Mitigating the Effects of Roads on Wildlife

For: Cold Hollow to Canada

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Executive summary

Wildlife-vehicle collisions have been reported to be the leading cause of vertebrate death in the United States, “with approximately one million vertebrates a day killed on the roads in the United States” (Putman 1997). Our group is working with Cold Hollow to Canada (CHC), a non-profit organization that aims to protect wildlife habitat and connectivity across the entire Northern Forest. This paper will address the deleterious effects forest fragmentation has on forty species of importance in the CHC region located in northern Vermont. The goal of our report is to increase landscape permeability[1] throughout the CHC region by proposing the implementation of appropriate and effective wildlife crossing structures. Our results will be given to the citizen science group, *Wildpaths,* to inform them about how to reduce the negative effects of roads on wildlife populations.

In order to have some context on the underlying drivers of road kill in the region and their change over time, we performed an I=PAT analysis. In the second section, a map analysis using GIS was conducted to determine the roads most in need of crossing structures. This was done by combining layers of existing culvert data, biodiversity hotspots, aquatic habitats, forest cover, and AADT (Average Annual Daily Traffic). Roads were ranked from highest priority to lowest as a guide for the monitoring of CHC’s citizen scientists. A literature review of 40 species in the CHC region was also conducted. The literature review was carried out to determine species habitats, species behavior, road avoidance type, as well as a crossing or mitigation structure that was best suited for the species. The design and material preference of the crossing structure was also accounted for in the review. All this information was compiled in a table for our client and their citizen scientists.

Our contextual quantitative analysis showed a strong relationship between traffic and population density in the CHC towns, implying that exurban sprawl, a leading cause of fragmentation through land use change, has an important effect on the environment. This means that future development will need to be planned in order to counter habitat loss. In the context of this study, however, given our time and resource constraints, the focus will be on shorter term solutions.

Our goal is to mitigate the effects of roads on wildlife by recommending effective crossing structures. After thorough research, we concluded that the highest priority road segments were Jay Rd. (Richford), Vermont State Route 118 (Belvidere), Bakersfield Rd. (Fletcher), and Vermont State Route 118 (Montgomery). The literature review suggests that a series of crossing structures must be installed to accommodate both large and small species. The structures must also be suitable to the preferences of the species in the area. Culverts with a high openness ratio, detritus-lined floors and grates for airflow and light penetration are optimal for multi-species use.

Our goal is to provide Cold to Hollow Canada with a framework with which they can actively address the problem of biodiversity loss in relation to roads of the Cold Hollow region.

[1] Landscape permeability is defined as the ability for animals to move about a landscape freely (Bissonette and Cramer, 2008)

We do this by recommending mitigation strategies that we found to be most effective for species in given habitats.

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Section 1. Introduction

1.1 An Introduction to Road Ecology:

Our society relies on the convenience of the roads system, with no regard for its devastating effects on local wildlife. We rely heavily on roads as a means to maintain human connectivity. This study documents the ways in which roads and their construction affect natural habitat and wildlife populations (van der Ree et al., 2011). Roads cut through natural habitats, causing fragmentation, disturbing complete ecosystems, and provoking environmental damage (Forman, 2003). The study of road ecology thus seeks to improve the interaction between our road system and affected species.

This research project focuses on road ecology in Northern Vermont's Cold Hollow to Canada region. Our goal is to help protect the region's local wildlife by increasing landscape connectivity through the implementation of crossing structures.

1.2 The Effects of Roads on Wildlife:

One often neglects the intrinsic value of nature when engaging in society's vehicle-based transport system. The negative effects of roads are extensive and far-reaching, particularly on wildlife populations, an area of typically low concern. According to Trombulak and Frissell (2001), the presence of roads can modify animal behavior through five mechanisms: the shift of species' home ranges, altered movement patterns, altered reproductive success, changed escape responses, and impacted physiological state. Roads cause both direct and indirect effects to our environment, both from physical habitat fragmentation and from the extending effects. The "barrier effect" causes population fragmentation (Coffin, 2007), which is when populations of animals are subdivided into smaller groups; consequently, genetic exchange between groups ceases because roads act as a barrier. Species are more prone to local extinctions in these situations. ‘Landscape connectivity’, “the degree to which the landscape facilitates animal movement and other ecological flows” (Clevenger & Huijser, 2011), is optimized when there are large expanses of habitat without barriers, allowing animals to meet their biological needs by moving freely. It is also crucial for animals to be able to disperse in order to minimize inbreeding depression (Clevenger & Huijser, 2011).

Among the negative effects brought on by roads is the introduction of a phenomenon entitled the “road-effect zone”: significant ecological effects can be detected some distance from the road itself (van der Ree, 2011). According to research conducted by Eigenbrod et al. (2009), of the seven species studied there were strong negative effects on four of them, per the road-effect phenomenon (van der Ree, 2011). These effects had an impact up to 250 meters away from the road surface. Another study indicated that roads’ effects extend 100 to 800 meters from their edge, making a total of 15-22% of US land impacted by roads, by conservative estimates (Andrews, Gibbons, and Jochimsen 2008). Microclimatic changes can occur at great distances from roads, changing the vegetation and having the potential to seriously harm ecosystems. Furthermore, road edges are problematic in themselves as they are human-induced and thus have an unnatural, linear shape (Coffin, 2007). Finally, roads impede animal movement and migration patterns, resulting in road kill and injury to wildlife.

In general, roadsides as an environment are windier, more turbulent, hot, dry, and sunny (Coffin, 2007). They impact biotic and abiotic components of the environment, indirectly impacting wildlife through habitat change. These changes include altered hydrological systems as sediment and debris transport increases, altered water and air chemistry, and increased noise, wind, and light levels adjacent to the roadside. The changes to the hydrological system are particularly impactful as many vulnerable species tend to be found in wetland habitats (Andrews, Gibbons, and Jochimsen 2008). Road construction is also harmful as it introduces heavy metals, ozone, salt, and organic molecules into the ecosystem (Trombulak & Frissell, 2001). Increased concentrations of dust in the air settles on vegetation, inhibiting their photosynthesis and transpiration (Coffin, 2007), while toxic chemical runoff enters nearby streams or groundwater reserves (Coffin, 2007). The spread of dust and reduction in moisture extends past construction. In 1991, there were as many deaths associated with motor vehicle pollution as from direct motor vehicle collisions, causing pollution to be the most significant indirect environmental effect of road-related transport (Coffin, 2007). Finally, increased noise levels can interfere with birds' communication, depending on frequency.

There are identified positive effects as well, including the provision of new habitat by roadside vegetation, though species inhabiting these areas have to deal with the negative effects of noise pollution from their proximity to the road (Van der Ree, 2011). Furthermore, roadside vegetation species are often invasive, as roads comprise a convenient system of dispersal for such species. Indeed, species that do benefit from roads are generalist species, able to exploit highly variable ecological conditions and use the road to their advantage to spread and persist, including invasive species (Coffin, 2007).

1.3 The Importance of Biodiversity:

A decline in biodiversity is a major component of the current rapidly accelerating global environmental change. Biodiversity loss includes species extinction, as well as change in the combination of species genotypes, populations, functional groups, and ecosystems that allow for their structure and function. An increasing human ecological footprint leads to a decline in biodiversity; as such, genetic and species biological traits conducive to ecosystem functioning are lost. Loss in ecosystem function, such as biomass production or nutrient cycling, can drastically alter ecosystems that benefit humans (Cardinale et al., 2012). According to the World Wildlife Fund, global LPI indexes indicate that vertebrate populations have been declining steadily for the last 40 years (McLellan et al., 2014). One of the main threats to biodiversity decline is habitat loss, in which a habitat is no longer inhabitable by its native species. Habitat loss and degradation[2] are main threats to biodiversity decline, through the cyclical process of environmental deterioration from human development. Moreover, Forman states that there is a time lag between when habitat loss takes place and when ecological effects are detectable (2003). Therefore, vertebrate population mortality from motor vehicle collisions is only visible once traffic has already increased significantly (given a steady increase) (Forman, 2003).

Vermont is a unique ecosystem. Part of a temperate deciduous forest biome, it is home to a wide variety of species. The American state encompasses multiple mountain ranges all included within the Great Appalachian Mountains. Within the state's range we find the Green Mountains, the Taconic Mountains, and the Piedmont Mountains (Allen et al., 1986). As a landscape filled with valleys, lakes, watersheds, and a 78.2% forest coverage (Wildmann, 2006), the Green Mountain State comprises large biodiversity and serves as a habitat link for a North Eastern habitat network. In this state-wide forest biome we find more than 250 species of birds, 54 species of mammals, 11 species of snakes, dozens of amphibians, and thousands of insects (Klyza & Trombulak, 1999). Although this heterogeneous topography and vegetation supports large

[2] In this paper we refer to both habitat loss and degradation, the primary concern being habitat destruction. Fragmentation is a type of habitat destruction in which habitat is not totally lost, but is broken into smaller pieces thus reducing its quality.

biodiversity, complex movement patterns emerge as the local species look to meet their daily basic needs from the different habitat patches (Gross et al., 1995), whereby contact with roads occurs. The forest is deeply ingrained within Vermont's cultural heritage; it plays an important role in the local economy through tourism, industry, and the provision of raw materials (CHC, 2015). Our area of research focus is along the Cold Hollow Mountains, off the western face of the Green Mountains' main range. It stretches 51 km south from the Quebec border and includes these seven towns: Bakersfield, Belvidere, Enosburg, Fletcher, Montgomery, Richford, and Waterville(figure 4).

Our first visit with our client, Cold Hollow to Canada (CHC), confirmed the ecological importance of the Northern Forest. We learned about the forest range, the species that inhabit it, and the relationships of the local inhabitants to the forest. We also learned about the area's road network and its effect on the environment. Solutions and strategies to avoid and limit these negative effects exist and have been used in the state of Vermont. We observed physical strategies for road ecology damage and roadkill mitigation such as culverts, bridges, road signage, yet more strategies of mitigation and avoidance are needed, a task taken on by CHC.

1.4 Quantitative Analysis as Context: I=PAT and Connectivity

Since the 1960s, environmentalists have looked for ways to quantify ecological impact. An important quantitative analysis of anthropogenic impact dates back to Ehrlich and Holdren' s (1971) I=PAT equation, in which ecological impact is the result of three drivers: population, economic affluence and technology. To set up the context of our research, we use a conceptual model derived from the I=PAT equation to understand the ecological impact over time in the Cold Hollow to Canada region. The general formulation of the I=PAT equation goes as follows:

$$Environmental\ impact = Population \times Affluence \times Technology$$

Where each factor is defined such that:

$$Environmental\ Impact = Population \times \frac{total\ income}{population} \times \frac{environmental\ impact}{total\ income}$$

The factors within each variable eventually cancel each other out, however this elaboration allows us to identify the baseline drivers of impact.

For the more localized context of Cold Hollow to Canada, we derive the IPAT equation according to our main focus, by adding a "biodiversity loss" variable into the equation.

Biodiversity loss in CHC = Human population of CHC x Per-capita Income of CHC x Biodiversity loss per dollar of income CHC

$$Biodiversity\ loss\ in\ CHC = human\ population\ of\ CHC \times \frac{total\ income}{population} \times \frac{biodiversity\ loss}{total\ income}$$

As a final step, we further expand the IPAT equation to include our focus variable, road disturbance. Our environmental impact variable is assumed to be defined by the Average Annual Daily Traffic (AADT) for the Cold Hollow to Canada region. We simplify the definition of impact to reflect that a major factor of the impact of roads on the environment is traffic:

$$Biodiversity\ Loss = Human\ Population\ of\ CHC \times \frac{total\ income\ of\ CHC}{human\ population\ of\ CHC} \times \frac{AADT\ Car\ traffic\ CHC}{total\ income\ of\ CHC} \times \frac{biodiversity\ loss\ in\ CHC}{AADT\ Car\ Traffic\ CHC}$$

This conceptual model allows us to observe the drivers of biodiversity loss independently. Our project will focus on the last factor in our expanded equation: biodiversity loss per unit of car traffic, as we look to reduce negative road effects of the biodiversity through the implementation of mitigation strategies such as road culverts, bridges and other such infrastructure. Our second focus is the technological factor of the expanded equation, as we look at ways to reduce car traffic of CHC per unit of income for the longer term, through the removal of secondary roads, as well as the reduction of general road usage.

This equation highlights the drivers of ecological impact in the CHC context. Our results show their varying influence on the overall ecological impact over the last 20 years. There are three options in overcoming the effects of roads: road removal, population reduction, or mitigation. By the results of our analysis, as well as for the scale at which we are working, we see why it would be feasible to focus on mitigation, i.e. changing animal behaviour, rather than introducing human population-wide or structural changes (Forman, 2003).

<u>1.5 Results of I=PAT Analysis:</u>

We began this analysis by comparing the change in population, affluence and technology (defined in our study as impact/per unit of total income) in the whole of the Cold Hollow to Canada region over the last 23 years. Impact is defined as the AADT for CHC. This time frame was chosen due to date availability and the income values were corrected for inflation.

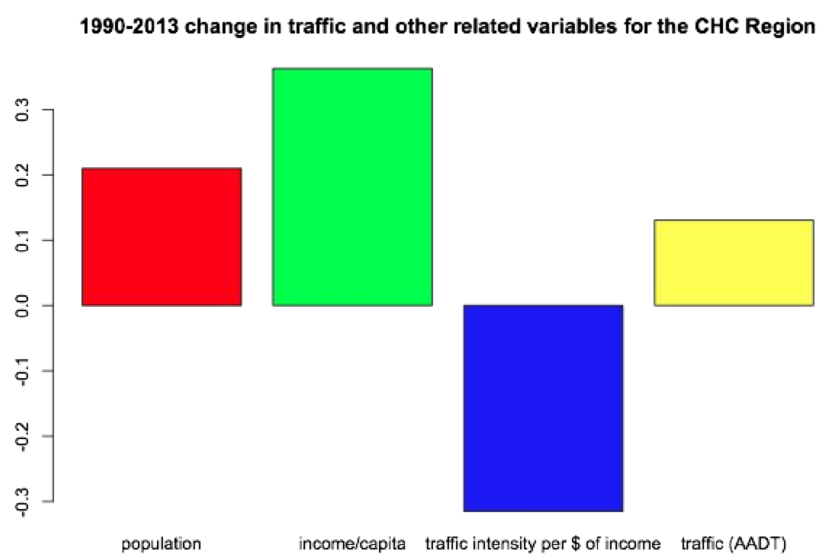


Figure 1: Bar graph of the change in I=PAT variables for the CHC region from 1990 to 2013.

