Surveying vernal pools in Halifax County, Nova Scotia to identify landscape correlates of pool features and pilot a survey methodology

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1. List of Abbreviations

NS – Nova Scotia

US – United States

ELC– Ecological Land Classification

DNR – Department of Natural Resources

PVP – Potential Vernal Pool

GPS – Global Positioning System

GIS – Geographic Information System

HSD – Honestly Significant Difference

ANOVA – Analysis Of Variance

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3. Author Contributions

John Brazner proposed the idea for this thesis and contributed significantly to the experimental design and survey methodology. Peter Bush also assisted in developing the survey methodology.

Anna Bishop collected the data, conducted the data analysis, and wrote the thesis paper. John Brazner, Tarah Wright, and Shannon Sterling provided comments, edits, and feedback on previous drafts of the thesis.

4. Summary

Vernal pools are small, ephemeral wetlands that provide critical breeding habitat for amphibian populations, increase biodiversity on a landscape scale, and influence local and regional hydrography. They have unique annual hydroperiods, typically going from full inundation to full desiccation within a single growing season. This project addresses the current lack of research on vernal pools in specifically Nova Scotian landscapes. A cross-sectional, systematically random pool survey has been conducted within Halifax County, NS. Differences in pool features and dominant land-cover were compared among three ecoregions (Atlantic Coastal Ecoregion (800), Western Ecoregion (700), Eastern Ecoregion (400)), and between two ecodistricts within Ecoregion 400 (Eastern Granite Uplands Ecodistrict (430), Eastern Interior Ecodistrict (440)). Differences in pool features were additionally compared among well-sampled ecosections within each ecoregion, and between well-sampled ecosections in each ecodistrict. Systematic sampling at the ecosection level was not possible due to logistical constraints. This project aims to provide baseline data on the distribution and characteristics of vernal pools within Halifax County, to investigate possible landscape influences on pool features among ecoregions and between ecodistricts, and to evaluate the efficiency and reliability of the survey methods in the context of future provincial vernal pool surveys.

A total of 156 pools were surveyed in the field. The percent canopy per pool, pool surface area, and pool density per site (# pools/site) were recorded for survey sites in each ecoregion and ecodistrict. Pool pH levels were also recorded within Ecodistricts 430 and 440. The total means for all recorded values were: percent canopy = 46.9, surface area = 46.1m^2, density = 1.3, and pH = 5.1. The dominant land-cover (forest, wetland, open) was also recorded for each site. Pool features and land-cover were tested in Minitab (Minitab 16) for significant differences among

ecoregions (ANOVA) and between ecodistricts (2 sample t-test). Pairwise comparisons were conducted (Tukey HSD) among ecoregions for pool features that differed significantly. Among ecoregions there were significant differences in percent canopy levels ($p=0.014$), forest land-cover ($p=0.033$), and open-land cover ($p=0.000$). Between ecodistricts there was a significant difference in pH ($p=0.000$). The type of ecosection each survey site occurred in was determined retroactively in a GIS (ArcGIS 10.1) through visually analyzing the overlay of survey site locations (input from a Garmin eTrex Legend GPS) on the Halifax County ecosection layer. Pool features were tested for significant differences among the dominant ecosections within each ecoregion (ANOVA) and between the dominant ecosections of each ecodistrict (2 sample t-test). All results were insignificant.

The total mean values of recorded pool features were compared to relevant literature, and it was found that all means fell within expected ranges. Pool density per km^2 was relatively high when compared with a small amount of literature.

Both the barren heath/shrub ecosystem typical of Ecoregion 800 and the high abundance of forest cover in Ecoregions 700 and 400 contributed to significant differences in percent canopy levels, forest land-cover, and open land-cover among ecoregions. Differences in wetland abundance, exposed granite bedrock, and possibly pool substrate contributed to a significant difference in pool pH between ecodistricts. Differences in pool surface area and pool density were insignificant at all geographic scales, indicating that a) variation in vernal pool site density and surface area are not significantly affected by variation in geographic landscape features at the ecosection, ecodistrict, or ecoregion scale or b) that the sample size of this study was not large enough to reflect significant variation in pool site density and surface area among distinct landscape settings. There were no significant differences in pool density or pool surface area at the ecosection, ecodistrict or ecoregion scales. Tentative relationships between landscape factors and Ecodistrict 440's high pool density and Ecoregion 700's large pool surface were suggested, however the significance of these relationships will remain in question until an increased survey sample size is obtained.

Data trends in pool features on the ecosection scale mimicked trends on the ecodistrict scale but not the ecoregion scale. This indicates that sites within well-sampled ecosections provide similar depictions of landscape variability in pool features as those stratified within ecodistricts, and that sites surveyed in well-sampled ecosections may allow for the determination of landscape trends that are not apparent at the ecoregion scale. However, if a pool survey obtained adequate sample sizes from all ecosections within an ecodistrict or ecoregion, the recorded pool features are likely to reflect a finer level of local landscape variation than that attained on both ecodistrict and ecoregion scales.

The survey methods were expected to be efficient and reliable. However, designating area as the control variable for each transect decreased efficiency, as the uniform transect route was inflexible to variations in terrain difficulty. The uniform transect route was also inflexible to changes in visibility levels. This increased the potential of false negatives in areas with low visibility and diminished the overall reliability of the survey. An alternative survey method has been suggested that uses survey time as the control variable for each transect, which increases flexibility in response to difficult terrain, changes in visibility, and habitat variability. The benefits of incorporating remote sensing into the survey methods depends on the quality of the images, the training of the analyst, and the time of year the images were taken, however benefits remain minimal if the survey area is heavily forested.

Finding relatively high density of vernal pools in Halifax County suggests that other counties in NS may have high densities of vernal pools as well. This provides scientific rationale for the initiation of a provincial vernal pool assessment project, as well as the development of a vernal pool conservation plan within Halifax County. This project has provided baseline data on the characteristics and features of vernal pools in Halifax County, which lays the groundwork for future research in other geographic regions in NS. Ultimately, it provides some first steps towards protecting vernal pool ecosystems from anthropogenic impact within NS.

5. Key Words

vernal pools, vernal pools in Nova Scotia, vernal pools in the landscape, surveying vernal pools, survey methodology, vernal pool ecology, vernal pool hydrology, vernal pool conservation, landscape differences, ecoregions/ecodistricts/ecosections in Nova Scotia

6. Introduction

6.1 Rationale

Although vernal pools have been studied extensively in other regions such as California and the Northeastern US, there have been few studies on vernal pools in Nova Scotia. There are many different wetlands present in Nova Scotia, including bogs, fens, salt marshes, freshwater marshes, swamps, and vernal pools (Nova Scotia Environment, 2011). Vernal pools are among the least understood of all wetland types present in Nova Scotia, as they are not included in Nova Scotia's current wetland inventory (Nova Scotia Environment, 2011) and no standardized surveys have been conducted on their abundance, distribution, or features in specifically Nova Scotian Landscapes (John Brazner, Nova Scotia Environment, personal communication). Vernal pools are difficult to detect in aerial surveys, as they can be obscured from remote sensing due to forest canopy cover (Lathrop, 2005) and their relatively small size in comparison with other wetland ecosystems (Tiner, 2003). They are also temporally transient (Brooks, 2005), which further increases the difficulty of conducting accurate assessment projects.

There is currently no conservation policy in Nova Scotia that specifically protects all vernal pools in the province. Vernal pools are only regulated under Nova Scotia's Wetland Policy if they are larger than 100 m² (Nova Scotia Environment, 2011), but this excludes smaller pools from regulation. The ecological importance of vernal pools as breeding sites for amphibian species, as well as their transient but potentially important hydrologic role in the landscape, suggests a need for current baseline data on vernal pool distribution and characteristics within Nova Scotia. This project aims to address the lack of research on vernal pools in Nova Scotian landscapes through a ground-based pilot vernal pool survey within Halifax County, Nova Scotia.

6.2 Background Context

Wetlands are a crucial component of maintaining regional hydrology, nutrient cycling, and biodiversity. Much of the Nova Scotian landscape is dominated by wetlands. The Nova Scotia Wetland Inventory (2004) estimates that there are 5.5 million hectares of wetlands in the province occupying over 6.5% of the landscape, but this likely a significant underestimate (John Brazner, Nova Scotia Environment, personal communication).

To better protect and manage the ecosystem services that wetlands provide in Nova Scotia, the Wetland Conservation Policy was developed in 2011. This policy outlines conservation requirements for projects that might alter a wetland, such as urban development, forestry, and agriculture (Nova Scotia Environment, 2011). One difficulty in developing and implementing the provincial wetland policy is related to the limited understanding of the ecology of and ecosystem services provided by different wetlands types in Nova Scotia. Although wetlands have been well studied in other parts of North America (Mitsch and Gosselink, 2007), there is relatively little published research on wetlands in Nova Scotia. This makes it difficult to implement science-based conservation measures for wetlands in Nova Scotia.

Vernal pools are wetland ecosystems with distinct hydrologic and ecologic characteristics. They are small, shallow ponds of water that appear in the landscape due to meltwater runoff and increases in precipitation (Calhoun and deMaynadier, 2008). Vernal pools are often smaller than 0.1 ha or 10,000 m^2 and less than 1m deep during the spring (Colburn, 2004). They are typically isolated from surrounding surface water sources (Brooks 2005), though many have inputs from groundwater sources for at least part of the year (Whigham, 2003).

The vernal pool hydroperiod can fluctuate dramatically. After reaching peak volume in the spring, water levels usually drop and pools can be completely dry by late summer/early fall due to increased evaporation, increased uptake and evapotranspiration by surrounding vegetation, and decreased precipitation as the growing season progresses (Brooks, 2002). There is variation among vernal pool hydroperiods due to regional variation in climate and local landscape differences: some pools re-fill in autumn while some stay fully inundated throughout the growing season, and some only fill bi- or semi-annually (Colburn, 2004). Limited study in Nova Scotia suggests most pools dry down once a year in August and refill during October and November, however some pools only fully dry down once every two or three years (John Brazner, personal communication).

Although vernal pools are isolated from continuous surface water inflows, they can serve as groundwater storage and recharge sites depending on their elevation (Rains et. al, 2008). The hydrologic influence of individual vernal pools is relatively small, but the cumulative hydrologic impact of a network of pools throughout the landscape has the potential to affect watershed dynamics. A high abundance of vernal pools with groundwater inputs in a watershed could significantly improve groundwater quality, as excess nutrients like nitrogen and phosphorous are removed through uptake by surrounding vegetation (Whigham, 2003). Vernal pools situated relatively high in the watershed have a greater potential to improve the water quality of the watershed as a whole, as groundwater purified in headwater regions will be clean before it reaches bodies of water farther down (Trochlell and Bernthal, 1998; Semlitsch and Bodie, 1998). Some studies also suggest that isolated wetlands can prevent flooding and soil erosion within the watershed, as their basins allow for the collection of excess surface water, which diminishes the amount and speed of surface water travelling across the landscape (Leibowitz, 2003; Winter and LaBaugh, 2003).

Vernal pools play important ecological roles as providers of amphibian breeding habitats (Veysey et. al, 2011; Karraker and Gibbs, 2009; Gibbons, 2006; Burne and Griffin, 2005; Paton and Crouch, 2002), as their isolation from surface waters usually excludes larger aquatic predators like fish from their hydrologic environment. Some characteristic vernal pool amphibians include the blue-spotted salamander (*Ambystoma laterale*), the wood frog (*Rana sylvatica*), and the yellow-spotted, or spotted salamander (*Ambystoma maculatum*) (Calhoun and deMaynadier, 2008). Vernal pools also offer habitat for macroinvertebrate insect larvae during the aquatic phase of their life cycles (Alexander and Schisling, 1998), which in turn support many other organisms in the ecosystem. Fairy shrimp (*Branchinectida paludosa*) are obligate vernal pool species and rely on non-permanent, isolated waters for their habitat (Colburn, 2004). Vernal pools typically thaw earlier than lakes in the spring and can provide habitat for waterfowl when resources are scarce (Silveira, 1998).

Vernal pool networks increase biodiversity on a landscape scale (Linquist, 2013) and facilitate amphibian dispersal and migration, allowing for the development of amphibian meta-populations (Semlitsch, 2008). Vernal pool networks can also increase beta diversity levels (regional species richness) when differences in water chemistry, vegetation, and hydroperiod among individual sites result in differences in species composition (Calhoun and deMaynardier, 2008). It is difficult to estimate the ecological significance of vernal pool networks in the landscape when conservation policies and conservation management plans operate on the scale of indicator species or individual pools (Freeman, 2010; McGuire, 2010). Without baseline data on vernal pool abundance and distribution to guide policy, it is doubtful these unique ecosystems will be conserved in a manner that maximizes benefits to amphibian populations or biodiversity in general.

6.3 Knowledge Gaps in the Literature

Liu (2012) completed an undergraduate thesis at Dalhousie University on the detection of vernal pools in the landscape through GIS manipulation of aerial satellite imaging in Halifax County, Nova Scotia. However, there has been no previous research at the graduate or post-graduate level on the distribution and characteristics of vernal pools in specifically Nova Scotia landscapes.

Landscape-scale vernal pool mapping and assessment projects have occurred in New Jersey (Lathrop, 2005), Maine (Calhoun et. al, 2003; Jansujwicz, 2013), California (Zedler, 1987), Conneticut (Pressier, 2000), and Massachusetts (Grant, 2005), but there have been no previous vernal pool surveys in Nova Scotian landscapes. The majority of vernal pool surveys in the literature rely primarily on remote sensing to identify PVP sites through the use of aerial satellite imagery, infra-red imagery, orthophotography, or some combination of the three (Holland, 1996; Burne et. al, 2007; Lathrop et. al, 2005; Veysey et. al, 2011, Grant, 2005; Van Meter et. al, 2008; Liu, 2012). Most studies only engage in ground-based surveys to field verify a small proportion of remotely identified PVPs (Liu, 2012; Van Meter et. al, 2008; Lathrop et. al, 2005). Out of the reviewed literature, this project is the only landscape-scale vernal pool survey that employs a strictly ground-based methodology.

6.4 Research Objectives

This purpose of this study is to provide baseline data on pool features and distribution, identify potential relationships between pool features and landscape influences, and offer a methodological framework for vernal pool documentation and assessment in Nova Scotia on a landscape scale.

There are four questions this project seeks to answer:

1) What is the mean percent canopy, pool surface area, and pool density per site within three separate ecoregions in Halifax County, Nova Scotia?
2) Are there significant differences in percent canopy, pool surface area, and pool density per site among the Atlantic Coastal Ecoregion (800), the Western Ecoregion (700), and the Eastern Ecoregion (400), and to what extent can those differences be attributed to variation in landscape features including, but not limited to, the dominant land-cover and ecosection characteristics of those ecoregions?
3) Are there significant differences in percent canopy, pool surface area, pool density per site, and pH between the Eastern Granite Uplands Ecodistrict (430) and the Eastern Interior Ecodistrict (440), and to what extent can those differences be attributed to variation in landscape features including, but not limited to, the dominant land-cover and ecosection characteristics of those ecodistricts?
4) Would the survey methodology maximize efficiency and reliability on a provincial scale, and if not, what alternative recommendations can be made?

Data collection for this survey occurred from May – November 2013 in three ecoregions (Atlantic Coastal (800), Western (700), Eastern (400)) and two ecodistricts (Eastern Granite Uplands (430), Eastern Interior (440)) in Halifax County, NS. These regions were delineated according to the NS ELC Guide (Neily et. al, 2003). Nova Scotia is situated within the Acadian ecozone, which is subdivided into nine ecoregions with differing regional vegetation, topography, and climate. Ecodistricts further subdivide ecoregions based on finer landscape differences like geology, geomorphology, soils and moisture. Ecosections further subdivide ecodistricts and demonstrate local landscape differences such as distinctive topography, soil texture, and soil drainage.

All survey sites were in Crown Land, 100 m from a trail or road, and equal to or greater than 200 m apart. Local survey areas were chosen to maximize the distribution of survey sites across each ecoregion and ecodistrict, and individual survey sites were chosen to maximize habitat variability within the local survey area.

6.5 Study Approach

These research questions have been addressed through three separate methods of analysis. The first method involved calculating the overall mean percent canopy cover, pool surface area, pool density per site, and pH levels from the mean values in each ecoregion. Percent canopy cover has been recorded to make inferences on the productivity of pool ecosystems. The second method involved identifying significant differences in pool features (density, surface area, and percent canopy cover) among three Ecoregions (Atlantic Coastal (800), Western (700), Eastern (400)) in Halifax County, Nova Scotia through ANOVA testing. Two ecodistricts within Ecoregion 400 (Eastern Interior (440), Eastern Granite Uplands (430)) were systematically surveyed so that significant differences in pool features between ecodistricts could be determined with a 2 sample t-test. Logistical constraints did not allow for a systematic survey approach at the ecosection scale, however differences in the pool features of the well-sampled ecosections were identified among ecoregions (ANOVA) and between ecodistricts (2 sample t-test). Differences in the dominant land-cover per survey site (forest, wetland, open) were also examined statistically to determine if land-cover could be a potential explanatory variable for variations in pool features among ecoregions and between ecodistricts. The third method involved an evaluation of this survey's methodology in the context of relevant literature, and the development of alternative recommendations to improve methodological efficiency and reliability.

7. Literature Review

7.1 Introduction

This literature review offers a spatial and temporal overview of the relevant research on vernal pools. Subtopics include vernal pool ecology, hydrology, anthropogenic impacts, conservation management practices, and landscape correlates of vernal pool occurrence. Each subtopic is reviewed in terms of the areas of research emphasis and the remaining gaps in the literature. Although these subtopics address major focal areas in vernal pool research, not all of them relate specifically to the focus of this project. These subtopics were chosen to provide readers and researchers with a greater depth of knowledge on vernal pool ecosystems.

Vernal pools have recently been classified as a subset of "geographically isolated wetlands" (U.S. Environmental Protection Agency, 2013). The terms "geographically isolated wetland" (Tiner, 2003), "isolated wetland" (Leibowitz, 2003), "seasonal wetland" (Karraker and Gibbs, 2009), or "ephemeral wetland" (Marty, 2005; Zedler, 2003), are often used as synonyms for vernal pools due to their shared ecologic and hydrologic features (Winter and LaBaugh, 2003). Research that addresses geographically isolated or ephemeral wetlands will be included in this literature review.

Research that identifies vernal pools as distinct wetland ecosystems has been occurring for a number of decades. Some of the earliest studies were conducted in the 1950's (Stone, 1959; Childs, 1953), continuing on through the 1960's (Genthy and Miller, 1965), 1970's (Crampton, 1976; Jain, 1976; Linhart, 1976; Thorp, 1976; Barlocher, 1977), and 1980's (Wiggins, 1980; Balko and Ebert, 1984; Rabe 1984; Zedler, 1987). Vernal pool research continued throughout the 1990's and grew in the 2000's with the publication of numerous studies on the varied interactions between vernal pools and their biotic and abiotic environments.

A major focus area of research in the early 1990's was on the significance of vernal pools as biological habitat. Studies involved amphibian species (Portnoy, 1990; Griffiths, 1997; Morey, 1998), macroinvertebrate and vascular plant species (Alexander and Schlising, 1998), crustacean species (King, 1996), and avian species (Silveira, 1998). A single study focused on vernal pool soil forming processes (Hobson and Dahlgren, 1998). Mapping, documentation, and the development of conservation plans occurred in the 1990's in the Western and Eastern US. Californian efforts characterized current and historical distributions of vernal pools on local and global scales (Keeley and Zedler, 1998; Bauder and McMillan, 1998), as well as developed ecosystem-based conservation strategies (Leidy and White, 1998). In 1998 a watershed-scale vernal pool inventory was conducted in Massachusetts (Brooks et. al 1998). Reviews of the cumulative impacts of small wetland losses were conducted in Wisconsin (Trochlell and Bernthal, 1998) and South Carolina (Semlitsch and Bodie, 1998).

