An Assessment of the Risk of Landscape Fragmentation In the Lake Champlain Basin

Charlotte Low
Matthew Gustafson
Walker Brown

April, 2011
**Executive Summary:**

As humans colonize and develop a landscape, they tend to have a significant impact by displacing natural ecosystems to make them available for human use. This creates gaps that make it difficult for wildlife to move fluidly across the landscape, as well as disrupting the natural dynamics of ecosystems. Habitat loss is inextricably linked to landscape fragmentation. In addition to habitat loss, a fragmented landscape can generate isolated pockets of habitat where there is limited exchange of genetic material between sub-populations, leading to inbreeding and loss of fitness. Without this exchange, the ecosystem becomes stagnant and can degrade quickly, allowing invasive species to invade and further disrupt the natural dynamics of the system. This fragmented habitat also becomes less resilient and resistant to disturbances and stress. If major structures and components of the ecosystem sustain heavy damage or are lost during a disturbance event, the area may not be able to recuperate this biological loss. Biological legacies, which are those remaining organic structures after the disturbance event, may not be sufficient to contribute to the successional recovery of the system as a result of the compounded effects of land fragmentation. Similarly to the effects of isolation, the loss of biological legacies can result in an opportunity for fast-spreading invasive species that are well adapted to these damaged areas to colonize and take over. There are many detrimental ecological consequences associated with the fragmentation of the landscape, and we have only just begun to truly understand what these are and how to quantify their effects.

By assessing habitat fragmentation in a region, this report allowed us to determine where it is having the most significant effect. We used GIS mapping to analyze how pronounced the landscape fragmentation is in each watershed. In this way, we were able to create a risk ranking system for different levels of fragmentation. We were then able to assign a risk ranking for the habitat fragmentation within the entire Lake Champlain Basin. Each watershed was assigned a ranking of low risk (2), medium risk (4), or high risk (6). We are hoping that this information will lead to a restoration effort on the areas most at risk and help to revitalize the native ecosystems of Vermont.

With the land fragmentation analysis performed using GIS and the results collected it is suggested that management efforts are directed in the eight critical risk regions denoted with risk rankings of 6. These areas are at the greatest current risk from land fragmentation and much of these areas are in critical wetlands, riparian, and core forest habitats.
**Problem Statement:**

Land Fragmentation within the Lake Champlain Basin, resulting from agriculture, industry, urban development, and transportation networks, has a dramatic effect on the function, value, and quality of wetlands, forests, and herbaceous landscapes by disrupting the natural dynamics of these systems.

**Goal Statement:**

At the completion of this group’s assessment of land fragmentation and its effects on habitats, a relative risk ranking system will be constructed using reviewed literature and a GIS analysis, as well as inclusion of connections and importance matrices between sources and stressors, and stressors and habitats.

**Objectives:**

- Research previous studies that pertain to landscape fragmentation and its effects on habitats and receptors. These do not necessarily have to be specific to the Lake Champlain Basin.
- Develop a diagram illustrating the existing connections between sources and landscape fragmentation, as well as habitats and landscape fragmentation.
- Create GIS maps analyzing land use and transportation networks and how they fragment the landscape.
- Using background information and GIS maps, define the context for a risk ranking system for the fragmentation of landscape as a stressor.
- Assign a risk ranking landscape fragmentation as a stressor for the Lake Champlain Basin.

**Background:**

Landscape fragmentation is a combination of habitat separation, isolation, and loss. Natural ecosystem habitats in the landscape are divided by changes in land use and an increase of sources acting on the landscape (Rochelle et. al. 1999). These sources can be natural, for rivers and streams, or artificial, such as roads or urban centers. For the purpose of this risk assessment we are focusing solely on anthropogenic sources. Human generated sources include roads and the development of land for industry, recreational parks, and urbanization. As these human habitats grow, wild habitats are divided and pushed to margins of the landscape.

Habitat loss effects flora and fauna in an ecosystem. Populations of species in a community decline without adequate resources to sustain a population (Rochelle et. al., 1999). Fragmentation reduces the availability of shelter, cover for predators and prey, food, water,
and other components of refuge. Additionally, it invites increased competition in isolated habitats with limited resources (Rochelle et. al., 1999). The report, _Forest fragmentation: Wildlife and Management Implications_, created through a conference in Oregon, stated that "among bird species strongly associated with riparian areas, 15 of 35 (43%) nested predominantly in hardwood trees or shrubs" (Rochelle et. al., 1999). The study that these data come from was performed in riparian areas throughout Oregon and demonstrated the need for particular habitat for certain birds that nest up off the ground. The loss of trees and shrubs resulting from the fragmentation of landscape directly reduces the nesting ground and reproduction rates of many bird species (Rochelle et. al., 1999). In an ecological context, habitat loss and landscape fragmentation are inseparable occurrences.