Looking at the ratios of each variable over the studied time period, affluence appears to change most dramatically with an increase of approximately 36%. Meanwhile, the population in CHC has increased by 21%. The impact of technology (traffic intensity per dollar of income) over the 23 years, has on the other hand decreased, by 30%. The impact variable, defined by AADT, has increased by 13% over time (*Figure 1*). Our I=PAT equation analysis reiterates that ecological impact in the CHC region has increased over time, through the increase in traffic. Upon completion of these statistical analyses, the regression of each of the variables resulted in statistically insignificant p-values above 0.05. Despite the universal use of the I=PAT equation, it appears, following our analysis, this equation does not apply appropriately to small towns, such as those in CHC. Our analysis is skewed because of our preset definition for technology. A more complete definition of this variable that account for more than simply annualized average daily traffic per unit of total income would better represent the impact the road use has on the environment. For example, the variable should account for the way roads have fragmented habitats, polluted the environment, caused sedimentation, and introduced a "road-effect zone".

Upon an additional regression done with population density data, we found that there was a relationship between humans per square km and traffic (AADT) (*Figure 2)*. The relationship between AADT and human residents per km^2 is illustrated on a log graph. Based on our results, we see a positive relationship between AADT and population density. Enosburg, the largest town in CHC, has the highest human density and highest AADT while Belvidere, one of the smaller towns in the area, experiences the least amount of AADT and has low population density.

Population density in the state of Vermont is related to a phenomenon known as exurban sprawl: scattered rural residential development near (oftentimes protected) biodiversity areas, originating from individuals who wish to retreat away from urban areas. This results in housing locations removed from the town center, which give the impression of solitude. Ironically, exurban sprawl, driven by the desire to live within "nature," necessitates road construction and infrastructure, eventually fragmenting landscapes and inhibiting forest connectivity. Exurban land use in the US occupies 5 to 10 times more land than urban or suburban densities, and is growing at a rate of 10-15% annually (Theobald, 2005). The relationship between traffic and population density supports the idea that ex-urban sprawl and forest fragmentation are key drivers of impact. Therefore, we believe that urban planning in the CHC region must incorporate high-density development as population continues to increase, i.e. growth must be accounted for in development to ensure the protection of wildlife and the environment. In the meantime, our project seeks to mitigate the effects of growth on ecological impact within our capacity.

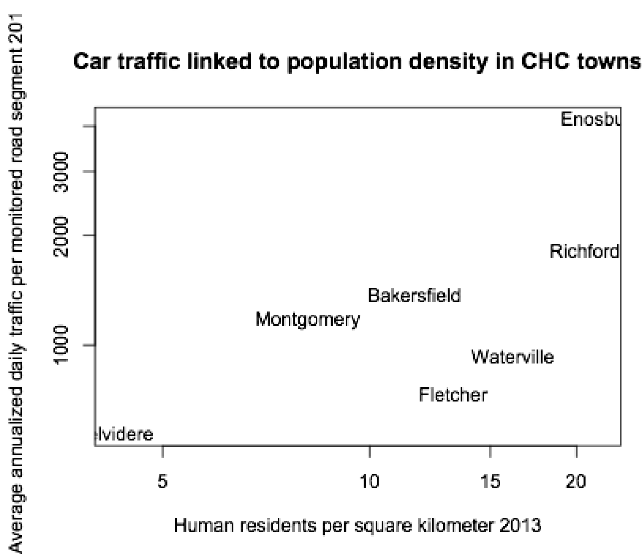


Figure 2: The amount of car traffic in the CHC region vs. town population for each of the 7 towns in the CHC region.

1.6 Our Client:

Cold Hollow to Canada is a local non-profit conservation organization that aims to protect the forests, their connectivity role, and the overall ecosystem services they provide with respect to the area. Based across seven small towns along the Cold Hollow Mountain range, CHC focuses on decreasing forest and ecosystem fragmentation and its adverse effects to the forest through the mitigation of man-made barriers such as roads. CHC has an overarching goal of protecting over 40% of Vermont's unfragmented forest, identified under the Priority Forest Blocks. Currently only 20% of forests are protected (CHC, 2015). The nonprofit works to achieve this goal with the help of volunteer programs.

Partnered with larger conservation organizations such as *Nature Conservancy*, the *Vermont Natural Resource Council* and the *Vermont Land Trust*, CHC serves as a link between the local population of CHC and larger conservation groups .

Cold Hollow to Canada takes a 'citizen science' approach to conservation through *Keeping Track* and *Wild Paths*, two animal tracking programs in which CHC participates:

- *Keeping Track* is a volunteer program based on citizen science that provides training to track and identify signs of the presence of species that are indicators of ecosystem health. This training aims to empower the community to be more ecosystem-aware and to complete their own ecosystem monitoring over the long term. This program is focused on species sightings within the forest.
- *WildPaths* is the second volunteer program in which Cold Hollow to Canada participates. Also utilizing the framework of citizen science, *Wildpaths* aims to encourage the locals to identify and share roadkill signs, and overall wildlife activity on the sides of roads. The goal is to

compile significant data on the observed ecological disturbances caused by roads in CHC to deduce where and what wildlife is most likely to be at risk. As a local nonprofit conservation organization and through its partners, CHC can further influence statewide policy on the location and implementation of mitigation and protection strategies.

1.7 What is Citizen Science?

With rise of ex-urban sprawl and the occupancy of wildlife habitat by residential area, citizen science emerges as a useful tool in evaluating human influence on ecosystems (Cooper et al., 2007). According to Cooper et al., citizen science "engages a dispersed network of volunteers to assist in professional research using methodologies that have been developed by or in collaboration with professional researchers", thus aiding in data collection (2007). It is collaborative in nature; citizen science is beneficial for increasing environmental democracy, scientific literacy, citizen inclusion, and social capital (Conrad & Hilchey, 2011). It makes scientific information more accessible to the public, while also increasing scientists' awareness of local knowledge. Citizens involved in citizen science research are more engaged with local issues and community development. One of the benefits of citizen science is that large geographic areas can be studied extensively. In the case of Cold Hollow to Canada, the whole area of the seven towns can be extensively studied, even though the towns are relatively sparsely-populated.

It is important to clarify that our research project does not directly employ citizen science methodology; rather, it is the framework under which our client, CHC, operates. We hope that our research will supplement/benefit CHC, allowing them to be more informed in their citizen science as we provide them with relevant scientific data and deliverables (a species table and road segment ranking list).

1.8 Species of Interest:

Anurans have suffered significant consequences relating to roads and traffic. They are most likely to have reduced abundance near roadways, though this exact relationship depends heavily on the specific species and its behaviors (van der Ree, 2011). For example, it is known that the Northern Leopard frogs' migration is impacted as roads cause them to deviate from linear paths, thus spending more time on roads in the presence of traffic. Such changes in animal movement in response to roads varies among species, and as such, a compilation of species' behaviors is a component of our project. Herptiles possess biological characteristics that make them more susceptible to the effects of roads, including high skin permeability, thermoregulatory body processes, and reliance on olfactory and pheromonal cues for migration and orientation (Andrews et al., 2008). They are therefore more prone to endocrine disruption and must exert more energy to maintain optimum moisture levels. As herptiles have increased vulnerability to the effects of roads, we studied 29 species of herptiles with ranges overlapping the CHC area and their characteristics with regards to roads.A

We also focused on ten additional species found in the CHC region, being the ten animals of focus in the CHC *WildPaths* program. These species are indicative of healthy habitats. These species include small and large mammals (Appendix: Species Table).

1.9 Mitigation of Road Effects

Roads possess many different variables that can deter animals: traffic volume, traffic speed, road width, habitat alterations, etc (Clevenger & Huijser, 2011). For this reason, we will be primarily examining physical structures but will also look into mitigation strategies that focus on changing human behavior. Mitigation structures increase landscape permeability and reduce collisions (Clevenger & Huijser, 2011). Structure siting is as important as the design, so our research will examine both these things with GIS and a literature review. According to Glista, DeVault and DeWoody (2009), it is much more effective to implement mitigation strategies that alter animal behavior rather than human behavior. Animal modifications include the installations of wildlife crossing structures, such as exclusion fences, culverts, and overpass and underpass systems. Culvert systems can be used by a variety of species, and are among the most economical out of all structures. Sometimes they are too small to be used by larger mammals, but are generally versatile and can be modified with water/vegetation/natural substrate to be more appealing to animals. Pipe, or circular, culverts are usually built for the purpose of water divertment while box culverts or rectangular culverts are often times bigger and generally built for the purpose of wildlife movement. They also allow for waterstream passage if necessary. Wildlife passages can be outfitted with ledges in case of heavy water flow. To decrease animal mortality, animal habitats can be modified, such as with the planting of unpalatable vegetation near roadsides to prevent animals from habiting there, or the channeling of animals to designated locations (Forman, 2003).

Nonetheless, mitigations strategies concerning human behavior can also be considered, including reduction of speed limits, installation of roadside lights, and warning signs. Speed bumps can be integrated into road systems to reduce speed, as high-speed traffic is one of the main causes of collisions, as well as an improvement of motorist field-of-view, restriction of roads during critical times such as migrations, or implementing traffic calming techniques (structures that reduce speeds). Our study focuses mostly on mitigation structures that can be introduced to pre-existing roads (Forman, 2003).

<u>Section 2. Research Question/ Hypothesis</u>

The main goal of this study is to provide the *WildPaths* citizen science program with sufficient information and direction to decrease the deleterious effects of fragmentation, caused by roads, in the Cold Hollow to Canada Region. In order to do this we have formulated two questions that we would like to answer. The first question is: Which are the highest priority road segments for the implementation of mitigation strategies in the CHC region?

After some initial research and analysis using GIS mapping program, we hypothesize that the 118 state highway in the Belvidere region is the road that will have the greatest need for mitigation strategies in the CHC region. We base our hypothesis on the fact that this road appears to intersect through high quality wetlands habitat (a habitat of high animal activity), there is a dearth of culverts or crossing structures, and the abundance of recorded road kill from the past. In addition to this road this study will have a ranking of roads based on a GIS analysis in which there is a vital need for crossing structures in the Cold to Hollow Canada region.

The second research question we ask is: What mitigation strategies are best for a species or species groups? And how can these mitigation strategies be best implemented for animal behavior and preference?

Through our preliminary literature review, we conclude that multiple culverts and underpasses in high crossing regions will be the best strategies for mitigation. By grouping together species that live in similar habitats and identifying their crossing strategy preference, our research can help CHC reach an optimal crossing structure solution.

Section 3. Methodology

3.1 Modeling: I=PAT

Given the importance of the Cold Hollow to Canada region's ecosystem, it is important to evaluate the context of our region quantitatively to determine the drivers of ecological change in the area. In order to evaluate these changes and provide insight to the context of our research question, Ehrlich and Holden's I=PAT equation (1971) was employed in this study. This equation is recognized as a standardized equation to determine the anthropogenic impact on the environment of a given area using a through a quantitative framework.

Environmental scientists have used this equation to measure the increasing global impact of anthropogenic activity, as well as to compare this impact between countries. The equation highlights the significance of population growth in accordance with wealth and technology, as key drivers of environmental damage. The equation measures environmental impact using the multiplicative of three variables assumed to be equally influential.

For the purposes of our paper, we have modified the equation to the following:

$$\textit{Biodiversity Loss} =$$

$$\textit{Human Population of CHC} \times \frac{\textit{Total Income of CHC}}{\textit{Human Population of CHC}} \times \frac{\textit{AADT Car traffic CHC}}{\textit{Total Income of CHC}} \times \frac{\textit{Biodiversity Loss in CHC}}{\textit{AADT Car Traffic CHC}}$$

The use of this equation in our research is to determine the change in impact over time in the whole CHC region. We retrieved population (P) and income (A) data for each of the seven towns in the CHC region between 1990 and 2013 from US Census (while correcting for inflation) and city-data.com/income-vermont. We summed the population data while we averaged the income data to represent all of CHC. We assume impact(I) to be the Average Annual Daily Traffic (AADT) for the context of Cold Hollow to Canada. As technology (T) is generally defined as impact per dollar, T refers to AADT per dollar of the average income from those 7 towns. AADT data was retrieved from Vermont Transportation Agency database. The change in impact thus accounts for the entire CHC region. To calculate change in each of the variables between 1990 and 2013 we used the equation ((*Income in* 2013 - *income in* 1990*)/ Income in* 1990) to compare the importance of each of those changes.