The recognition of widespread amphibian population declines in the 2000's (Houlahan et. al, 2000, Blaustein et. al, 2003) heralded a growth in vernal pool research studies. These included further research on vernal pool ecology, including amphibian population dynamics on both an ecosystem and landscape scale (Faccio, 2003; Vasconcelos and Calhoun, 2004; Homan et. al, 2004; Burne and Griffin, 2005; Baldwin et. al, 2006; Gibbons et. al, 2006; Semlitsch, 2008; Compton et. al, 2007; Gahl et. al, 2009; Karraker and Gibbs, 2009; Veysey et. al, 2011), plant population ecology (Palik et. al, 2007; Collinge and Ray, 2009; Palik et. al 2007), macroinvertebrate ecology (Brooks, 2000), and aquatic microorganism community ecology (Carrino-Kyker and Swanson, 2008; Carrino-Kyker et. al, 2012). Vernal pool hydrology and the interactions between pool hydrology and ecology have been studied extensively (Brooks, 2000; Brooks, 2002; Winter and LaBaugh, 2003; Brooks, 2004; Pyke, 2004; Bauder, 2005; Brooks, 2005; Baldwin et. al 2006; Boone, 2006; Korfel et. al 2009).

There has been some research on the ecologic and hydrologic value of vernal pools in the landscape (Semlitsch, 2000; Tiner, 2003; Leibowitz, 2003; Whigham and Jordan, 2003; Kangas, 2005; Babbar-Sebens et. al 2012), as well as the correlation between vernal pool distribution and composition and landscape features like geology, soil, and groundwater flow (Grant, 2005; Rains et. al, 2006; Winter, 2007; Rains et. al, 2008). However, the majority of reviewed research in the 1990's and 2000's focuses primarily on the ecologic and hydrologic components of the vernal pool ecosystem rather than its role in the landscape.

There has been a growth in studies looking at the impact of anthropogenically-caused disturbances such as agriculture (Marty 2005; Goldberg and Waits, 2010, Gosejohan, 2012), habitat loss (Homan et. al, 2004; Baldwin and deMaynadier, 2009; Windmiller et. al, 2008) and climate change (Pyke, 2005; Hayhoe et. al, 2007; Brooks, 2009, Nova Scotia Department of Environment, 2005) on vernal pool ecology and hydrology, and a corresponding surge of publications on the importance of developing vernal pool conservation strategies at local and regional scales (Preisser et. al, 2000; Paton and Crouch, 2002; Calhoun et. al, 2003; Lichko and Calhoun, 2003; DeMeester et. al, 2005; Burne and Griffin, 2005; Baldwin et. al, 2006; Oscarson and Calhoun, 2007; Cappiella and Fraley-McNeal, 2007; Freeman, 2010; McGuire, 2010; Lindquist, 2013; Jansujwicz et. al, 2013). Vernal pool mapping and assessment projects have occurred in the Northeastern US (Lathrop et. al, 2005; Grant, 2005) in tandem with studies that analyze the efficacy of various survey methodologies (Van Meter et. al, 2008, Burne et. al, 2007; Holland, 1996).

Two seminal pieces of work in the field of northeastern vernal pool ecology were published in the 2000's. *Vernal Pools: Natural History and Conservation* was compiled and written by Elizabeth Colburn in 2004, and *Science and Conservation of Vernal Pools in Northeastern North America* was compiled and written by Aram Calhoun and Phillip deMaynadier in 2008. By providing comprehensive reviews of completed research and recommending areas of further study, these texts have greatly advanced the field of vernal pool science.

The majority of reviewed literature published before 2000 was conducted in western US. Out of 12 vernal pool field research studies published before 2000 (not including literature reviews or citizen conservation manuals), nine occurred in California and three occurred in Northeastern USA (Cape Cod, Massachusetts, and Wisconsin). Out of 52 vernal pool field studies conducted post-1999, only 11 occurred in Western US (California and Idaho) compared to 41 in Northeastern USA. Northeastern states involved in vernal pool field research post-1999 include Massachusetts, Minnesota, Maine/New England, Ohio, New Hampshire, South Carolina (southeastern), New Jersey, Vermont, Conneticut, and Rhode Island. There has been some research on vernal pools conducted in Ontario (Barlocher, 1977; Williams, 2007) and Nova Scotia (Collins and Russell, 2009), but relatively little when compared to California or the Northeastern US, and none that investigate vernal pools on a landscape scale.

7.2 Vernal Pool Ecology

Vernal pools exhibit a variety of biological activity, providing habitat for amphibian species, waterfowl, vascular plants, macroinvertebrates, and microorganisms, and have seasonally variable hydroperiods (Tiner, 2003). Vernal pools are ideal habitats for specialists that can survive full inundation and full desiccation, as well as organisms that shift between aquatic and terrestrial habitats in different life stages of growth and development such as amphibians and insects (Colburn, 2004). A study by Lindquist (2013) found more specialist species in forest habitat with vernal pools than in forest habitat without vernal pools.

Various research studies document the importance of vernal pools as breeding habitats for amphibian species. Burne and Griffin (2003) found 11 amphibian species in 85 pools surveyed in northeastern Massachussetts. A fair number of studies have documented the extent amphibian species use vernal pools as breeding habitat in varying conditions. It has been found that the yellow-spotted, or spotted salamander (*Ambystoma maculatum*) (Veysey et. al, 2011; Vasconcelos and Calhoun, 2004; Faccio, 2003), the blue-spotted salamander (*Ambystoma laterale*) (Regosin et. al, 2005), wood frog (*Rana sylvaticus*) (Veysey et. al, 2011; Burne and Griffin, 2005; Karraker and Gibbs, 2009), green frog (*Rana clamitans*) (Burne and Griffin, 2005; Lamoureux and Madison, 1999), leopard frog (*Rana pipiens*) (Burne and Griffin, 2005), spring peeper (*Pseudacris crucifer*) (Burne and Griffin, 2005), and American bullfrog (*Rana catesbeiana*) (Gahl et. al, 2009), are common pool-breeding amphibian species. Comprehensive lists of common vernal pool species have been compiled by both Colburn (2004) and Calhoun and DeMaynadier (2008) in their texts.

A study conducted by Karraker and Gibbs (2009) in the Adirondack region of the US compared the use of seasonal and semi-permanent pools by wood frogs (*Rana sylvatica*) and spotted salamanders (*Ambystoma maculatum*) over 3 years. They found that the seasonal pools contained four times as many spotted salamander egg masses as the semi-permanent pools, and that wood frog survival rates to metamorphosis and juvenile production were higher than in semi-permanent wetlands. One study in Maine found a higher density of American bullfrogs in seasonal pools than permanent pools during periods of full inundation, and that bullfrogs only migrated to permanent pools after the seasonal pools had reached full desiccation (Gahl et. al, 2009). Burne and Griffin (2005) found that amphibian species richness was positively correlated with pool surface area, inundation period length, the amount of emergent vegetation, and the presence of another pool within 1km. Baldwin et. al (2006) found that pool-breeding salamander populations were largest in relatively mature forests. Thus, not only the presence of individual vernal pools but their size, length of inundation, the amount of surrounding vegetation, the type of surrounding land-cover, and whether or not the pool exists within a network are factors that influence the reproduction, fitness, and mortality of amphibian populations.

One study (Portnoy 1990) directly relates to common conditions of the Nova Scotian landscape. Portnoy examined the breeding and mortality rates of spotted salamanders in acidic pools (average pH=4.82), and found that salamander survival to hatching was over 80% at 8 of 12 monitored ponds. This is significant because Nova Scotia’s waters are chronically acidic due to high historical levels of acid precipitation input (Ginn et. al, 2007), dissolved organic acid inputs from peatlands (Gorham et. al, 1986), and a large percentage of surface bedrock, which has a very low acid buffering capacity (Freedman, 2012). Portnoy’s study indicates that at least some amphibian species may not be adversely affected by Nova Scotia’s chronic acidic conditions. The lethal acidity threshold for piscean species is between a pH of 4-5 (Lacroix, 1989; DeLonay et. al, 1993; Vuorinine et. al, 1993), and research suggests this lethal threshold range applies to amphibian species as well (Clark and Lazerte, 1985). A study by Freda (1986) documented lethal pH levels for certain amphibian species within the 3.0-4.0 pH range.

The hydrology and distribution of vernal pool ecosystems affects the life cycles, mortality, and population dynamics of surrounding amphibian species. Amphibian species that metamorphose from aquatic to terrestrial life stages are directly influenced by seasonal variation in vernal pool hydroperiods, as pools with longer inundation periods facilitate larger juveniles (Morey, 1998). Due to their isolation from surrounding surface-water systems, vernal pools provide a refuge for amphibian species that would be otherwise be preyed upon by aquatic predators like fish (Zedler, 2003). On a landscape scale vernal pool networks provide sites for amphibian migration, supporting amphibian meta-populations and thus facilitating increases in genetic diversity (Vasconcelos, 2004; Compton et. al, 2007). In a synopsis of literature concerning population dynamics of pool-breeding amphibian species, Semlitsch (2008) found migrations at the local population level averaged approximately 700m and took place over a relatively short period of time (1-5 yrs.) when compared to dispersal patterns at the meta-population level, which involved migrations of up to 10km over 10-20 yrs. The continued presence of vernal pool networks in the landscape thus ensures long-term meta-population development.

A study in California determined that vernal pool landscapes provide migratory waterfowl with feeding and nesting grounds (Silveira, 1998). During the spring when other food sources are less abundant, migratory avian species were observed spending hours grazing on the protein-rich plants surrounding the pools. On a regional scale, vernal pools in the landscape enhanced the total available migratory habitat for avian species.

The primary control factor for the community composition of aquatic vernal pool macroinvertebrates is most likely the duration of inundation (Brooks, 2000), and the amount of canopy cover, as aquatic macroinvertebrate communities rely on carbon inputs from overhead vegetation (Colburn, 2004; Inkley et. al, 2008). In a study conducted by Brooks between 1994 and 1996, a survey of 5 vernal pools 3 times per year yielded macroinvertebrate specimens from 57 taxa. Common vernal pool macroinvertebrate species taxa include Chironomidae, Oligochaeta, Culicidae, Gastropoda, Cyperididae, and Eremaeidae, as well as the genus *Daphnia* (Brooks, 2000; Colburn, 2004). Eukaryotic and bacterial species are more influenced by variation in chemical and pH levels. Carrino-Kyker and Swanson (2008) documented spatial and temporal community dynamics of eukaryotic and bacterial species in a microcosmic, laboratory replication of vernal pool ecosystem dynamics. They tested the effects of pH and nitrate pulses on these community dynamics, and found that bacteria denitrification rates increased with nitrate input. Decreasing pH caused an increase in microbial respiration, but had little influence on denitrifying bacteria. The dynamics of mirco- and macro-organism communities in vernal pool ecosystems are influenced by inundation duration and changes in chemical and pH levels. Research on the influence of changes in these aquatic communities to vernal pool amphibian and vegetative communities is relatively scarce, but the field holds potential in developing early indicators of vernal pool ecosystem health.

The range of vascular plant communities surrounding vernal pools can be highly variable, as documented in a study on the Vina Plains Reserve in California (Alexander, 1998). The composition of vernal pool plant communities depends primarily on the duration of inundation of the pool (Palik et. al, 2007) and the dispersal capability of individual species (Collinge and Ray, 2009). Functional plant groups around vernal pools in the Great Lakes region of northern

Minnesota were different between forested upland areas and low-lying wetland areas (Palik et. al, 2007). In the upland areas the plant community included upland trees, sedges, and perennial forbs, and in wetland areas plant variation included wetland sedges, grasses, and forbs. The study concluded that the duration of inundation of the pools accounted for 36% of this variation, and the relative influence of the surrounding ecological landscape was negligible.

Research on amphibian species that use vernal pools as breeding, larval, and juvenile habitat sites dominates the literature. Studies suggest that the length of pool inundation significantly influences the reproduction, fitness, and mortality of amphibian and macroinvertebrate populations, as well the composition of surrounding plant communities. Research clarifying these relationships in specifically Nova Scotian landscapes would increase our understanding of vernal pool community ecosystem dynamics and the implications of changes in inundation length for amphibian conservation and biodiversity in this province. Woodland vernal pools are detritus-based ecosystems (Colburn, 2004; Inkley et. al, 2008), and as such it would be valuable to study the influences of detritus input levels on macroinvertebrate community composition, and of macroinvertebrate community composition on vertebrate communities, so that indicators for ecosystem health and resilience could be developed. Determining how differences in overhead canopy cover influence the abundance of detritus in vernal pools and the community composition of aquatic macroinvertebrates would help identify relationships between canopy cover and the productivity of the pool ecosystem. It would also be useful to investigate lethal temperature threshold levels for macroinvertebrate and amphibian vernal pool species to provide baseline data to measure the progress of climate change in the coming years.

Although the ecology of individual vernal pools has been researched extensively, there is less literature available on the meta-population dynamics of amphibians between pools and the dispersal patterns of vernal pool plant specialists. Addressing species richness and biodiversity on a landscape scale would contribute to an assessment of the ecological significance of vernal pool networks and the development of regional conservation strategies.

7.3 Vernal Pool Hydrology

Due to their hydrologic characteristics vernal pool ecosystems can be classified as a sub-type of geographically isolated wetlands (Tiner, 2003; Zedler, 2003; Whigham, 2003; Leibowitz, 2003), yet distinct hydrologic features define vernal pools from geographically isolated wetlands as separate ecosystems. These features include water inputs, the duration of inundated and desiccated phases, and the timing of those phases (Keeley and Zedler, 1998). In addition to enhancing biodiversity on local and landscape scales, vernal pools can also affect watershed hydrology on local and landscape scales.

Vernal pools have unique seasonal hydroperiods. Pools typically refill in the spring from precipitation and snowmelt due to the rate of water input exceeding the rate of water loss from evaporation and evapotranspiration (Zedler, 1987). However, some pools only reach full desiccation every few years and as such do not refill completely in the spring (Colburn, 2004). After the spring, pools undergo a period of inundation until the rates of evaporation and evapotranspiration exceed precipitation and/or groundwater inputs. Rising temperatures cause evaporation rates to increase, and the emergence of leafy vegetation causes evapotranspiration rates to increase. Continuous drawdown occurs through late spring to summer resulting in fully desiccated soils in the late summer or fall, which draws the vernal pool’s annual hydroperiod to a close (Keeley and Zedler, 1998). However, the timing of inundation and desiccation can vary annually (Brooks, 2000), regionally (Zedler, 2003), and even seasonally within a single region (Brooks, 2004) due to differences in precipitation and primary water inputs. For example, pools in Nova Scotia often refill in the fall due to high precipitation levels (John Brazner, Nova Scotia Environment, personal communication). The annual hydrologic budget of a vernal pool can be classified as the difference between precipitation, groundwater, and runoff inputs, and evaporation, spillage, and evapotranspiration outputs over a single growing season (Brooks, 2004).

Vernal pool hydroperiod assessment studies can be short or long term. In a 10-year project assessing the influence of weather patterns on pool hydroperiod, Brooks (2005) determined that the amount of local precipitation dominates the inundation levels and drawdown rates of individual vernal pools. A 20-year hydrologic study of 10 pools conducted in San Diego, California, also concluded that the reliance of vernal pools on precipitation inputs causes their duration of inundation to be strongly correlated to local weather conditions (Bauder, 2005). This study found that pool elevation was a control factor for the duration of inundation, as pools higher in the watershed held water for less time than pools in low-lying, collecting areas (Bauder, 2005). A shorter study sampled eight vernal pools over a time period of two years to develop depth profiles, which were then compared to depth profiles simulated by a hydroperiod model (Boone, 2006).

A study by Pyke (2004) did not complete long-term field observations. Instead, they compared simulated hydroperiods modeled from regional precipitation levels, basin morphology, soil characteristics, and vegetation cover with field observations of pool hydroperiods over a timeframe of four years. Simulated results were similar to field results, demonstrating that vernal pool hydroperiods can be modeled primarily on precipitation as well as evapotranspiration levels. A study by Boone et. al (2006) also compared simulated hydroperiods to field observations over a relatively short time period, however the simulation was modeled exclusively on the water budget of the pools. Whether the research objective is to describe the hydrologic dynamics of the pool (Boone et. al, 2006) or the dominant influences of hydrologic dynamics (Pyke, 2004), hydroperiod simulation modeling can be an effective tool to better understand the dynamics of and influences to vernal pool hydrology.

A study of 34 vernal pools in Massachusetts demonstrated that the hydroperiods of shallow vernal pools are influenced by basin morphology (Brooks, 2002). This project determined that the pool's perimeter-to-area ratio influenced the pool's length of inundation. Increased shoreline length increased the amount of evapotranspiration occurring by shoreline vegetation, causing pools with higher perimeter-to-area ratios to have shorter inundation periods (Brooks, 2002). Although the study concluded that there was a correlation between the hydroperiod of shallower pools and basin morphology, this correlation was variable among pools of greater volume, indicating that there are other control factors of potentially greater significance on the hydroperiod of deeper pools such as temporal precipitation patterns, evapotranspiration, and groundwater exchange.

Many geographically isolated wetlands are still hydrologically connected to other water systems or wetland complexes, and Winter and LaBaugh (2003) argue that the entire hydrologic system needs to be considered before defining wetlands as isolated. Even though vernal pools are isolated from continuous surface flow, vernal pools can be connected to surrounding hydrologic systems via groundwater flow (Tiner, 2003), intermittent overflow spillage (Winter and LeBaugh, 2003), or intermittent streams (Colburn, 2004). Both pool surface area and pool pH have been found to correlate positively with intermittent surface water connectivity (Cook and Hauer, 2007; Cook, 2001). In a summary of the major hydrologic characteristics of isolated American wetlands (Tiner 2003), groundwater inputs are stated as typically coming from local flow systems. Groundwater accumulates in depressions when the water table rises above surface ground level, creating geographically isolated but hydrologically connected pools (Tiner, 2003). Vernal pools surrounded by impermeable substrates like clay, hardpan, or rock basins are often isolated from groundwater inputs (Rains et. al 2008). In a review of literature on vernal pool hydrology, Brooks (2005) determined that the exchange between vernal pool groundwater and surface water affects pool hydroperiod. If the groundwater table is below the pool bottom, precipitation inputs are lost to groundwater seepage. If the groundwater table is above the pool's bottom, groundwater inputs maintain pool inundation for a longer period of time than precipitation inputs alone. Thus, during periods of low precipitation levels vernal pools may act as groundwater recharge sources, as long as the water table is at or above the bottom of the pool basin.

An assessment of the relationship between groundwater inputs and surface water outputs among 7 streams in a study by Winter (2007) determined that most streams needed groundwater inputs to maintain consistent water levels, and groundwater inputs that occurred higher in the watershed ensured greater volume and stability lower in the watershed. From this, we can infer that a high abundance of vernal pools in elevated locations or in the headwater region of a watershed could potentially recharge surface water systems lower in the watershed. In conclusion, the literature suggests that the hydrologic significance of vernal pools in a watershed depends on their abundance and distribution, groundwater table levels (Brooks, 2005), pool elevation (Bauder, 2005), and the presence of permeable geologic substrates (Rains et. al, 2006).

Land-use/land-cover in a watershed also influences the hydrologic significance of vernal pools. In areas that are dominated by agricultural development or heavily drained, the presence of small wetland and vernal pool networks are crucial to the management of storm water runoff and flood prevention. Through spatial ArcGIS analysis, restoration methods have been developed which consistently predict the optimal location of pools within the agricultural matrix in order to best control run-off (Babbar-Sebens et al., 2012). Two studies by Leibowitz (2003) and Winter and LaBaugh (2003) suggest that isolated wetlands can prevent flooding and soil erosion within the watershed, as their basins collect excess surface water and thus diminish the amount and speed of surface water travelling across the landscape. One study on vernal pool networks in Indiana predicts that a network of small wetlands covering 1.5% of the total watershed area could capture runoff from 29% of the total watershed (Babbar-Sebens et al., 2012).

This review on vernal pool hydrology addressed hydroperiod dynamics, the influence of intermittent hydrologic connectivity of both surface and groundwater, and the potential for vernal pools to prevent flooding and erosion and manage stormwater runoff. I recommend further research on the relationship between pool distribution within the watershed and the extent of hydrologic services provided. I also recommend further study on the role vernal pools play in buffering excess nutrients in groundwater and precipitation, and mitigating the effects of stormwater runoff, flooding, and erosion.

7.4 Anthropogenic Impacts

The distinct combination of ecologic and hydrologic vernal pool dynamics has the potential to enhance their sensitivity to anthropogenic impacts such as habitat loss and climate change on both a local and regional scale.

In Nova Scotia, only vernal pools larger than 100 m^2 are regulated under the current provincial wetland conservation policy. This increases the potential impact of anthropogenic developments like the urbanization of natural habitats (Baldwin and deMaynadier, 2009). In the US, the Supreme Court case ruling between the Solid Waste Agency of Northern Cook County (SWANCC) v. U.S. Army Corps of Engineers resulted in the exclusion of geographically isolated wetlands (and thus, vernal pools) from the Clean Water Act (Fitzgerald, 2003). The detrimental ecological impacts of this ruling have been identified in a number of studies, as means that geographically isolated wetlands are now excluded from protection at the federal policy level (Semlitsch and Bodie, 1998; Whigham, 2003; Leibowitz, 2003, Zedler, 2003).

