1-1-2008

Habitat suitability index models for the wood frog (*Rana sylvatica*) and boreal chorus frog (*Pseudacris triseriata maculata*) in the foothills parkland natural sub-region and Bow River sub-basin, Alberta

Zachary Edward Otke
Ryerson University

Follow this and additional works at: <http://digitalcommons.ryerson.ca/dissertations>

Part of the [Biology Commons](#)

Recommended Citation

Otke, Zachary Edward, "Habitat suitability index models for the wood frog (*Rana sylvatica*) and boreal chorus frog (*Pseudacris triseriata maculata*) in the foothills parkland natural sub-region and Bow River sub-basin, Alberta" (2008). *Theses and dissertations*. Paper 638.

This Thesis is brought to you for free and open access by Digital Commons @ Ryerson. It has been accepted for inclusion in Theses and dissertations by an authorized administrator of Digital Commons @ Ryerson. For more information, please contact bcameron@ryerson.ca.

64
541.15
113
085
0008

HABITAT SUITABILITY INDEX MODELS FOR THE WOOD FROG (*RANA*
SYLVATICA) AND BOREAL CHORUS FROG (*PSEUDACRIS TRISERIATA*
MACULATA) IN THE FOOTHILLS PARKLAND NATURAL SUB-REGION AND
BOW RIVER SUB-BASIN, ALBERTA

by

Zachary Edward Otke

Bachelor of Science, Concordia University College of Alberta, 2006

A Thesis

presented to Ryerson University

in partial fulfillment of the

requirements for the degree of

Master of Applied Science

in the Program of

Environmental Applied Science and Management

Toronto, Ontario, Canada, 2008

© (Zachary Edward Otke) 2008

Author's Declaration

I hereby declare that I am the sole author of this thesis or dissertation.

I authorize Ryerson University to lend this thesis or dissertation to other institutions or individuals for the purpose of scholarly research.

I further authorize Ryerson University to reproduce this thesis or dissertation by photocopying or by other means, in total or in part, at the request of other institutions or individuals for the purpose of scholarly research.

Abstract

HABITAT SUITABILITY INDEX MODELS FOR THE WOOD FROG (*RANA SYLVATICA*) AND BOREAL CHORUS FROG (*PSEUDACRIS TRISERIATA MACULATA*) IN THE FOOTHILLS PARKLAND NATURAL SUB-REGION AND BOW RIVER SUB-BASIN, ALBERTA

Master of Applied Science, 2008

Zachary Edward Otko

Environmental Applied Science and Management

Ryerson University, Toronto, Ontario

Habitat suitability index (HSI) models were developed for the wood frog (*Rana sylvatica*) and for the boreal chorus frog (*Pseudacris triseriata maculata*) in the Foothills Parkland Natural Sub-region and Bow River Sub-basin in west-central Alberta. The models are based on key habitat variables that had significant relationships with the population estimates determined from night calling surveys. The models were first derived from literature that was related to wood frog and boreal chorus frog habitat and then tested in the field. Using chi-square analysis with a significance level of 0.01, fish presence, water movement, and dominant vegetation were discovered to be key habitat variables for both species. The key habitat variables for each species were integrated into HSI models. The HSI models can be used to determine the baseline and future quality of habitat for each species.

Acknowledgements

I first would like to thank the Department of Geography and the School of Graduate Studies at Ryerson University for providing financial support for this thesis. I would like to thank my graduate supervisor, Dr. Mike Bardecki, for guiding me through my research and helping me with other life problems. I also want to thank Dr. Ronald Pushchak for guiding me through my research and graduate studies.

Thank you to the Cochrane Ecological Institute for providing me with a place to stay during my fieldwork. Thank you to Dr. Lynda McCarthy for allowing me to use her department's multi-parameter water quality probe. Thank you to the landowners for allowing me to sample on their property.

Thank you to my parents and family for raising me and helping me to complete my graduate studies. Thank you to Dr. Sheri Dalton at Concordia University College of Alberta for encouraging me to continue my academic studies. Thank you to Mark and Ruth Verlinden for providing me a place to stay during my graduate studies and helping through many other life situations. Thank you to all my friends for helping me and encouraging me throughout my graduate studies and everything else in my life.

Table of Contents

Chapter 1.	Introduction.....	1
	1:1 Causes for Amphibian Decline.....	2
	1:2 Amphibians and Metapopulations.....	6
	1:3 Amphibian Habitat.....	8
	1:4 Amphibian Conservation.....	13
Chapter 2.	Background of Study Area and Study Species.....	19
	2:1 Objective of Study.....	19
	2:2 Environmental Problems in Alberta.....	20
	2:3 Amphibians in Alberta.....	22
	2:4 General Description of the Wood Frog (<i>Rana sylvatica</i>).....	23
	2:5 General Description of the Boreal Chorus Frog (<i>Pseudacris triseriata maculata</i>).....	24
Chapter 3.	Habitat Models Developed From Literature.....	28
	3:1 Introduction.....	28
	3:2 Habitat Suitability Index Models.....	28
	3:3 Methodology of Constructing a Habitat Suitability Index Model.....	32
	3:4 Wood Frog Habitat Suitability Index Model.....	34
	3:5 Boreal Chorus Frog Habitat Suitability Index Model.....	45
Chapter 4.	Fieldwork Methodology.....	51
	4:1 Introduction.....	51
	4:2 Study Area.....	51
	4:3 Frog Population Sampling.....	53
	4:4 Habitat Characteristics.....	55
	4:5 Statistical Analysis of Habitat Variables.....	56
Chapter 5.	Results.....	61
	5:1 Calling Surveys.....	61
	5:2 Habitat Variables.....	61
	5:3 Statistical Analysis.....	70
Chapter 6.	Discussion.....	78
	6:1 Introduction.....	78
	6:2 Fish.....	78
	6:3 Standing Water.....	80
	6:4 Dominant Vegetation.....	81
	6:5 Water Quality.....	83
	6:6 Pond Isolation.....	88
	6:7 Road Density.....	91

Chapter 7.	Modifications of the Habitat Suitability Index Models.....	95
	7:1 Introduction.....	95
	7:2 Wood Frog Habitat Suitability Index Model.....	95
	7:3 Boreal Chorus Frog Habitat Suitability Index Model.....	100
Chapter 8.	Recommendations for Future Research.....	103
	8:1 Introduction.....	103
	8:2 Using Mesocosms for Future Fish and Water Quality Studies.....	103
	8:3 Forest Cover and Vegetation.....	105
	8:4 Conclusion.....	106
References.....		108

List of Tables

Table 1.	Results from sources that were used to derive the wood frog hydroperiod habitat variable.....	39
Table 2.	Locations of Sample Sites.....	60
Table 3.	Maximum rank and maximum estimate of calling males of each frog at each site.....	63
Table 4a.	Unpaved road density, road density, total road density, number of wetlands, and average distance to the closest ten ponds at each sample site.....	64
Table 4b.	Unpaved road density, road density, total road density, number of wetlands, and average distance to the closest ten ponds at each sample site.....	65
Table 5.	Dominant vegetation, fish presence, and water movement observations at each sample site.....	66
Table 6.	Mean pH, mean dissolved oxygen, and mean conductivity measurements at each sample site.....	69
Table 7.	Mean air temperature and mean water temperature and their standard error at each sample site.....	70
Table 8a.	Spearman rank correlation coefficients comparing maximum ranks of the wood frog and certain habitat variables at each site.....	71
Table 8b.	Spearman rank correlation coefficients comparing maximum ranks of the boreal chorus frog and certain habitat variables at each site.....	72
Table 9a.	Chi-square analysis comparing population of wood frog and category of dominant vegetation (null distribution = 1:1:1, equal distribution between each dominant vegetation type).....	73
Table 9b.	Chi-square analysis comparing population of wood frog and category of dominant vegetation (null distribution = 1:0.1:0.2, emergent:shrub:none).....	73
Table 9c.	Chi-square analysis comparing population of wood frog and category of dominant vegetation (null distribution = 1:0.1:0, emergent:shrub:none).....	74