3.2. GIS Component:

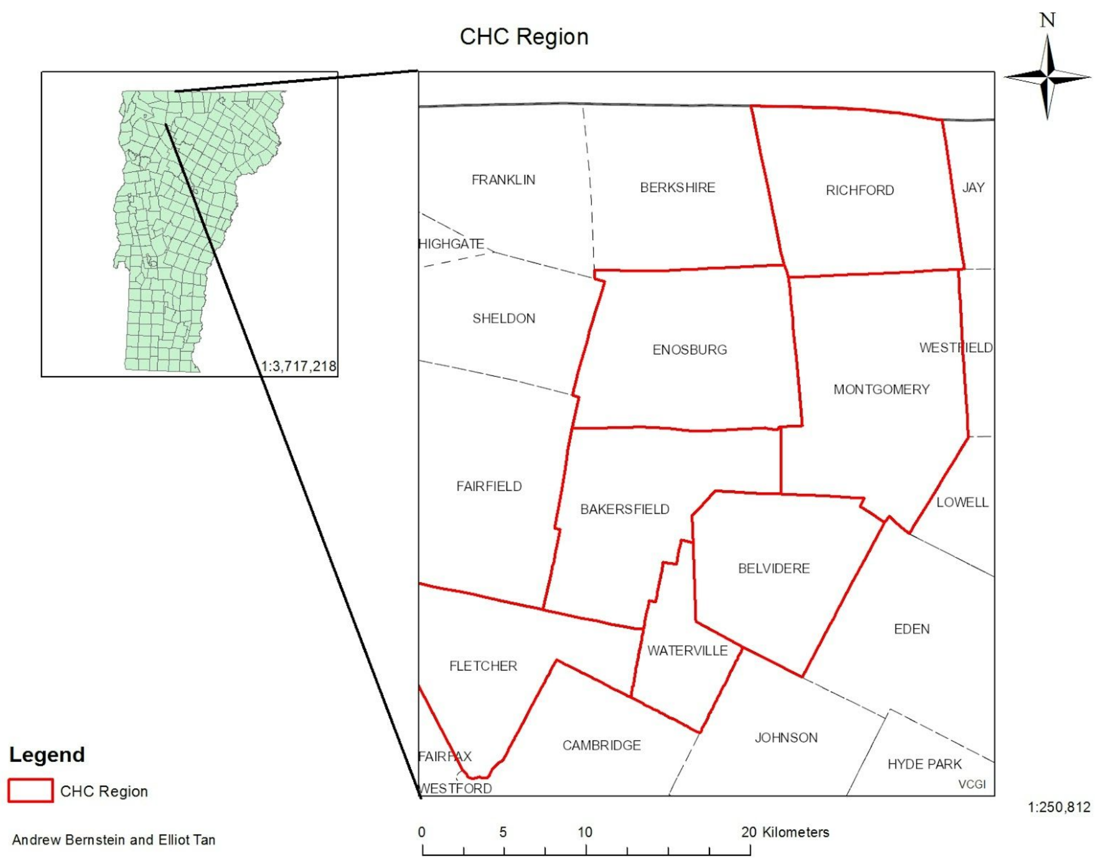


Figure 3: 7 towns in the CHC region

In order to locate areas of likely animal crossings (referred to as 'hotspots' for the purpose of this paper), we conducted a GIS analysis through ArcGis 10.3.1. All GIS layers were downloaded from the Vermont Center for Geographic Information's open GeoData Portal (Vermont Center for Geographic Information, 2015).

To create a base map, we used vector data consisting of town boundaries and roads, clipped for just the CHC region. Subsequent data downloaded would also be clipped to account for just the CHC region in our analysis.To define the criteria for a hotspot, we used a combination of surrounding habitat and infrastructure qualities. The specifics of the criteria are as follows:

1. *Vermont Agency of Natural Resources BioFinder Tiered Contribution to Biodiversity Data* (Vermont Agency of Natural Resources, 2013):

After working with the Vermont Agency of Natural Resources' online GIS software 'BioFinder' (Vermont Agency of Natural Resources, 2013) for our startup assignment, we decided to use their Tiered Contribution to Biodiversity Data (TCBD) as a main component of our hotspot criteria. TBCD data was chosen as a component of our GIS hotspot analysis because it represents the areas with high biodiversity, indicative of rich wildlife activity.

The TBCD is a core component of the BioFinder program, comprising 21 different components of biodiversity (see Appendix 3.3, Figure 1). These 21 components are analyzed within a 10m x 10m location in Vermont, and placed into one of six tiers (Vermont Agency of Natural Resources, 2013). Each tier represents a concentration of component contributing to biodiversity, with Tier 1 having the highest recorded concentration of components and Tier 5 the lowest recorded concentration of components; Tier 6 represents a lack of these components. This data was downloaded in the form of a raster file, with different shadings depending on the tier. In order to conduct analysis on this layer, we converted the raster file into polygons, and cut out the non-Tier 1 data.

2. Aquatic Habitats

Water bodies, rivers, and wetlands were merged to create a single layer for aquatic habitats. Given that a large proportion of our species list is made up of species that reside primarily around water bodies, creating a separate layer for aquatic habitats further defines areas of potential crossings. These were downloaded in the form of polygon and line shapefiles[3].

3. Culverts

Culverts were chosen as component of hotspot as they are fairly versatile in their application and cost (Forman, 2003), and the data is easily accessible through the Vermont Center for Geographic Information's website[4]. These were downloaded in the form of point shapefiles.

Methods of analysis:

A series of analyses in arcGIS was next conducted in order to identify roads that require a mitigation strategy according to the above criteria.

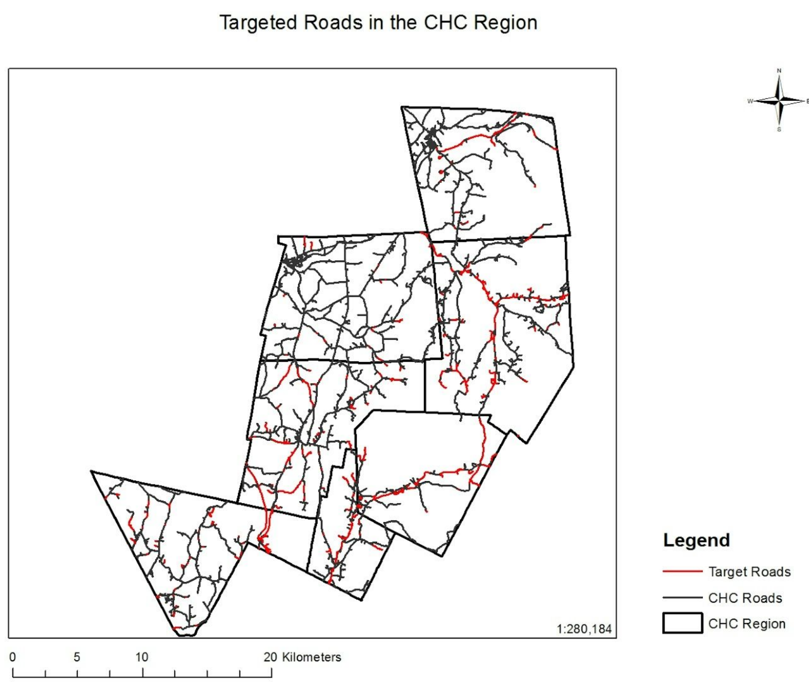
1. Buffered and dissolved culverts for a radius of 200 meters around each culvert (Dissolved Culverts Layer).
2. Buffer and dissolve BioFinder Tier 1 layer data for 200 meters (ClippedBio200 Layer).
3. Intersect roads, wetlands, water bodies, and rivers.
4. Merge dissolved Biofinder data and intersect data from step 3. (MerBioWR200 Layer).
5. Merge BioFinder Data, intersect data, and dissolved culvert data (MerBioWR200Cul Layer)
6. Erase MerBioWRcul from MerbioWR200 to get targeted roads (Targeted Roads Layer[5]).

[3] Definitions can be found in the glossary.
[4] The culvert database is not 100% accurate; non-inventoried culverts were found during our field study.
[5] See appendix for pictures of this layer.

Methods of ranking:

To create a list of ranked roads of importance, we did further analysis on the targeted roads created in the previous section. This analysis was as follows:

1. Select roads based on length/ type of road[6], and clipped to make them a separate layer (AllRoads).
2. Buffered these roads for 200 m (AllRoadsBuff).
3. Combined BioFinder Tier 1-3 data and waterways (BiodivWater).
4. Created new layer which consisted of any BiodivWater layer within the AllRoadsBuff layer.
5. Calculated the area ratio of AllRoadsBuff:BiodivWater to get the percentage of area that a road radius of 200m has BiodivWater areas in it[7].



[6] Some of the longer roads were actually footpaths, and thus were not a part of this study.
[7] See appendix for map of this layer.

3.3. Mitigation

This section of the paper will focus on finding optimal crossing structures in the hotspot areas we identified. We did this by answering two questions: 1) which mitigation structures are best suited for a species or species groups and 2) how can the crossing structures be implemented in a way that accounts for individual species behavior and preferences.

The first task we undertook was deciding specific species to focus our research on. The species we decided on are the herptiles, amphibians and reptiles, of the CHC region (found in the metadata analysis by Fahrig and Rywinski, 2009 and in Peterson and Audubon Society Field Guides). We also chose species which are examined at in the *Keeping Track Monitoring Program*. These species include black bear, moose, lynx, bobcat, cougar[8], river otter, mink, fisher, timber wolf, and American martin (CHC, 2015).

We studied a total of 40 species in the Cold Hollow to Canada region. The reasoning for our decision is that the CHC organization is particularly concerned about the impact habitat fragmentation, caused by roads, is having on their herptile populations. The *Keeping Track Species* were chosen on the basis that they serve as a "natural indicator for the health of [CHC's] forests" (CHC, 2015). Thus the ability for these species to successfully travel from one natural area to another is important in maintaining the health of CHC's biodiversity.

After we determined the species, we conducted an extensive literature review to gain a thorough understanding of the effectiveness of road structures on different species. This involved searching available online databases for peer-reviewed publications, as well as agency and government reports. We reviewed both past and present research projects to retrieve as much

[8] Although cougars and wolves have not been seen recently in the CHC region, there is hope from the CHC organization that they will return. As a result, they are placed on our species list.

pertinent information as possible on what made a wildlife crossing structure successful. We then compiled all the variables that affected the likelihood of a given structure's use. These variables are organized into six different categories. These categories act as a guide for CHC's citizen science groups in identifying habitats and isolating structures that would be best suited for their region's species. The six different categories are as follows:

1. Habitat of species. When implementing a crossing structure, the surrounding habitat should always be taken into consideration, as it is indicative of the type of species that will likely use the crossing structure.
2. Road avoidance/detrimental road effects on species. This corresponds to how species react when they come into contact with a road and how the road affects their behavior (e.g. whether they are attracted to roads for thermoregulation or avoid the road at all costs).
3. Species movement. This is telling of how often a given species is likely to come into contact with a road, based on their foraging and migrating behavior.
4. Human influence. This describes how human presence influences the use of a crossing structure; for example, some species may completely avoid crossing structures that are regularly used by hikers.
5. Culvert type/ material preferences. Species are more likely to use a culvert or a bridge built with certain materials and of certain dimensions. These materials include substrate, vegetative cover, and dimensions that allow light permeability, as well as varying moisture contents and temperatures, depending on the species.
6. Best structure. This is our final recommendation on what we believe to be the best suitable crossing structure for the given species.

For the purpose of our analysis we define direct effects as physical habitat fragmentation. This results in what is known as the 'barrier effect', which is when animals are unable to move between landscapes. Barriers to species movement can cause both direct wildlife mortality and road avoidance behaviors. We have also decided to include indirect effects in our table. These are effects that can be felt hundreds of meters away from the road itself, which include habitat loss and degradation due to increased noise, water, and air pollution. While the bulk of our analysis is focused on direct impacts of roads on wildlife, we fully acknowledge the indirect effects of roads and cars on animal populations and would like to address this concern.

Field Study Day: November 28th, 2015:

The final step in our methodology was completed by an analysis of the physical area of our study. Our group visited the road segments that we identified as high priority from the GIS component of of our project. We examined road segments and assessed the quality of the current crossing structures in place, as well as the surrounding habitat and road characteristics. However, due to time constraints during our field study, we were only able to thoroughly examine the Vermont State Route 118 in Belvidere. Field study is important when assessing roads as small-scale features, such as visibility for cars on the road, is not picked up by GIS analysis.

Section 4. Analysis

4.1 . Mapping Target Roads in GIS

Target roads were identified using GIS software. They were ranked using six different variables, listed as follows:

(1) Surrounding biodiversity: Roads located adjacent to areas of high biodiversity; for example, forested areas or wetlands within 200 meters, were of importance in determining the likelihood of species coming into contact with a given road segment. Natural areas were classified into Tier 1, Tier 2, and Tier 3 biodiversity zones, ranging from highest, very high, and high contributors to biodiversity, respectively.

(2) Road Length: On longer stretches of road, wildlife is forced to cover broader distances before they encounter a crossing structure. These are areas where multiple crossing structures need to be implemented in order for the structures use to be effective.

(3) Lack of existing crossing structures: We sought out road segments that did not already have a crossing structure in place[9].

(4) Speed limit: Roads with higher speed limits make species more susceptible to road mortality, as drivers are less likely to stop in time to prevent wildlife-vehicle collisions.

(5) Average Annual Daily Traffic: Increased traffic volumes make it more difficult for species to cross roads successfully.

(6) Historical wildlife-vehicle collision data: We retrieved data from 1984-2003 on reported wildlife-vehicle collisions from the *Vermont Transport Agency.*

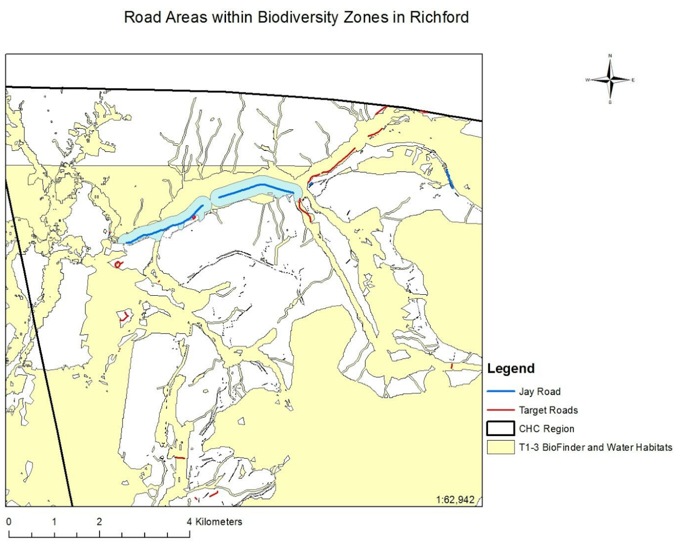
Highest Priority Road Segments:

High priority road segments have significantly large areas of habitat adjacent to them, which promote high biodiversity and wildlife movement. Additionally, they have relatively high AADT

[9] Further monitoring should take place, as the culvert data is incomplete.