A study conducted by Homan et. al (2004) found that there is a critical threshold level between available natural habitat in a vernal pool landscape and amphibian population levels. A study by Windmiller et. al (2008) demonstrated sharp declines in breeding populations of two typical vernal pool species, *Rana sylvatica* and *Ambystoma maculatum,* after the construction of a shopping centre and housing units. The construction of the shopping centre destroyed 90% of the upland forest surrounding the vernal pool, and the construction of the residential unit destroyed 41% of the forest within 300m of the vernal pool. Anthropogenic impacts to surrounding landscapes alter the community composition of remaining vernal pool ecosystems.

The ecologic and hydrologic significance of individual vernal pools diminishes when vernal pool landscape networks are fragmented by anthropogenic development. A study conducted by O’Neill et. al (2006) uses HANPP (human appropriation of net primary production) to measure the magnitude of human activity in specific areas with respect to the available ecological energy flows. In Nova Scotia, humans appropriate over 25% of available ecological energy production through harvesting (forestry and agriculture) and land-cover change. In the north-central counties of Nova Scotia this amount increases to 50% (O’Neill et. al, 2006). This has implications for provincial vernal pool conservation, as well as the ecological significance of remaining Nova Scotian vernal pools in anthropogenically-impacted regions. Anthropogenic development is usually accompanied by increased water usage on a landscape scale. Sustained usage of groundwater aquifers would decrease the water table and consequently decrease the duration of inundation of pools with groundwater inputs. This has implications for the life cycles of vernal pool organisms and the community composition of pool vegetation (Winter and LaBaugh, 2003).

Some research predicts the future impact of climate change on vernal pool ecosystems. In a report given by the International Panel of Climate Change scientists, northeastern North America is predicted to undergo increases in average annual temperature and changes to precipitation patterns, resulting in more intense precipitation events separated by longer periods of drought (Solomon et. al, 2007). The predictions of climate change in Nova Scotia include rising sea levels and corresponding increases in coastal erosion and flooding, as well as more frequent occurrences of extreme rainfalls, storms, and hurricanes. These impacts are compounded by the fact that Nova Scotia is vulnerable to tropical hurricane systems due its proximity to the Gulf Stream (Nova Scotia Department of Environment, 2005; Nova Scotia Department of Environment, 2009). According to Nova Scotian climate change predictions, precipitation levels and temperatures are expected to increase (Nova Scotia Depratment of

Environment, 2005; Nova Scotia Department of Environment, 2009). This could either increase or decrease the duration of pool inundation, depending on the relationship between input precipitation rates and output evaporation rates.

Another study predicts that shrinking snow cover, more frequent droughts, and extended summer low-flow periods (Hayhoe et. al, 2006) in the Northeastern US. Brooks (2009) suggests that vernal pools in Northeastern North America will undergo increases in evapotranspiration rates, resulting in enhanced surface and soil water losses and decreased periods of inundation. Predicted impacts by Brooks (2009) also include “flashier” hydroregime patterns due to increased precipitation levels and evapotranspiration/evaporation rates. As the period of inundation is a control factor in the ecological composition of vernal pool vertebrate, invertebrate, and plant communities, alterations to the length of inundation induced by climate change will undoubtedly result in changes to the typical vernal pool community compositions.

Most of the research on anthropogenic impacts to vernal pool ecosystems has been conducted with a focus on amphibian conservation. As such, further research on the consequences of cumulative vernal pool loss to regional biodiversity levels and the hydrologic functioning of the watershed is recommended. Research is also recommended that investigates the cumulative historical loss of vernal pool habitat on a landscape scale in Nova Scotia. Determining what amount of vernal pool habitat loss can be tolerated by amphibian meta-populations before the population as a whole is diminished past recovery would be a crucial aspect of any landscape-scale conservation plan. Due to the high levels of agriculture and forestry in Nova Scotia, it would be interesting to conduct a comparative study on the biodiversity levels and hydrologic dynamics of pools within those anthropogenic land-use types (monoculture farms and monoculture silviculture plantations) and within a natural forest ecosystem.

7.5 Conservation Strategies

The recognition of the ecological value of vernal pools has triggered conservation efforts in the Western and Northeastern US alike. In 2001, the federal Supreme Court ruled to exclude isolated wetlands from the Clean Water Act's jurisdiction in the case between SWANCC and the U.S. Army Corps of Engineers (Fitzgerald, 2003). This decision only increased awareness of the need to create regional and local conservation plans for isolated wetlands (Cappiella and Fraley-McNeal, 2007; Winter and LaBaugh, 2003). In urbanized areas with less habitat connectivity, it is especially necessary to consider vernal pool conservation in a landscape context (Baldwin et. al, 2006). Vernal pool conditions can be replicated in the laboratory in a fairly straightforward manner, indicating that vernal pools could be ideal sites for more general ecological research (DeMeester, 2005). Leidy (1998) proposed the following criteria for the development of a successful vernal pool conservation strategy: accurate regional classification and assessment, protecting vernal pool networks in the landscape, prioritizing functional integrity over ecological variability, and determining compensation measures for losses in hydrogeomorphic features and ecosystem services. Taking a landscape approach to conserve vernal pools ecosystems makes sense due to their value as a network in supporting amphibian dispersal, migration, meta-population dynamics, increasing biodiversity, and providing hydrologic services.

Establishing the methodology to approach vernal pool conservation from a landscape perspective is key. The New Jersey Department of Environmental Protection (NJDEP) has undertaken a statewide vernal pool mapping project using digitized orthophotography to develop a map of pool hotspots (Lathrop, 2005). One study in Pennsylvania took an indirect approach, using Morisita's index of community to quantify the biodiversity in forests with and without vernal pools in order to rapidly assess the ecological significance of individual vernal pools in the landscape (Lindquist, 2013).

However, conservation management practices in Massachusetts under the Massachusetts Wetlands Protection Act (MESA) have been called inadequate by some due to their ability their focus at the species rather than ecosystem level (McGuire, 2010). In Massachusett's wetland conservation policy, the ecological value of vernal pools is tied to their status as priority habitat for threatened and/or endangered species. The study highlights the importance of creating vernal pool conservation strategies at the level of the entire vernal pool ecosystem, so that the hydrologic benefits they provide and the significance as habitat for other species are not overlooked. In addition, MESA does not specifically protect vernal pools unless they are verified by a field identification process (Grant, 2005). Although this is practical, this does not take a landscape approach and thus does not provide adequate protection for migrating amphibian populations, as maintaining critical upland habitats surrounding vernal pools and habitat corridors between pools in areas influenced by anthropogenic land-use are not addressed in the conservation plan.

A study in Maine surveyed 304 vernal pools throughout the state to assess the statewide applicability of the Maine Natural Resources Protection Act's proposed definition of Significant Vernal Pool as a subset of the Significant Wildlife Habitats designation (Calhoun et. al, 2003). Researchers recorded the presence of vernal pool indicator species and egg mass counts as measures of the pool's local ecological significance, and provided recommendations on conserving pools at a regional scale. They concluded that delineating vernal pool regions based on abundance may exclude smaller networks of vernal pools in other areas, and recommended a landscape approach which takes into account the land-use history and cumulative anthropogenic impacts.

Another study in Maine examined the connectivity between breeding pools, between breeding pools and non-breeding habitat, and between clusters of breeding pools to assess the value of buffer zones (Freeman, 2010). The study emphasizes the need for conservation strategies to take landscape approaches, as buffers around individual pools offer little protection to amphibians once they migrate from their original breeding pool (Harper et. al, 2007). In the context of regional development planning, Freeman proposes conservation zones as an effective model for vernal pool and amphibian protection on a landscape scale. Conservation zones would protect areas where there are high densities of vernal pools, ensuring that the network is not fragmented and the biodiversity of the landscape remains consistent.

Two long-term vernal pool creation projects were reviewed, which created vernal pools in attempts to replicate the hydrologic functions of natural vernal pools. After 9 and 15 years, respectively, researchers found that the hydrologic characteristics of the created pools were not similar to the original pools and thus failed to replicate the hydrologic characteristics distinct to vernal pools (Lichko and Calhoun, 2003; Korfel et. al, 2009). Both projects directly highlight the need to develop better vernal pool creation techniques, and indirectly stress the importance of continuing to develop comprehensive assessment and conservation policies for naturally formed vernal pools.

In Connecticut, researchers engaged in dialogue with 9 separate interest groups to provide recommendations on conservation methods (Preisser, 2000). These interest groups provided a fair representation of the stakeholders in vernal pool conservation, including municipal, state, and federal government bodies, land-use organizations, environmental organizations, consultants, developers, scientists, and educators. The stakeholders in each region were composed of the industries, organizations, and communities that would be affected by the implementation of conservation strategies. As such, the process of developing the conservation policies was flexible to input. For example, if this method was employed in Nova Scotia, the forestry sector would undoubtedly be a stakeholder in the development of any conservation plans and would influence the plan according to their interests.

Some research has highlighted the importance of engaging the public through education and outreach (Preisser, 2000). Other efforts focus on a community-based, citizen-scientist conservation approach to increase public education and engagement, provide data for privately owned land, and supplement decreases in funding. Maine's Vernal Pool Mapping and Assessment Program (VMPAP) teaches volunteers how to classify individual pools based on a 3-tier system of conservation priority depending on the pool's ecological activity and surrounding natural land cover (Oscarson and Calhoun, 2007; Jansujwicz, 2013). Colburn (1995) developed a comprehensive, step-by-step guide for citizens wishing to engage in vernal pool identification and documentation. The State of New Hampshire has also produced a similar citizen-friendly identification and documentation guide (Tappan, 1997).

Vernal pools are mentioned as a class of wetland in the Nova Scotia Wetland Conservation Policy, however they are not granted comprehensive protection as the scope of the policy does not apply to any wetland less than 100 m^2 (Brazner, 2011). In the future, effective conservation of vernal pools in Nova Scotia at the municipal and provincial level may come from any combination of legislated buffer zones, migratory corridors, protected areas, or other methodologies that are determined to be necessary. Due to the increased ecologic and hydrologic significance of vernal pool networks in the landscape, any vernal pool conservation strategy established in Nova Scotia should take a landscape ecology approach and focus on maintaining networks of vernal pools in a given area, rather than protecting individual vernal pool ecosystems or species. Engaging citizens in small communities throughout Nova Scotia in vernal pool mapping and assessment on privately owned land would be a time- and fund-efficient method of creating a provincial vernal pool database and developing local vernal pool conservation strategies.

7.6 Landscape Correlates

The formation of vernal pools within the landscape depends on the interrelation of climatic, geologic, hydrologic, topographic, ecologic, and anthropogenic factors. This subtopic will be addressed in a Nova Scotian context, as landscape determinants of vernal pool features in Nova Scotia are the focus of this research project.

Research suggests that the local and regional topography surrounding a vernal pool influences its formation, size, and abundance. A study conducted in Massachusetts dealt specifically with landscape correlates of vernal pool occurrence, and found that the formation of a vernal pool is correlated positively to slope (Grant, 2005). On the scale of microtopography this means that, like other wetland types, vernal pools are likely to form in basins, depressions, or at the bottom of slopes, due to the tendency of groundwater tables to come closer to surface level when the ground is at a low elevation and of water to naturally collect in low-lying areas. On a regional scale, a landscape dominated by hummocks, pit-mound topography, large expanses of flat terrain with natural basins, or steep ridges with long depressions at the base of their slopes would be conducive to vernal pool formation. Vernal pool formation is negatively correlated with other anthropogenic land-use such as cropland, urban/commercial, and high density residential units (Grant, 2005).

The type of underlying substrate also influences vernal pool formation. Similar to other wetland types, subsurface soil regions rich in clay are conducive to vernal pool formation as the hydrophobic nature of clay particles allows the pool water to stay perched above the clay layer (Rains et. al, 2008). Hardpan subsurface soil formations in California are also strong geologic correlates of vernal pool formation as they limit water seepage (Rains et. al, 2008). One study concluded that vernal pools are more likely to be found on fine grained and floodplain/alluvium soils than on glacial till or bedrock (Grant, 2005). However, in Nova Scotia there is a high percentage of bedrock land-cover, and bedrock depressions would be conducive to vernal pool formation as water cannot drain from the depression.

The Nova Scotia Ecological Land Classification Guide (ELC) (Neily et. al, 2003) describes the geology of Ecodistrict 440 as thin glacial till, quartzite and slate bedrock. The predominant soils are sandy, stony, well-drained loams and the district is predominantly hilly. The 430 Eastern Granite Upland district is underlain by granite bedrock. Granite is resistant to erosion, and most of the soils derived from granite are coarse and shallow. There is a high proportion of exposed bedrock and glacial granite erratics in this ecodistrict, and the dominant topography is drumlinoid. In Ecoregion 700 the bedrock is quartzite and the dominant topography is that of low hills. The soils are made up of glacial till and are coarse, stony and shallow. Ecoregion 800 is 21.6% exposed bedrock, the highest percentage of any ecodistrict in Nova Scotia (Neily et. al, 2003). The bedrock is primarily granite with some slate and greywacke. Close coastal proximity increases the amount of water held in soils, however the amount of exposed granite bedrock also increases. If they are sheltered from the coastal environment, soils can be well drained. The dominant topography in this area is hummocky and drumlinoid (Neily et. al, 2003).

Areas high in annual precipitation are more conducive to vernal pool formation relative to areas with less annual precipitation, as increased precipitation levels increase the duration of pool inundation (Brooks, 2004). As a maritime province with a relatively high annual level of precipitation, Nova Scotia is climatically optimal for vernal pool formation. Within Nova Scotia, varying levels of regional precipitation (Neily et. al, 2003) likely affects vernal pool landscape density and pool surface area among different ecoregions.

As a whole, literature on the landscape influences to vernal pool features and distribution is substantially less than research on the ecology or hydrology of individual pool ecosystems. Further research on the influence of surficial geology, soil type, and vegetation patterns on vernal pool formation is recomended. Although the influence of vegetation on pool formation is primarily a hydrologic issue as the mechanism of influence is evapotranspiration, analyzing vegetation patterns landscape-scale influences to pool dynamics and distribution was not a research topic I found in the literature. Further studies on the influence of microtopography on vernal pool formation, as well as the relationship between microtopography and hydrologic inputs to vernal pools, are also recommended. In addition, more studies on the influence of elevation on pool hydroperiod would help predict where pools may hold more hydrologic significance within the watershed.

7.7 Conclusion

This literature review has provided a summary of the temporal and spatial development of a portion of the field of vernal pool science. It has discussed vernal pool ecology, hydrology, anthropogenic impacts, conservation, and landscape correlates in an effort to familiarize the reader with these major focal areas of vernal pool research, and provide recommendations on areas of further research. In summary, there has been extensive research on vernal pools for the last 20 years in both the Western and Northeastern US. Research has concentrated on the ecological value of vernal pools as amphibian habitats, the input-output relationships of the vernal pool hydroperiod, the length of hydroperiod and the life cycle stages of the pool’s ecological community, the loss of vernal pools through urbanization and agriculture, and on the types of conservation approaches employed in various regions. Further studies on how vernal pools affect regional biodiversity and watershed dynamics should be a top priority, as the outcomes of that research will allow for a more thorough comprehension of the significance of vernal pool networks and provide key data for the development of conservation programs on a landscape scale.

8. Methods

8.1 Experimental Design

This is a cross-sectional, systematically random survey (Rudestam and Newton, 2007). Rectangular transects of uniform area (100 m x 200 m) were traversed at systematically randomized sites within the study area. All sites were on Crown Land to eliminate access issues and remain in natural landscapes, within 100 m of a road or trail to maintain safety, and farther than 200 m from another survey site. A study conducted on songbirds compared the sampling bias of roadside samples compared to inland samples, and concluded that there was not a significant bias to sampling near roads (McCarthy et al. 2011). However, the influence of roadside sampling on vernal pools is likely to differ somewhat from the impact on avian species. Vernal pools that have formed from road or trail construction will not be included in the data collection, as they are not a representation of naturally formed vernal pools in the region. Some vernal mapping and assessment projects have used digital orthophotography to estimate vernal pool distribution, and field-verified subsamples to estimate the percentage of false positives and false negatives the imagery produced (Lathrop, 2005). This project was completely ground-based because a key objective was to directly estimate the distribution of vernal pools across the landscape rather than to identify likely vernal pool hotspots, as is often the goal with remote-sensing survey methods.

Possible site locations were determined by overlaying different map layers in a GIS (ArcGIS 10.1) in the appropriate ecoregions and ecodistricts. Map layers included the Hants and Halifax County land cover, Crown Land cover for Hants and Halifax County, roads and trails, and urban land cover within those counties. Potential survey sites were identified with the Random Point Generator tool in ArcGIS. Spaces designated as optimal local survey areas had high densities of random points. Local survey areas were chosen with the goal of equal distribution across each ecoregion and ecodistrict. Within each local survey area, individual survey sites were selected in the field. The goal of individual site selection was to attain a fair representation of local habitat variation. The researcher walked for a set distance along the road/trail, recorded changes in land-cover along the route, and conducted site surveys in each distinct type of land-cover on the return.

The sample size per ecoregion was determined by the study's available timeframe and an estimate of an acceptable sample size. The initial study objective was to obtain a sample size of 30 survey sites per ecoregion and 15 sites within Ecodistricts 430 and 440. Due to logistical considerations, I ended up with 37 survey sites in the Ecoregion 700, 30 sites in Ecoregion 800, and 47 sites in Ecoregion 400 (17 in Ecodistrict 430 and 13 in Ecodistrict 440).

Survey sites were transected from the front to the back end of each site (Appendix I). There was approximately 30 m between each transect within the 100 m x 200 m survey site, requiring a visual range of 15 m on either side of the transect line. Although the visual distance varied depending on vegetation conditions within transects, a 15m range was almost always easily achievable. Approximately 5 – 10 sites were surveyed per day depending on weather conditions and terrain. A compass was used for orientation within the site and to ensure a relatively straight transect path. The dimensions of the site were measured with a combination of GPS, pacing, and visual estimation.

8.1.1 Data Collection

Site coordinates and pool coordinates were logged at the starting point of each survey site and at each identified vernal pool with a GPS (Garmin eTrex Legend H). The criteria for vernal pool identification related to the maximum pool size that could a) support biological life and/or b) influence local groundwater flow. Pools $\leq 3\ m^2$ with a depth $< 15cm$ were not recorded. The percent canopy cover was estimated to the nearest 10% by observing the area directly above the pool and comparing the amount of open sky to tree cover. The pool surface area was visually estimated in square meters. The pool density per site was determined by tallying the total number of pools within a single survey site. The dominant land-cover was estimated by observing the type of land surrounding each pool, and classifying it as forest, wetland, or open to the nearest 10%. Pool pH levels were measured with a pH meter from Dalhousie's Environmental Science Department (Oaklon PTTestr 35).

8.1.2 Data Analysis

Area and canopy cover values per pool were averaged with respect to the overall number of pools per site. At each vernal pool, the surrounding land-cover was recorded as forest, wetland, or open. The land-cover that was recorded for the most vernal pools within a site was determined as the dominant land-cover for that site, and then given a value of 1 for that site. For example, if there were five vernal pools found within a site and forest cover surrounded four pools, the entire site would be given the value of 1 for forest cover. If a survey site contained an even number of pools, and the half of the pools were surrounded by one land-cover type and the other half by a different land-cover type, each type of land-cover was given the value of 0.5 for that site. Total mean pool values for each ecoregion were calculated in Minitab (Minitab 16).

The null hypothesis is that there is no significant difference in pool features or land-cover among ecoregions or between ecodistricts.

Significant differences in pool features and land-cover were tested in Minitab with a univariate ANOVA test among ecoregions and a 2-sample t-test between ecodistricts. Pair-wise comparisons were conducted on ecoregions with significant differences in pool features and land-cover using Tukey's HSD method. Residual plots were generated to assess the normality of the data (Appendix II**).** Pool density and surface area values were transformed to log(density) and log(area) to improve normality in the ANOVA test.