Table 10a.	Chi-square analysis comparing population of boreal chorus frog and category of dominant vegetation (null distribution = 1:1:1, emergent:shrub:none).....	74
Table 10b.	Chi-square analysis comparing population of boreal chorus frog and category of dominant vegetation (null distribution = 1:0.1:0.2, emergent:shrub:none).....	74
Table 10c.	Chi-square analysis comparing population of boreal chorus frog and category of dominant vegetation (null distribution = 1:0.1:0, emergent:shrub:none).....	75
Table 11a.	Chi-square analysis comparing population of wood frog with fish presence (null distribution = 1:1).....	75
Table 11b.	Chi-square analysis comparing population of wood frog with fish presence (null distribution = 1:0).....	75
Table 12a.	Chi-square analysis comparing population of boreal chorus frog with fish presence (null distribution = 1:1).....	75
Table 12b.	Chi-square analysis comparing population of boreal chorus frog with fish presence (null distribution = 1:0).....	76
Table 13a.	Chi-square analysis comparing population of wood frog with stream obstruction (null distribution = 1:1).....	76
Table 13b.	Chi-square analysis comparing population of wood frog with stream obstruction (null distribution = 1:0).....	76
Table 14a.	Chi-square analysis comparing population of boreal chorus frog with stream obstruction (null distribution = 1:1).....	76
Table 14b.	Chi-square analysis comparing population of boreal chorus frog with stream obstruction (null distribution = 1:0).....	77

List of Figures

Figure 1.	Distribution of the wood frog throughout Alberta.....	26
Figure 2.	Distribution of the boreal chorus frog throughout Alberta.....	27
Figure 3.	Suitability index of hydroperiod for the wood frog.....	40
Figure 4.	Suitability index of road density for the wood frog.....	43
Figure 5.	Suitability index of dominant vegetation for the boreal chorus frog.....	47
Figure 6.	Suitability index of pond isolation for boreal chorus frog.....	48
Figure 7.	Foothills Natural Sub-region and Bow River Sub-basin.....	52
Figure 8.	Mean pH and rank for the wood frog.....	67
Figure 9.	Dissolved oxygen and rank for the wood frog.....	67
Figure 10.	Conductivity and rank for the wood frog.....	68
Figure 11.	Dissolved oxygen and rank for the boreal chorus frog frog.....	68
Figure 12.	Suitability index of dominant vegetation for the wood frog.....	96
Figure 13.	Mean conductivity of each rank for the wood frog.....	97
Figure 14.	Mean dissolved oxygen of each rank for the wood frog.....	97
Figure 15.	Mean pH of each rank for the wood frog.....	98
Figure 16.	Mean dissolved oxygen of each rank for the boreal chorus frog.....	101

Chapter 1: Introduction

In many parts of the world, populations of amphibians are declining. More than 5,700 amphibian species have been discovered throughout the world, and scientists claim that many more amphibian species have yet to be discovered (Young et al. 2004: 5). Out of the 5,700 amphibian species, approximately one third are severely threatened (facing a high risk of extinction in the wild) or extinct (Beebee and Griffiths, 2005; Young et al. 2004: 9). Thirteen amphibian species have been classified as extinct since the 1980s (Young et al. 2004: 5). The decline of amphibians is not limited to small geographic areas, but large areas all over the world: Australia, Africa, Asia, North America, and South America; most of the amphibians that have been identified as threatened are found in North and South America (Young et al. 2004: 5).

Historically, conservation efforts did not focus specifically on the status of amphibians. When conservationists were first looking at the status of organisms, amphibians were put into a general animal category; however, this was a problem because amphibians have unique physiological characteristics compared to other animals, such as having permeable, vascular skin used to obtain oxygen (Young et al. 2004: 7). Amphibians are now being examined as a separate category (Hazell et al. 2001). When looking at amphibians as a separate entity for conservation purposes, population data on many amphibian species are lacking compared to long-term monitoring studies of other organisms (Parris, 2001). While trying to determine the global inventory of amphibian species and their population status, it has been discovered that amphibians are disappearing at a faster rate than other species (Young et al. 2004: 5); they have been found to be declining faster than birds or mammals (Cushman, 2006). The World

Conservation Union (IUCN) Red List lists animals that have been classified as critically endangered or vulnerable (Standards and Petitions Working Group, 2006). In the most recent updated IUCN Red List (2004), approximately one third of the species are amphibians (Cushman, 2006). In North and South America, 10% of the species found in the IUCN Red List are birds, 16% are mammals, and 39% are amphibians (Young et al. 2004: 24). Scientists are now trying to determine why amphibians are disappearing so fast, how to conserve historical populations, and how to encourage and sustain new populations (Young et al. 2004: 7).

1:1 Causes for Amphibian Decline

The decline of amphibians can negatively impact the environment. Negative impacts include a decline in biodiversity and interruptions in food webs (Young et al. 2004: 7). Amphibians are also important in the environment because they are a functional link between aquatic and terrestrial environments (Puchniak, 2002). Researchers have suggested that amphibians can be looked at as a biological indicator, where the status of amphibians indicates the status of the overall environment. A decline in amphibians can be used as an early warning sign to indicate that the overall ecological status of an environment is deteriorating (Young et al. 2004: 7; Wilhm, 1974). In order to determine how amphibians relate to a clean environment and to determine how to slow down the rate of extinction, causes of amphibian decline need to be determined; however, no clear causes have been discovered (Storfer, 2003).

Many possible causes for amphibian declines have been identified. Habitat destruction has been suggested as the primary cause, as researchers are finding that amphibian populations are decreasing in relation to habitat destruction (Gardner et al.

2007). One of the primary sources of habitat destruction is urbanization. In Canada, over 80% of wetlands near urban centres have been lost to agriculture or urbanization (Government of Canada, 1991: 3). Since European settlement in Canada, there has been a 65% wetland loss in southern Ontario, 71% in the Prairies, and 80% in the Fraser River Delta, British Columbia (Wiken et al. 2003: 11). These losses are generally correlated with the major urban centres in Canada (Wiken et al. 2003: 11). In the Prairie Pothole Region of Canada, more than 40% of wetland has been lost, but more than 70% of wetland has been lost in urban areas (Puchniak, 2002). Urbanization is also a major source of habitat loss in the United States. Between 1986 and 1997, 30% of wetland loss was caused by urban development, 26% of wetland loss was caused by agriculture, 23% of wetland loss was caused by silviculture, and 21% of wetland loss was caused by rural development (Dahl, 2000: 11). As urban areas are expanding, habitat that can support amphibian populations is being reduced and urban barriers between water bodies that prevent amphibians from migrating to support a greater amphibian community are increasing.

Even though habitat destruction is considered to be the primary cause of amphibian decline, it is very difficult to measure. It is also difficult to imply that habitat destruction directly causes declines in amphibian populations. Woodford and Meyer (2003) tried to directly relate habitat destruction to amphibian decline. They used linear regression to quantify the decline in green frog (*Rana clamitans melanota*) abundance against the increase in lakeshore development in northern Wisconsin (United States). They found a negative linear relationship between green frog abundance and lakeshore development; however, there still is the possibility that lakeshore development was not

the only cause for the decline in green frog abundance because other environmental variables, which could have interfered with the results, may not have been controlled during their study.

Another potential cause of amphibian decline is exposure to toxins. Agricultural activities use nutrients, pesticides, and other chemicals that can be toxic to amphibians. Bishop et al. (1999) determined that organophosphates used as pesticides for agricultural activities can create deformities in tadpoles. The study also found that there is a lower degree of egg hatching success and a higher amount of tadpole deformities in wetlands with high nutrient loads, particularly ammonium nitrate. Northern leopard frog (*Rana sylvatica*) embryos are sensitive to ammonium nitrate fertilizer levels above 0.27 mg/L; levels above the 0.27 mg/L can result in larvae developmental abnormalities (Bishop et al. 1999). Bishop et al. (1999) found ammonium nitrate levels above 0.27 mg/L in one of their agricultural zones. Conservation efforts need to consider the protection of wetlands that are near agricultural land. Research on the effects of toxic chemicals on amphibians needs to be conducted and methods to prevent toxic chemical consumption need to be developed (Young et al 2004: 35).