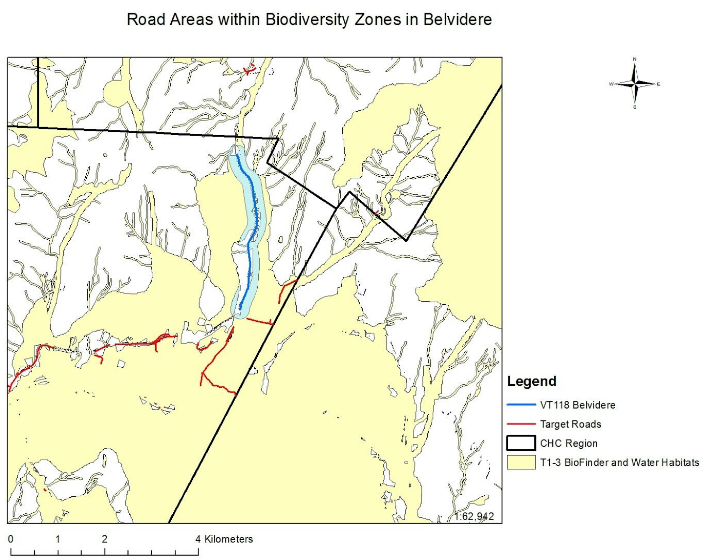
and speed limits since they are state routes.We were also able to access data on historical wildlife-vehicle collisions on a high priority road segment we identified, which corroborates our findings.

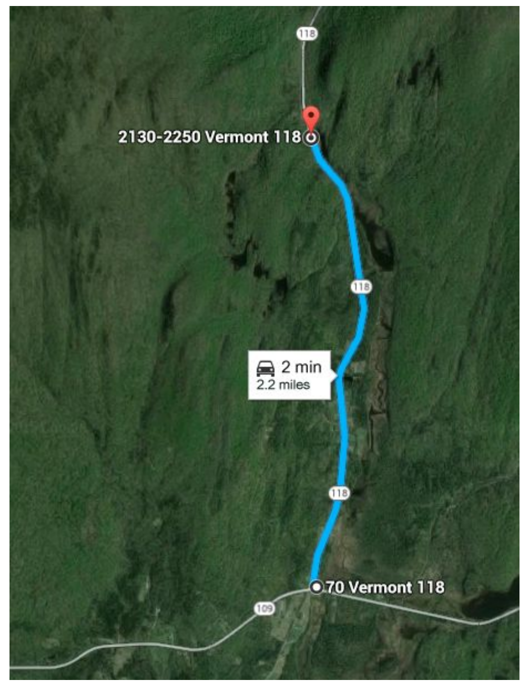
Jay Road - Vermont State Route 105, Richford



This 5 km stretch of highway runs partly adjacent to the Missisquoi river, and cuts through stretches of forest. Although the forest blocks on either side of the road are not as big as those in Belvidere, the total area of of adjacent tier 1-3 zones/water bodies is 81%. Although there is no historical data of reported wildlife-vehicle collisions, the has an AADT of 1000 cars per day and a speed limit of 55 MPH, and thus is susceptible to animal vehicle collisions.

Vermont State Route 118, Belvidere, VT:





This 3.5 km stretch of highway connects the towns of Montgomery and Belvidere. There are large continuous forest blocks on either side of the road, which act as corridors for wildlife movement. To the east of the road is the south branch of the Trout River and an adjacent stream. In addition, 67% of area within 200 m of the road is either tier 1, 2 or 3 contributors to biodiversity or water, making this environment a hub for animal movement.

The high speed limit of 55 MPH increases the likelihood of wildlife-vehicle collision. In fact, between 1984 and 2003, there were 9 reported road collisions with moose and 1 reported collision with a bear, all within a short distance or along the 3.5 km target road identified by GIS analysis[10]. There are only 18 total reported collisions[11] within the CHC region in the historic data, with 9 of them originating in Belvidere.This section of road has a somewhat low AADT compared to other high priority roads – only an average of 590 vehicles travel along this segment per day. However, with low AADT values throughout the CHC region, highways generally do not act as a barrier to road crossing for animals.

There is also a culvert under one part of this highway which is not in the Vermont Culvert Database. This culvert was identified during our visit to vermont in late November. This gap in data that should be addressed by VTrans, perhaps with help from Cold Hollow to Canada. This culvert is not ideal for large mammals, as it does not have dry or natural substrate, which is preferred by large mammals, as well as a very low openness ratio due to its long length, narrow width and short height. This does not permit adequate light to illuminate the structure, making it uninviting to many animals.

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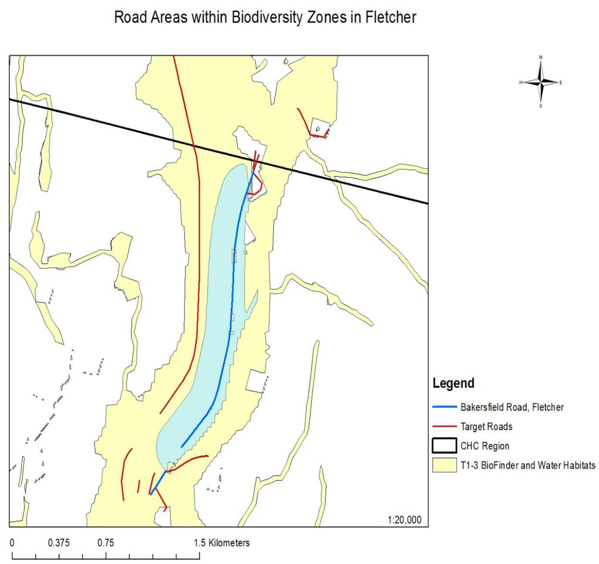
[10] Although there is a moose crossing sign, Studies show that warning signs have little effect on reducing mammal collisions (Forman, 2003)

[11] The reported collisions were mostly medium to large mammals; our study focuses on smaller wildlife, which is less likely to be reported.

Bakersfield Rd. - Vermont State Route 108, Fletcher



This road is the highway connecting Fletcher and Bakersfield. Black Creek, a meandering creek runs to the west of the road and there is a large block of continuous forest to the east.

Vermont State Route 118, Montgomery

This road runs through Montgomery and eventually leads to Belvidere, where another high priority road is located. The section we identified is next to a stretch of the Black Creek Brook and has continuous forest to the east. There also was 1 reported vehicle collision with a bear in 1997.

Medium Priority Roads

These roads have significant traffic and high speed limits, and crossing structure spacings of at least 1 km. However, the habitats around these roads are not likely to be as populated by wildlife as higher priority roads, meaning there is likely less wildlife crossing on these roads. Roads classified as medium priority are South Main Street in Montgomery, a part of the State Route 118, and Main Street North in Bakersfield, a part of State Route 108. It is important to note that although the habitat blocks surrounding these roads are not as significant, they can still be areas of collisions.

Low Priority Roads

Low Priority Roads are long stretches of road identified in GIS as likely to have animal movement, but that do not necessarily have enough traffic to have a high risk of vehicle related collision.

Roads that are considered low priority are VT-109 in Belvidere and Glen Sutton Road in Richford (VT-105A). These are state routes which are not relatively high in traffic. Other low priority roads are stretches of County Rd., Locke Rd., Bog Rd., and Old Stage Coach Rd. These dirt roads reside in residential areas[12], but they have suitable habitat on either side of the road. There are other roads that could be considered low priority, but these are the road segments that are at least 700 m long. Wildlife is not as threatened by collision on these roads, but rather the indirect impacts of roads may incur greater harm on wildlife – and so different mitigation strategies should be considered, perhaps even road removal.

4.2. Variables in Mitigation Strategies

There are many variables to take into account when placing a crossing structure. Too often, costly mitigation measures are implemented with low functionality (Podloucky, 1989;

[12] Reduced animal collisions due to lower speed

Meinig, 1989). The three main failures of such structures stem from "inadequate considerations of placement, behavior of targeted organisms, and architectural design" (Podloucky, 1989; Puky, 2003; Barnum, 2004; Woltz, 2008). The aim of our research is to address and improve on the shortcomings of unsuccessful crossing structures to provide the CHC citizen science program with information on optimal placement and design for species in their region.

To incorporate all of the factors influencing the effectiveness of wildlife crossing structures, we organized this section into three categories: (i) species behaviour, (ii) structural design, and (iii) structure spacing.

4.2.1. Behavior of Targeted Species

Wildlife Movement and Roads

The pattern of wildlife movement in the Cold Hollow to Canada region varies both spatially and temporally between species. For example, lynx have a home range of 41.7 km (Kramer-Schadt et al., 2004), but spotted salamander have a limited range of 200 m (Karraker & Gibbs, 2010). Species have with high mobility are generally more vulnerable to roads (Foreman et al., 2003). Temporally, cougars, bullfrogs, otters, wood frogs and blue spotted salamanders are nocturnal (Lynn, 2008; Brady, 2012; Morrison et al., 2015). Due to low visibility during the night, these species highly vulnerable to being hit by cars.

Seasonal migrations and movement for breeding must also be considered. Some species such as green frogs, moose, and milk snakes have high migration times during the summer (MacKinnon et al., 2005; Beyer et al., 2013; Ashley & Robinson, 1996), whereas other species such as otters migrate most during winter (Philcox et al, 1999; Mackinnon et al, 2005; Healy, 1975; Ashley & Robinson, 1996). Migration of species may be interrupted, not only due to road kill, but also due to road avoidance of species (Foreman et al., 2003). Landscape connectivity is altered and animals meet road barriers that do not facilitate movement during migration season (Foreman et al., 2003) Mitigation strategies must take these seasonal migrations into account, as there will inevitably be certain species less favored depending on the season.

In order to find breeding grounds or mates, wildlife will often migrate, as in the case of spring salamanders, eastern newts, and otters (Healy, 1975; Mazerolle, 2004; Defenders of Wildlife). For example cougar males will move up to 750 km in search of mates (Morrison et al, 2015). Other species such as snapping turtles female migrate more frequently in order to find nesting sites (Steen, 2006). The increased movement of a gender increases their contact with roads and may cause more deaths of a particular gender. This may alter the ratio of males to females for a species population and will decrease mating success thus threatening the species population. As we can see seasonal migration is important for many species in the CHC region. Each season is important for a different set of species, meaning that a mitigation strategy that focuses on one season will not encompass all species. For this reason this study does not focus on any single season to implement mitigation strategies.

Road density in roads per square mile, is also vastly detrimental to a large number of species by acting as a barrier to movement. For example, wolves fail to persist when road densities exceed .93 mile/miles^2 (Thiel, 1985) and thus are selective of areas of low road density (Kohn, 2001). Additionally the presence of roads alters the behaviour of species in close proximity to roads. For instance, black bears shift their home ranges away from areas with high road densities (Coady, 2001). With the addition of more and more roads to the land there is more fragmentation and a loss of animal habitats. Many species in the CHC region, including the ones above, will have to move home ranges with the addition of roads in the CHC.

Despite the large number of the negative effects roads have on wildlife movement, the roads themselves can create habitats for herptiles; both painted turtles and snapping turtles utilize roadside rubble such as loose sandy soil for nesting environments (HLREMP, 2013; Patrick, 2010). Although these micro-habitats may be perfect for nesting, their proximity to roads cause an increase of mortalities in both mothers and babies. Other species such as spotted salamanders lay fewer eggs close to highways which means there is a loss of habitat (Karraker & Gibbs, 2010). This is similar to the northern two-lined salamander for which roads do not act as much of a barrier as a loss of habitat (Ward et al., 2006).

Types of habitats and their importance

The 40 species examined in this study are classified into eight habitats. Generally, animals don't live in just one habitat, they require multiple habitats for different needs. The need to move between habitats increases the likeliness that they will encounter a road, and so when examining a road one must plan for the animals that could be potentially found in the habitats adjacent to the road. This habitat classification is based on where a species is most likely to cross a road. For instance, wetland habitats are extremely important for many species on our species list. Thus, roads next to wetlands are likely to be crossed by many different species.

The eight main habitats that are important for the 40 species reviewed in this study are as follows:

1. **Mixed forest**: This habitat can be characterized by an abundant mix of gymnosperms and angiosperms with a dense undercover, as well as pools and coarse woody debris (Basille et al.,

2013; Vermont Reptile and Amphibian Atlas). This habitat is inhabited by a range of species, from reptiles such as salamanders, to large mammals such as black bears. Crossing structures implemented here must accommodate a wide size range of species. Typically, species of this habitat will prefer wildlife overpasses or underpasses with waterflow (see glossary) as the crossing structure of choice (Chung, 2014; Forman et al., 2003). For example, the timber wolf is a species which prefers overpasses, while several salamander species prefer culverts/underpasses (Forman et al., 2003; Gibbs, 1998; Patrick et al., 2012). This habitat should have a system of both overpasses and underpasses to accommodate the largest amount of wildlife crossings.

2. **Lowlands/slow-moving water**: This habitat includes slow moving rivers, ponds and lakes (Crowley, 2015), and abundant vegetation near the slow moving waters (The Vermont Reptile and Amphibian Atlas). All species in this habitat are herptiles except for mink and river otters. While species found in this habitat are not exclusive, smaller animals are the predominant type. Species in this habitat are most likely to use underpasses such as culverts and small to medium size mammal underpass (glossary) as crossing structures (Philcox et al, 1999; Bouchard et al., 2009; Austin & Garland, 2001). Additional aesthetic preferences that are important in the implementation of culverts in this habitat include built in grates for aeration and light penetration, detritus or leaves on the floor of the culvert, and large diameter culverts (Jochimsen, 2004) (Woltz et al 2008).

3. **Saturated/moist soils**: This habitat is located by springs and streams, forests, and meadows (The Vermont Reptile & Amphibian Atlas). Species found in this habitat are herptiles that are dependent on wet soils for survival. The crossing preference for the species of this habitat is a

culvert (Ward et al., 2006; Knoot & Best, 2011). Culverts built in this habitat must have a width greater than the river/stream allowing for some streamside land cover (Ward et al., 2006). Additionally, at the end of the culvert there must not be an overhang (creating a small waterfall) as this prevents species from moving through the culvert (Wand et al., 2006). Finally these culverts must additionally have some plant litter coverage (Knoot & Best, 2011).

4. **High elevation streams and springs**: This habitat is similar to the slow moving water habitat except that it is at high elevation. It tends to be in upland meadows near mountain ponds or reservoirs (The Vermont Reptile & Amphibian Atlas). There are not a large number of species found in this region as the Cold Hollow to Canada is not a high elevation region. Both species, the spring salamander and pickerel frog, found here are herptiles and prefer culverts as crossing structures (Gibbs, 1998; Ward et al., 2006). The culverts here should be built as streambed culverts that are at grade with the stream bed above and below the road (Gibb, 1998; Ward et al., 2006).