The number and type of ecosections surveyed per ecoregion and ecodistrict were obtained post-survey through GIS analysis. Halifax County ecosection and ecodistrict layers were downloaded from the GIS section on the NS DNR Forestry website and input into the GIS. Survey site coordinates were transferred from the GPS to the GIS. Survey site points were placed on top of the ecoregion, ecodistrict, and ecosection layers, and through visual analysis, the types and amount of ecosections surveyed per ecoregion and ecodistrict were obtained. A map was created that displays the completed survey sites on top of the ecodistrict and ecosection layers for Halifax County (Appendix I). Ecosections that had sample sizes ≥ 10 within each ecoregion were compared among ecoregions. Ecosections with the largest sample sizes in Ecodistricts 430 and 440 were compared between ecodistricts. The objective of comparing data at the ecosection level was to determine whether there was variation within ecoregions or ecodistricts that ecosection variation explain.

8.2 Study Area

This study is limited to three ecoregions: Western (700), Atlantic Coastal (800), and Eastern (400). Within those ecoregions the survey area also focused on two ecodistricts within Ecoregion 400: Eastern Interior (440), and Eastern Granite Uplands (430) (Appendix I).

These ecoregions and ecodistricts were chosen to maximize the diversity of assessed landscapes and to provide multiple geographic scales of comparison. They were also chosen for their proximity to Halifax, NS (the residence of the researcher), which reduced travel time and transportation costs.

8.3 Physical and Conceptual Limitations

Fieldwork was limited by inclement weather such as rain, sleet, and hail as well as difficult terrain (e.g. heavy hurricane damaged trees, dense forest, steep slopes). Some access points to Crown Land were on private land and accordingly inaccessible. In early May the researcher was injured, so surveying was postponed for three weeks and could not be finished by the end of June. Data collection continued on weekends from September-November. Surveying was also postponed twice during the fall due to the lack of an available vehicle. Working solo for the majority of the fieldwork was a limitation, as the survey speed, efficiency, and overall visibility were lower than when surveying with a partner.

Surveying vernal pools systematically at the ecosection level has been excluded from this study due to logistical constraints. Time constraints have also excluded an analysis of the mean pool values per ecosection and ecodistrict and whether they relate to the mean pool values per ecoregion from this study. Providing an in-depth logistical framework for a provincial vernal pool survey, assessing the feasibility of implementing vernal pool conservation plans at municipal and provincial levels, or addressing possible stakeholders in those conservation plans have all been excluded from this study due to time constraints.

8.4 Timeline

Project planning was conducted from February – April 2013. Data collection in Ecoregions 800 and 700 occurred from May – June 2013. Data collection in Ecoregion 400 (Ecodistricts 440 and 430) occurred from September – November 2013. The introduction, literature review, and methods were completed in December 2013, and the final report including the results, discussion, and conclusion was written from January – March 2014.

9. Results

9.1 Total Mean Values

Overall, 156 pools were identified. The total mean of each pool feature out of all three ecoregions was calculated (Table 1). A table of the mean values for each ecoregion is provided in Appendix I.

TABLE 1 Total recorded vernal pools and mean percent canopy, area, and density for Ecoregions 800, 700, and 400, and mean pH for Ecodistricts 430 and 440.

Pool features	Total mean
canopy	46.9 %
area	46.1 m^2
density	1.30 pools/site
pH	5.13

9.2 Significant Differences

There were significant differences in percent canopy levels (p=0.014), forest land-cover (p=0.033), and open land-cover (p=0.000) associated with each pool when compared across ecoregions. Differences in pool density, pool surface area, and wetland cover among ecoregions were insignificant (p=0.377, p=0.237, p=0.253).

Pairwise comparisons (Tukey HSD test) for percent canopy cover demonstrated that Ecoregion 400 (mean=57.87, s.d.= 33.86) differs significantly from Ecoregion 700 (mean=51.97, s.d.=38.58, and Ecoregion 700 differs significantly from Ecoregion 800 (mean=28.87, s.d.=28.87). Pairwise comparisons for forest cover demonstrated that Ecoregion 800 (mean=0.3226, s.d.=0.4752) differs significantly from Ecoregions 700 (mean=0.6216, s.d.=0.4804) and 400 (mean=0.5532, s.d.=0.5532), and that Ecoregion 700 differs significantly from Ecoregion 400. For open land cover, pairwise comparisons indicated that Ecoregion 800 (mean=0.3226, s.d.=0.4752) was significantly different from Ecoregion 700 (mean=0.0541, s.d.=0.2292) and 400 (mean=0.0213, s.d.=0.1459).

Mean pH in Ecodistrict 430 (mean=4.3, s.d.=0.371) was significantly lower than in Ecodistrict 440 (mean=5.46, s.d.=1.15, p=0.000). Differences in canopy, density, area, forest land-cover, and wetland cover were insignificant (p=0.587, p=0.244, p=0.505, p=0.229, p=0.151). There was one site with open land-cover in Ecodistrict 440, and zero sites with open land-cover in Ecodistrict 430. Statistically comparing differences in open land-cover between ecodistricts was impossible due to this relative lack of data.

There were no significant differences in pool density, pool surface area, or percent canopy (p=0.532, p=0.100, p=0.233) among well-sampled ecosections (WCRD, WCKK, WCHO, ICHO, IMHO) within Ecoregions 800, 700, and 400. Differences in density, area, percent canopy, and pH were also insignificant between Ecodistrict 430 (dominant Ecosection IMHO) and Ecodistrict 440 (dominant Ecosection WMRD) (p=0.520, p=0.652, p=0.983, p=0.900).

9.3 Statistically Insignificant Data Trends

Ignoring the lack of statistical significance and focusing only on tendencies in the data, pools in Ecoregion 800 had the lowest percent canopy, Ecoregion 400 had the highest site density of pools, and pools in Ecoregion 700 had the largest surface area (Fig. 1). Pools in Ecodistrict 430 had larger canopies and surface areas, while pools in Ecodistrict 440 had higher density and pH levels (Fig. 2).

Among dominant ecosections in Ecoregions 800, 700, and 400, pools in Ecosection WCHO (Ecoregion 700) had the largest area, and pools in Ecosection WCKK (Ecoregion 800) had the lowest percent canopy. Ecosection WCKK (Ecoregion 800) had the highest pool density, followed closely by Ecosection IMHO (Ecoregion 400). Ecosection ICHO (Ecoregion 700) was the only ecosection that had a density level less than 1 pool/site (Fig. 3).

Between Ecosection IMHO (Ecodistrict 430) and Ecosection WMRD (Ecodistrict 440) pool features were relatively similar. The greatest difference was in surface area, as pools in Ecosection IMHO were notably larger than in Ecosection WMRD (Fig. 4).

Statistically insignificant land-cover data trends among ecoregions auggest that Ecoregion 700 tended to have higher forest cover, Ecoregion 400 had somewhat higher wetland cover, and Ecoregion 800 tended to have more open land (Fig. 5). In addition, forest cover tended to be higher in Ecodistrict 440, just as wetland cover tended to be higher in Ecodistrict 430 (Fig. 6).

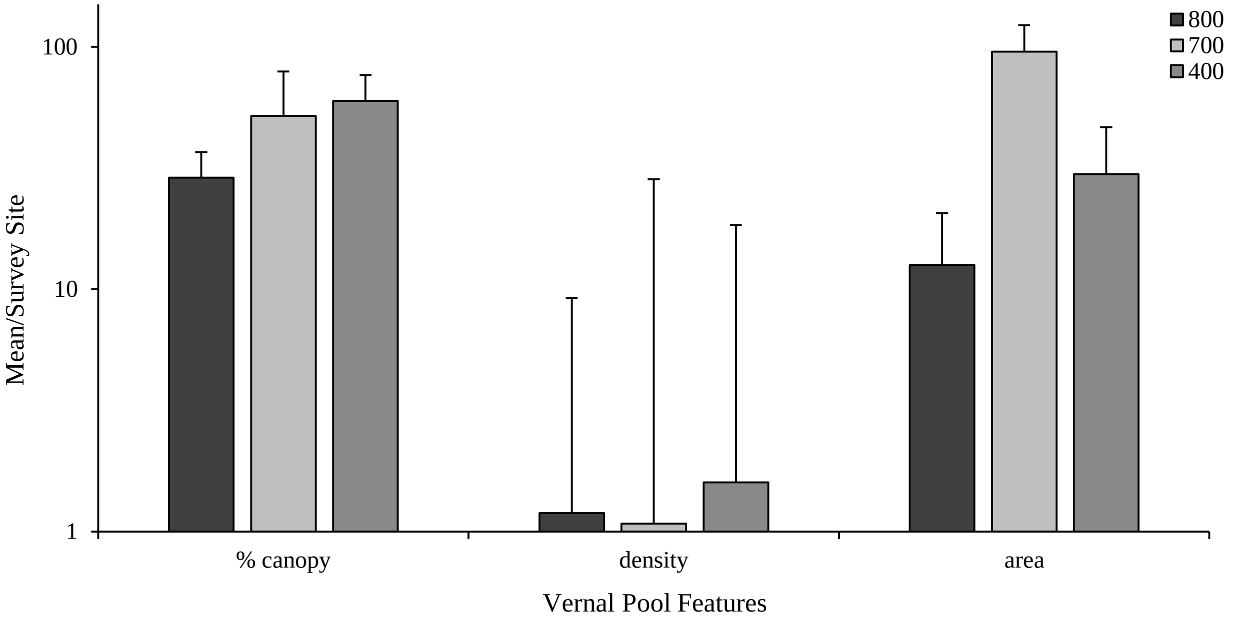


FIGURE 1 Variation in percent canopy, density and area among Ecoregions 800, 700 and 400 with standard error bars.

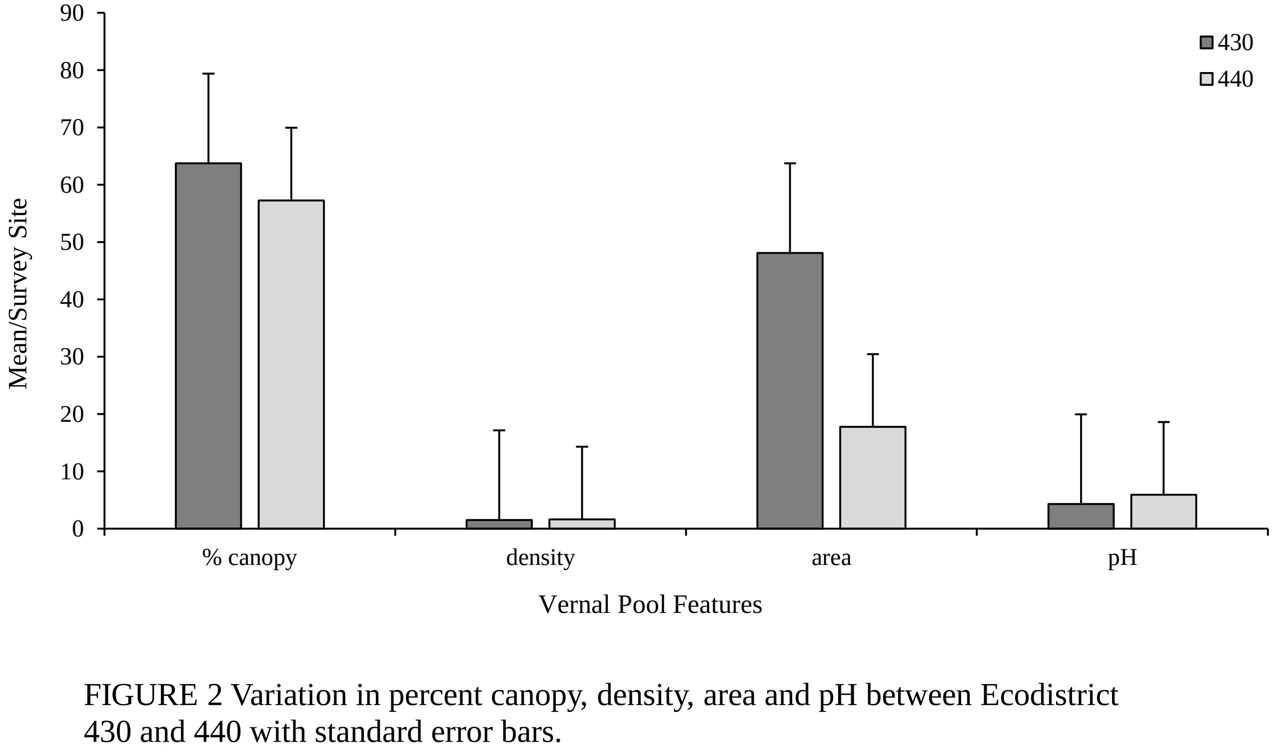


FIGURE 2 Variation in percent canopy, density, area and pH between Ecodistrict 430 and 440 with standard error bars.

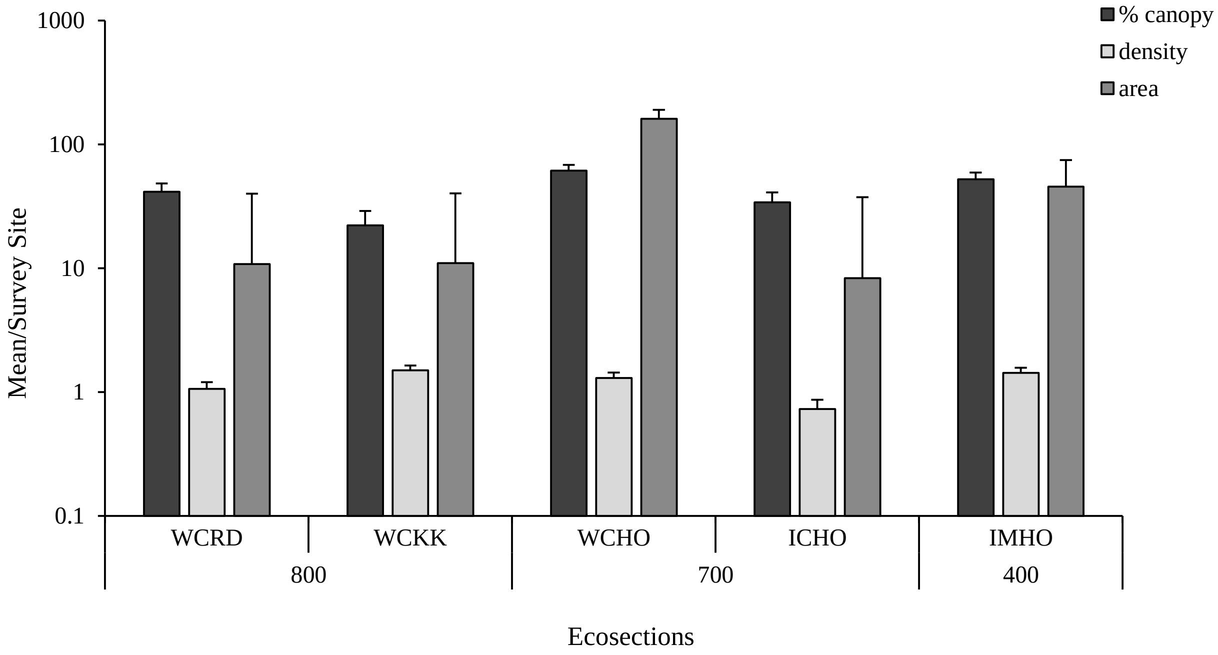


FIGURE 3 Variation in percent canopy, area, and density among ecosections with equal to or greater than 10 survey sites among Ecoregions 800, 700, and 400 with standard error bars.

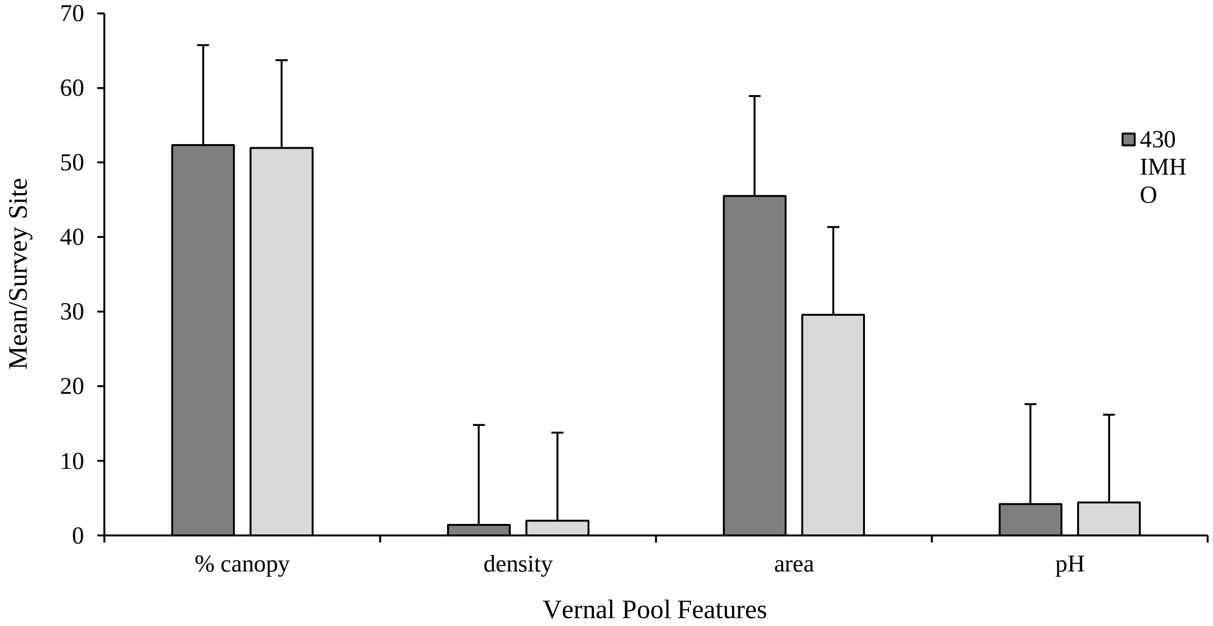


FIGURE 4 Variation in percent canopy, density, area, and pH between the Ecosection IMHO in Ecodistrict 430 and the Ecosection WMRD in Ecodistrict 440 with standard error bars.

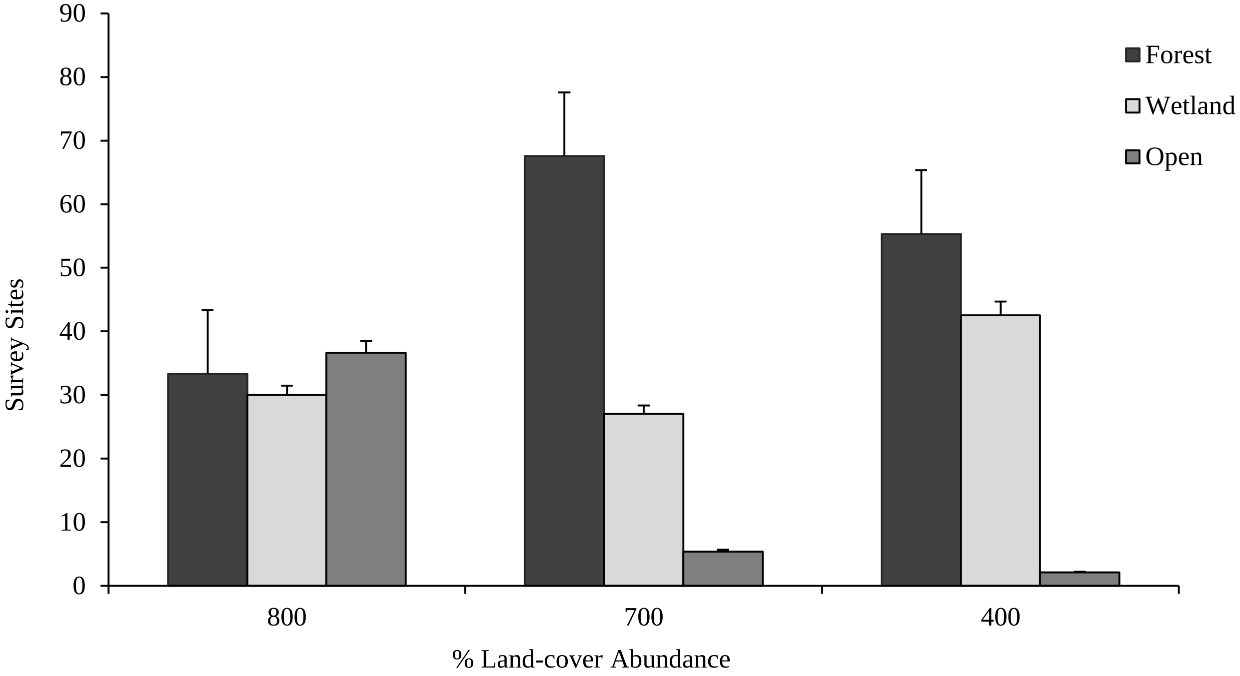


FIGURE 5 Variation in percent land-cover among ecoregions 800, 700, and 400 with standard error bars.