**Roads**

Roads are a major contributor to landscape fragmentation, by the separation and loss of habitat, in the Lake Champlain Basin. A recent report titled, _Critical Paths; Enhancing Road Permeability for Wildlife in Vermont_, is useful in defining the magnitude and probability of risk associated with roads as a source of landscape fragmentation. The study was compiled by a team of scientists and specialists from the Vermont Natural Resources Council, the Vermont Fish and Wildlife Department, the National Wildlife Federation, and two private contractors; a consulting biologist and a tracker. The report examines the impact of roadways on the ability of wildlife to move through habitats in Vermont. It then assesses recommendations for increasing the fluidity of this movement throughout the state by increasing permeability around roadways (Leoniak, G., et. al., 2009). This study is particularly valuable in conjunction with GIS data on road density in Vermont and New York. The data offer a quantitative summary of risk stemming from roads, and this study details the qualitative justification for the risk rankings. It is also a well informed source of recommendations to reduce the adverse effects of roads on wildlife populations in Vermont.

Roads contribute to the decline of wildlife populations in a variety of ways. Deaths resulting from automobile collisions, known as “road kill,” are common. The physical barrier of the road, especially busier highways and interstate routes, impedes the flow of wildlife across the landscape throughout larger habitats and ranges. The inability of wildlife to pass through areas with roads disrupts migration patterns, isolates populations, reduces genetic diversity, and decreases the resiliency and adaptability of species (Leoniak, G., et. al. 2009). These affects are compounded by the fact that more houses are being built each year in Vermont, and more roads are being built to connect houses and people (Smartgrowth Vermont 2011). The Critical Path report states “Vermont’s transportation system is an important and growing feature in the state. In the last quarter of the 20th century, Vermont expanded its road system by an average of 26 miles per year to a total of about 14,251 miles. The number of vehicle miles traveled by Vermont residents is growing at seven times the rate of population growth” (2009). As road density increases, the probability and magnitude of the risk also increases.
Urban, Development, and Industry

Vermont is 80% forested. Wildlife populations in the state are adapted to the wide range of habitat, and local population dynamics have been formed around it. However, in the past fifty years Vermont residents have become less localized in villages and the amount of sprawl has increased, thereby increasing fragmentation (Leoniak, G., et. al., 2009). Smartgrowth Vermont defines sprawl as development, outside of villages or concentrated urban areas, which is dependent on the construction of roads and the use of automobiles (2011). Exurban areas are a form of development which also contributes to land fragmentation. Exurban is a term used to define residential sprawl outside of, but still connected to, urban centers. This type of development is characteristic of more rural areas where humans have settled (Glennon and Krestor 2005).

Mates are prevented from meeting and reproducing by barriers which separate habitats into isolated patches (Collingham 2000). Urban and developed areas are large enough obstructions to facilitate this level of fragmentation. As a result the genetic robustness of some species suffer from this loss of connectivity. For plants this translates into fewer available seed sources and the obstruction of successful pollination (Collingham 2000).

Additionally, fragmentation by urbanization and development leads to habitat loss. Along with the consequences of habitat loss mentioned previously, is a reduction in ecological diversity. Generalist species are favored in fragmented conditions as they are more able to adapt and compete successfully. Specialized species, however, face great challenges without access to fundamental or realized niches. Therefore, ecosystems become more populated with generalist species and ecological diversity is reduced (Collingham 2000). The magnitude of these risks is even greater for endemic populations or threatened wildlife species (Leoniak, G., et. al. 2009).

Approach:

An analytical approach was taken in order to assess the risk to the Lake Champlain Basin from stresses due to land fragmentation. A separate literature review was conducted in effort to direct the analysis and support connections between stressors and habitats/sources. The literature review was focused around articles specifying the effects land fragmentation has on individual species, communities, habitats, and connectivity (most articles were not from the Lake Champlain Basin area). Literature was chosen that highlighted these qualitative impacts of landscape fragmentation. Scientific case studies that documented specific consequences of forest fragmentation were especially relevant. All of the resources used are credible secondary sources, which were transferable to this assessment. The analytical approach included using the GIS platform ArcMap and a number of data sets within the Lake Champlain Basin. As land fragmentation is a unique stressor our group sought to compensate for the complexity in analyzing land fragmentation by adding a separate risk ranking index for land fragmentation within each watershed through the use of GIS. It is proposed that this land fragmentation risk ranking (2, 4, 6 scale) is integrated into the model in the future. One possible way of incorporating this metric would be to develop similar matrices for other stressor groups by sub-watershed. Another potential option is to use the score of ‘6’ as a place holder for all other
stressor groups within the model in order to keep them constant while still compensating for different effects of land fragmentation by sub-watershed.