5. **Valley and forest edge-near meadows/water**: These species live in a habitat characterized by valleys or forest edge containing wetlands and open areas with abundant ground cover (The Vermont Reptile & Amphibian Atlas; Dussalt et al., 2006). This habitat contains a range of species such as moose, cougars, and woodfrogs. The large diversity in species denotes that a wide variety of crossing structures is necessary. For example, moose prefer wildlife overpasses, whereas other species in this habitat prefer underpasses with waterflow or culverts (Gunson et al., 2010; Forman, 2003; Cain et al., 2003; Jochimsen et al., 2004). In places where there is evidence of cougars, or could be cougars, small to medium sized mammal underpasses should be implemented. It is important when constructing crossing

structures that the structures themselves are placed close to forest cover (Clevenger & Waltho, 2004). The structural preferences for these species are underpass with large openness ratios, high light permeability, and moist soils within the underpass (Cain et al., 2003; Jochimsen, 2004; Woltz, 2008; Glista, 2009). Additionally, for many species of this habitat such as bobcats and wood turtles, the use of fences, used to funnel species into underpasses is useful in the implementation of crossing structures (Cain et al., 2003; City of Kingston, 2013).

6. **Water**: Species in this habitat are restricted to water, moving from their habitats very rarely (The Vermont Reptile & Amphibian Atlas). It is thus difficult to suggest road crossing structures for this species; however, streambed culverts are likely the best mitigation structure (HLREMP, 2013). The use of directional fencing is also recommended as snapping turtles (found in this habitat) will move until they find a sandy habitat for nesting (HLREMP, 2013).
7. **Grassland**: This habitat is characterized by dry environments at low elevation with abundant grassland (Burgess, 2013). The species found here is the milksnake (Burgess, 2013). The crossing structures best suited for this species are large underpasses with built in grates for aeration and a layer of detritus on the floor of the underpass (Jochimsen et al., 2004).

Additionally there is a classification of species that do well in an urban setting. While these species may not have urban environments as their primary habitat, they can survive here and will adjust to fragmentation. There are species that are not seen in orange on the table that also do well this environment; these are: moose, bobcat, and black bear. These are all generalist species, and due to their behavior of adjustment to urban settings they are in high danger of road mortality. The bobcat is a species that can persist in a fragmented environment as long as there are connectivity structures implemented, thus they are a good species to determine how well implemented crossing structures are working (Litvaitis, 2014).

4.2.2. Design

This section will discuss how different species have different requirements when it comes to wildlife passages (Forman et al., 2003). In order to address the lack of a 'one size fits all' mitigation strategy, a detailed list of effective wildlife passages for each species was compiled. This will help resolve any discrepancies that may emerge when species of opposing structural preferences live in the same habitat, by eliminating any structures which act as an absolute barrier to either species (Barnum, 2004).

As species have specific structural and habitat preferences for crossing structures, an understanding of the needs of individual species is vital for determining a crossing structure's effectiveness. This includes the length, width and height of the structure as well as the substrate, vegetative cover, light permeability, moisture and temperature within the structure (Glista, 2009).

Structure Dimensions

Many studies suggest that the openness ratio of a crossing structure was an important aspect for larger and medium sized mammals (Cain et al., 2003; Clevenger et al., 2002). Openness ratio is defined as a "function of the structures length, which corresponds to the width of the roadway" calculated as (Openness ratio = (Height x Width)/ Length)) (Cavallaro et al. 2005). Therefore, the road width will be a telling variable in the appropriate structural dimensions. Structures that tend to be long and narrow, providing low openness, have proven to be fewer successful than shorter and wider crossing structures (Yanes et al., 1995). While there are less studies conducted on amphibians, research suggests that they are less bothered by relatively long (exceeding 40 m) and narrow crossing structures (Langton, 1989). However, reptiles prefer larger sized tunnels, this has been attributed to the species' need for thermoregulation (Rodriguez et al., 1996). Very few reptile species, such as painted turtles, were shown to increase their movement in constricted tunnels (Woltz, 2008). Therefore, the optimal underpass dimension has been recommended at a width of 2.5-5 meters and should not exceed a length of 70-80 meters to accommodate both smaller and larger species (U.S Department of Transportation, 2011) (Jochimsen et al, 2004) (Rodriguez et al, 1996).

We also found that overpasses that were less than 20 meters wide were used significantly less by wildlife than wider structures. Structures with a width ranging between 50-60 meters appeared to fulfill the requirement of all larger wildlife (Forman, 2003).

Internal Design

The ability of a species to move within the culvert, tunnel or underpass is of paramount importance. As these structures are often implemented for other purposes, such as directing water flow, measures that facilitate animal movement are neglected (Ruediger, 2013). Our group visit to the CHC region on November 28th, corroborated this finding. In the town of Belvidere, on state highway 118 a culvert had been implemented with the sole purpose of managing water flow. The culvert was in a prime location for wildlife crossing and could be adjusted to be more suitable and inviting for species in the area. In addition to implementing new crossing structures, we propose that "taking advantage of existing structures or for structures which primary use is not wildlife could be the single greatest contribution to habitat connectivity in the next 50 years" (Ruediger, 2013). The *internal design* section is thus applicable to both existing and newly designed crossing structures.

<u>Lighting and Temperature</u>

The use of culverts and underpasses is more successful when they have a high degree of openness (Jochimsen et al., 2004). Grates or slots placed at the ceiling of underpasses aid in the circulation of air, regulating the temperature difference between the interior and exterior of the structure (Glista, 2009). Langton (1989) has reported that temperature differences act as a barrier to entry for some amphibians, otherwise known as "tunnel hesitancy" (Woltz, 2008) (Brehm, 1989). Moreover, grate tops and slots also allow for rain to moisten the passage, which is important for amphibians during migration. They also permit more ambient light to enter the structure, rendering it more inviting for a larger number of species (Glista, 2009). There has been evidence to suggest that the "see throughness" of a tunnel or culvert is an important area of focus. This refers to the ability of a given species to see through the structure without unnecessary climbing or descending (Jackson, 2002). This holds true for mammals and herptile species.

<u>Substrate</u>

Underpasses and Overpasses should be lined with natural substrate on either side of the structure, consistent with the external natural habitat. The substrate should run throughout the entire length as it "will maintain habitat continuity and, therefore encourage animals to pass through" (Yanes et al., 1995; Jackson, 2000; Hartmann, 2003). Soil, gravel or plant litter coverage is preferred on the floor of culverts and underpasses, as concrete and metal is deemed undesirable because of its "high conductivity and coldness during spring migratory periods" (Jochimsen et al., 2004; Chambers, 2008; Beebee, 2013; Carcnet, 2000).

Ledges or "Catwalks"

The addition of elevated ledges on one or both sides of the interior walls of the crossing structure allows wildlife to move within it when there are heavy flows of water (Barnum, 1999; Cain et al., 2003; Forman and Alexander, 1998; Hartmann, 2003; Jacobson, 2002). Ledges should line the entire length of the culvert or tunnel and be covered in natural substrate. They should also be constructed at a width large enough to accommodate all types species in the surrounding area. It is also important that the ledges extend to "a height above peak water flow" (Cavallaro, 2005). This includes ledges in culverts or tunnels that are already implemented in the CHC area could help improve their usage by wildlife. If the structures already set in place are too narrow or small to accommodate ledges, additional culverts should be constructed to allow an alternative route for wildlife when existing structure is filled with water (Cavallaro, 2005).

Noise Reduction

Many species are deterred from using wildlife crossing structures due to the high noise component of traffic and other human disturbances, such as American martens and black bears. To combat noise disturbance, dense vegetation can be added adjacent to the structure to help reduce exposure to traffic noise. There are also certain sound proof building materials that can be incorporated into the structure (Cavallaro, 2005).

Directional Fencing

An important finding in our research was the use of directional fencing, also known as drift or guide fencing. By adding a guiding fence, wildlife are more likely to use a crossing structure (Cain et al., 2003). Wildlife crossing structures used in combination with directional fencing reduce wildlife mortality of large mammals in upwards of 80% (Clevenger et al., 2001; Dodd et al., 2007). Another study conducted by Meinig (1989) indicates that once effective fencing was installed, it was used by 85% of amphibians in the area, reducing road deaths from 109 per night, to just 20.

The height of fencing varies with different species. For instance, fences of 0.3m are effective barriers to divert movement for painted turtles (Woltz, 2008), but wood turtles require fencing up to 0.9 m (Woltz, 2008). The fence should be topped with a structure that prevents animals from climbing over. Conversely, if the target species is a burrower, measures should be taken to prevent animals from burrowing under the fence (Carcnet, 2000). Fencing must extend far enough on either side of the crossing structure to promote guidance. A fence that cuts off too abruptly, or in an area suitable to wildlife crossing could have devastating effects on the animal population, as it "creates the potential for wildlife vehicle collision hotspots centered around the fence ends" (Fairbank, 2013). Thus the length of fencing should be dictated by the target species and the surrounding terrain (Glista, 2009). As there is no universal design for all roads when it comes to implementing a fence, it is recommended that "that transportation officials work with wildlife biologists to customize fencing regimes" (Glista, 2009).

4.2.3. Crossing Structure Spacing

Examining the spacing between crossing structures is essential to avoiding creating unintended barriers to wildlife mobility (Jochimsen, 2004). The barrier effect becomes problematic when there are an insufficient amount of crossing structures provided. This is especially pertinent to species with smaller home ranges or less mobility, such as herptile populations (Fairbank, 2013). Due to the variability across landscapes, terrains, habitat types, and population densities, there is no set distance for the spacing of wildlife crossing structures. In a region with high habitat fragmentation and fewer natural areas, crossing structures can be more spread out and fewer would need to be available, as there are likely fewer species. However, due to the CHC region's largely intact natural habitat and less fragmented landscapes, there should be many crossing structures for a given road segment, with relatively close proximity to one another.

For areas primarily occupied by larger mammals, spacing intervals could vary from "one crossing structure per 1.5 kilometers to one crossing structure per 6.0 km" (Federal Highway Administration, 2011). However, many literature reviews suggest that the average spacing for areas with vast amounts of natural habitat is approximately 1.5-1.9 km apart. (Federal Highway Administration, 2011; Mata et al., 2005; Clevenger et al., 2001). The distance between crossing structures suitable for larger mammals, such as Black bears and moose, varies for smaller, less mobile species. The spacing of crossing structures for amphibians and reptiles is recommended at intervals of 150-300 meters (Clevenger et al., 2001).

4.3. Additional Findings

The ramifications of roads go beyond decreasing the connectivity land for wildlife. There are many side effects that can be equally detrimental to the survival of wildlife populations, but are not as easily identified and/or mitigated. For most wildlife, roads are avoided, and only approached when in great need for dispersal. For other wildlife, roads may have microhabitats that attract them, such as moose and snapping turtles (Laurian et al., 2008; Patrick, 2010). Shoulders on the sides of roads cause brackish pools to form, creating optimal drinking sites for moose (Laurian et al., 2008). Roadside margins with sandy soils can also be optimal areas for laying eggs for snapping turtles (Patrick, 2010). In both these scenarios, the risk of road collision increases due to the proximity to the road. To mitigate the risk of road collision, larger shoulders can be constructed to remove moose further from the road (Laurian et al., 2008). Sand hills can also be constructed between roads and ponds to ensure a safer nesting region for snapping turtles (Patrick, 2010). Roads can also cause indirect effects which are detrimental to surrounding wildlife populations. For many types of frog species, roads can be detrimental for breeding calls. The loud noises of cars on the road prevent females from hearing male mating calls (Bee & Swanson, 2007). Additionally during day hours, males will make fewer mating calls as a result of heavier traffic and sound pollution (Bee & Swanson, 2007). A mitigation option for this scenario is to implement earth berms in areas of large roadside noise pollution. As opposed to walls, wildlife use these earthen structures (Forman, 2003).

Roads can also be detrimental to persistence of wildlife populations through the runoff of pollutants into roadside water. Many amphibians such as the blue spotted salamander, are sensitive to road contaminants. Due to their high skin permeability, water downstream from roads can be so contaminated that populations cannot survive (Brady, 2012). Road contaminants may also change the pheromone scents left by snakes to track mates which threatens breeding success (Shine et al., 2004).

Roads additionally change runoff regimes and increase sediment content of rivers and streams during storm events (Coffin, 2007). This can change the chemistry of waterways and thus the biota living in/ near the rivers (Coffin, 2007). Both of the previous road effects can be mitigated through the planting of vegetation, as it can reduce runoff velocity and filter chemical pollutants and sediments from runoff (Forman, 2003).

Section 5. Conclusion and Recommendations

5.1 Conclusion.

Over the course of the semester, we have undertaken an analysis of road ecology in Northern Vermont with our client, Cold Hollow to Canada. We have examined the impacts roads have on wildlife populations and looked at ways to improve habitat connectivity within the Northern Vermont ecosystem. As a region with a variety of natural landscapes and supporting rich species diversity, it is essential to remove the barriers roads have on species movement between habitats and resource patches.

As the Cold Hollow to Canada region develops, road traffic increases in accordance with a rise in affluence and population. The increase of exurban sprawl[13] (as represented by population density) also relates to traffic, demonstrating the importance of forest fragmentation as an important driver of environmental change. Roads not only have a direct impact on threatened species populations' survival, through road kill and crossing inhibition, but they also have indirect impacts such as chemical and noise pollution and the dispersal of non-native species that severely

[13] a region or settlement that lies outside a city and usually beyond its suburbs

disrupt the ecosystem (Forman, 2003). A focused road ecology conservation effort is necessary in this region, as it possesses important cultural and ecological value.

Cold Hollow to Canada, a local conservation non-profit in the Cold Hollow Mountain Range, aims to address the local road ecology issues through a citizen science approach in the *Wildpaths* program. Such an approach allows for efficient and valuable data information at the local scale for CHC (Dickenson et al., 2010), and also connects citizens with their environment and reinforces the importance of the issue at hand as they learn about their species, their movements, and the ecosystem services. This bottom up approach to data collection and education generates local empowerment that can influence policy at the municipal and state level.

As we worked with this local non profit, we offer ways to enhance the citizen science program focused on road ecology through the provision of both a species table ranked by habitat type and a road list ranked by priority level for mitigation.