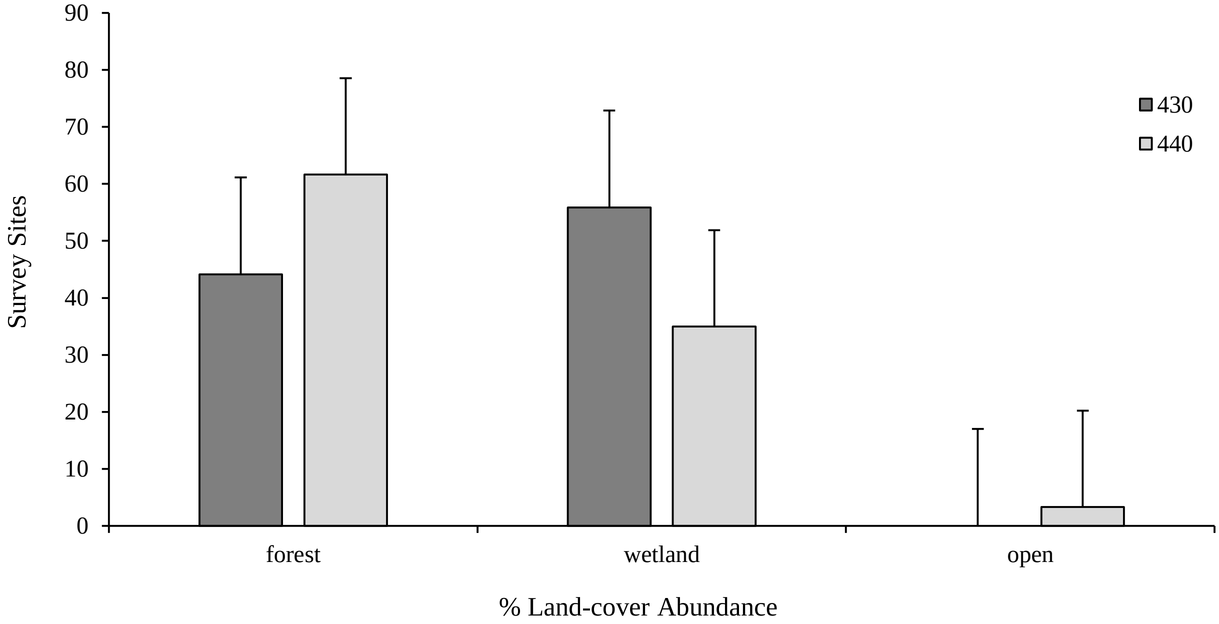


FIGURE 6 Variation in percent land-cover among Ecodistricts 430 and 440 with standard error bars.

TABLE 2 Total amount and percentage of land-cover type within each ecoregion and ecodistrict.

Ecoregion/ Ecodistrict	n	Forest	Wetland	Open	Forest %	Wetland %	Open %
800	30	10	9	11	33.3	30.0	36.7
700	37	25	10	2	67.7	27.0	5.40
400	47	26	20	1	55.3	42.6	2.13
440	30	18.5	10.5	1	61.7	35.0	3.33
430	17	7.50	9.50	0	44.1	55.9	0.00

9.4 Reliability of Ecosection Data

Sites were surveyed in a total of 22 ecosections within the three ecoregions and two ecodistricts. In Ecoregion 800, survey sites occurred in 5 out of 9 total ecosections (55.5%). In Ecoregion 700, survey sites occurred in 5 out of 12 total ecosections (41.7%). In Ecodistrict 440, survey sites occurred in 9 out of 14 total ecosections (64.3%). In Ecodistrict 430, survey sites occurred in 3 out of 8 total ecosections (37.5%) (Neily et. al, 2003).

TABLE 3 The specific ecosections surveyed in each ecoregion/ecodistrict, and the amount of sites surveyed per ecosection (Neily et. al, 2003).

Ecoregion /ecodistrict	Ecosection	Sum
800	WCRD	17
	WCKK	10
	WFDM	2
	ICHO	1
	WCHO	1
700	WCHO	20
	ICHO	11
	WCKK	5
	WCDM	1
	WCRD	1
400/440	WMRD	9
	IMRD	8
	WFKK	5
	WFDM	3
	IMHO	2
	WMHO	1
	WMKK	1
	WMDM	1
400/430	IMHO	11
	WMDM	3
	WCRD	1

10. Discussion

10.1 Total Mean Values

The overall mean percent canopy level of pools surveyed across all ecoregions was mid-range. This indicates Halifax County has a mixture of ecoregions with both high and low canopy levels. This is similar to what has been reported in the literature, as Ecoregions 700 and 400 are heavily forested (Townsend, 2008) and Ecoregion 800 has a high abundance of open land (Neily et. al, 2003; Oberndorfer and Lundholm, 2008).

The overall mean pool surface area was within the range reported in published literature. It is smaller than the average surface area of most studied pools, but larger than the smallest reported sizes. Colburn (2004) reported that vernal pools are usually less than 1ha (10 000 m^2). The smallest values in a study of 64 vernal pools in Massachusetts ranged from 10 – 20 m^2 (Colburn, 2004), which the average mean pool surface area in this study exceeded. In various hydroperiod studies throughout the Northeastern US however, vernal pool surface areas ranged from 114 m^2 – 3334 m^2 (Boone, 2006), 251 m^2 – 1320 m^2 (Brooks, 2000), less than 1000 m^2 (Brooks, 2004), and 6 m^2 – 506 m^2 (Brooks, 2002). This could indicate that the pool surface area mean for Halifax County is relatively small compared to pools in other regions, or that small pools included in this survey were excluded from the reviewed surveys.

The mean pool density for this study was 1.3 pools/20,000 m^2 (1 transect = 100 m x 200 m = 20,000 m^2), which results in 65 pools/km^2 (Appendix I). A statewide vernal pool mapping and assessment project in New Jersey (Lathrop, 2005) found a density of 0.1756 pools/km^2 (3425 pools/19 500km^2), which is far lower than the pool density value obtained from this study. However, Colburn (2004) states that some landscape pool densities can be greater than 12 pool/km^2, which coincides with the pool density value for this study. Compared with these two sources, it is evident that the mean pool density per km^2 attained in this study is relatively high. However, this could be due to differences in pool survey methodology, i.e. this survey may have included pools of smaller area that were excluded from the reviewed surveys. There are few other studies that include a density value of vernal pools in the landscape. Landscape-scale surveys often focus on wildlife conservation (Weese, 1998) or mapping techniques (Holland, 1996; Grant, 2005) rather than the density of pools. Further research is recommended on the landscape densities of vernal pools in different natural and anthropogenic regions of Nova Scotia, Canada, and the Northeastern US.

The mean pool pH level within Ecodistricts 430 and 440 coincide with average pH levels in Nova Scotian freshwater systems. Nova Scotian freshwater systems have low pH levels due to the production of organic acids by wetlands, low natural buffering capacities of regional bedrock, and acid deposition from anthropogenic emissions (Clair et. al, 2007). Although anthropogenic acid deposition has decreased since the 1980's, freshwater conditions have not returned to previous background pH levels and remain chronically acidified (Clair et. al, 2002). Whitfield et. al (2006) analyzed the critical ion and pH thresholds for 20 lakes in Nova Scotia, finding a pH range of 4.5 – 6.65. In another study, pH ranged from 3.64 - 8.85 in 159 field sites containing ditches, bogs, marshes, ponds, and lakes South and Central Nova Scotia (Dale and Freedman, 1984). The mean ecodistrict pH level for this study (pH = 5.13) corresponds with Nova Scotia's typically low pH levels, and falls within the pH range documented by Whitfield et. al (2006) and Dale and Freedman (1984).

10.2 Significant Differences

The three significant differences in pool features and land-cover among ecoregions are interrelated, as percent canopy levels increase when a pool is surrounded by forest, and decrease when a pool is in an open area. The significantly different pairs of percent canopy, forest, and open land-cover agree with this correlation. Ecoregion 700 has the both the highest percent canopy cover level and the greatest forest abundance, while Ecoregion 800 has both the lowest percent canopy cover and the greatest abundance of open land. Significantly different ecoregion pairs for forest land-cover coincide with current biomass levels. According to the NS forest inventory published by the DNR, Ecoregion 700 (Western) has the greatest forest biomass out of all 9 ecoregions at +80t/ha, Ecoregion 400 (Eastern) has the third lowest biomass at 60-70t/ha, and Ecoregion 800 (Atlantic Coastal) is second last at 50-60t/ha (Townsend, 2008). Significant pairs of open land-cover correspond with current ecological classifications. Nova Scotia's ELC Guide (Neily et. al, 2003) describes Ecoregion 800 as dominated by granite barrens and a harsh coastal environment that hinders or stunts forest growth. Ecoregion 800 has been typified as a coastal barrens ecosystem characterized by ericaceous vegetation (heath) and pockets of *Sphagnum* bog, in addition to sparse tree cover and stressful climatic conditions (Oberndorfer and Lundholm, 2008; Burley et. al, 2010; Cameron and Bondrup-Nielsen, 2013). Since Ecoregion 800 is dominated by granite barrens and heath, it makes sense that it has higher open land-cover than Ecoregion 700 and 400. This data could also imply that due to their low canopy cover and consequent low leaf (energy) input into the pool ecosystem, vernal pools in Ecoregion 800 are less productive than vernal pools in Ecoregions 700 and 400.

The high abundance of wetland cover in Ecodistrict 430 likely contributes to Ecodistrict 430's greater acidity. Wetland ecosystems are often dominated by *Sphagnum* moss (Mitsch and

Gosselink, 2007), which has a high cation exchange capacity due to its ability to release hydrogen cations into its surrounding environment in exchange for nutrients (Stalheim et. al, 2009). This persistent release of H+ ions from *Sphagnum* moss lowers the pH level in its surrounding aquatic environment (Stalheim et. al, 2009). Wetlands can also produce high amounts of organic acids that are input directly into surface water systems (Mitsch and Gosselink, 2007). These acidic waters can reach vernal pools through precipitation or meltwater overflow, connectivity with intermittent streams, or inputs from the local groundwater flow. Colburn (2004) notes that *Sphagnum* is often a common pool substrate, thus Ecodistrict 430's high acidity could also indicate that Ecodistrict 430 had more pools with *Sphagnum* moss as a substrate than pools in Ecodistrict 440. Greater amounts of exposed granite bedrock in Ecodistrict 430 (Neily et. al, 2003) may also be a factor of influence in its significantly higher acidity levels, as granite is typically resistant to erosion and thus has a low buffering capacity (Marshak, 2011). 15% of Ecodistrict 430 is covered by exposed granite bedrock, compared to 9.3% in Ecodistrict 440.

10.3 Statistically Insignificant Data Trends

Ecoregion 400 had a higher pool density than Ecoregion 800 and 700, and Ecodistrict 440 had a higher pool density than Ecodistrict 430. Ecoregion 400 has higher precipitation levels than Ecoregions 800 and 700 (Neily et. al, 2003), which may contribute to Ecoregion 400's relatively high vernal pool density. The majority of sampled ecosections in Ecodistrict 430 had hummocky topography (IMHO), whereas the topography of the well-sampled ecosection in Ecodistrict 440 was ridged-drumlinoid (WMRD). This could indicate that ridged-drumlinoid topography is more conducive to vernal pool formation than hummocks, possibly due to the higher slope of basins formed at the base of drumlinoid ridges compared to basins formed by hummocks (Neily et. al, 2003). The greater abundance of wetland cover in Ecodistrict 430 coincides with its predominantly hummocky topography, as hummocks are created by wetland vegetation in response to regular inundation (Mitsch and Gosselink, 2007).

The tendency towards higher forest cover in Ecoregion 700 may contribute to the generally larger pool area in Ecoregion 700. There is nothing in the literature to directly support this speculation, although it has been reported that the majority of vernal pools occur in forested areas (Colburn, 2004). Pools in Ecosection WCHO within Ecoregion 700 tended to have the largest area, indicating that hummocks in Ecosection WCHO may be spaced such that relatively large basins are created. In a study by Cook and Hauer (2007) between isolated and intermittently connected small wetlands, it was found that wetlands with greater hydrologic connectivity had a greater surface-water area than completely isolated wetlands. This could indicate that vernal pools in Ecoregion 700 are intermittently connected to local surface water systems more than pools in Ecoregions 800 or 400. It must be noted that there were large outliers in Ecoregion 700, and this small number of large pools influenced the overall mean pool surface area for the ecoregion.

10.4 Methodological evaluation

In a survey conducted by De Weese (1998), vernal pool sites were chosen from a pre-existing pool database in landscape settings that were known to have historically supported vernal pools. Due to the lack of any pre-existing data on vernal pools in Nova Scotia, this approach was not an option. Keeping the survey area within Halifax County lowered travel time and transportation costs, increasing the amount of sites surveyed per day. Minimizing travel time was an important consideration for my work, and will be a key budgetary and logistics factor in any field-based study. Expanding this project to a provincial scale will undoubtedly require a substantial increase in travel budget. Conducting survey sites on Crown Land ensured easy access, and is recommended for future studies. Municipal and provincial public lands could be added as potential survey areas for future studies in order to increase the amount of available survey area. Surveying municipally owned public land in this survey was not necessary, as there was a fair amount of Crown Land in Halifax County in the form of Wilderness Areas. However, other counties may not have as high of an abundance of Crown Land, thus including municipally owned public lands could increase the available survey area. Maintaining site proximity to a road or trail is also recommended for safety and efficiency. Although some research demonstrates that roadside sampling of avian populations produces biased results (Harris and Haskell, 2007), another study compared roadside avian samples to off-road avian samples and found no significant difference in the results (McCarthy et. al, 2011). Avian population ecology is different than vernal pool ecology, thus the effect of roadside sampling will not influence vernal pool sample bias in the same way avian samples are affected. As long as vernal pools formed by road construction are excluded from future samples, significant roadside bias should be eliminated.

Due to the fact that vernal pools did not show any more significant differences on the ecosection scale than at the ecoregion scale, and that there were no significant differences in vernal pool surface area or density at any of the surveyed geographic scales, landscape characteristics that were not recorded or analyzed in this survey may have more influence on vernal pools in Nova Scotia. These could include, but are not limited to, the local site microtopography and the local site hydrography. Recording the surrounding topography and hydrography of each vernal pool in future surveys may produce a more accurate depiction of the landscape factors of influence on vernal pools.

Many vernal pool studies delineate survey areas according to specific landscape features rather than certain geographic regions. This is an optimal approach for research projects that investigate specific factors of pool formation like soil type (Bauder and McMillan, 1998), (Rains et. al, 2008). The availability of desired landscape features such as surficial geology, land-use, topography, hydrology, and precipitation can be the primary deciding factor in choosing the survey area (Grant, 2005). A study conducted by Babbar-Sebens et. al (2013) layered rasters of individual landscape features onto areas containing optimal vernal pool landscape features in a GIS, so that survey areas were stratified within areas likely to contain vernal pool. This approach could be used as a follow-up to ground-based vernal pool surveys. Raster layers (microtopography, hydrology, wetland cover, forest cover, open cover, soil type) could be combined in a GIS to identify potential vernal pool hotspots using the recorded data that was specific to each surveyed landscape.

In this study, individual site selection requires that surveyors know how to identify different kinds of habitat and have a standardized method of doing so to avoid sampling bias. If surveyors were trained in habitat identification this bias would be minimized. If training is not possible in future surveys, a more reliable methdod of survey site selection would involve identifying sites in a GIS, recording their GPS coordinates, and then using GPS in the field to find the exact survey site locations. This method would not ensure maximum habitat variability, but would likely increase the reliability of site selection by minimizing individual bias. A study by Veysey et. al (2011) used digitized orthophotoquads to calculate the number of pools and the percent of forest cover within the study area, then chose vernal pool survey sites that ranged along the entire wetland-forest cover gradient to ensure local habitat variation was systematically accounted for. A survey by Grant (2005) used digitized aerial photography to identify existing vernal pool sites in ArcGIS, then generated random sites as controls to contrast landscape characteristics with those specific to the vernal pool sites. A regression model was used within the GIS program that modeled the probability of finding a vernal pool in relation to the independent landscape variables, the results of which are discussed in Section 7.4 and 7.6.

Conducting a strictly ground-based vernal pool field survey without using any remote sensing is a relatively uncommon method. Even in 1996 researchers were using aerial slide images projected onto a wall to remotely identify potential vernal pools (Holland, 1996). A study by Burne et. al (2007) that reviewed optimal vernal pool survey methods recommended that survey areas larger than a single property should employ remote sensing to maintain a level of practical efficiency. Most of the recent surveys reviewed in the literature relied on various combinations of satellite/aerial imagery, inventory maps, and orthophotography to remotely identify potential vernal pools prior to entering the field. Some researchers have used a combination of wetland inventory maps and digital orthophotoquads (Veysey et. al, 2011), others have used digitized aerial photography (Grant, 2005), and some have used a combination of orthophotography and infrared aerial photography (Van Meter et. al, 2008). However, these surveys were trying to identify vernal pool hotspots, not obtain an unbiased estimate of vernal pool distribution across the landscape.

A Dalhousie Honours thesis completed by Liu (2012) input digitized aerial photography from the Williams Lake watershed in Herring Cove, NS, into a GIS program, and then used GIS to identify PVP sites such as depressions at the base of water flow systems. Only a very small percentage of total PVPs were field verified, however. Those that were field-verified demonstrated that most PVPs were in depressions, but only two out of eleven PVP sites were actually vernal pools. There were several false negatives such as bedrock and shadow. Liu's study suggests that using satellite imagery to identify PVP's is not an efficient survey method, as pools beneath canopy are not visible at all, and the potential sites identified did not have a high positive verification level. This is similar to the "dual frame" method used in a survey conducted by Van Meter et. al (2008): PVP sites are obtained though remote sensing (orthophotography and infra-red imaging), and the probability of false negatives and false positives from the remote sensing is determined from a random field sample within the survey area. The accuracy of such methods depends on the quality of available photo imagery, the amount of forested land, and the interpretation skills of the researcher. Further research is needed that investigates the level of false negatives and positives resulting from PVP site identification with remote photo-interpretation in specifically Nova Scotian landscapes.

Future studies should ensure that the sample size is equal within ecoregions, ecodistricts, and ecosections to maintain a higher level of statistical validity. I recommend increasing the survey sample size to improve statistical power and to more accurately depict trends in the vernal pool population. Completing the chosen sample sizes took a month and a half of consecutive fieldwork, as well as 3 months of going out 1-2 times per week. If the survey is limited to a single growing season and a single researcher, increasing the sample size is likely unfeasible. Increasing the number of researchers doing consistent survey fieldwork or extending the timeframe to longer than a single growing season would allow for the completion of a larger sample size.

Maintaining an optimal level of standardization between sites meant that the transect paths had to have minimal variation and remain as straight as possible. This was difficult in terrain dominated by wetlands, large areas of deadfall, and thick brush and impacted the study's efficiency. A survey transect method that could allow for flexibility when encountering difficult terrain, while still remaining standardized between sites, would increase efficiency in time and energy. To increase consistency and minimize individual bias, I recommend that future surveys measure transect distance with a GPS to record the precise amount of meters walked. An interesting survey transect method was used in a study by Van Meter et. al (2008), as its approach allowed for the discovery of vernal pool networks in the field. Every time a vernal pool was found, four adjacent, identical survey plots were added to each side of the initial plot. Those plots were then surveyed, and additional plots were added to each exposed side every time a new vernal pool was found in the plot being surveyed, until there remained a ring of exposed edges along the perimeter of all of the plots.

The level of visibility varied dramatically between survey sites. Because the standardization of each site's area was dependent on uniform transects, it was impossible to modify the distance between transect lines according to visibility levels. In sites of low visibility the potential of false negatives were much higher, which decreased the overall reliability of the survey. A survey method that could adapt to site-specific visibility levels and thus mitigate the probability of false negatives would be ideal.

In conclusion, the methods employed in this study were adequate and allowed for the documentation of 156 vernal pools in Halifax County, NS, yet improvements can still be made. If future studies aim to document as many pools as possible in a minimal timeframe, integrating remote sensing imagery like aerial photos or orthophotoquads into survey area delineation would improve survey efficiency, as areas with higher abundances of PVP sites could take priority over areas with lower abundances. However, in this study the objective was to determine the natural distribution of pools across various landscapes, so utilizing remote sensing to prioritize areas with higher pool densities would have skewed the sample distribution. Accounting for changes in visibility levels between sites in the survey methodology would have decreased the probability of recording false negatives in the field and increased the overall survey reliability. Survey efficiency would have been improved if transect lines had been flexible to the presence of rough terrain.