Disease is a potential cause for global amphibian decline. The disease primarily responsible for the decline is chytridiomycosis (Hamer et al. 2002). Chytridiomycosis, found responsible for many population crashes, is caused by *Batrachochytrium dendrobatidis*. This species is a fungus and part of the chytrid family. The fungus has been found to be responsible for crashes of amphibian populations in areas that have been primarily undisturbed. A major problem with this fungus is that it is very widespread, as it has been detected in many parts of world including Australia, Costa Rica, and North

America (Young et al. 2004: 33, 35). While disease may not be the primary cause of amphibian decline, it has been found that combined with other causes, such as predators and pesticides, a synergistic effect can be developed and generate an even faster rate of amphibian decline (Thiemann and Wassersug, 2000).

Invasive species can also be a potential cause for amphibian decline. Amphibian populations can decline from the effects of invasive species if the amphibians' habitat is altered (Thiemann and Wassersug, 2000). Fish stocking is a form of species invasion. Introducing predatory fish into an area that historically did not have predatory fish can be detrimental to amphibian species that inhabit the area. In Yosemite National Park (United States), fishermen stocked historically fishless lakes with various species of trout for the purpose of recreational fishing. Afterwards, the mountain yellow-legged frog (*Rana muscosa*) populations declined; the probability of finding a mountain yellow-legged frog was three times greater in a fishless water body than a fish-containing water body (Young et al. 2004: 36; Knapp and Matthews, 2000). Some other domestic species in North America have been discovered to have a negative impact on amphibian populations. Bullfrogs (*Rana catesbeiana*) can out-compete leopard frogs (*Rana pipiens*) as the bullfrog has expanded its historical range, and purple loosestrife (*Lythrum salicaria*) has been found to be responsible for drying up wetlands and causing a reduction in amphibian habitat (Young et al. 2004: 38).

It has also been suggested that climate change is a major cause for the global amphibian decline (Young et al. 2004: 37). Global warming causes an increase in average atmospheric temperature (Beebee and Griffiths, 2005). Global warming can reduce or shift the time period for amphibians to breed and juveniles to grow by reducing

the hydroperiod of many amphibians' aquatic habitat. Global warming also can affect the ranges of many organisms causing an unwanted shift in ecosystem characteristics. Although global warming has been suggested as a potential cause for global amphibian decline, it is very difficult to support, since there is a lack of long-term data for amphibian populations, even though there might be adequate long-term climate data (Young et al. 2004: 37).

The increase of UV-B radiation, caused by ozone depletion and greenhouse gases, has also been suggested as a cause for the global amphibian decline (Beebee and Griffiths, 2005). Amphibians have permeable skin and therefore may be more sensitive to UV-B radiation (Young et al. 2004: 7). Further research is needed to determine if UV-B radiation is a significant cause of global amphibian decline, since it has been discovered that it does not negatively affect all amphibians (Beebee and Griffiths, 2005). Häkkinen et al. (2001) found that common toad (*Bufo bufo*) tadpoles exposed to UV-B treatments had a lower survival than tadpoles exposed to the control treatments. For the common frog (*Rana temporaria*) and the moor frog (*Rana arvalis*), there was no significant difference in tadpole survival between the UV-B and the control treatments.

1:2 Amphibians and Metapopulations

Many researchers suggest that amphibian population dynamics follow a metapopulation theory system (Marsh and Trenham, 2001). Amphibians are believed to live in subpopulations. Each water body supports an amphibian subpopulation, and the group of neighbouring subpopulations makes a larger metapopulation. As amphibians are capable of migrating from one water body to another, a group of water bodies that are close enough to allow amphibians to migrate can support a metapopulation. The

metapopulation allows genetic flow between sub-populations and can support the general amphibian community if one subpopulation crashes (Marsh and Trenham, 2001). If the amphibian species of interest is organized into a metapopulation, conservation efforts need to take the metapopulation concept into consideration. Urban development and other forms of habitat destruction can eliminate water bodies that are part of a metapopulation or increase the distance between water bodies. If the distance between the water bodies is increased, then the metapopulation may become fragmented. Amphibians may not be able to migrate from a water body that can no longer support the population because the migratory distance is too far. The population could crash resulting in a significant decline in the metapopulation. Conservation efforts need to be made in order to keep water bodies in a cluster. If wetlands are to be constructed, a cluster of heterogeneous wetlands need to be developed. Regulations also need to consider the conservation of smaller wetlands, not just large permanent wetlands. Smaller wetlands may also support subpopulations that are part of a metapopulation (Gibbs, 2000).

Other studies have found that not all amphibians work on a metapopulation level. Some studies have tested amphibian populations for genetic differences and have found that there is very little difference between the subpopulations. A lack of gene flow and migrating amphibians between the populations would mean that the populations are not grouped into a metapopulation (Squire and Newman, 2002). Other studies have tried to determine the exact mechanisms that support a metapopulation system and to find ways of measuring how strongly the metapopulation concept applies to a particular amphibian, since the mechanisms behind the metapopulation theory are still not fully understood

(Joly et al. 2003; Casagrandi and Gatto, 2002; Gyllenburg and Hanski, 1997). For conservation purposes, management plans should be different for amphibians that do not work on a metapopulation system compared to amphibians that work on the metapopulation level. If certain amphibians are not organized into a metapopulation, then it may be sufficient to protect general areas of wetlands that support amphibian populations, rather than trying to focus on the protection of the connectivity between wetlands (Squire and Newman, 2002).

1.3 Amphibian Habitat

Wetlands, semi-aquatic ecosystems, act as filters of nutrients and provide habitat for many flora and fauna. Many of these flora and fauna depend on these semi-aquatic environments. Under the Canadian Wetland Classification System, the official definition of a wetland is "land that is saturated with water long enough to promote wetland or aquatic processes as indicated by poorly drained soils, hydrophytic vegetation, and various kinds of biological activity which are adapted to a wet environment" (National Wetlands Working Group, 1997: 1). There are many types of wetland around the world. In South America, important types of wetland are wet meadows and peatland (Brinson and Malvárez, 2002). In southern Australia and New Zealand, wetland includes upland swamps, coastal lagoons, and mound springs (Brinson and Malvárez, 2002). In Canada, wetland types include marshes, swamps, bogs, and fens (National Wetlands Working Group, 1997: 9). Wetland types are influenced by their sources of water, the length of their hydroperiod, soil type, and vegetation (National Wetlands Working Group, 1997: 3). Wetland not only plays an important part in supporting wildlife and vegetation, but also

attracts human attention, as wetland is a source of water and can have aesthetic value (Kupchella and Hyland, 1993: 414-415).

Most industrialized countries have identified their loss of wetland and are making efforts to keep it sustainable. Wetland conservation is more difficult for less industrialized countries, which are experiencing wetland declining at a faster rate (Brinson and Malvárez, 2002). Most countries, highly industrialized and less industrialized, do not have accurate inventories of their wetland to help them determine its status and the biodiversity within it (Brinson and Malvárez, 2002).

Instead of developing conservation plans for an entire ecosystem, it may be more efficient to focus on a particular wetland species, such as amphibians, which are a semi-aquatic species. Researchers have suggested amphibians may be biological indicators that reflect the quality of wetland (Young et al. 2004: 7). Biological indicators are selected species that have sensitive responses on an organism, population, or community level to physical, biological, or physical changes in the environment, such as habitat change, contamination, changes in food availability, or changes in predator-prey relationships (Adams, 2002: 2-4). Organisms that have a narrow ecological tolerance or are very sensitive to changes in the environment can be used as early warnings signs for negative changes in the environment (Jackson, 1974: 27). Organisms that are thought to be biological indicators can be tested by comparing present populations with historical populations. Over a certain time frame, change in a particular ecosystem will most likely occur. A decrease in the population of the selected organism during the time frame will show that the organism has a narrow ecological tolerance and could be used as a biological indicator (Stuckey, 1974: 27-28). Amphibians have permeable skin and can

accumulate contaminants quicker than other organisms and can be affected quicker by environmental change (Young et al. 2004: 7); therefore, a healthy population of amphibians present in a selected wetland may indicate that the wetland is high-quality (Brodman et al. 2006). By focusing on conserving amphibians, the indirect preservation of wetlands may result.

Amphibians rely on both the aquatic and terrestrial component of wetland ecosystem (Baldwin et al. 2006). The terrestrial component of wetland, or any other water body, acts as a physical and chemical filter that aids in the protection of the aquatic component. Many amphibians rely on the terrestrial component during the year. In the spring, many amphibians use the aquatic habitat for breeding and ovipositing (Semlitsch and Bodie, 2003). During the rest of the year, many amphibians use the terrestrial component for foraging and overwintering. Amphibians also need a terrestrial corridor between their terrestrial and aquatic habitats to aid in successful migration (Semlitsch and Bodie, 2003).