The first question we asked was, *"What streets/road sections have the highest priority to implement mitigation strategies in the CHC region?*". Based on data that showed high abundance of road kill, that within the CHC region, we hypothesized the 118 State highway in Belvidere is the road segment that would have the greatest need for the implementation of a mitigation strategy given the effects of traffic.

Our hypothesis is partially supported as this road is a high priority for mitigation given the GIS analysis we completed. According to our GIS analysis, we found Jay road to have the greatest need for the implementation of mitigation strategies. However the the field study we did in Belvidere underscored the need for further field studies to be conducted; data was found to be missing once we went into the field, such as the culvert inventory data. Furthermore, we identified (5-10) road segments in the region which are a priority for mitigation using the GIS analysis[14].

The second part of our research asked: "*What mitigation strategies are best for a species given their behaviors and preferences?*". Through data compiled in a preliminary literature review, we hypothesized that multiple culverts and underpasses in high wildlife crossing regions would be the best strategies for mitigation. Our analysis supports this hypothesis, and adds more detailed information based on a set of species and their habitats and preferences.

5.2 Recommendations for Cold Hollow to Canada:

1. Monitoring of hotspot areas
2. Maintenance and modification of existing culverts
3. No new roads

1. Our first recommendation is that the *WildPaths* program focuses on the following regions that we have classified as high-priority, in order to confirm the need to implement mitigation structure in the areas:

Priority	Name of Road	Town	Length of Road needing mitigation	Speed Limit	2013 AADT (Type of Road)	% area of Tier 1-3 and water bodies within 200 m of road	Historical Data (Number of reported collisions)
High	Jay Rd.	Richford	5 km	55 MPH	1000 (State Route)	81%	N/A
High	Vermont State Route 118	Montgomery	1.3 km	55 MPH	1000 (State Route)	79%	1

[14] See appendix for full table.

High	Vermont State Route 118	Belvidere	3.5 km	55 mph	590 (State Route)	67%	9
High	Bakersfield Rd.	Fletcher	1.8 km	55 MPH	1000 (State Route)	65%	N/A

Due to a lack of data regarding animal sightings in the field, we cannot give exact structure recommendations; however the species list we provide can be used to determine the most appropriate structure type for the most common species in the area. Prevalent species can be determined through data compiled by *WildPaths* volunteers. Thus *WildPaths* data, combined with our hotspot GIS map and our species table, can be used to give a well-informed recommendation on optimal species crossing structures and locations to VTrans. We have performed one example of the intended use of the two deliverables in the appendix (See example in appendix).

2. Our second recommendation is that CHC develops a new citizen science program regarding the maintenance of culverts and underpasses. Forman states that although mitigation structures may be in place, the lack of their maintenance averts animals from using them (1995). Upon our inspection of select culverts in the region, we noticed that many culverts in place are not suitable for animal crossing. For example, some were covered with unideal material (like cement), while others were blocked by rocks. Citizen science may be useful in examining the state of these culverts, and adding to data lacking on vtculverts.org; perhaps a new, up-to-date database with all existing CHC animal crossing structures may be created. We also noticed that many existing culverts in place

were created specifically for the passage of water systems. While these may be successfully used by animals, they are not always ideal. Existing culverts and underpasses should be inspected and modified to meet species' specific requirements. Future culverts built should accommodate these species preferences.

3. Our third recommendation is CHC should take a stance against the implementation of new roads, thus limiting fragmentation and reducing habitat loss/degradation. Attention must be paid to reduce traffic.

5.3 Future Research:

In this paper, we focus predominantly on the mitigation strategies that can be implemented in the short term. Since culverts and bridges have been widely implemented and studied, they have been our main focus as mitigation strategies. Through our literature review and our mapping analysis, we have compiled areas and ways these strategies can help the ecosystem of Northern Vermont. We completed our analysis with a field day visit to the Cold Hollow to Canada region, reaffirming the need for mitigation on certain roads while also revealing limitations in the data used for our GIS component (i.e. missing culverts). Visibility on the road is also a variable that should be studied in future research, as it was not accounted for in our study.

Another viable solution that could be used by CHC is the strategy of compensation to ease the environmental damage caused by roads. For example, Cold Hollow to Canada could require that every given mile of road be associated with an equivalent protected area providing the ecological benefit lost from the road (Forman et al., 1995). This compensation principle, which seeks to counteract the costs of infrastructure development, has had success in the Netherlands.

The Dutch highway system compensates for damaged habitat by replacing the area with the same ecological features at a new location (Cuperus et al., 1999). The strategy of compensation can greatly benefit the region of CHC, not only by protecting a greater forested area, but also by its ability to enforce a limit on the development of new infrastructure, as per our third recommendation. For Northern Vermont, a region comprised of a rural community, populating areas within the towns' centers and discouraging urban sprawl could greatly benefit the ecosystem. Compensation could help move the future of Vermont's infrastructure development in the direction of urban densification while accounting for population growth; more people will live in constrained areas, while more protected areas will be allocated, maintaining the State's biodiversity. It is argued that habitat degradation has been accelerated by anthropogenic impacts to a point where conservation strategies should take not only a preservation approach but also a habitat renewal approach, with which habitat loss can be balanced by habitat renewal (Sinclair et al., 1995). Compensation fits into this approach, however road removal can fulfill this habitat renewal objective most ideally, a full restoration of a fragmentation area.

Despite their widespread use, these mitigation and compensation strategies can appear like band-aid solutions. Roads have much greater negative impacts to the environment than positive impact and the only way to stop them is through avoidance and removal. By removing a road, one removes its entire associated ecological impact. Swatalski et al. (2004) define road removal as “the physical treatment of a roadbed to restore the form and integrity of associated hill slopes, channels, and floodplains and their related hydrologic, geomorphic, and ecological processes and properties.”

Similar to river restoration, projects for road removal are simply the restoration of previously fragmented ecosystem processes. There have been several success stories of road removal as an improvement strategy to the ecological impact of roads. For example, the designation of the Redwood National Park in Northern California in 1978 began a long term project of removing more than 300 km of road (Havlick, 2008). Road removal can completely reverse the negative impact they cause, restoring aquatic systems, microhabitats, and protecting larger terrestrial species. The Western Toad in Montana, for example, has been found to have re inhabited microhabitats at the road location, following road removal (Swatalski et al., 2004; Bradley et al., 1997). Still, road removal can be a daunting task, and may be as expensive as building a road. Therefore, road removal specialists must select and prioritize roads with both low densities and the presence of watersheds, an indication of likely biodiversity (Swatalski et al., 2004). Cold Hollow to Canada's *Wildpaths* program can consider road removal as a long term mitigation project for roads that qualify.

One problem still remains. We have built our lives around our roads and, as Forman says, "transportation lies in the core of our society" (Forman et al., 1995). Therefore it is understandable that the removal of such essential infrastructure can and will be, politically challenging. Road removal for the sake of protecting our forest connectivity may require a sacrifice, to say the least, or a change of society mindset altogether, from the part of the American citizen who is reliant on such form of transportation. It may mean more people sharing the same road and more time needed to get from one place to another by car, or developing at a grand scale the attempts that have been done to encourage companies and workers to telecommute. Nevertheless, this more radical conservation approach can encourage the switch to reliable or clean public transportation, even in small towns such as the ones in the Cold Hollow Mountains. The development of infrastructure that supports sustainable transportation, such as travel by train, bike, or foot, is necessary. Inevitably, road removal may also encourage a shift away from the individualist nature of our society, made possible by the nature of capitalism and consumerism. A new more communal approach where sharing is the core of society could take off. We can begin today by putting an end to the development of new roads in the State of Vermont and across the United States.

Appendix:

Example of a road mitigation structure:

During our visit to Vermont, we conducted a field study on the condition and status of target roads. We examined the Vermont State Route 118 in Belvidere, and monitored it in detail in order to test the citizen science-based monitoring program, using the species table and road segment table. It is a 3.5 km stretch of road that has a speed limit of 55 mph and AADT value of 590. The habitats surrounding the region are a combination of lowland wetlands, mixed forest, and valley and forest edge.

In the lowland wetlands habitat, there is likely to be an abundance of herptiles and small mammals. In the valley and mixed forest habitats, there are likely to be large mammals such as bear and moose, medium mammals such as fisher and bobcat, as well as many herptiles.

One underpass (See picture in appendix) that we saw was a culvert in a valley in the middle two mixed forests. It had a stream running down it and there was a small culvert to divert the water under the road. This is a perfect place to install an underpass with waterflow. However, it should be large enough to fit large and small species. A box culvert or a viaduct would be optimal features to implement with dimensions as wide as 10 feet tall and 20 feet wide. The vegetation on the floor of the feature should be continuous with the surrounding vegetation.

Should a box culvert be implemented, we also recommend a directional fencing to route the species towards the culvert.

Species Table: Species of the Cold Hollow to Canada Region:

Species	Species habitat	Species Movement-foraging and Migration	Type of Road avoidance	Best structure	Structure Specifics	Human influence on species	Indirect effects
Lynx	Found in boreal forest, or mixed forest with dense undercover. (Basille et al., 2013)	huge migration, female up to 100km2 and male up to 500km2 (Kramer-schadt et al, 2004)	avoidance of all types of open habitat, will cross due to large dispersal pattern but will avoid (Basille et al, 2013)	Wildlife overpass (Huck et al., 2010)	n/a	Can survive in human dominated landscapes but are at great risk of hunting and road kill (Kramer-schadt et al, 2004)	
Spotted salamander	Found in upland and hardwood mixed forests and pools or ponds. (The Vermont Reptile & Amphibian Atlas)	Limited movement, range max 210m from pond. (Karraker and Gibbs, 2010)	Less eggs laid near highways (Karraker and Gibbs, 2010)	Culvert (Patrick et al, 2012)	Prefer marsh, leafy floor (Chambers, 2008)	Habitat undermined and modified around roads (Chambers, 2008)	
Eastern Red-Backed Salamander	Coarse woody debris in mixed forests (The Vermont Reptile & Amphibian Atlas)	As low as .4m but when displaced will move as far as 30m (Noel et al, 2007)	hinder movement (Gibbs, 1998)	Culvert (Gibbs, 1998)	moist soils (Noel et al, 2007)	Actually resilient to fragmentation, and can be found in highly patchy habitats. (Noel et al, 2007)	
Fisher	Coniferous or mixed hardwood forests with snags and fallen trees. Restricted by deep snow ,stays on ground. (Vermont Fish and Wildlife Department 2015)	Active during the early morning and late evening. 6-15 square miles range, but can roam up to 60 miles for food.	n/a	n/a	Continuous overhead coverage to help their mobility in the winter (Vermont Fish and Wildlife Department 2015)	n/a	
Timber Wolf	Live in remote wilderness. Public forest land and private industrial forest land are both important in managing for a broad-ranging animal such as the wolf (Mladenoff, 2003)	Wolves failed to survive when road densities exceeded 0.93 mile/mile2. (Thiel, 1985) Average road density in wolf territories was 0.25 km/km2; road density was found to be the best predictor of suitable wolf habitat (Kohn, 2001) Wolves selected areas of low road density, travel areas selected by	Wolves preferred to cross highways where they bisected large patches of similar habitat, especially lowland complexes. They avoided developed lands, and did not cross highways in areas adjacent to homes, lakes, or large rivers. (Kohn, 2001)	Prefer overpasses to underpasses (Forman et. al 2003)	-An unobstructed view of the habitat on the far side of a wildlife passage(Forman et al, 2003) -Crossing structures that were high, wide and short in length strongly influenced passage by wolves (Clevenger, 2005) Widths of 50-60 m appeared to fulfill the requirements for large mammals (Forman et al, 2003)	Crossing structures were less frequently used near continual disturbance (e.g. humans) (Forman et al, 2003)	

		packs were generally close to trails and forest roads.					
Black Bear	Generally, extremely adaptable. Bears can live in a variety of habitats. However, primarily found in forested areas with thick ground vegetation where there is an abundance of fruits or nuts. (Coady, 2001)	Shift their home ranges away from areas with high road densities (Coady, 2001)	Bears can control the encounter of roads through movement patterns. Usually a function of traffic volume (# of vehicles/ unit length of road/time) And road density (length of road per area of habitat) (Brody, 1989) Vehicle-related mortalities tend to increase during seasons with increased bear movements (i.e., fall) and when availability of food sources is limited. (Van Manen, 2001)	Concrete box structures. Research shows that black bears have a preference for underpasses, and use them to cross the Trans-Canada Highway frequently. (Chung, 2014) However, bears will use both over and underpasses (Forman, 2003)	-Prefer more constrictive structures (Glista, 2009) -Crossing structures were less frequently used near continual disturbance (e.g. humans) -Should be at least 6 feet high. -Have an openness ratio of at least 0.75, but preferably 0.9 (Bellis, 2008)	n/a	
American Marten	Found in coniferous and mixed coniferous forests. (Clevenger, 2001)	Reluctant to travel through open habitat to access remaining patches. (Mowat, 2006)	n/a	Culvert. The American marten have been seen using drainage culvert to cross the Trans-Canada HW. (US Department of Transportation 2011)	Have a tendency to use culverts with low clearance and high openness ratios. Prefer areas with dense canopy cover and complex understore. (Clevenger, 2001)	Tends to avoid highly populated areas disturbed by noise (Clevenger, 2001)	
Gray Treefrog	Found in slow moving water with abundant vegetation and Lowlands. (The Vermont Reptile & Amphibian Atlas)	movement for breeding (Bee and Swanson, 2007)	n/a	n/a	n/a	Noise affects Breeding calls . (Bee and Swanson, 2007)	less mating calls during high traffic hours, or when there is mating calls they are not heard (Bee and Swanson, 2007)
Northern Watersnake	Found in permanent bodies of freshwater, such as lakes, rivers, and wetlands. Can be found in shoreline vegetation, under rocks, logs, or beaver lodges. (Crowley, 2015)	The northern water snake increases in May, when they migrate because of mating and hibernation. Snake roadkill in general peaks in late summer.	Enter the road and then deter 50% of the time. (Andrews et al, 2005)	Culverts and tunnels (Jochimsen et al, 2004).	Larger tunnels with built-in grates to allow for aeration and maximization of natural light. A Layer of detritus or leaves on ground of tunnel; circular openings; at least 2 m wide	n/a	