As a note to those readers unfamiliar with GIS and ArcMap the next section is a narrative on the GIS analysis used in order to construct a relative risk score for each sub-watershed from the effects of land fragmentation. In order to assess the relative risk associated with land fragmentation within the Lake Champlain Basin (LCB) two key base data sets were utilized. These data sets included road center-line vector data from Vermont, New York, and Canada (VCGI, Clearing Warehouse NY, and GeoGratis are respective sources of data), land use/land cover raster data, watershed and sub watershed boundaries data. These base layers can be observed in Figure 1 attached. Consulting previous literature and professorial advice an approach was developed to assess land fragmentation as a function of cover type and proximity to roads. A flowchart is provided as a figure below to visually display the narrative that follows. After coalescing road and sub-watershed layers and ensuring similar coordinate systems a raster calculation was used in order to separate land use cover types deemed as ‘habitat types’ and ‘fragmentation sources’. Habitat types included brush, forest, and wetland while fragmentation sources included cover types urban, agriculture, water, barren, and urban/open. The logic behind selecting these two categories was informed by previous literature and course work on sources of habitat fragmentation and the definition of habitat types like forest, brush, and wetlands. Next, a proximity analysis was done using the coalesced roads layer. This new raster layer depicted how far any pixel was from the nearest road, an important metric when considering edge effects from land fragmentation. These two raster layers (calculation layer and roads proximity) where multiplied creating an index where each pixel in the layer represented how far a ‘habitat type’ (forest, brush, wetland) was from a road. Using zonal statistics this was averaged over each sub-watershed in order to assess the relative risk to each sub-watershed. Additionally, a zonal statistic of the calculation layer was performed in order to calculate the percent ‘habitat type’ within each watershed. This fraction of habitat types within each sub-watershed was then multiplied by averaged fragmentation index to create a final fragmentation index. The reasoning behind this procedure was to account and compensate for sub-watersheds that had high proportions of fragmented cover types (original fragmentation index did not account for the amount of fragmented landscape within each sub-watershed). Three classes of relative risk (high, moderate, and low) were created when depicting the relative risk to each sub-watershed from land fragmentation (see Figure 2).

Findings:

The results of this GIS analysis produced a ranking scheme that ranked the level of risk by sub-watershed. Graphical and tabular representation of the final data is depicted below in Table 1 and Graph 1. As shown, a total of 8 sub-watersheds were deemed to have a high risk from land fragmentation. The greatest associated with risk is seen in the Burlington Bay sub-watershed with St. Albans Bay, Shelburne Bay, and Shelburne Bay all displaying relatively high final index scores (deemed risk ranking of ‘6’). Also important to note would be that Cumberland Bay and Main Lake NY sub-watersheds had very low relative risk associated with them (risk ranking of ‘2’). From viewing the roads and land use/land cover base layers and
seeing where high densities of development, agriculture, and roads the results of this analysis confirm that areas closer to the lake which have seen increased human development and use have higher associated risk associated with land fragmentation. See Figure 2 for a map depicting these risk scores by sub-watershed.

The literature review provided a second analysis providing the reasoning behind developing an effect filter. Previous literature cited supported that there were significant connection between land fragmentation as a stressor and agriculture, urban, roads, and industry as sources, as well as forests, and wetlands as habitats and received an effect filter value of 1 (refer to Background Section). Moderate connections between land fragmentation as a stressor and recreational parks as a source as well as herbaceous areas as a habitat were identified also (effect filter value of ½). It was reasoned that herbaceous areas such as those along roads contribute to land fragmentation, but these same areas are also used by some edge species. Similarly, it was reasoned that though recreational parks are areas typically reserved as natural areas, their associated political boundaries result in the park itself being fragmented from surrounding ecosystems (justifying the .5 effect filter denotation). Connections between land fragmentation and forest and wetlands as habitats were created to show that land fragmentation has equal detrimental effects irrelevant of the habitat sensitivity (wetlands, generally being more sensitive diverse ecosystems, are going to be inherently at a greater risk than a forested region). See Table 2 (attached) for impact and effect link filter matrices.