There has been great progress in protecting the aquatic component of wetland; however, the terrestrial component is often overlooked. Research on the terrestrial component of wetland and its ecological significance for amphibians is poorly understood (Gibbons, 2003). Many regulations are primarily focused on the aquatic component of wetland, such as the wetland delineation process in the United States (Hermann et al. 2005; Maisonneuve and Rioux, 2001). In Quebec, one regulation, the Protection Policy for Lakeshores, Riverbanks, Littoral Zone, and Floodplains, states that a riparian buffer strip needs to be established between the agricultural landscape and the bordering water body; however, it only has to be three metres wide (Maisonneuve and Rioux, 2001).

Even though part of the terrestrial environment is protected, this regulation is intended to meet the purpose of protecting the water quality by preventing sediment and nutrient runoff, even though it seems to be insufficient, since studies have discovered that a 6-m buffer is a sufficient buffer width (Borin et al. 2005; Borin and Bigon, 2002), and the United States Forest Service recommends a three-zone buffer with a total width of 28.5 m to sufficiently protect the water from sedimentation and nutrient run-off (Corell, 2005). There are fewer regulations to protect the terrestrial component of wetlands. Lee et al. (2004) reviewed the guidelines to retain treed riparian buffers after timber harvest between jurisdictions in Canada and the United States. Only 48% of the jurisdictions stated the protection of both aquatic and terrestrial habitats and aquatic and terrestrial biota in their guidelines; however, there was no statistical difference in the buffer widths between the jurisdictions who stated the protection of the aquatic and terrestrial component in their guidelines and the jurisdictions who stated the protection of only the aquatic component in their guidelines. Some organisms, such as forest-dwelling birds and moose, require wider buffer widths than the mean buffer widths in the Canadian jurisdictions (Darveau et al. 1995; Brusnyk and Gilbert, 1983). The mean buffer widths in the study conducted by Lee et al. (2004) were 54.6 m for large lakes, 47.1 metres for small lakes, 43.8 m for large permanent streams, 29.6 m for small permanent streams, and 13.8 m for intermittent streams. Forest-dwelling birds require a 60-m buffer and moose require a 60-m buffer for a sufficient amount of habitat area (Darveau et al. 1995; Brusnyk and Gilbert, 1983).

It has been discovered that amphibians require a wider buffer than the guidelines set out by many Canadian and American jurisdictions (Lee et al. 2004). Semlitsch and

Bodie (2003) have determined that an adequate terrestrial buffer for majority of amphibians that inhabit wetlands should range from 142 m to 289 m. Other researchers have determined adequate buffer widths for particular species. Bulger et al. (2003) have determined that an adequate buffer width for the California red-legged frog (*Rana aurora draytonii*) is to be at least 100 metres.

Buffers also need to reflect the natural habitat for the species of interest. In forest management, undeveloped or natural areas bordering water bodies are left untouched in order to prevent an increase in sedimentation, an increase in the temperature of the water body, and to help protect wildlife that require a riparian area (Olson et al. 2007; Macdonald et al. 2006). Once a buffer is implemented, the natural quality of the buffer needs to be retained (Dupuis and Steventon, 1999). A buffer is useless if there is no suitable protection to retain the buffer's ecological integrity. The quality of the riparian buffer strip that needs to be protected from agricultural developments in Quebec, implemented under the Protection Policy for Lakeshores, Riverbanks, Littoral Zones, and Floodplains, is usually deteriorated because farmers have been found to spray pesticides and burn the area to prevent the growth of cover vegetation for pests. The buffers need to have minimum disturbance (Maisonneuve and Rioux, 2001). If it is not possible to retain an undeveloped, natural buffer, a buffer can be created that reflects the habitat characteristics of the species of interest. This may be difficult, as the terrestrial habitat characteristics for many amphibian species may be unknown (Rodríguez-Prieto and Fernández-Juricic, 2005; Bulger et al. 2003).

In order for a wetland to have optimum biodiversity, both the aquatic and terrestrial components of the wetland need to be adequately protected (Semlitsch and

Bodie, 2003). It may be difficult to separate the niche of each environment for amphibians. Wetlands are a transition zone between the aquatic and terrestrial environment. Because amphibians rely on a habitat where two environments overlap, there is a great potential for a number of environmental variables, that have not been accounted for, to interfere with the observations of a study, and it may be very difficult to look at habitat variables independently. It may be difficult to isolate one variable and show that it directly impacts an amphibian population (Guerrey and Hunter Jr., 2002); however, mesocosms could be used to address this problem (Caquet et al. 1996).

1.4 Amphibian Conservation

Some conservation methods have been developed in order to protect and sustain amphibian populations. One amphibian conservation method is wetland restoration. Damaged wetland is restored to a better state in order to improve the water quality and biodiversity (Zedler, 2000). In California (United States), it was discovered that introducing non-native trout had a negative impact on the mountain yellow-legged frog (Knapp and Matthews, 2000). Knapp et al. (2007) looked at mountain yellow-legged recovery after fish were removed from water bodies that were stocked with trout. Knapp et al. (2007) discovered that mountain yellow-legged frog population densities significantly increased after fish were removed from the sample water bodies.

Habitat creation is also used to generate and sustain amphibian populations. In the Greater Toronto Area (Ontario), amphibian tunnels have been constructed to join wetland areas that have been separated by the Bayview-Avenue roadway. It has been somewhat successful, since they have found the wood frog (*Rana sylvatica*), northern leopard frog (*Rana pipiens*), and the spring peeper (*Pseudacris crucifer*) using the

tunnels, but they did not find their target species, the tiger salamander (*Ambystoma tigrinum*), present in the tunnels. More research to make the tunnels suitable habitat for the tiger salamander has been suggested (Gartshore et al. 2006).

Translocations of amphibians to a newly constructed or historical habitat have proved successful in the view of some researchers (Kendell, 2002b: 16; Seigel and Dodd Jr., 2002; Weyrauch and Amon, 2002). South of Lethbridge, Alberta, efforts have been made to generate new populations of the threatened northern leopard frog (*Rana pipiens*). Egg masses were gathered from known populations and transported to new sites. The egg masses were put into floating enclosures for protection from predators. Once the egg masses hatched and the tadpoles were mobile, they were released into suitable habitat. This seems to be a success since northern leopard frogs have been found the following spring seasons confirming that they survived the overwintering. Breeding behaviour has also been observed at the translocation sites (Romanchuk and Quinlan, 2006: 1-2, 14-15). Successful translocations of the northern leopard frog has also been done in Crimson Lake Provincial Park, near Rocky Mountain House, Alberta and the Raven Brood Trout Station, near Caroline, Alberta (Kendell, 2002a: 3, 19).

Researchers are also trying to determine how the public can cooperate and help protect amphibians. Marty et al. (2005) found that cattle grazing, if managed properly, can support sufficient amphibian populations, as well as invertebrate and native plant communities. Hazell et al. (2001) examined how farmer's dams affected amphibian populations. The study examined the status of amphibian populations, and whether the dams caused a negative or positive impact; it focused on how farmers can help keep the populations sustainable. Hazell et al. (2001) discovered that there was a positive

relationship between native vegetation in the surrounding landscape and frog species richness. The researchers suggested that since the farm dams are on private land, it is necessary to try to make the dams serve two functions: act as a water system for agriculture and act as habitat for frogs occurring on the property. It is important to find ways for landowners to maintain their business and land activities while keeping amphibian populations present on their land and neighbouring lands sustainable.

In order for these amphibian conservation methods to be successful, habitat requirements must be understood. It has been suggested that many constructed wetlands do not reflect the habitat needs of the amphibian species have been selected for conservation. Many managers have simply dug a large hole with steep slopes and filled it with water to make a wetland (Porej and Hetherington, 2005). Euliss and Mushet (2004) determined that the excavation of wetland, in the Little Missouri National Grassland in the (United States), lengthened the hydroperiod of the wetland. They discovered a drop in amphibian populations and an increase in predator species in the wetland that became permanent. The wetland that was once seasonal wetland allowed amphibians to thrive because a seasonal hydroperiod prevented the wetland from being permanent habitat for predators.