		(MacKinnon et al, 2005).			(Jochimsen et al, 2004)		
Northern Map Turtle	Not recorded in CHC (from Herp atlas). Almost entirely aquatic, around Lake Champlain. Ponds, river bottoms, lakes.	Will sometimes migrate to new breeding sites (HSUS) on roads, but usually through aquatic paths.	n/a	n/a	n/a	n/a	
River Otter	slow-flowing creeks and rivers, low sloping banks with good cover and, preferably, easy access to small forest creeks or swampy areas and, in broader rivers, access to shallower areas such as rapids or waterfalls with pools and ponds between boulders and sandbars. (Duplaix, 1980); riparian forest (Weber and Allen, 2010)	In Winter, we more likely to be found by streams/bogs than large lakes (Reid et al. 1994); mating from Dec-April (Defenders of Wildlife); higher casualties in winter (Philcox et al, 1999); most active at night (Lynn, 2008)	Specialized feeders with linear habitats, therefore they often come into contact with roads. (Kruuk, 2006)	Wide-span bridges, over-sized culverts or artificial ledges, and fences as long as they are not a barrier. (Philcox et al. 1999) span should extended past waterway, covering at least 8m buffer zone. (Macdonald and Smith, 1999); Avoid jersey median barriers (Van Der Ree et al, 2015)	Use ledges with air-space above the water, use ledges with ramps to bank and ensure retention of river bank under bridge. (Philcox et al. 1999)	n/a	
Painted Turtle	Most likely to be found on Roads close to wetlands and aquatic-terrestrial interface. (Patrick, 2010)	Substantial terrestrial movement (Dole, 1968) Female turtles are indeed more likely to cross roadways than are males due to nesting (Steen, 2006) Regularly move overland between nearby wetlands and thus may be at; elevated risk of mortality where roads bisect these wetland networks. (Bowne et al. 2006; (HLREMP, 2013)	Gravel shoulders on roads provide ideal nesting sites,	Culvert with directional fence Aresco (2005) found that drift fencing in conjunction with drainage culverts significantly reduced turtle road mortality.	-Preferred tunnels of intermediate (0.5–0.6 m) diameter. (Woltz, 2008) -Painted turtles showed non-random choice of different lengths of tunnel, possibly indicating some avoidance of the longest tunnel (9.1 m) (Woltz, 2008) -Fences 0.3 m in height were effective barriers	roads cause decreased female reproductive success (Laporte et al, 2012)	
American Bullfrog	Found in permanent bodies of water with vegetation on shoreline (lakes, ponds, marshes) Also, seems to have a preference for human	Nocturnal. If water is found on both sides of the road, crosses road to respond to calls.	Road avoidance mainly as a result of noise.	n/a	n/a	n/a	

	modified water bodies (Orchard et al, 2015;Burges,2015)	(Belher et al, 1979)					
Green Frog	prefer permanent bodies of water with Fish (Semlitch et al, 2015)	n/a	If water is found on both sides of the road, crosses road to respond to calls. Studies showed most involved in roadkill from July to September. (Ashley and Robinson, 1996).	n/a	a soil or sand substrate increases usage 3 to 8-fold compared with bare concrete (Beebee, 2013)	n/a	
Northern Leopard Frog	Three-habitat species: It needs permanent water for overwintering, floodplains and marshes for breeding, and wet meadows and fields for foraging. It is fairly common in the Lake Champlain Basin. (Burgess, 2013)	Leave usual spots on rainy nights, sedentary in summer (Dole, 1965); spring migration (Bouchard et al, 2009)	No behavioral avoidance of roads or traffic (van der Ree et al, 2015); Immobile as vehicles approach, so takes longer to move in high traffic, making them highly vulnerable. (Bouchard et al, 2009)	Directional fencing to funnel and modified culverts that accommodate amphibians, road signage (Bouchard et al, 2009)	Larger diameter tunnels, tunnels > 0.5 m in diameter lined with soil or gravel and accompanied by 0.6–0.9 m high guide fencing (Woltz et al, 2008)	n/a	
Blue Spotted Salamander	Found in moist deciduous forests, coniferous forests, and swamps. Also, woodland or roadside pools are important breeding grounds. They have "high site fidelity" and spend a lot of time underground. (michigan.gov)	Springtime migration to breeding ponds.	Move slowly across roads, in comparison to anurans (Gibbs and Shriver, 2005) They are primarily nocturnal, crossing occurs when there are fewer cars on the road (Brady, 2012). Often cross roads in the spring when they migrate to breeding ponds.	n/a	3- to 8-fold compared with bare concrete (Beebee, 2013)	they are a little less vulnerable to human disturbance, but fragmentation has harmed this species classified as Endangered.	Runoff affecting the roadside pools cause smaller and fewer embryos in females. Still, the populations adapt to the changes in their home environment as a result of the road, "eco evolutionary approach." (Brady, 2012).
Mink	Minks live near water and are found beside riverbanks, lakes and marshes. Minkes may leave riverside for a few hundred meters, to hunt for prey such as rabbits (Austin and Garland, 2001)	Even when roaming, they tend to follow streams and ditches.	Mink's home range is 3 km^2 (Austin and Garland, 2001)	The Underpass are best followed by culverts. Mink prefer to use crossing structures than crossing roads directly (Austin and Garland, 2001)	n/a	n/a	

Northern Two-Lined Salamander	Found in wet soil along streams, seeps and springs. (The Vermont Reptile & Amphibian Atlas, 2013)	They move within springs and streams (Price et al, 2006)	Roads are not acting as barrier but rather destructor of habitat. Roads are detrimental (Ward et al, 2006)	The Culvert (Ward et al, 2006)	The structure must not have an over hang, be part of river bed, and we must avoid large amount of sediment on floor (Ward et al, 2006)	Loss of habitat and decline of population in places of large urbanization (Price et al, 2006)	
Racer	Found in abandoned fields, grassland, sparse brushy grass, mountain meadows and grassy bordered streams (The Vermont Reptile & Amphibian Atlas, 2013)	It does move through short (30m) sections of woodlands between patches. It may move larger distances through woodlands to denning sites. (The Vermont Reptile & Amphibian Atlas, 2013)	n/a	n/a	n/a	Commonly seen twenty-five or more years ago, Eastern Racer has not been seen in recent years. Habitat loss due to succession is likely negatively affecting this species as increasing road-building and traffic flow cause mortality and isolate populations. (Vermont Wildlife Action Plan, 2015)	
Northern Dusky Salamander	Found in saturated soil near streams and seepages in forested areas (The Vermont Reptile & Amphibian Atlas)	n/a	roadkill occurs where they cross between stream beds (Ward et al, 2006)	Culverts (Ward et al, 2006)	should not have overhang and width must be greater than river (Ward et al, 2006)	Affected by loss of riparian zones due to roads (Ward et al, 2006)	
Smooth Green Snake	Found in meadows, grassy marshes, moist grassy field on forests edge. (The Vermont Reptile & Amphibian Atlas)	movement during day (Knoot and Best, 2011)	Roads create linear grasslands with little edges. hinder movement due to loss of habitat. (Knoot and Best, 2011)	Culverts (Knoot and Best, 2011)	Structure needs plant litter coverage (Knoot and Best, 2011)	Listed as a special concern species (Knoot and Best, 2011)	
Brown Snake	Found in moist uplands, woodland, and in lowland freshwater and saltwater marshes (The Vermont Reptile & Amphibian Atlas, 2013)	Move during day (Knoot and Best, 2011)	Appears to be no road effect i this species positions itself (Patrick and Gibbs, 2009)	n/a	sun and moist floor (Patrick and Gibbs, 2009)	Population has decline due to loss of habitat (Knoot and Best, 2011)	Roads are a good place to bask and may create mortality (Patrick and Gibbs, 2009)
Eastern ribbon snake	Found in wet meadows, marshes bogs, ponds and weedy lake shorelines	Migration over the Summer Months. Individual snakes were documented moving up to 391 m from April to October	Highways with high traffic volume are a barrier to their movement. (Andrews and Gibbons, 2005) Roadkill observed frequently where roads bisect wetland habitats or shorelines	Underpass with guide fence	ERS were found to use small road underpasses of less than 1.2 m in height	Habitat loss is considered to be the primary threat. Development around wetlands, lakes and streams has an important impact on this species' population	Road contaminants (e.g., oil residues), or particular road substrate types may alter pheromone scent trailing and threaten successful breeding

	(The Vermont Reptile & Amphibian Atlas)	(Garrah, 2012)	(Crowley, 2012). Losses of ribbon-snakes due to road effects have been documented even in areas of low traffic density. (Crowley, 2009).	(Stewart, 2015)	(Garrah, 2012)	(eNature, 2011)	(Shine et al, 2004).
Eastern Newt	Eastern newts are found in both coniferous and deciduous forests. They need a moist environment with either a temporary or permanent body of water, thriving best in a muddy environments. They frequent small lakes, ponds, and streams or near-by wet forests. (Rinehart et. al, 2009)	They have been tracked nearly 800 m from natal waters over a year of movement meaning dispersal ranges could exceed several kilometers. (Healy, 1975)	Road density negatively influences occupancy of eastern newts Many newts are killed on roads every spring and fall during migration to breeding ponds. (Rinehart et. al, 2009).	n/a	n/a	Land use and development by humans generally means creation of land cover types that are inhabitable to newts. (Rinehart et. al, 2009)	some evidence found that road salt can cause mortality in certain newt species larvae.
Spring Salamander	Found in streams and springs in high elevations (The Vermont Reptile & Amphibian Atlas) Travel to and from breeding sites (Mazerolle, 2004)	Loss of riparian ecosystem not a huge barrier but Salamanders become motionless when they see traffic. (Ward et al, 2006; Mazerolle et al, 2005)	Culverts (Ward et al, 2006)	Culverts with widths greater than channel width, contain rubble substrate and are at grade with stream bed (Ward et al, 2006)	when on roads will not avoid and instead will be on road but not move (many deaths), roads alter community composition (Mazerolle, 2004)		
Pickerel Frog	Found in mid and high elevation, near ponds reservoirs or upland meadows (The Vermont Reptile & Amphibian Atlas, 2013)	The Pickerel Frog forages in wet, weedy areas (Gibbs, 1998)	no road avoidance found but often killed by road effects and lose mating calls (Gibbs, 1998)	Culvert (Gibbs, 1998)	Stream bed facilitates movement (Gibbs, 1998)	n/a	n/a
Common Garter Snake	A Generalist species, the garter snake can be found in a wide variety of habitats, including forests, shrublands, wetlands, fields and rocky areas. (The Vermont Reptile & Amphibian Atlas, 2013)	They avoid Road as they are reluctant to go into open areas. Mates searching male snakes were less able to follow substrate-deposited pheromonal trails left by females if those trails crossed a road than if the trails were entirely within the surrounding grassland. ((Joshimsen, 2004; Shine, 2004)	Roads may significantly modify snake movement patterns, as well as the ability of males to locate reproductive females (Shine, 2004)	Ecopassages: Culverts, tunnels, underpasses	There has been evidence of a higher crossing rate in culverts and underpasses **2 meters** wide and culverts with natural light via grates. (Rodriguez et al. 1996)	Roads tend to kill higher portion of male snakes and hamper their ability of males to locate reproductive females. (Joshimsen, 2004) (Shine, 2004)	

Moose	Travel along valleys, wetlands, and forest edges. Often venture into some urban areas. (Dussalt et al, 2006)(Gunson et al, 2010)	Travel large distances, especially during summer. More roadkill when there is movement during the summer. (Beyer et al, 2013).	Roads create a Barrier effect, Moose tend to avoid roads. (Beyer et al, 2013)	Fences, bridges are best structures for moose. Also, moose benefit from a decreasing presence of road shoulders, lower the amount of fewer brackish pools along roadsides. (Gunson et al, 2010; Dussalt et al, 2006)	Modify type of vegetation along roads to deter moose from feeding there. (Beyer et al, 2013)	high density roads cause less crossing, inability to migrate and loss of dispersal capabilities. (Beyer et al, 2013)	brackish ponds on the side of roads are a source of salt for moose and cause collisions (Laurian et al, 2008)
Wood Turtle	Riparian areas or flood plains. There are 3 key habitat components: a stream or river, a sandy nesting substrate, and a forested area (The Vermont Reptile & Amphibian Atlas)	wood turtle has an average home range of 28.3 ha. (MacGregor, 2003)	n/a	A "Chain Link" Fence with an underpass, which can guide turtles to a passage that enables safe crossing. (City of Kingston, 2013)	Prefer tunnels > 0.5 m in diameter lined with soil or gravel and accompanied by 0.6–0.9 m high guide fencing (Woltz, 2008)	n/a	n/a
Red-Bellied Snake	Forest edge habitats, fields and meadows with abundant ground cover, under logs, rocks, scrap piles and building foundations. Absent in areas with low forest cover. (Joshimsen, 2004)	Very small home ranges. Over the entire summer, an individual may move no more than 500 meters from its hibernation site. Forage in temporary wetlands (Joshimsen, 2004)	Road avoidant Reluctant to go into open areas (Joshimsen, 2004)	Rectangular eco-passages (underpass or culvert) (Forman, 2003)	Favored vegetative cover surrounding passage entrance (Rodriguez et al. 1996)	Roads are effective barriers to gene flow resulting from avoidance and/or mortality. (Joshimsen, 2004)	
Wood Frog	Found in woodlands and vegetated wetlands, breed in vernal pools. (The Vermont Reptile & Amphibian Atlas)	Most calling and movement occurs at night (Todd and Winne, 2006)	Avoiding breeding sites near highways, most likely a result of the unusually high nighttime noise levels interfering with calling activity. -They will also stop moving in response to oncoming traffic There is evidently an Increasing risk of mortality as increases time spent on road. (Mazerolle, 2004).	Culverts or tunnels > 0.5 m in diameter lined with soil or gravel and accompanied with fence 0.6 - 0.9 m high fencing would best facilitate road crossing (Woltz, 2008)	Prefer structure with light permeability (Woltz, 2008) Generally require moist conditions during migration, thus designing passages to allow rain to moisten the passage may be important (Glista, 2009). Frogs are deterred from bare concrete due to its alkalinity (Glista, 2009)	-Generally unaffected by traffic mortality (Egenbrod, 2009) Breakpoint occurred 600-1000m from highway nighttime traffic volumes has a greater negative effect on anuran populations such as the wood frog.	
Spring Peeper	Adult Spring Peepers can be found in herbaceous vegetation or woods nearby heavily vegetated swamps and marshes.	More movement noticed during months of April-May and August-Septem	Generally unaffected by traffic mortality (Egenbrod, 2009)	Eco tunnel and passages	n/a	-Reduced calling intensity in the presence of low-frequency anthropogenic disturbances, (i.e.traffic noise).	

