on the impacts of HWA on water quality; these maps will directly aid researchers in identifying locations for intensive study.

## Acknowledgements

This project was identified as a need by the FEMC's NY State Partnership Committee and we appreciate the continued support and guidance provided by this and the other FEMC committees. We are thankful to Benjamin Letcher and Kyle O'Neil (SHEDS) for sharing riparian buffer spatial data used in this project. This work was made possible by long-term funding from the U.S. Department of Agriculture, Forest Service, Northeastern Area - State & Private Forestry.

## Data and Scripts

Interactive maps are available at https://arcg.is/1D1LXe
Data, along with the scripts and models used to develop these maps will be available at the FEMC data archive (https://www.uvm.edu/femc/data/archive/project/hemlock-woolly-adelgid-riparian-losses-new-york)

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