10.5 Methodological recommendations

A site transect method that uses time as the control variable instead of area would maximize survey efficiency and reliability. Each researcher would estimate and record the visibility of the site in meters. The researcher would then walk through the site for a uniform amount of time while recording the distance walked on a GPS in meters. While they walk they would aim to traverse as many different microhabitats within the site as possible to account for the maximum variability in habitat. This way the researcher could avoid exceedingly rough terrain, as well as investigate areas that look like vernal pool habitat more closely. At the end of the pre-determined timeframe, the researcher would record the distance traveled (m) and multiply that distance by their visibility (m) to attain the total area of the site. This approach would increase the efficiency as well as the validity of the survey methodology. Every researcher would need to be equipped with a GPS device, and have knowledge of the area’s distinct habitats so that they were fully aware of habitat variation and could traverse the site accordingly.

10.6 Implications

The relatively high pool density per km^2 in Halifax County indicates that high pool densities could currently exist within other Counties in Nova Scotia. Although this does not provide justification for a provincial vernal pool conservation plan, it does reveal that vernal pools are common amongst certain Nova Scotian landscapes, and offers impetus to initiate vernal pool mapping and assessment in other geographic regions of Nova Scotia to determine whether they are a common ecosystem throughout the province. The underlying implication is that if vernal pools are common in one county they could be common in various counties, and as such their exclusion from conservation management plans makes these ecosystems, and the various species that rely on them for habitat, especially vulnerable to anthropogenic impacts.

The survey methodology's unexpected impacts on efficiency and reliability should guide the methodological design of future surveys in NS. Maintaining time as the uniform variable between transects, as well as recording visibility levels per site, will likely increase the efficiency and reliability of any pool survey conducted on a provincial scale. To accurately depict pool distribution and features across different landscapes in future surveys, there should be a fairly large sample size and the survey should be stratified at an ecosection or ecodistrict level.

The statistical insignificance of pool surface area and pool density per site differences among different landscape settings is an interesting result. It could indicate that pool surface area and pool density per site are more influenced by surrounding hydrologic conditions, which were not addressed in this study. Further research should investigate this relationship more fully. It could also indicate that the sample size of this survey was not large enough to accurately depict significant differences in pool surface area and pool density per site among different landscapes, which has methodological implications for any future vernal pool surveys.

A conceptual limitation of this project is that the landscape characteristics of the studied ecoregions were not compared to others in Nova Scotia, such that additional ecoregions with potentially similar vernal pool distributions and features were not identified. Another limitation is that a thorough analysis of the logistics required (human resources, equipment, transportation, funding) for a provincial survey was not conducted, which slows the process of initiating that survey. The data was limited by not using statistical tests designed for count data, such as the chi-squared test or contingency tables. Parametric statistics were used and the variables were transformed to increase normality, however non-parametric statistics may have resulted in greater statistical accuracy.

Possible areas of future research include, but are not limited to: vernal pool mapping and assessment in other geographic regions in Nova Scotia, identifying new landscape factors of influence on vernal pool features, clarifying the relationships between landscape factors and pool features suggested in this study, investigating ecologic and hydrologic dynamics within a single vernal pool ecosystem or network, determining the logistics (economic, social, political) of a provincial vernal pool survey, and assessing the political feasibility of a vernal pool conservation policy at the municipal and provincial scale by identifying private and public stakeholders in vernal pool conservation.

11. Conclusion

In spite of extensive research documenting the ecologic and hydrologic significance of the vernal pool ecosystem in the landscape, research on vernal pools in Nova Scotian landscapes has been nonexistent until now. This study has provided baseline data on vernal pool characteristics in Nova Scotian landscapes. We can conclude that pools in Halifax County have on average low percent canopy cover levels due to the proliferation of open land-cover in coastal ecoregions. Pools in Halifax County have relatively low surface area, which could indicate they are on average more isolated from intermittent surface water connectivity. It could also be a result of the number of small pools that were recorded through this ground-based methodology in comparison to surveys that rely on remote sensing. The pool pH of two ecodistricts in Nova Scotia falls within the typical acidity range of freshwaters in Nova Scotia. There is a high pool density per km^2, however more research is needed to fully verify this claim relative to other regions.

This study also demonstrated that the percent canopy of vernal pools in Halifax County is responsive to dominant land-cover on an ecoregion scale, and that the pH of vernal pools is responsive to land-cover on an ecodistrict scale. These were both expected findings after comparison with relevant literature. The insignificance of pool surface area and pool density per site at all tested geographic scales was unexpected, as it challenges previous research that has identified relationships between vernal pool surface area and water budget, climate, surficial geology, and soil type, and between pool density and land-cover, climate, surficial geology, and soil type. An alternative explanation is that the sample size per ecoregion, ecodistrict, and ecosection was too small to accurately exhibit significant differences in pool surface area and pool density per site.

Although most vernal pool surveys rely on remote sensing, this project has piloted a ground-based survey methodology and provided recommendations to improve methodological efficiency and reliability for future pool surveys on a provincial scale.

References

Alexander, D. G., & Schlising, R. A. (1998). Patterns in time and space for rare macroinvertebrates and vascular plants in vernal pool ecosystems at the Vina Plains Preserve, and implications for pool landscape management. In *Ecology, conservation, and management of vernal pool ecosystems. Proceedings of the 1996 conference of the California Native Plant Society*. Retrieved from http://www.vernalpools.org/proceedings/alexander.pdf

Babbar-Sebens, M., Barr, R. C., Tedesco, L. P., and Anderson, M. (2012). Spatial identification and optimization of upland wetlands in agricultural watersheds. *Ecological Engineering,* 52: 130-142.

Baldwin, R. F., and deMaynadier, P. G. (2009). Assessing threats to pool-breeding amphibian habitat in an urbanizing landscape. *Biological Conservation, 142*(1), 1628-1638. doi: 10.1016/j.biocon.2009.02.039

Baldwin, R. F., Calhoun, A. J. K., and deMaynadier, P. G. (2006). The significance of hydroperiod and stand maturity for pool-breeding amphibians in forested landscapes. *Can. Journal of Zoology, 84*(1), 1604-1615. doi: 10.1139/Z06-146.

Balko, M. L., & Ebert, T. A. (1984). Zooplankton distribution in vernal pools of Kearny Mesa, San Diego, California. *Vernal Pools and Intermittent Streams. Institute of Ecology Publication*, *28*, 76-89.

Barlocher, F., Mackay, R. J., & Wiggins, G. B. (1977). Detritus processing in a temporary vernal pool in southern Ontario. *Archiv fur Hydrobiologie*, *81*(3), 269-295.

Bauder, E. T. (2005). The effects of an unpredictable precipitation regime on vernal pool hydrology. *Freshwater Biology 50:2129-2135.* doi: 10.1111/j.1365-2427.2005.01471.x

Bauder, E. T., and S. McMillan. (1998). Current distribution and historical extent of vernal pools in Southern California and Northern Baja California, Mexico. Pages 56-70 *in* C. W. Witham, E. T. Bauder, D. Belk, W. R. Ferren, Jr., and R. Ornduff, editors. Ecology, Conservation, and Management of Vernal Pool Ecosystems – Proceedings from a 1996 Conference. California Native Plant Society, Sacramento, CA.

Blaustein, A. R., Romansic, J. M., Kiesecker, J. M., and Hatch, A. C. (2003). Ultraviolet radiation, toxic chemicals, and amphibian population declines. *Diversity and Distributions, 9(1),* 123-140. doi: 10.1046/j.1472-4642.2003.00015.x

Cameron, R., Miller, C., MacKinnon, D., deGooyer, K., Boates, S., and Towers, J. K. (2010). Beyond boundaries of the species paradigm: identifying and mapping rare ecosystems for protected areas planning in Nova Scotia. *Proceedings of the Sixth International Conderence of Science and the Management of Protected Areas. 21 – 26 May 2007, Acadia University, Wolfville, Nova Scotia*. Science and Management of Protected Areas Association, Wolfville, NS.

Boone R. B., Johnson C. M., and Johnson, L. B. (2006). Simulating vernal pool hydrology in central Minnesota, USA. *Wetlands, 26*(1), 581-592**.** Retrieved from http://link.springer.com/article/10.1672/0277-5212(2006)26%5B581:SVPHIC%5D2.0.CO%3B2#page-1

Brazner, John. (2013). Nova Scotia Wetland Inventory. Retrieved from http://novascotia.ca/natr/wildlife/habitats/wetlands.asp

Brooks, R. T. (2009). Potential impacts of global climate change on the hydrology and ecology of ephemeral freshwater systems of the forests of the northeastern United States. *Climatic Change*, *95*(3-4), 469-483. doi: 10.1007/s10584-008-9531-9

Brooks, R. T. (2005). A review of basin morphology and pool hydrology of isolated ponded wetlands: Implications for seasonal forest pools of the northeastern United States. *Wetlands Ecology and Management,*13(1), 335-348. Retrieved from http://link.springer.com/article/10.1007/s11273-004-7526-5#page-1

Brooks, R. T. (2004). Weather-related effects on woodland vernal pool hydrology and hydroperiod. *Wetlands, 24*(1), 104-114. Retrieved from http://link.springer.com/article/10.1672/0277-5212(2004)024%5B0104:WEOWVP%5D2.0.CO%3B2#page-1

Brooks, R. T. (2002). Depth-area-volume and hydroperiod relationships of ephemeral (vernal) forest pools in southern New England. *Wetlands, 2*(1), 247-255. Retrieved from http://link.springer.com/article/10.1672/0277-5212(2002)022%5B0247:DAVAHR%5D2.0.CO%3B2#page-1

Brooks, R. T. (2000). Annual and seasonal variation and the effects of hydroperiod on benthic macroinvertebrates of seasonal forest ("vernal") ponds in central Massachusetts, USA. *Wetlands*, 20(1), 707-715. Retrieved from http://link.springer.com/article/10.1672/0277-5212(2000)020%5B0707:AASVAT%5D2.0.CO%3B2#page-1

Brooks, R. T., Stone, J., & Lyons, P. (1998). An inventory of seasonal forest ponds on the Quabbin Reservoir watershed, Massachusetts. *Northeastern Naturalist*, 219-230. Retrieved from http://www.jstor.org/stable/3858622

Burley, S. T., Harper, K. A., & Lundholm, J. T. (2010). Vegetation composition, structure and soil properties across coastal forest–barren ecotones. *Plant ecology*, *211*(2), 279-296. DOI 10.1007/s11258-010-9789-7

Burne, M. M., and Griffin, C. R. (2005). Habitat associations of pool-breeding amphibians in eastern Massachusetts, USA. *Wetlands Ecology and Management, 13(1),* 247-259. DOI 10.1007/s11273-004-7519-4

Burne, M. R., & Griffin, C. R. (2005). Protecting vernal pools: A model from Massachusetts, USA. *Wetlands Ecology and Management, 13*(3), 367-375. doi:http://dx.doi.org/10.1007/s11273-004-7528-3+ Kangas, M. (2005). Vernal pools: a little known but critical habitat. *Frontiers in Ecology and the Environment, 3*(5), 286. Retrieved from http://web.ebscohost.com/ehost/detail?vid=3&sid=ae97bd13-e5d2-4953-8fed-c77ea00dbeeb%40sessionmgr114&hid=112&bdata=JnNpdGU9ZWhvc3QtbGl2ZQ%3d%3d#db=8gh&AN=17290057

Calhoun, A. J. K., and de Maynadier, P. (Ed.). (2008). *Science and conservation of vernal pools in Northeastern North America.* Taylor and Francis Group: Boca Raton, FL.

Calhoun, A. J., Walls, T. E., Stockwell, S. S., and McCollough, M. (2003). Evaluating vernal pools as a basis for conservation strategies: a Maine case study. *Wetlands, 23(1),* 70-81. Retrieved from http://link.springer.com/article/10.1672/0277-5212(2003)023%5B0070:EVPAAB%5D2.0.CO%3B2#page-1

Cameron, P., and Bondrup-Nielsen, S. (2013) Plant communities within Atlantic Coastal heathlands in Nova Scotia. *Northeastern Naturalist*, *20*(4), 694-709.

Cappiella, K., and Fraley-McNeal, L. (2007). The importance of protecting vulnerable streams and wetlands at the local level. *Office of Wetlands, Oceans and Watersheds.* U.S. Environmental Protection Agency: Washington, DC.

Colburn, E. A. (2004). *Vernal pools: natural history and conservation.* McNaughton & Gunn: Saline, MI.

Colburn, E. A. (1995). Certified: a citizen's step-by-step guide to protecting vernal pools. Retrieved from: http://eric.ed.gov/?id=ED401111

Collins, S. J., & Russell, R. W. (2009). Toxicity of road salt to Nova Scotia amphibians. *Environmental Pollution*, *157*(1), 320-324.

Compton, B. W., McGarigal, K., Cushman, S. A., & Gamble, L. R. (2007). A resistant-kernel model of connectivity for amphibians that breed in vernal pools. *Conservation Biology, 21*(3), 788-799. doi: 10.1111/j.1523-1739.2007.00674.x

Cook, B. J., & Hauer, F. R. (2007). Effects of hydrologic connectivity on water chemistry, soils, and vegetation structure and function in an intermontane depressional wetland landscape. *Wetlands*, *27*(3), 719-738. Retrieved from http://download.springer.com/static/pdf/721/art%253A10.1672%252F0277-5212%25282007%252927%255B719%253AEOHCOW%255D2.0.CO%253B2.pdf?auth66=1395808085_aa1977ab10df73d04cb12caff3cf4b9e&ext=.pdf

Carrino-Kyker, S., R., and Swanson, A. K. (2008). Temporal and spatial patterns of eukaryotic and bacterial communities found in vernal pools. *Appl. Environ. Microbiol.*, *74*(8), 2554. doi:10.1128/AEM.01482-07

Carrino-Kyker, S. R., Smemo, K. A., and Burke, D. J. (2012). The effects of pH change and NO3 pulse on microbial community structure and function: a vernal pool microcosm study. *Microbial Ecol., 81*(1), 660-672. doi: 10.1111/j.1574-6941.2012.01397.x

Childs Jr, H. E. (1953). Selection by predation on albino and normal spadefoot toads. *Evolution*, 228-233.

Clair, T. A., Ehrman, J. M., Ouellet, A. J., Brun, G., Lockerbie, D., & Ro, C. U. (2002). Changes in freshwater acidification trends in Canada's Atlantic Provinces: 1983–1997. *Water, Air, and Soil Pollution*, *135*(1-4), 335-354.

Clair, T. A., Dennis, I. F., Scruton, D. A., & Gilliss, M. (2007). Freshwater acidification research in Atlantic Canada: a review of results and predictions for the future. *Environmental Reviews*, *15*(NA), 153-167. doi:10.1139/A07-004

Clark, K. L., & Lazerte, B. D. (1985). A laboratory study of the effects of aluminum and pH on amphibian eggs and tadpoles. *Canadian Journal of Fisheries and Aquatic Sciences*, *42*(9), 1544-1551.

Collinge, S. K., & Ray, C. (2009). Transient patterns in the assembly of vernal pool plant communities. *Ecology*, *90*(12), 3313-3323. Retrieved from http://www.esajournals.org/doi/abs/10.1890/08-2155.1

Cook, B. J. (2001). *Temporary hydrologic connections make "isolated" wetlands function at the landscape scale.* (Doctoral Dissertation). University of Montana, Missoula, MT, USA. [Citation from Leibowitz, 2003]

Crampton, B. (1976). A historical perspective on the botany of the vernal pools in California. *Vernal Pools: Their Ecology and Conservation. Institute of Ecology Publication*, (9), 5-10.

Dale, J. M., Freedman, B., & Kerekes, J. (1985). Acidity and associated water chemistry of amphibian habitats in Nova Scotia. *Canadian Journal of Zoology*, *63*(1), 97-105.

DeLonay, A. J., Little, E. E., Woodward, D. F., Brumbaugh, W. G., Farag, A. M., & Rabeni, C. F. (1993). Sensitivity of early- life- stage golden trout to low pH and elevated aluminum. *Environmental toxicology and chemistry*, *12*(7), 1223-1232.

De Meester, L., Declerck, S., Stoks, R., Louette, G., Van De Meutter, F., De Bie, T., ... & Brendonck, L. (2005). Ponds and pools as model systems in conservation biology, ecology and evolutionary biology. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *15*(6), 715-725. doi: 10.1002/aqc.748

Faccio, S. D. (2003). Postbreeding emigration and habitat use by Jefferson and spotted salamanders in Vermont. *Journal of Herpetology*, *37*(3), 479-489. Retrieved from http://www.bioone.org/doi/abs/10.1670/155-02A

Fitzgerald, E. A. (2003). Sold Waste Agency of Northern Cook County v. US Army Corps of Engineers: Isolated Waters, Migratory Birds, Statutory and Constitutional Interpretation. *Nat. Resources J.*, *43*, 11. Retrieved from http://lawlibrary.unm.edu/nrj/43/1/03_fitzgerald_isolated.pdf

Freda, J. (1986). The influence of acidic pond water on amphibians: a review.*Water, Air, and Soil Pollution*, *30*(1-2), 439-450.

Freeman, R. C. (2010). *Land use planning and vernal pool conservation in a southern maine town.* Transcript of Master's thesis project. Retrieved from http://ezproxy.library.dal.ca/login?url=http://search.proquest.com/docview/869570360?accountid=10406

Freedman, B. 2009. *Environmental Science. A Canadian Perspective, 5th ed.* Prentice Hall Canada, Toronto, ON

Gahl, M. K., Calhoun A. J. K., and Graves, R. (2009). Facultative use of seasonal pools by American Bullfrogs (Rana *catesbeiana). Wetlands, 29* **697-703.** Retrieved from http://link.springer.com/article/10.1672/08-56.1#page-1

Genthy, H. S., & Miller, R. W. (1965). The search for new industrial crops IV. Prospectus of Limnanthes. *Economic Botany*, *19*(1), 25-32.

Gibbons, J. W., C. T. Winne, D. E. Scott, J. D. Willson, X. Glaudas, K. M. Andrews, B. D. Todd, L. A. Fedewa, L. Wilkinson, R. N. Tsaliagos, S. J. Harper, J. L. Greene, T. D. Tuberville, B. S. Metts, M. E. Dorcast, J. P. Nestor, C. A. Young, T. Akre, R. N. Reed, K. A. Buhlmann, J. Norman, D. A. Croshaw, C. Hagen, and B. B. Rothermel. (2006). Remarkable amphibian biomass and abundance in an isolated wetland: Implications for wetland conservation. *Conservation Biology 20:1457-1465.* doi: 10.1111/j.1523-1739.2006.00443.x

Ginn, B. K., Cumming, B. F., & Smol, J. P. (2007). Long-term lake acidification trends in high- and low-sulphate deposition regions from Nova Scotia, Canada.*Hydrobiologia*, *586*(1), 261-275.