	Breed in vernal pools (The Vermont Reptile & Amphibian Atlas)	ber than in June-July (Ashley, 1996)	The Number found dead on the road increased with decreasing traffic intensity (Mazerolle, 2004). -Breakpoint occurred 200-300 m from highway (Egenbroad, 2009) May be due to a reluctance to venture onto road surfaces at high traffic intensities, thus resulting in lower casualties (Ashley, 1996)	(Gartshore, 2006)		(Egenbroad, 2009) -Increases both its calling frequency and amplitude in response to traffic noise, with 37% more energy expended when calling in the noisiest vs. the quietest environment (Parris et al. 2009). Such interference lowers breeding success and leads to smaller populations over time (Warren et al. 2006; Parris et al., 2009)	
Bobcat	The bobcat persists in fragmented landscapes as long as there are habitat linkages. A useful indicator species of landscape connectivity (Litvaitis, 2014)	males move more than females and thus are more affected by roads. (Poessel et al, 2014)	bobcats avoid regions close to roads when deciding placement of home. (Poessel et al., 2014)	Best are Culverts with fences funneling them in, in large wetland and riparian corridors. (Cain et al 2003)	Need large **openness ratio** (width x height/ length) and a large amount of adjacent shrub cover. (Cain et al 2003)	bobcats are sensitive to fragmentation. (Poessel et al, 2014)	
Ring-Necked Snake	Found in warm, exposed areas, often near water with abundant bark, log, or rock cover (Burgess, 2013)	Snake roadkill in general peaks in late Summer. In May, they migrate to mate or hibernate. (MacKinnon et al, 2005.)	Near absolute road avoidance (Gross, 2013) . Frequently attempt to cross but rarely do. (Andrews, 2003)	Culverts and tunnels. (Jochimsen et al., 2004)	larger tunnels with built-in grates to allow for aeration and maximization of natural light; layer of detritus or leaves on ground of tunnel; circular openings; at least 2 m wide (Jochimsen et al, 2004)	n/a	
Cougar	Found around riparian vegetation and other vegetation that provide horizontal cover. (Dickson et al, 2005)	Males move more than females (some males travel over 750km). Also they move more at night as they are able to cover more terrain and search for mates and resources. (Morrison et al, 2015)	Will use dirt roads for movement but not paved roads (Clevenger and Waltho, 2004)	Underpass and Overpass. They use underpasses more often in the summer but overpasses more often in the winter (Clevenger and Waltho, 2004)	Crossing must be close to forest cover and structures should be more constricted. Underpass should be large enough to fit a Cougar. (Clevenger and Waltho, 2004)	Cannot expand range due to loss of habitat. Roads trauma is the largest contributor of cougar mortality (Thompson et al., 2014)	
Mudpuppy	Found in freshwater ponds, lakes, streams, canals, reservoirs and rivers. Entirely aquatic species,	n/a	n/a	n/a	n/a	n/a	

	generally remain in 30 meters below surface (The Vermont Reptile & Amphibian Atlas)						
Snapping Turtle	Snapping turtles spend almost all their time in water, but go on land to lay their eggs in sandy soils. Most likely to be found on Roads close to wetlands, aquatic-terrestrial interface (Patrick, 2010)	The mean speed of travel can be up to 1 mile (1.7 km) per day. Female turtles are indeed more likely to cross roadways than are males due to nesting (Steen, 2006)	Linked to the location of suitable nesting sites around loose, sandy soil (often roadside margins) (Patrick, 2010)	Culvert accompanied with directional fence. Additional mitigation options for this site include installation of turtle nesting and basking beaches (HLREMP, 2013)	-Preferred larger diameter tunnels (>0.5 m) -Fences 0.6 m in height were effective barriers (Woltz, 2008)	1,501 vehicles/lane/day with a standard deviation of 753 = annual road mortality of at least 25%. (Bradford, 2003)	
Milk Snake	Milksnakes inhabit old fields, old buildings, stone walls, and ledges. It is widespread at lower elevations in Vermont. (Burgess, 2013)	Migration and dispersal rates often intersect with roads (Fischer, 2002)	Snake roadkill in general peaks in late Summer. May is when they migrate because of mating and hibernation. (MacKinnon et al,2005).	Culverts and Tunnels (Jochimsen et al, 2004).	larger culverts with built-in grates to allow for aeration and maximization of natural light; layer of detritus or leaves on ground of tunnel; circular openings; at least 2 m wide (Jochimsen et al, 2004)	n/a	

Biofinder Tiered Data:

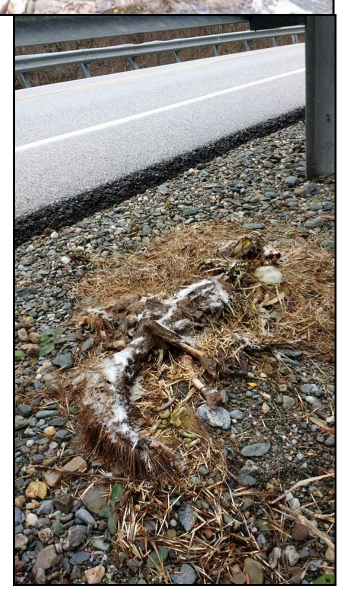
The 21 Components Contributing to Biological Diversity	
#	**Component Name**
Landscapes	
L1	Habitat Blocks
L2	Grasslands and Shrublands
L3	Rare Physical Landscape
L4	Representative Physical Landscape
L5	Connecting Lands (<2000ac)
L6	Connecting Blocks (2,000-10,000ac)
L7	Anchor Blocks (>10,000ac)
L8	Riparian Connectivity
L9	Wildlife Road Crossings
Aquatics	
A1	Surface Waters & Riparian Areas
A2	Representative Lakes
A3	Important Aquatic Habitats & Species Assemblages
Species & Natural Communities	
SN1	Rare Species
SN2	Uncommon Species
SN3	Rare Natural Communities
SN4	Uncommon Natural Communities
SN5	Common Natural Communities
SN6	Vernal Pools
SN7	Vernal Pools (Potential)
SN8	Wetlands
SN9	Mast production areas

(Vermont Agency of Natural Resources, 2013)

Road Priority Table:

Priority	Name of Road	Town	Length of Road needing mitigation	Speed Limit	2013 AADT (Type of Road)	% area of Tier 1-3 and water bodies within 200 m of road	Roadkill Data (Number per road)
High	Jay Rd.	Richford	5 km	55 MPH	1000 (State Route)	81%	N/A
High	Vermont State Route 118	Montgomery	1.3 km	55 MPH	1000 (State Route)	79%	1
High	Vermont State Route 118	Belvidere	3.5 km	55 mph	590 (State Route)	67%	9
High	Bakersfield Rd.	Fletcher	1.8 km	55 MPH	1000 (State Route)	65%	N/A
Medium	South Main Street – Vermont State Route 118	Montgomery	1.2	55 MPH	1000 (State Route)	56%	N/A
Medium	Main Street North – VT108	Bakersfield	1.3 km	55 MPH	1300 (State Route)	52%	N/A
Low	Vt-109	Belvidere	1.5 km	55 MPH	430 (secondary)		N/A
Low	Glen Sutton Rd.	Richford	.94 km	55 MPH	210 (secondary)		N/A
Low	County Rd.	Bakersfield	1.1 km	25 MPH	(track)		N/A
Low	Locke Rd.	Waterville	.78 km	45 MPH	Very Low (Residential)		N/A
Low	Bog Rd.	Belvidere	1.4 km	45 MPH	(residential)		N/A
Low	Old Stage Coach Rd	Bakersfield	2.3 km	25 MPH	Very Low - exact AADT unknown		N/A

					(Residential)		



Clockwise from above:
I) Photo of the culvert on the Vermont State Route 118. Note the low openness ratio and concrete substrate

ii)*Photo of a culvert with a large openness ratio*

iii) An example of roadkill (porcupine) found along State Route 118 in Belvidere.

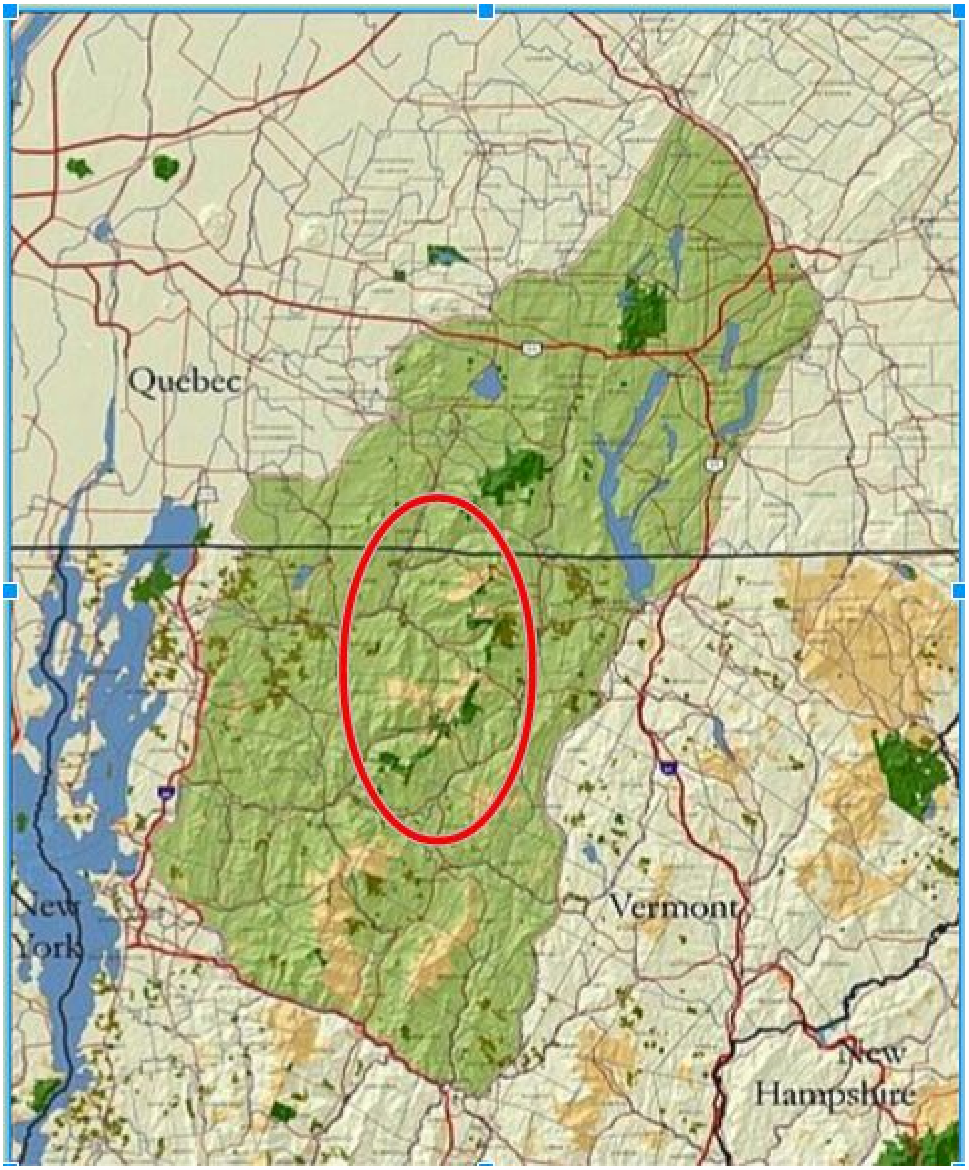


Figure 4: Photo of the Cold Hollow to Canada Mountain Range in the broader context.

Glossary

Box culvert: Rectangular opening with a top slab, bottom slab and walls. Box culverts are used to move water during brief runoff periods and are used more by animals as they generally provide more room and remain dry most of the year. (US Department of Transporation, 2011)

Buffer: A polygon created around another set of vector data of specific radius .

Clip: Extraction of vector data within the boundary of another set of vector data.

Intersect: Combining geometric features of different vector data types.

Landscape bridge: Bridge over large roads that is built only for wildlife with a width of 330 ft and abundant vegetation atop. No human use. (US Department of Transporation, 2011)

Large mammal underpass: These are designed for large species but allow for smaller species as well. Minimum height of 10ft and width of 20ft. (US Department of Transporation, 2011)

Layer: The visual representation of a geographic dataset in any digital map environment.

Pipe culvert: Circular opening with outer and inner circular cage. Openings are suitable for large waterways. The shape has more hydraulic advantage for fishes at low flows. (US Department of Transporation, 2011)

Polygon: A shape other than a point or a line (2D) in GIS

Raster: A data model in GIS that has attributes in grid cells. Each cell has a value that represents the data. Much like pixels

Small to medium sized mammal underpass: Designed for small and medium sized animals. Can be a culvert. (US Department of Transporation, 2011)

Underpass with waterflow: Designed for dual need of moving water and wildlife. Used mostly by small and medium animals and amphibians, but some large mammals also pass under. (US Department of Transporation, 2011)

Vector data: A coordinate-based data model that represents geographic features as points, lines, and polygons. Each point feature is represented as a single coordinate pair, while line and polygon features are represented as ordered lists of vertices. Attributes are associated with each vector feature, as opposed to a raster data model, which associates attributes with grid cells.

Viaduct or flyover: Wildlife underpass for animal and human use. Used by all wildlife species. These are large constructed bridges with road above land. (US Department of Transporation, 2011)

Wildlife overpass: Wildlife only for large, medium and small mammals, and some reptiles 165-230 ft. continuity of vegetation from surrounding forest cover (US Department of Transporation, 2011)

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Additional Reading

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