There is a problem with the general assumption that any water body is better than no water body at all. A water body that is not designed specifically to support an amphibian population may not support a high level of biodiversity. Wetland with steep slopes can support a permanent hydroperiod, can support predatory fish, and therefore may not support a large amphibian population. Restored and constructed wetland that is

designed to support amphibian populations must reflect the habitat characteristics of the amphibian species of interest (Porej and Hetherington, 2005).

It may be necessary to use mesocosms to determine the habitat requirements of a selected amphibian species (Marsh et al. 1999). Mesocosms are created man-made systems that are designed to simulate certain habitat conditions and prevent other environmental variables from interfering with the results of a study (Caquet et al. 1996). Roe et al. (2006) took cattle tanks, placed sediment and pond water from their sample area in the tanks, and then placed mole salamanders (*Ambystoma talpoideum*) from their sample area into the tanks. A specific treatment was added to each tank to test how salamanders responded to coal-combustion waste. The tanks had mesh covers to prevent predator intrusion and the water levels were lowered to simulate the drying of temporary ponds. By using these tanks, predator intrusion, water levels, and soil dynamics were all accounted for, so they could isolate coal-combustion waste as a variable and study its direct impact on green frog population dynamics. Roe et al. (2006) discovered that coal-combustion waste has a negative impact on salamander larvae; the number of mole salamander larvae that reached metamorphosis was reduced by 57-77%, compared to the reference tanks.

When trying to conserve amphibian populations, scientists have found that it is inefficient to develop a general conservation strategy. Each amphibian species has different habitat characteristics. A general conservation strategy may overlook the primary needs of one amphibian species, even though the strategy may help the majority of amphibian species in the area of interest. Each conservation strategy must be species-specific, in order to optimize the success of each amphibian species of interest. Guerry

and Hunter Jr. (2002) have results that support this conservation method. They compared species presence with forest area and discovered that some amphibians have a positive relationship with forest area and some have a negative relationship with forest area. If a general conservation strategy was developed to focus on preserving the forest area, the amphibian species with a negative relationship may struggle to keep its population sustainable.

Some researchers are trying to inform managers that the terrestrial component of a wetland needs to be protected. Regulations need to focus on the protection of the aquatic environment as well as the terrestrial environment. In order to determine whether the amount of area of land bordering a wetland is sufficient to protect amphibians, researchers are determining the migratory distance of their species of interest. By looking at the literature that focused on migratory distances of amphibians, Semlitsch and Bodie (2003) determined the mean minimum core terrestrial habitat and maximum core terrestrial habitat for frogs and salamanders. For frogs, the mean minimum and maximum terrestrial habitat is 205 m and 368 m from a wetland; for salamanders, the mean minimum and maximum terrestrial habitat is 117 m and 218 m. Each amphibian species has a different migratory distance, since Semlitsch and Bodie (2003) compared the migratory distances of 19 frog species and 13 salamander species; therefore, it may be more efficient to develop a terrestrial environment protection plan that is species-specific. Some threatened species may not be properly protected if a general terrestrial environment protection plan was developed (Semlitsch and Bodie, 2003). Also, the area should be able to support the majority of migrations that happen within the season. If the

area is too small, some amphibians may become susceptible to dangers outside of the buffer zone (Regosin et al. 2005).

In order for researchers and managers to determine an amphibian species' habitat characteristics with a high level of accuracy and precision, long-term monitoring is recommended. Many studies are short-term (studies taken over a few years) and therefore have a lower level of confidence. Long-term studies (studies taken over many years or decades) can also allow for researchers and managers to determine the status of amphibian populations from historical data or determine the success of restored or constructed wetlands (Wicknick et al. 2005). The main problem with long-term monitoring is that it can be expensive to acquire sufficient data for highly accurate results (Cushman, 2006)

Long-term monitoring helps to get a clear picture of the past and to be able to determine patterns in wildlife behavior, populations, habitat change from both natural and anthropogenic sources, and climate change. Based on monitoring data, patterns can be determined and the data can be used develop models in order to predict future patterns in amphibian populations. Models can also be used to predict how changes in certain variables may impact the species. Habitat models can be a useful tool for the conservation of amphibians and land-use management (Downey et al. 2004: 1-7).

Chapter 2: Background of the Study Area and Species of Study

2:1 Objective of the Study

The objective of this study was to develop habitat suitability index (HSI) models for frogs found in the Foothills Parkland Natural Sub-region and the Bow River Sub-basin of Alberta during their breeding season. The boreal chorus frog (*Pseudacris triseriata maculata*), the northern leopard frog (*Rana pipiens*), and the wood frog (*Rana sylvatica*) are known to be present in the selected geographic area (Alberta Conservation and Alberta Sustainable Resource Development, 2003: 6, 9, 20). These models are specific to Foothills Parkland Natural Sub-region and the Bow River Sub-basin of Alberta, and they may be used to help conserve amphibian habitat and wetland for a geographic area that may experience heavy habitat destruction as a result of Calgary's expansion (Government of Canada, 2006: 25).

In Alberta, very few HSI models have been developed for amphibian conservation management purposes. So far, HSI models have been developed for the long-toed salamander (*Ambystoma macrodactylum*), western toad (*Bufo boreas*), and northern leopard frog (*Rana pipiens*) in the Oldman River Basin; HSI models have been developed for the great plains toad (*Bufo cognatus*) and plains spadefoot toad (*Spea bombifrons*) in the Milk River Basin; and a HSI model has been developed for the long-toed salamander in the Foothills Model Forest (Blouin et al. 2004: 136-169, Downey et al. 2004: 99-111; Graham et al. 1999: 1-6). The HSI models developed in this study are the first known habitat models to be developed for amphibian species that have been found in the selected geographic area.

Through a literature review, habitat variables and their relationship with the population dynamics for a particular frog species that is known to be present within the selected geographic were first determined. Studies that were reviewed included Burton, 2001; Cushman, 2006; Eaton, 2004; Egan and Paton, 2004; Findlay, 2001; Findlay and Bourdages, 2000; Kolozsvary, 2003; Norris, 2006; Patrick et al. 2006; Pearson, 2004; Petranka et al. 2007; Porej et al. 2004; Rubbo and Kiesecker, 2005; Skelly et al. 1999; Stevens et al. 2007; Stevens et al. 2006; Stevens et al 2006; and Vasconcelos and Calhoun, 2006. HSI models that are species-specific and can be used to determine overall habitat quality were developed using the habitat variables. The habitat variables were then tested in the field within the selected geographic area in order to verify the models by conducting amphibian population surveys and measuring the habitat variables that are in each model.

Field sampling took place during the frogs' breeding season (mid-April – mid-May) within the selected geographic area to determine species presence and estimate population. For each species that was found during the field sampling period, the habitat variables that were determined for their HSI model were measured. The northern leopard frog was not found during the field sampling period, so no model was developed.

2:2 Environmental Problems in Alberta

Alberta has the highest population growth rate in Canada (Government of Alberta 2007: 4). The main area experiencing the growth rate is the Edmonton-Red Deer-Calgary corridor. The oil industry is the primary cause of the high growth rate in Alberta (Statistics Canada, 2007: 17, 21). To keep pace with the high population growth rate, rural areas that are neighbouring urban centres are being converted into expanded urban

developments of the major urban centres (Government of Alberta, 2007: 4). Many cities are converting land that was primarily used for agriculture and ranching into acreages and urban subdivisions. This horizontal expansion is putting pressure on many natural areas that are near these urban centres (Government of Alberta, 2007: 25). Edmonton, a major urban centre in Alberta, is found in the Aspen Parkland Natural Sub-region (Natural Regions Committee, 2006: 113); however, just north of Edmonton is the Aspen/Boreal interface. Urban expansion, along with agriculture, has contributed to heavy deforestation of the Aspen/Boreal interface (Young et al. 2006).