**Conclusions/Recommendations:**

The Critical Paths report is full of pragmatic recommendations to reduce the fragmentation which exists as a result of the vast network of roads in Vermont. The study focuses on the development of forty-four corridors and safe crossings on thirteen roadways in the state. The purpose of the corridors is to increase habitat accessibility for wildlife and to reduce mortality from automobile collisions. There are several designs for corridors discussed in the paper. Wide cement culverts, tall enough for deer, bear, and moose, to travel under have been built under some roadways. Bridges on dry land above and below roadways have also been constructed, with positive results. Trackers provide anecdotal reports of deer, bear, moose, raccoon, and other wildlife crossings along these corridors (Leoniak, G., et. al., 2009). There are many roads in Vermont that do not have safe crossing areas. Wildlife in these habitats, including interstate 89, would benefit from the construction of corridors. Additionally, road signs alerting motorists of high traffic wildlife areas have been shown to reduce wildlife mortality. All of these concepts proposed in this paper are potential management recommendations for the Lake Champlain Basin to reduce the effects of land fragmentation.

Ideally the sources of landscape fragmentation; roads, urban areas, agriculture, and recreational parks, can be controlled and reduced in the future. To prevent further fragmentation towns might adopt policies and zoning regulations, which keep populations, localized around urban centers and villages and protect important wildlife corridors. Additionally, to encourage habitat accessibility in agricultural areas the establishment of riparian buffers and wildlife corridors is recommended on farms in Vermont. The methodology behind implementing these changes on farms would have to be discussed by farmers and other stakeholders. It is possible that the UVM extension program could be
involved with the project. However, those details would be fleshed out in the future, once the framework created in this project had data and a fully developed assessment was complete for the Lake Champlain Basin.

For future Landscape Fragmentation groups we recommend working with the Barriers to Aquatic Organisms group to establish the differences between the two stressors. This year the distinction between the two groups was unclear in terms of roads. Both groups accounted for the risk of roads on animal populations. However, neither group defined which animals, or animal classes, this included. Therefore, risk was counted twice for amphibians and other aquatic creatures. Our group's suggestion to resolve this problem was to allow the double counting to occur to reflect the cumulative effects roads have on both aquatic and terrestrial organisms. The delineation between the two groups is similarly proposed to occur between aquatic and terrestrial habitats. Barriers to aquatic organisms are defined as those effects and sources that contribute to the blocking of natural migration regimes. The definition of the land fragmentation group would be the same context but within the framework of terrestrial habitats and organisms.

With the land fragmentation analysis performed using GIS, and the data collected, it is proposed that management efforts are focused in the eight critical sub-watersheds/risk regions denoted with risk rankings of 6. These areas are at the greatest current risk from land fragmentation and much of these areas are in critical wetlands, riparian, and core forest habitats. With the GIS approach taken to assess land fragmentation within each sub-watershed it is possible to increase the quality and specificity of the index used. This can be accomplished by including variable beyond proximity to roads including proximity to wetlands, edge permeability, agricultural field permeability, etc.

**Acknowledgements:**

Certain individuals, groups, and organizations provided significant input and resources in order to effectively assess the risk of land fragmentation to the Lake Champlain Basin. Project managers including Breck Bowden and Pooja Kanwar provided direction and collaboration between groups which served as an invaluable asset. The sources and habitat groups provided important data sets for the GIS analysis such as the watershed and sub-watershed layers. A number of GIS data sets were used from VCGI, NY Clearinghouse, and GeoGratis (Vermont’s, New York State’s, and Canada’s central locations for storing GIS data). Ernie Buford, a GIS professor within the Rubenstein School also provided important direction in designing the structure of the GIS analysis and providing resources for GIS data layers. Pam Johnston was an invaluable resource to our group. As a graduate student who had previous experience with land fragmentation work, she was able to provide a number of helpful articles and studies relating to land fragmentation.
**Literature citations:**