Goldberg, C. S., and Waits, L. P. (2010). Comparative landscape genetics of two pond-breeding amphibian species in a highly modified agricultural landscape. *Molecular Ecology, 19,* 3650-3663. doi: 10.1111/j.1365-294X.2010.04673.x

Gorham, E., Underwood, J. K., Martini, F. B., & Ogden, J. G. (1986). Natural and anthropogenic causes of lake acidification in Nova Scotia. Retrieved from http://www.nature.com/nature/journal/v324/n6096/abs/324451a0.html

Gosejohan, M. C. (2012). Effects of hydrology and livestock use on modoc plateau vernal pool region plant communities. Transcript of Master's thesis project. Retrieved from http://ezproxy.library.dal.ca/login?url=http://search.proquest.com/docview/1399915518?accountid=10406

Government of Canada. (2014). Climate station data. Retrieved from http://climate.weather.gc.ca/advanceSearch/searchHistoricDataStations_e.html?searchType=stnProx&timeframe=1&txtRadius=50&optProxType=city&selCity=44|40|63|36&selPark=&txtCentralLatDeg=0&txtCentralLatMin=0&txtCentralLatSec=0&txtCentralLongDeg=0&txtCentralLongMin=0&txtCentralLongSec=0&optLimit=yearRange&StartYear=2013&EndYear=2014&Year=2014&Month=2&Day=26&selRowPerPage=25&cmdProxSubmit=Search

Grant, E., Bailey, L., Mattfeldt, S., Nanjappa, P., & Jung, R. (2006). *Estimating the distribution and occupancy of vernal pool breeding habitat in the northeastern united states.* Retrieved from http://ezproxy.library.dal.ca/login?url=http://search.proquest.com/docview/40078939?accountid=10406

Grant, E. H. C. (2005). Correlates of vernal pool occurrence in the Massachusetts, USA landscape. *Wetlands, 25*, 480-487. Retrieved from http://link.springer.com/article/10.1672/22#page-1

Grant, E. (2005). Correlates of vernal pool occurrence in the Massachusetts, USA landscape. *Wetlands, 25*(2), 480-487. doi: 10.1043/0277-5212(2005)025[0480:COVPOI]2.0.CO;2

Griffiths, R. A. (1997). Temporary ponds as amphibian habitats. *Aquatic Conservation: Marine and freshwater ecosystems*, *7*(2), 119-126. doi: 10.1002/(SICI)1099-0755(199706)7:2<119::AID-AQC223>3.0.CO;2-4

Hayhoe, K., Wake, C. P., Huntington, T. G., Luo, L., Schwartz, M. D., Sheffield, J., ... & Wolfe, D. (2007). Past and future changes in climate and hydrological indicators in the US Northeast. *Climate Dynamics*, *28*(4), 381-407. doi: 10.1007/s00382-006-0187-8

Inkley, M. D., Wissinger, S. A., & Baros, B. L. (2008). Effects of drying regime on microbial colonization and shredder preference in seasonal woodland wetlands. *Freshwater biology*, *53*(3), 435-445.

Jain, S. (1976). Some biogeographic aspects of plant communities in vernal pools. *Vernal Pools: Their Ecology and Conservation. Institute of Ecology Publication*, (9), 15-21.

Jansujwicz, J. S., Calhoun, A. K., & Lillieholm, R. J. (2013). The Maine vernal pool mapping and assessment program: Engaging municipal officials and private landowners in community-based citizen science. *Environmental Management, 52*(6), 1369-1385. doi: 10.1007/s00267-013-0168-8

Hobson, W. A., and R. A. Dahlgren. (1998). Soil forming processes in vernal pools of Northern California, Chico area. Pages 24-37 *in* C. W. Witham, E. T. Bauder, D. Belk, W. R. Ferren, Jr., and R. Ornduff, editors. Ecology, Conservation, and Management of Vernal Pool Ecosystems – Proceedings from a 1996 Conference. California Native Plant Society, Sacramento, CA.

Homan, R. N., Windmiller, B. S., & Reed, J. M. (2004). Critical thresholds associated with habitat loss for two vernal pool-breeding amphibians. *Ecological Applications, 14*(5), 1547-1553. Retrieved from http://www.esajournals.org/doi/pdf/10.1890/03-5125

Houlahan, J. E., Findlay, C. S., Schmidt, B. R., Meyer, A. H., and Kuzmin, S. L. (2000). Quantitative evidence for global amphibian population declines. *Nature, 404*(1), 752-755. doi: 10.1038/35008052

Karraker, N. E. and Gibbs, J. P. (2009). Amphibian production in forested landscapes in relation to wetland hydroperiod: A case study of vernal pools and beaver ponds. *Biological Conservation, 142*(1), 2293-2302. doi:10.1016/j.biocon.2009.05.002

Keeley, J. E. and Zedler, P. H. (1998). *Characterization and global distribution of vernal pools.* Proceedings from a 1996 Conference. California Native Plant Society, Sacramento, CA.

King, J. L., Simovich, M. A., & Brusca, R. C. (1996). Species richness, endemism and ecology of crustacean assemblages in northern California vernal pools. *Hydrobiologia, 328*(2), 85-116. Retrieved from http://link.springer.com/article/10.1007/BF00018707#page-1

Korfel, C. A., Mitsch, W. J., Hetherington, T. E., Mack, J. J. (2009). Hydrology, physiochemistry, and amphibians in natural and created vernal pool wetlands. *Restoration Ecology 18*(6), 843-854. doi: 0.1111/j.1526-100X.2008.00510.x

Lacroix, G. L. (1989). Ecological and physiological responses of Atlantic salmon in acidic organic rivers of Nova Scotia, Canada. *Water, Air, and Soil Pollution*, *46*(1-4), 375-386.

Lathrop, R. G., Montesano, P., Tesauro, J., & Zarate, B. (2005). Statewide mapping and assessment of vernal pools: A New Jersey case study. *Journal of Environmental Management*, *76*(3), 230-238. doi: 10.1016/j.jenvman.2005.02.006

Lamoureux, V. S., and D. M. Madison. (1999). Overwintering habitats of radio-implanted green frogs, *Rana clamitans. Journal of Herpetology 33*(1), 430-435. Retrieved from : http://www.jstor.org/stable/1565639

Leibowitz, S. G. (2003). Isolated wetlands and their functions: an ecological perspective. *Wetlands*, *23*(3), 517-531. Retrieved from http://link.springer.com/article/10.1672/0277-5212(2003)023%5B0517:IWATFA%5D2.0.CO%3B2#page-4

Leidy, R. A., & White, E. G. (1998). Toward an ecosystem approach to vernal pool compensation and conservation. *Ecology, Conservation and Management of Vernal Pool Ecosystems. California Native Plant Society, Sacramento, California*, 263-273. Retrieved from http://vernalpools.org/proceedings/leidy.pdf

Lichko, L. E., and Calhoun, A. J. (2003). An evaluation of vernal pool creation projects in New England: Project documentation from 1991 – 2000. *Environmental Management, 32*(1), 141-151. doi: 10.1007/s00267-003-2967-9

Lindquist, E. D., Foster, D. K., Wilcock, S. P., & Erikson, J. S. (2013). Rapid assessment tools for conserving woodland vernal pools in the northern blue ridge mountains. *Northeastern Naturalist*, *20*(3), 397-418. doi:http://dx.doi.org/10.1656/045.020.0303

Linhart, Y. B. (1976). Evolutionary studies of plant populations in vernal pools.*Vernal pools: their ecology and conservation. Institute of Ecology publication*, (9), 40-46.

Liu, H. (2012). *Vernal pool mapping in the Williams Lake Watershed, Halifax: supporting small wetland identification in advance of development*. (Undergraduate Honours Thesis). Dalhousie University, Community Design and Planning.

Marty, J. T. (2005). Effects of cattle grazing on diversity in ephemeral wetlands. *Conservation Biology, 19*(5), 1626-1632.doi: 10.1111/j.1523-1739.2005.00198.x

Marshak, S., & Prothero, D. R. (2008). *Earth: portrait of a planet*. WW Norton.

Mitsch, W. J., and Gosselink, J. G. (2007). Wetlands. John Wiley & Sons, Inc. Hoboken: NJ

McGuire, C. (2010). Sustainable approaches to managing small-scale ecosystems: A case study of vernal pool protection in the commonwealth of Massachusetts, United States of America. *Journal of Sustainable Development, 3(2),* 3-8. Retrieved from http://works.bepress.com/chad_mcguire/13/

Morey, S. R. (1998). Pool duration influences age and body mass at metamorphosis in the western spadefoot toad: implications for vernal pool conservation. In *Ecology, Conservation, and Management of Vernal Pool Ecosystems-Proceedings from a 1996 Conference. California Native Plant Society, Sacramento, CA* (pp. 86-91). Retrieved from http://vernalpools.org/proceedings/morey.pdf

Neily, P. D., Quiget, E., Benjamin, L., Stewart, B., Duke, T. (2003). *Ecological land classification for Nova Scotia: volume 1 – mapping Nova Scotia's terrestrial ecosystem.* Nova Scotia Department of Natural Resources: Renewable Resources Branch.

Nova Scotia Environment. (2009). *Toward a greener future: Nova Scotia's climate change action plan.* Province of Nova Scotia. Retrieved from http://climatechange.gov.ns.ca/doc/ccap.pdf

Nova Scotia Environment. (2005). *Adapting to a changing climate in Nova Scotia: vulnerability assessment and adaptation options.* Province of Nova Scotia. Retrieved from http://www.climatechange.gov.ns.ca/files/02/77/Adapting_to_a_Changing_Climate_in_NS.pdf

Nova Scotia Environment (2011). Nova Scotia Wetland Conservation Policy. Retrieved from http://www.novascotia.ca/nse/wetland/docs/Nova.Scotia.Wetland.Conservation.Policy.pdf

Oberndorfer, E. C., & Lundholm, J. T. (2009). Species richness, abundance, rarity and environmental gradients in coastal barren vegetation. *Biodiversity and Conservation*, *18*(6), 1523-1553.

Oscarson, D. B., & Calhoun, A. J. (2007). Developing vernal pool conservation plans at the local level using citizen-scientists. *Wetlands*, *27*(1), 80-95. Retrieved from http://link.springer.com/article/10.1672/0277-5212(2007)27%5B80:DVPCPA%5D2.0.CO%3B2#page-1

Palik, B., Streblow, D., Egeland, L., and Buech, R. (2007). Landscape variation of seasonal pool plant communities in forests of northern Minnesota, USA. *Wetlands, 27*(1), 12-23. Retrieved from http://link.springer.com/article/10.1672/0277-5212(2007)27%5B12:LVOSPP%5D2.0.CO%3B2#page-1

Paton, P. W., and Crouch, W. B. (2002). Using the phenology of pond-breeding amphibians to develop conservation strategies. *Conservation Biology*, *16*(1), 194-204. Retrieved from http://www.umaine.edu/vernalpools/PDFs/Using%20the%20Phenology%20of%20Pond-Breeding%20Amphibians%20to%20Develop%20C.pdf

Portnoy, J. W. (1990). Breeding biology of the spotted salamander *Ambystoma maculatum* (Shaw) in acidic temporary ponds at Cape Cod, USA. *Biological Conservation*, *53*(1), 61-75. Retrieved from http://www.sciencedirect.com/science/article/pii/000632079090063U.

Preisser, E. L., Kefer, J. Y., Lawrence, J. D., & Clark, T. W. (2000). Vernal pool conservation in Connecticut: an assessment and recommendations.*Environmental Management*, *26*(5), 503-513. 10.1007/s002670010108

Pyke, C. R. (2005). Assessing climate change impacts on vernal pool ecosystems and endemic branchiopods. *Ecosystems*, *8*(1), 95-105. doi: 10.1007/s10021-004-0086-y

Pyke, C. R. (2004). Simulating vernal pool hydrologic regimes for two locations in California, USA. *Ecological Modelling*, *173*, 19-127. National Center for Ecological Analysis and Synthesis: Santa Barbara, CA. doi:10.1016/j.ecolmodel.2003.08.014

Rabe, F. W. (1984). Free-Swimming Invertebrate Communities of Vernal Pools in Eastern Washinglon. *Northwest Science*, *58*(1), 177.

Rains, M. C., Dahlgren, R. A., Fogg, G. E., Harter, T., and Williamson, R. J. (2008). Geological control of physical and chemical hydrology in California vernal pools. *Wetlands, 28*(2), 347-362. The Society of Wetland Scientists. Retrieved from http://www.bioone.org/doi/pdf/10.1672/07-132.1

Rains, M. C., Fogg, G. E., Harter, T., Dahlgren, R. A., and Williamson, R. J. (2006). The role of perched aquifers in hydrological connectivity and biogeochemical processes in vernal pool landscapes, Central Valley, California. *Hydrological Processes, 20,* 1157-1175. doi: 10.1002/hyp.5937

Regosin, J. V., Windmiller, B. S., Homan, R. N., & Reed, J. M. (2005). Variation in terrestrial habitat use by four pool-breeding amphibian species.*Journal of Wildlife Management*, *69*(4), 1481-1493.

Rudestam, K. E., & Newton, R. R. (2007). *Surviving your dissertation: A comprehensive guide to content and process*. Sage.

Semlitsch, R. D. (2008). Differentiating migration and dispersal processes for pond-breeding amphibians. *The Journal of Wildlife Management, 72:260-267.* doi: 10.2193/2007-082

Silveira, J. G. (1998). Avian uses of vernal pools and implications for conservation practice. In *Ecology, Conservation and Management of Vernal Pool Ecosystems. Proceedings from a 1996 Conference. Sacramento, CA: California Native Plant Society*. Retrieved from http://vernalpools.org/proceedings/silveira.pdf

Semlitsch, R. D., and J. R. Bodie. (1998). Are small, isolated wetlands expendable? *Conservation Biology 12*(1), 1129-1133. doi: 10.1046/j.1523-1739.1998.98166.x

Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B. & Miller, H. L. (2007). IPCC, 2007: climate change 2007: the physical science basis. *Contribution of Working Group I to the fourth assessment report of the Intergovernmental Panel on Climate Change*.

Stalheim, T., Ballance, S., Christensen, B. E., & Granum, P. E. (2009). Sphagnan–a pectin- like polymer isolated from Sphagnum moss can inhibit the growth of some typical food spoilage and food poisoning bacteria by lowering the pH. *Journal of applied microbiology*, *106*(3), 967-976. doi:10.1111/j.1365-2672.2008.04057.x

Stone, D. E. (1959). A unique balanced breeding system in the vernal pool mouse-tails. *Evolution*, 151-174.

Thorp, Robbin W. (1976). Insect pollination of vernal pool flowers. *Vernal pools, their ecology and conservation,* 36-40.

Tiner, R. W. (2003). Geographically isolated wetlands of the United States. *Wetlands*, *23*(3), 494-516. Retrieved from http://link.springer.com/article/10.1672/0277-5212(2003)023%5B0494:GIWOTU%5D2.0.CO%3B2#page-1

Townsend, P. (2008) Forest biomass of living, merchantable trees in Nova Scotia. Department of Natural Resources, Renewable Resources Branch, Forestry Division, Forest Inventory Section. Retrieved from http://www.novascotia.ca/natr/forestry/reports/Biomass_Inventory.pdf

Trochlell, P. and Bernthal, T. (1998). Small wetlands and the cumulative impacts of small wetland losses: a synopsis of the literature. Wisconsin Department of Natural Resources: Madison, WI. Retrieved from http://dnr.wi.gov/topic/wetlands/documents/SmallWetlandLosses.pdf

Vasconcelos, D., & Calhoun, A. J. (2004). Movement patterns of adult and juvenile Rana sylvatica (LeConte) and Ambystoma maculatum (Shaw) in three restored seasonal pools in Maine. *Journal of Herpetology*, *38*(4), 551-561. Retrieved from http://www.bioone.org/doi/abs/10.1670/157-03A?journalCode=hpet

Veysey, J. S., Mattfeldt, S. D., and Babbitt, K. J. (2011). Comparitive influence of isolation, landscape, and wetland characteristics on egg-mass abundance of two pool-breeding amphibian species. *Landscape Ecology*, *26*, 661-672. doi: 10.1007/s10980-011-9590-6

Van Meter, R., Bailey, L. L., & Grant, E. H. C. (2008). Methods for estimating the amount of vernal pool habitat in the northeastern United States. *Wetlands*,*28*(3), 585-593. Retrieved from http://link.springer.com/article/10.1672/07-237.1#page-1

Vuorinen, M., Vuorinen, P. J., Hoikka, J., & Peuranen, S. (1993). Lethal and sublethal threshold values of aluminium and acidity to pike (< i> Esox lucius</i>), whitefish (< i> Coregonus lavaretus pallasi</i>), pike perch (< i> Stizostedion lucioperca</i>) and roach (< i> Rutilus rutilus</i>) yolk-sac fry.*Science of the total environment*, *134*, 953-967.

Wiggins, G. B., Mackay, R. J., & Smith, I. M. (1980). Evolutionary and ecological strategies of animals in annual temporary pools. *Archiv für Hydrobiologie supplement*, *58*(97), 206.

Whigham, D. F., and Jordan, T. E. (2003). Isolated wetlands and water quality. *Wetlands, 23(3):* 541-549. Retrieved from http://link.springer.com/article/10.1672/0277-5212(2003)023%5B0541:IWAWQ%5D2.0.CO%3B2#page-1

Whitfield, C. J., Aherne, J., Watmough, S. A., Dillon, P. J., & Clair, T. A. (2006). Recovery from acidification in Nova Scotia: temporal trends and critical loads for 20 headwater lakes. *Canadian Journal of Fisheries and Aquatic Sciences*, *63*(7), 1504-1514. doi: 10.1139/F06-053

Windmiller, B., R.N. Homan, J.V. Regosin, L.A. Willitts, D.L. Wells, and J.M. Reed. (2008). Breeding amphibian population declines following loss of upland forest habitat around vernal pools in Massachusetts, USA. *In:* Mitchell, R.E., J. Brown, and B. Bartholomew (eds). Urban Herpetology. Herpetological Conservation. Retrieved from http://www.umaine.edu/vernalpools/PDFs/Breeding%20Amphibian%20Population%20Declines%20following%20Declines%20fo.pdf

Winter, T. C. (2007). The role of ground water in generating streamflow in headwater areas and in maintaining base flow. *JAWRA Journal of the American Water Resources Association*, *43*(1), 15-25. doi: 10.1111/j.1752-1688.2007.00003.x

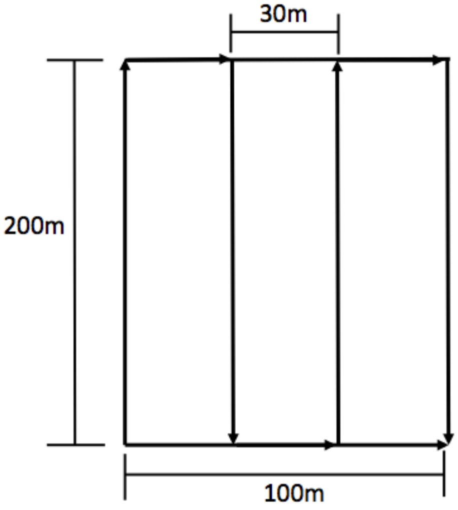
Winter, T. C., and J. W. LaBaugh. (2003). Hydrologic considerations in defining isolated wetlands. *Wetlands, 23,* 532-540. Retrieved from http://link.springer.com/article/10.1672/0277-5212(2003)023%5B0532:HCIDIW%5D2.0.CO%3B2#page-1

Zedler, P. H. (2003). Vernal pools and the concept of "isolated wetlands". *Wetlands, 23,* 597-607. Retrieved from http://link.springer.com/article/10.1672/0277-5212(2003)023%5B0597:VPATCO%5D2.0.CO%3B2#page-1

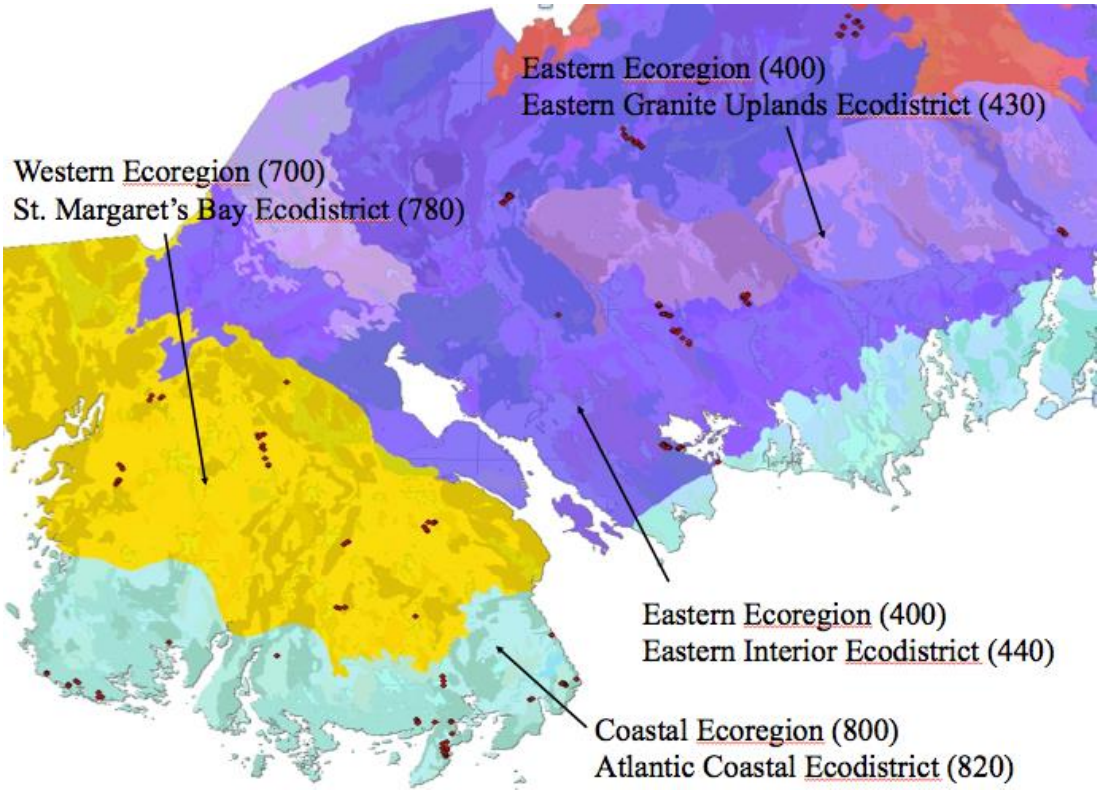
Zedler, P. H. (1987). The ecology of southern California vernal pools: A community profile. *USFWS Biological Report. 85,* 7-11. U.S. Fish and Wildlife Service, Washington, DC, USA.