The Foothills Parkland Natural Sub-region is one of the three sub-regions that make up the Parkland Natural Region (Natural Regions Committee, 2006: 109-110). The Parkland Natural Region is one of the six natural regions that make up Alberta. Out of these six natural regions, the Parkland Natural Region is the most densely populated region. Calgary is part of the Parkland Natural Region and is expanding its urban area toward its neighbouring communities, such as Cochrane, Alberta (Government of Alberta, 2007: 25). Conservation management needs to focus on natural areas that have been or will eventually be affected by Calgary's urban expansion. The Foothills Parkland Natural Sub-region is still a rural area, but is subject to urbanization and declines in its amphibian populations. Approaches to amphibian conservation, such as HSI models, need to be developed that can be used for amphibians that inhabit this area.

Population growth in Alberta is a major problem for Alberta's environment. Population growth may negatively impact the biodiversity and water supply in the areas where urban expansion occurs. Conservation management in Alberta needs to address the protection of the land and not just reclaim the land after urbanization and industrial

development takes place, since reclamation in Alberta can not keep up with urban and industrial development (Government of Alberta, 2007: 36). As urbanization negatively impacts biodiversity, determining how to protect and reclaim areas for specific species, such as the wood frog and the boreal chorus frog, is a necessary conservation management approach to guide future land-use in this area, which is most likely to be urban expansion (Government of Alberta, 2007: 25).

Agriculture in Alberta has negatively impacted wetland. Various land covers, including wetland and peatland have been cleared to support agriculture expansion (Wilson et al. 2001: 3, 11). Wetland has also been drained to for agriculture, as over one million acres of land is irrigated in Alberta (Government of Alberta, 2007: 18; Wilson et al. 2001: 18). Even though agriculture has been a hindrance on wetland, agricultural land is now being converted into urban and rural developments creating hardscape and fragmentation (Government of Alberta, 2007: 20).

2.3 Amphibians in Alberta

In Alberta, there are ten amphibian species. Eight species are frogs and toads: the wood frog (*Rana sylvatica*), boreal chorus frog (*Pseudacris triesseriata maculata*), Columbia spotted frog (*Rana luteiventris*), northern leopard frog (*Rana pipiens*), boreal toad (*Bufo boreas*), the Canadian toad (*Bufo hemiophrys*), great plains toad (*Bufo cognatus*), and the plains spadefoot toad (*Spea bombifrons*). The other two amphibian species found in Alberta are salamanders: the long-toed salamander (*Ambystoma macrodactylum*) and the tiger salamander (*Ambystoma tigrinum*).

Out of the ten species found in Alberta, only three species are classified as secure: the boreal chorus frog, the wood frog, and the tiger salamander (Alberta Conservation

Association and Alberta Sustainable Resource Development, 2001: 15, 28, 25; Wilkinson and Berg, 2004: 8). A species that is classified as secure is not at risk of extinction and not sensitive to human activities, the distribution of the species is widespread, the total population size is large (greater than 10,000), and there is no threat to the species' population and habitat (Fish and Wildlife Service, 2000: 3, 5, 7). It is obvious that conservation efforts need to focus on the protection of amphibians in Alberta, since less than one third of amphibians have been classified as secure. Secure species are species that are not at risk to extinction or extirpation and do not require special attention or protection (Fish and Wildlife Service, 2000: 3).

2:4 General Description of the Wood Frog (*Rana sylvatica*)

The wood frog (*Rana sylvatica*) is a true frog, since it is part of the Ranidae family. The wood frog is one of the smallest species in the Ranidae family; the maximum recorded size of the wood frog is 6.5 cm. It has a black stripe running across the side of its eyes with a white stripe below it. There is also a dark stripe running from the nostril to the eye. There are two folds running across the back, which are known as dorsolateral folds, and are contrasting to the background colour. Dark crossbands can also be found on the hindlegs (MacCulloch, 2002: 84). The background colour of the wood frog can be brown, black, pink, or coppery (Cochran and Goin, 1970: 78).

The wood frog's normal diet consists of worms and insects. The breeding season for this frog normally starts in April and can run until June; however, once the breeding period for a population starts, the period is very short and may only last up to two weeks (Alberta Conservation Association and Alberta Sustainable Resource Development,

2001: 35-36). During the breeding season, the call of the male frogs sounds like the quacking of ducks (Cochran and Goin, 1970: 78).

The wood frog has the widest range in Canada out of all the amphibian species (MacCulloch, 2002: 84). In Alberta, it also has a very wide range (Figure 1). It has a very high cold tolerance and therefore can be found at high elevations and is known to be found farther north than any other amphibian. The wood frog is on the Green List in the Status of Alberta Wildlife report. If an organism is on the Green List, it means the organism's populations in Alberta are not declining (Alberta Conservation Association and Alberta Sustainable Resource Development, 2001: 35-36). The Committee on the Status of Endangered Wildlife in Canada (COSEWIC), that determines an organism's status in Canada, has also classified the wood frog to not be at risk (MacCulloch, 2002: 84).

2:5 General Description of the Boreal Chorus Frog (*Pseudacris triseriata maculata*)

The boreal chorus frog (*Pseudacris triseriata maculata*) is a member of the Hylidae family (tree frogs) and is not a true frog, since it does not have dorsolateral folds on its back like the true frogs (Alberta Conservation Association and Alberta Sustainable Resource Development, 2001: 28-29). Because it is a tree frog, small discs can be found on the fingers and toes (Froom, 1982: 92). Even though the boreal chorus frog is a tree frog, it is rarely found in trees, since it has the shortest legs of any tree frog (Cochran and Goin, 1970: 117). The boreal chorus frog has a black stripe running out from the side of its eyes, and it also runs down the side of its body. It has three dark lines running along its back that can be broken or be in the form of spots. Its background colour can be grey, brown, or green, and its belly is white. The boreal chorus frog is smaller than the wood

frog with a maximum recorded size of 3 cm. This frog can be confused with another tree frog found in Canada: the western chorus frog (*Pseudacris triseriata triseriata*). The boreal chorus frog can be distinguished from the western chorus frog by its shorter hind limbs. Also, the ranges of the boreal chorus frog and western chorus frog do not overlap (MacCulloch, 2002: 80).

The boreal chorus frog eats many invertebrates, such as insects. The breeding season for the boreal chorus frog also begins in April and can run until June (Alberta Conservation Association and Alberta Sustainable Resource Development, 2001: 28-29). During the breeding season, the call of the males sounds like the scratching of hair combs (MacCulloch, 2002: 80).

The boreal chorus frog, like the wood frog, has a very large range in Alberta (Figure 2); it can be found almost anywhere, except for alpine environments. This frog is also on the Green List in the Status of Alberta Wildlife Report (Alberta Conservation Association and Alberta Sustainable Resource Development, 2001: 28-29). COSEWIC has also classified the boreal chorus frog to not be at risk (MacCulloch, 2002: 80).

Even though the wood frog and the boreal chorus frog are on the Green List, their habitat characteristics and the methods required to sustain non-declining populations need to be investigated, since amphibians, in general, are declining (Young et al, 2004: 7). By examining the habitat needs of the wood frog and boreal chorus frog, certain relationships may be found to contribute to our understanding why these two species have healthy populations in Alberta. Certain relationships that support amphibians with healthy populations could be used as guides for further research on amphibians with less healthy populations, such as the northern leopard frog (*Rana pipiens*) that has an overlapping

range with the wood frog and the boreal chorus frog (Alberta Sustainable Resource Development, 2003: 6, 9, 20). HSI models can be used to determine how future changes in the selected geographic area may affect populations of wood frogs and boreal chorus frogs during the breeding season (Downey et al. 2004). These species-specific models can also be used as a guide for other amphibians, since some of the habitat characteristics relationships may overlap with the habitat characteristics of other amphibian species inhabiting the same and neighbouring geographic areas.

Figure 1. Distribution of the wood frog throughout Alberta (Alberta Sustainable Resource Development, 2008).

Figure 2. Distribution of the boreal chorus frog throughout Alberta (Alberta Sustainable Resource Development, 2008).

Chapter 3: Habitat Models Developed From the Literature

3:1 Introduction

This chapter describes how preliminary habitat suitability index (HSI) models were developed for the wood frog (*Rana sylvatica*) and the boreal chorus frog (*Pseudacris triseriata maculata*). No HSI model was developed for the northern leopard frog (*Rana pipiens*) because there were no northern leopard frogs found during the fieldwork. The preliminary models represent the first four phases of developing a HSI model: model objective determination, model variable identification, model construction, and model documentation (Division of Ecological Services, 1981: 3-1 – 3-4). The developed models in this chapter are strictly based on previous research and not the fieldwork that was conducted for this study. By developing preliminary models, key habitat variables could be identified and were used as a guide for investigation during the fieldwork that was conducted for this study (Division of Ecological Services, 1981: 3-1 – 3-4).