### Appendix:

<table>
<thead>
<tr>
<th>Watershed/Risk Region</th>
<th>Percent Habitat Cover Types</th>
<th>Fragmentation Index Score</th>
<th>Final Index Score (F)</th>
<th>Risk Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burlington Bay</td>
<td>0.15</td>
<td>23.70</td>
<td>3.63</td>
<td>6</td>
</tr>
<tr>
<td>St. Albans Bay</td>
<td>0.31</td>
<td>96.50</td>
<td>30.33</td>
<td>6</td>
</tr>
<tr>
<td>Shelburne Bay</td>
<td>0.38</td>
<td>131.30</td>
<td>50.55</td>
<td>6</td>
</tr>
<tr>
<td>Lake Champlain (direct)</td>
<td>0.48</td>
<td>197.80</td>
<td>94.95</td>
<td>6</td>
</tr>
<tr>
<td>Northeast Arm</td>
<td>0.46</td>
<td>213.40</td>
<td>98.91</td>
<td>6</td>
</tr>
<tr>
<td>South Lake B</td>
<td>0.69</td>
<td>320.20</td>
<td>220.12</td>
<td>6</td>
</tr>
<tr>
<td>Otter Creek</td>
<td>0.60</td>
<td>395.10</td>
<td>237.65</td>
<td>6</td>
</tr>
<tr>
<td>Port Henry</td>
<td>0.51</td>
<td>514.10</td>
<td>264.03</td>
<td>6</td>
</tr>
<tr>
<td>Mallets Bay</td>
<td>0.76</td>
<td>411.20</td>
<td>311.02</td>
<td>4</td>
</tr>
<tr>
<td>Isle La Motte</td>
<td>0.74</td>
<td>426.00</td>
<td>316.54</td>
<td>4</td>
</tr>
<tr>
<td>Main Lake VT</td>
<td>0.80</td>
<td>405.30</td>
<td>324.38</td>
<td>4</td>
</tr>
<tr>
<td>South Lake A</td>
<td>0.70</td>
<td>548.30</td>
<td>381.72</td>
<td>4</td>
</tr>
<tr>
<td>Missisquoi Bay</td>
<td>0.68</td>
<td>725.80</td>
<td>495.42</td>
<td>4</td>
</tr>
<tr>
<td>Cumberland Bay</td>
<td>0.87</td>
<td>926.40</td>
<td>802.87</td>
<td>2</td>
</tr>
<tr>
<td>Main Lake NY</td>
<td>0.89</td>
<td>950.90</td>
<td>843.29</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Risk Rank</th>
<th>F Stat Range</th>
<th>Note: Habitat Cover Types included Forest, Brush, and Wetland</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>0 - 281</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>282 - 563</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>564 - 844</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Summary of Fragmentation Index and Relative Risk Ranks by Watershed

### Sources of Stress Matrix

<table>
<thead>
<tr>
<th>Effect Link</th>
<th>Agriculture</th>
<th>Urban</th>
<th>WWTP</th>
<th>Dams</th>
<th>Roads</th>
<th>Fisheries</th>
<th>Marinas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effect Importance</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Effect Link</th>
<th>Forest</th>
<th>Industrial</th>
<th>Parks</th>
<th>External</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effect Importance</td>
<td>0</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Impact Link</th>
<th>Open Water &gt;6'</th>
<th>Open Water &lt;6'</th>
<th>Developed</th>
<th>Forest</th>
<th>Herbaceous</th>
<th>Agriculture</th>
<th>Wetlands</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact Importance</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 2: Impact and Effect matrices for link and importance within the context of Land Fragmentation
Graph 1: graph depicting the final fragmentation index scores by sub-watershed to display the relative risk associated within each watershed from land fragmentation.
Figure 1: Land Fragmentation in the Lake Champlain Basin

Right: Map depicting the amount of roads present in the Lake Champlain Basin broken down by watersheds/risk regions

Legend
- Sub-Watershed
- Road Center-lines

Left: Map depicting land use/land cover type throughout the Lake Champlain Basin

Legend
- blank
- Urban
- Agriculture
- Brush
- Forest
- Water
- Wetland
- Barren
- Urban/Open

Source:
- Roads (VCGI, GeGrails, NY State Clearinghouse)
- Land Use/Land Cover Type (VCGI)
- Sub-Watershed Boundaries (VCGI)
Figure 2: Relative Risk Scores Associated with Land Fragmentation by Sub-Watershed

Legend

- High Risk (4-99)
- Moderate Risk (100 - 495)
- Low Risk (496 - 843)

Source:
- Roads (VCG, GeoGrafs, NY State Clearinghouse)
- Land Use/Land Cover Type (VCG)
- Sub-Watershed Boundaries (VCG)

Note: Land Fragmentation Index raster layer was developed using the two base layers (Figure 1) including road center-lines (processed using a proximity analysis) and land use/land cover.