Appendix I – Additional Figures, Tables, Calculations

a) Transect delineation



b) Survey area and survey sites (red dots)



c) Calculation of the density of pools per km^2

$$\frac{1.3}{20{,}000\ m^2} = \frac{x}{1{,}000{,}000\ m^2}$$

$$x = \frac{1.3(1{,}000{,}000\ m^2)}{20{,}000\ m^2}$$

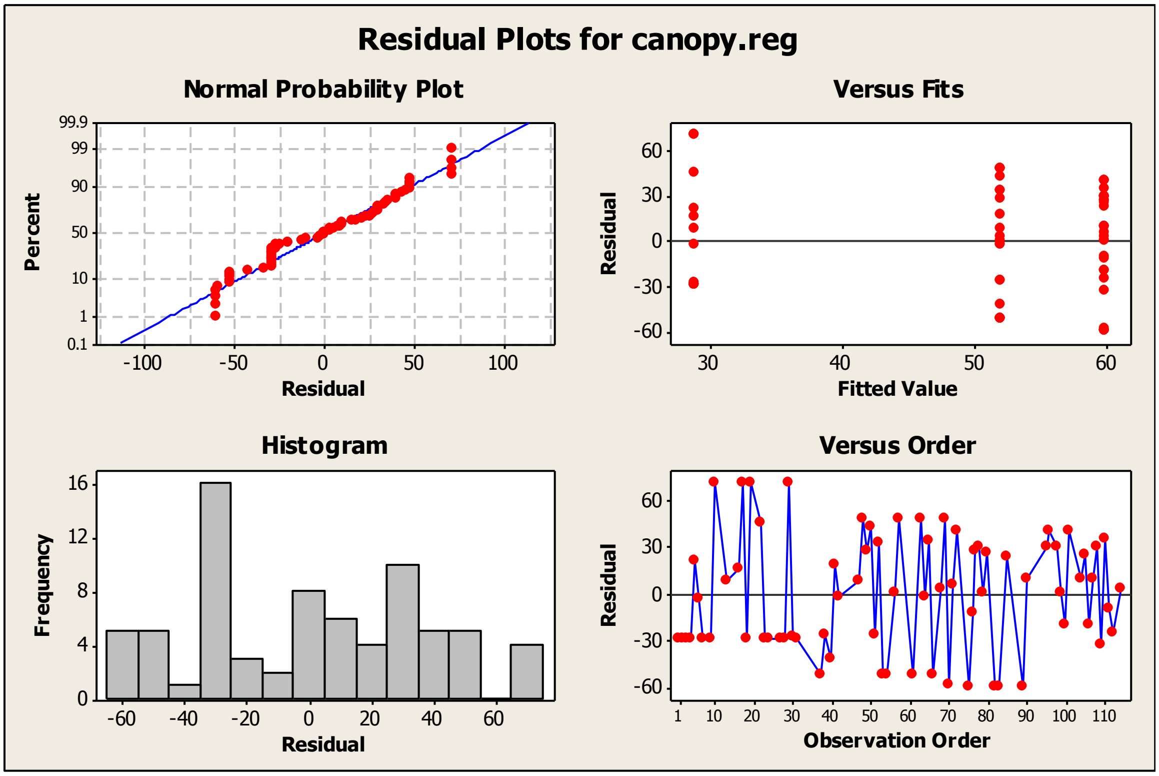
$$x = 65$$

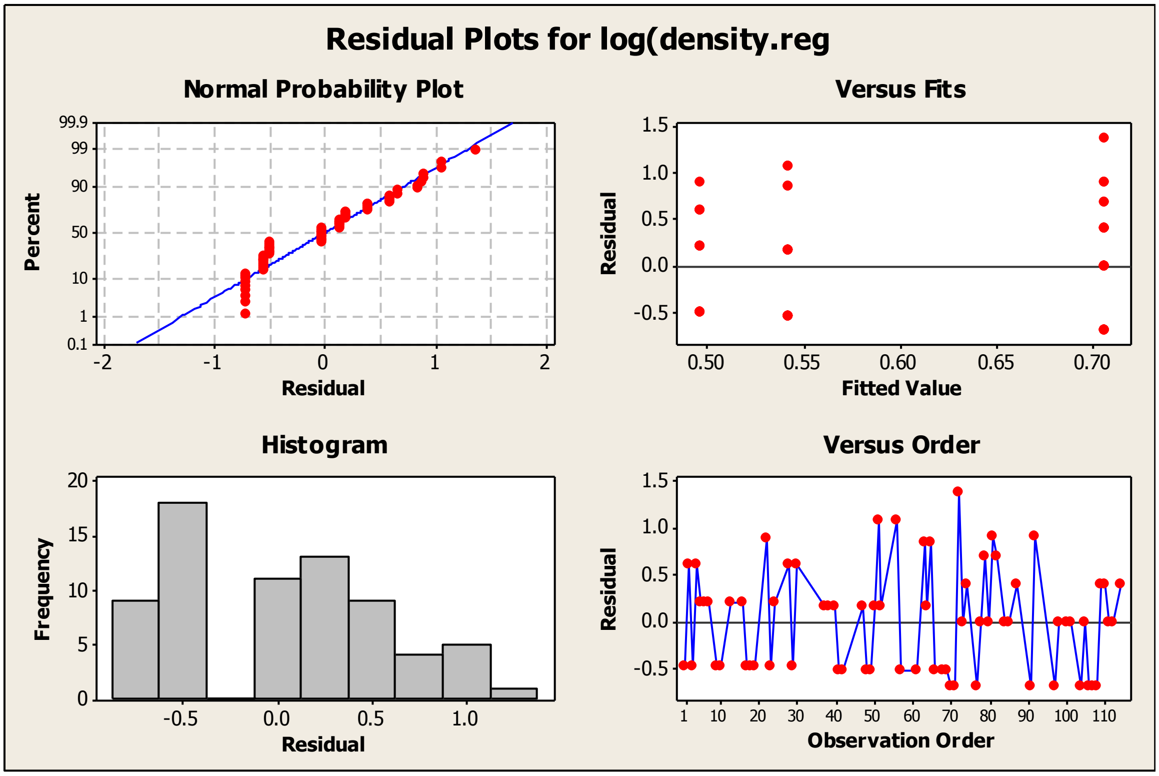
d) Mean values per ecoregion/ecodistrict and total means

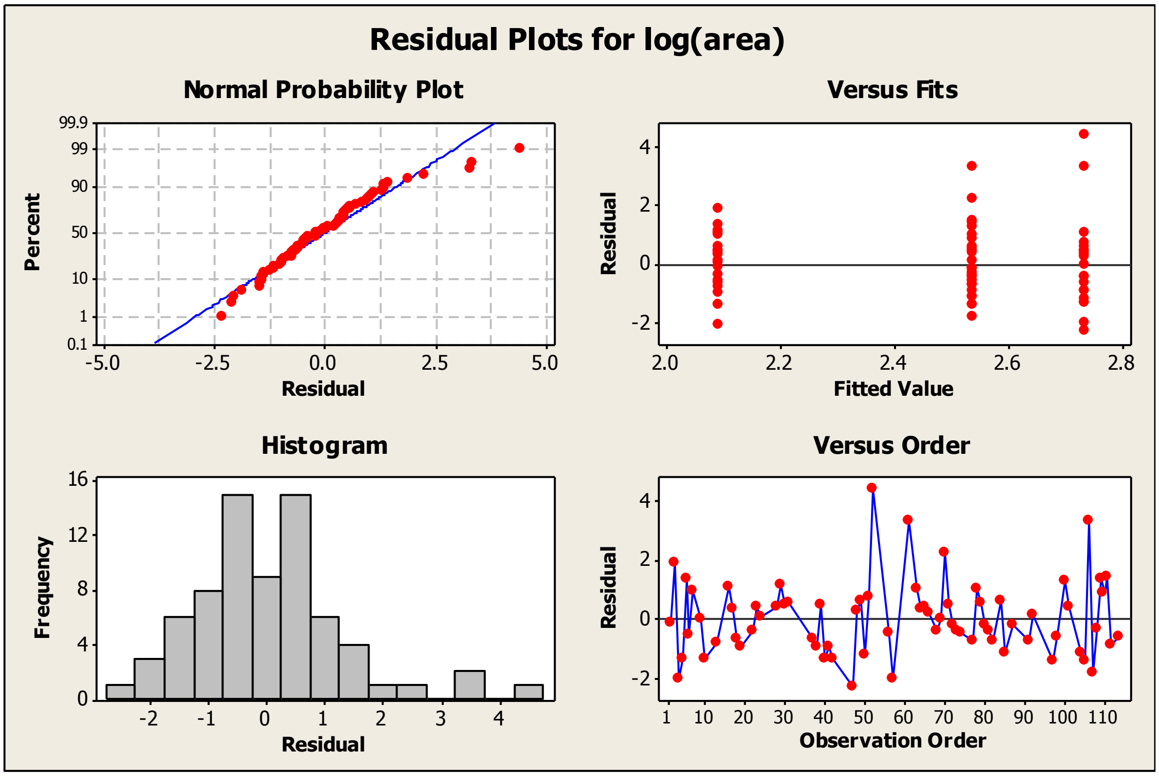
		Percent Canopy	Density	Area	pH
Ecoregion	800	28.97	1.194	12.6	
	700	51.97	1.079	95.8	
	400	59.87	1.60	29.9	
Total Mean		46.90	1.291	46.1	
Ecodistrict	430				4.3
	440				5.96
Total Mean					5.13

Appendix II – Residual Plots

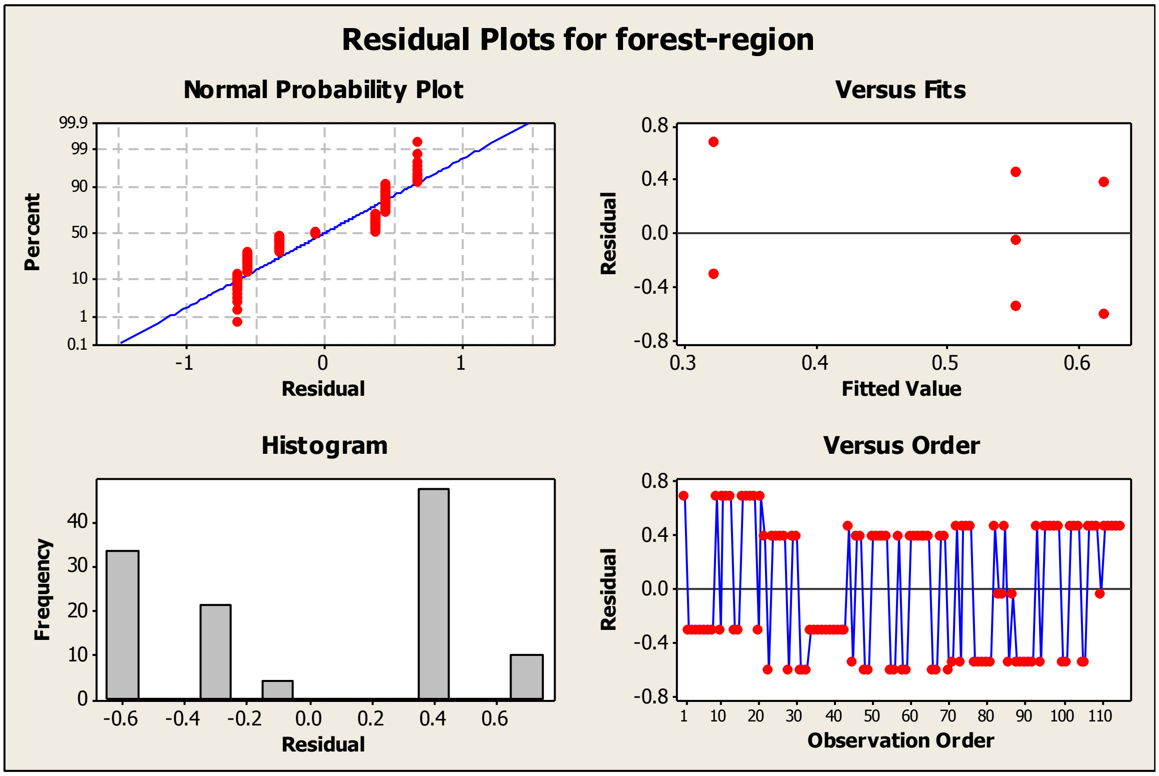
a) Differences among ecoregions – pool features

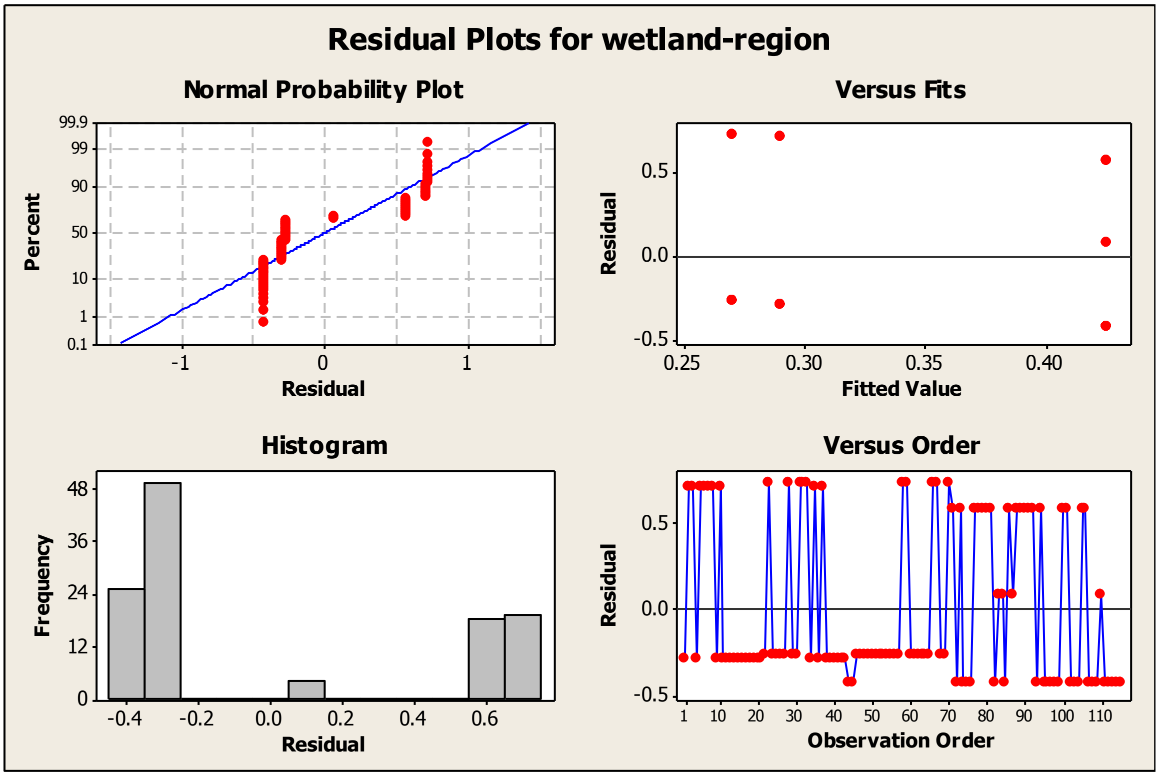


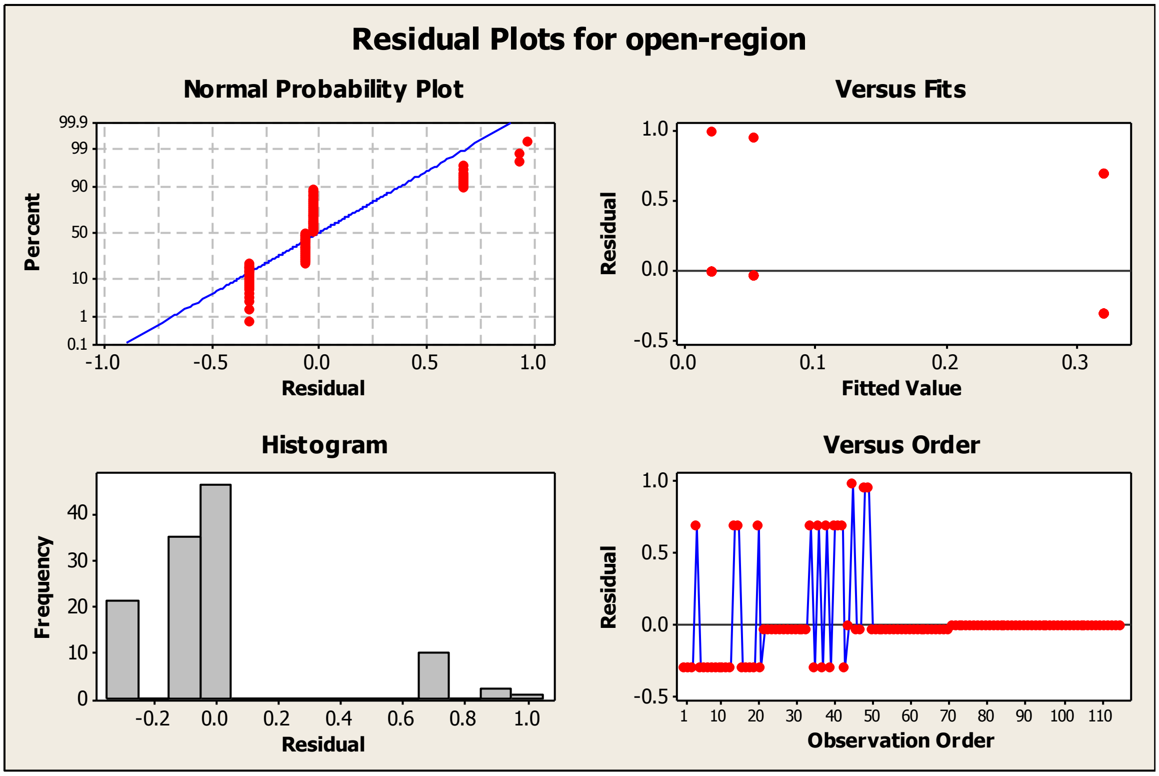

Residual Plots for log(density.reg
Normal Probability Plot
Percent
99.9
99
90
50
10
1
0.1
-2
-1
0
1
2
Residual
Versus Fits
Residual
1.5
1.0
0.5
0.0
-0.5
0.50
0.55
0.60
0.65
0.70
Fitted Value
Histogram
Frequency
20
15
10
5
0
-0.5
0.0
0.5
1.0
Residual
Versus Order
Residual
1.5
1.0
0.5
0.0
-0.5
1
10
20
30
40
50
60
70
80
90
100
110
Observation Order


Residual Plots for log(area)
Normal Probability Plot
Percent
99.9
99
90
50
10
1
0.1
-5.0
-2.5
0.0
2.5
5.0
Residual
Versus Fits
Residual
4
2
0
-2
2.0
2.2
2.4
2.6
2.8
Fitted Value
Histogram
Frequency
16
12
8
4
0
-2
-1
0
1
2
3
4
Residual
Versus Order
Residual
4
2
0
-2
1
10
20
30
40
50
60
70
80
90
100
110
Observation Order

b) Differences among ecoregions – land-cover






Residual Plots for open-region
Normal Probability Plot
Percent
99.9
99
90
50
10
1
0.1
-1.0
-0.5
0.0
0.5
1.0
Residual
Versus Fits
Residual
1.0
0.5
0.0
-0.5
0.0
0.1
0.2
0.3
Fitted Value
Histogram
Frequency
40
30
20
10
0
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
Residual
Versus Order
Residual
1.0
0.5
0.0
-0.5
1
10
20
30
40
50
60
70
80
90
100
110
Observation Order