3:2 Habitat Suitability Index Models

HSI models are word or mechanistic models that are used to determine the quality of habitat for a specific species based on certain habitat conditions (Division of Ecological Services, 1981: 1-1 – 1-2). The original methodology was developed by the United States Fish and Wildlife Services (USFWS) to meet new legal Acts related to environmental protection. The USFWS needed to develop a methodology for conducting habitat assessments to meet the requirements stated by the amendments of the Fish and Wildlife Coordination Act (1934) and the Endangered Species Act (1973). The Fish and Wildlife Coordination Act states that the USFWS must conduct surveys to determine

inventories and the status of United States fish and wildlife resources; the Endangered Species Act states that habitat for a particular species can be designated as critical habitat by conducting biological assessments. By designating land as critical habitat, the type and amount of development allowed on the land is limited. The method involves developing a documented model from measurable key habitat variables. Key habitat variables are identified by determining significant relationships between the population dynamics of a species and variables related to its habitat by examining the literature or by empirical observation. Before the HSI model method was developed, habitat quality was determined in a subjective fashion by a team of biologists; no standard methods or data were used (Division of Ecological Services, 1980a: 2.3-2.5).

The HSI model's primary purpose is to determine the baseline quality and amount of habitat for a specific species and to determine how proposed land and water developments may impact the habitat quality and quantity in the future for that specific species. The model is based on comparing existing habitat conditions for a specific species with its ideal habitat conditions. Ideal habitat conditions are the habitat conditions of sites where the highest population densities of the specific species are found in the selected area (Division of Ecological Services, 1980a: 5.1).

There are advantages and disadvantages to using the HSI model method. One advantage is that the baseline habitat quality and quantity in a selected area for a specific species can be determined based on a standardized method using standard data. Standard data are data collected using identical, documented procedures in order to control extraneous variables so other scientists can obtain similar results (Zolman, 1993: 5, 8). Once the status of a species is determined, conservation and land-use alternatives can be

developed in the decision-making process for future land and water developments (Division of Ecological Services, 1980b: 3-2). Since HSI models can be a controlled and cost-effective means to determine the status of one species' habitat, they can be used as a component of ecological assessments that are required by various authorities (Kapustka, 2005). The degree of impact for a particular land or water development can be predicted by comparing trade-offs in that land or water development (Division of Ecological Services, 1980b: 3-2). The disadvantage of predicting future changes using an assessment model is that future habitat changes can not be measured with a high level of confidence; they can only be estimated or predicted. The level of confidence of modeling may not be very high, and for this habitat model, a species may still not survive in a habitat, even though good habitat quality was predicted. Also, other environmental variables that may affect the population of a specific species may not be considered in the model (Division of Ecological Services, 1980a: 4.3-5.2).

Another advantage is that the model can be tailored to the user. One user may require a lower level of detail (lower amount of habitat variables, lower intensity of monitoring, and lower complexity of data) compared to another user. A lower level of detail for the model allows lower costs and shorter time periods to obtain a model output (Division of Ecological Services, 1980a: 4.3). Also, a preliminary model with few variables in a small area allows lower costs and shorter time periods. Once a model is developed, a user may require more extensive data, more habitat variables, or a larger area to allow a more accurate analysis of the habitat for a specific species. Once more complex data, more habitat variables, or a larger area is required, the costs to obtain a model output can be a lot higher, and the time period to conduct habitat variable

measurements and analyses can require a significantly longer time period to reach completion (Division of Ecological Services, 1980b: 2.1-2.2). For example, it is believed to be inefficient to develop a predator HSI model where the predator has various prey for its diet because there would be too many habitat variables to account for the many habitats that the prey use. It would be very difficult to monitor each habitat variable that would be in the model and would require a lot of resources and time to complete the monitoring and analyses (Jones et al. 2002: 94); therefore, HSI models can be very simplistic and can yield imprecise predictions (Zielinski et al. 2006).

Newer versions of models have been developed, which are adaptations of original models. A developed model has specific habitat variables and methods of determining the condition for each habitat variable, but another user may want to modify those variables or methods in order to reflect a different geographic area or a different function for the model. For example, newer HSI models for the American marten (*Martes americana*) in Ontario use different variables from the original marten HSI model in order to reflect a different area (Watt et al. 1996: 8). The original HSI model reflects a geographic area within the United States, but Naylor et al. (1994) wanted a model that reflected habitat quality for the marten in central Ontario. They replaced the successional stage variable with a stand height variable in order to accommodate Ontario's Forest Resource Inventory. They then verified the modified model in the field with their marten trapline harvest data collected in central Ontario (Watt et al. 1996: 8). Hodson et al. (2004) have looked at the habitat requirements of the marten in Temagami, Ontario, a forest management unit, to see if there is a difference in habitat requirements than the habitat requirements in the model set out by the Ontario Ministry of Natural

Resources; the original model reflects Algonquin Park, Ontario. Hodson et al. (2004) discovered that the marten habitat requirements were different between Temagami and Algonquin Park and have suggested that modifications of the model need to be made in order to reflect the Temagami Forest Management Unit.

Overall, HSI models are simple, basic tools for biologists and natural resource managers and they are good for regional-level conservation planning (Zielinski et al. 2006). Regional-level conservation planning involves managing a number of landscapes that makes a complex of climatic physiographic, biological, economic, social, and cultural characteristics. For example, one region may include an urban, suburban, and agricultural landscape (Forman and Godron, 1986: 13); a HSI model can be developed to reflect the entire region. HSI models that have already been developed can be expanded for other users or modified to reflect the needs of users in different geographic areas. HSI models appear to be a successful tool, as there are currently 157 published HSI models in the United States (National Wetlands Research Center, 2008); however, most HSI models are still at the stage where they are used to indicate future investigations; only a few have had some model verification where there has been some confirmation of the models' output and relationships between the selected species and the habitat variables used in the model (Jones et al. 2002: 94; Watt et al. 1996: 8).

3:3 Methodology of Constructing a Habitat Suitability Index Model

The HSI model methodology, developed by the Division of Ecological Services of the United States Fish and Wildlife Service (1981), consists of five phases: model objective determination, model variable identification, model construction, model documentation, and model verification. The model objective phase involves determining

the main purpose for developing the model. There are three parts to developing the model objective: defining the ideal and acceptable model output, defining the geographic area to which the model applies, and defining the season or time period to which the model applies. Both the ideal and acceptable model output has to be between 0 and 1; it is a rating system. An output of 0 means the area is very poor habitat for the species and an output of 1 means that the area is ideal habitat. The acceptable output represents the acceptable reliability of the model and is determined by correlating the model output with the carrying capacity of the species in the selected geographic area (Division of Ecological Services, 1981: 3-1 – 3-4).

Key habitat variables can be determined from observations of previous studies or can be determined from fieldwork; key habitat variables in these preliminary models were determined only from the literature. Once the key habitat variables were decided, a suitability index for each variable was determined based on the available literature. A suitability index, like the model output, is based on a weight system and has a range between 0 and 1. A suitability index of 1 reflects the ideal conditions for a particular variable; a suitability index of 0 means that the conditions for that particular variable are very poor for the species in question. For each species, each suitability index variable was entered into an equation to generate a HSI model. The model output resulting from the suitability index values being introduced into the model represents the quality of habitat for the selected species in the area. Habitat units that represent the combination of habitat quality and quantity can be determined by multiplying the HSI model output by the amount of available habitat for the specific species. The amount of available habitat for a selected species can be the sample area or the total area of cover types that are only

used by the selected species in the area. Cover types are specific areas of land with similar characteristics. For example, a red-tailed hawk uses grassland for food but also uses forest for nesting (Division of Ecological Services, 1981: 3-1 – 3-18).

The general structure of the equation follows a compensatory relationship, where the equation is controlled by a geometric mean:

$$HSI = (V_1 * V_2 * V_3 \dots * V_n)^{1/n} \quad [1]$$

HSI = Habitat suitability index

n = number of variables

V_i = suitability index value of variable i

The geometric mean allows the lowest value to influence the output. If a model has only two variables, and if one variable has a suitability value of 0.8 and the other has a suitability index value of 0.2, then the output will be 0.4. If one of the variables has a suitability index value of 0, then the output will be 0 (Division of Ecological Services, 1981: 3-32 – 3-33).

The fourth phase of developing a HSI model is model documentation. Model documentation involves documenting the steps taken to develop each HSI model and justifying each habitat variable relationship by verifying it with previous research (Division of Ecological Services, 1981: 3-50). Chapters 3, 4, 5, and 6 present the documentation of the HSI models for the wood frog and the boreal chorus frog.

3:4 Wood Frog Habitat Suitability Index Model

The objective for the wood frog HSI model is to determine key habitat variables that influence wood frog population dynamics and develop a model that can be used to determine the baseline and future conditions of wood frog habitat during its breeding season. This is a general proximity model; therefore, these suitability indexes reflect the

wood frog's entire range in North America and not the specific sample area of this study. The ideal output for the equation is 1, which represents ideal habitat for the wood frog during its breeding season. The model is supposed to have a determined ideal output and acceptable output. The acceptable output represents a reliable output, since it is rare to obtain the ideal output. The acceptable output is determined by measuring the carrying capacity of the selected species within the geographic area and correlating the carrying capacity with model outputs. It can also be determined by correlating model outputs with other habitat ranking systems that have been developed for the particular species (Division of Ecological Services, 1981: 3-1 – 3-3). Unfortunately, the acceptable model output could not be determined because the carrying capacity of the wood frog within the sample area was not determined in this study and no other habitat ranking system could be found for the selected species in the selected geographic area.

Based on the available literature, four key habitat variables and their suitability indexes were determined for the wood frog during its breeding season. The available literature that was used for selecting the habitat variables revealed the habitat characteristics of the wood frog. A habitat variable was selected if there was no disagreement between the sources' results. If a habitat variable's relationship with wood frog population dynamics was controversial in the literature, then it was not selected for the model (Division of Ecological Services, 1981: 3-27).

The presence of fish is a significant factor in determining suitable habitat for the wood frog. Fish, especially trout, have been found to eat amphibian eggs and larvae (Young et al. 2004: 36, 38). Also, besides direct predation, the introduction of fish into a fish-free water body can also allow the invasion of parasites. Parasites that are harmful to

fish can also be harmful to amphibians (Thiemann and Wassersug, 2000). Wood frog populations can be dramatically reduced by fish preying on their eggs and larvae during their breeding season. During a recolonization study, Petranka et al. (2007) observed a dramatic decrease in wood frog populations because fish invaded the constructed wetland because of beavers and flooding. After the fish invasion, the percentage of constructed ponds that were occupied by wood frogs went from 100% to 30%.

Wood frogs are able to breed in the presence of fish, but this may depend on the species of fish that is present. Eaton (2004) found that wood frog larval survival was negatively impacted by fathead minnows (*Pimephales promelas*) and brook stickleback (*Culaea inconstans*), which are small-bodied fish. Eaton also discovered that wood frog larvae were not significantly impacted by northern pike (*Esox lucius*) and yellow perch (*Perca flavescens*); both of these species are piscivores (fish that prey on other fish for their diet). Norris (2006) also found that stocking lakes with northern pike has no negative impact on wood frog abundance. Rainbow trout (*Onchorhynchus mykiss*), a common fish used for stocking in Alberta, is believed to be responsible for the decline in of the Columbia spotted frog (*Rana luteiventris*) in Peter Lougheed Provincial Park, Alberta (James, 1998: 12). In Waterton National Park, Alberta, Pearson (2004) found that rainbow trout, cutthroat trout (*Onchorhynchus clarki*), golden trout (*Onchorhynchus aguabonita*), and brook trout (*Salvelinus fortinalis*), all stocked fish, had a significant negative impact on long-toed salamander (*Ambystoma macrodactylum*) larvae. In the salamander's primary habitat, there were no larvae where trout were present; along the salamander's habitat perimeter, only four of the ten sites that contained trout had larvae.

It is possible for wood frogs to breed in sites that contain fish, but with such a dramatic decrease in site occupancy in the study done by Petranka et al (2007) and having no wood frogs in any of the sample sites looked at by Porej et al (2004), it is assumed that sites containing fish are poor wood frog habitat. Because of the strong impact fish can have on the presence of wood frogs in a water body and that none of the studies used for the suitability index compared fish populations with wood frog populations, only two suitability index values can be selected for this variable. If fish are not present at the site, then the condition is ideal, and the suitability index value is 1. Because research has found that wood frogs will be absent from a site containing fish, a selected site that has fish present is very poor wood frog habitat, and the suitability index value is 0. Even if northern pike are present at the site, there would still have to be other fish present that could prey on the wood frog. It could be possible to have a higher suitability index value for sites that contain fish, but studies to see if wood frog populations would remain sustainable would need to be conducted.

All of the studies that were used to determine the suitability index use fish presence as a binary variable: fish are present or not present. For future research, wood frog or wood frog larvae abundance can be compared with the amount of fish present at a site in order to have a suitability index that does not rely on binary data. Results in the studies conducted by Petranka et al. (2007) and Pearson (2004) had amphibians present even though fish were present as well. It can be assumed that amphibians, including the wood frog can survive in the presence of fish, but the rate of survival, the mechanisms for survival, and the difference in survival rate depending the amount of fish need to be further looked at.

Hydroperiod, the duration and frequency that a water body is flooded (Smith and Smith, 2001: 658), is important for wood frog habitat because they rely on the aquatic environment for egg laying and larvae growth. The hydroperiod is crucial for larvae development, since the eggs or larvae will die if the water body dries up before the larvae metamorphose into juveniles (Brooks, 2004). Permanent water bodies can support wood frog populations, but the populations are often very small compared to semi-permanent or non-permanent water bodies.

A permanent water body generally has a higher abundance of predators, such as fish (Boone et al. 2006; Rubbo and Kiesecker, 2005). Since fish usually are incapable of remaining in temporary or ephemeral water bodies, wood frogs and other amphibians tend to avoid permanent water bodies; their primary habitats have seasonal or temporary hydroperiods; a water body is classified as having a temporary hydroperiod if it dries up some years (Lichtenberg et al. 2006). Brodman et al. (2006) looked at the success of amphibian recolonization of restored wetland at Kankakee Sands in Indiana (United States). During the study, they discovered that late-stage larvae and tadpoles died from dessication in wetland that dried up before August; however, fish were found in the permanent wetland. It may be that fish presence is directly related to permanent water bodies, so the presence of fish may interfere with results when comparing hydroperiod with wood frog populations; however, no known studies have directly related permanent hydroperiod with fish presence, and no known studies have compared the isolated combination with wood frog population dynamics.

The suitability index values for the hydroperiod variable are derived from three sources: Vasconcelos and Calhoun, 2006; Kolozsvary, 2003; Skelly et al. 1999. Looking

at these sources, five hydroperiod categories with corresponding suitability index values were determined (Figure 3). For each study, the hydroperiod category with the highest number of wood frogs received a suitability index value of 1 (Table 1). Hydroperiod categories with lower wood frog populations received lower suitability index values by dividing the corresponding wood frog population value by the highest population value in the study. The suitability index values for each hydroperiod category of each study were averaged to determine an overall suitability index value for the model. It is possible that the hydroperiod category with the highest wood frog population in each study is not the ideal condition; however, the only way to determine the ideal condition is to find out the carrying capacity of the wood frog within the sample area that was used for each study (Division of Ecological Services, 1981).

Table 1. Results from sources that were used to derive the wood frog hydroperiod habitat variable. A temporary pond annually dries up and an intermediate pond dries up some years.

Source	Results
Vasconcelos and Calhoun, 2006	Temporary: 600 breeding adults Intermediate: 300 breeding adults Permanent: 160 breeding adults
Kolozsvary, 2003	Temporary: 0.4 egg masses/m ² Permanent: 0.04 egg masses/m ²
Skelly et al. 1999	Temporary: 8 ponds had breeding adults Intermediate: 14 ponds had breeding adults Permanent: 1 pond had breeding adults

The ideal condition for wood frog aquatic habitat is if the water body has a temporary hydroperiod: the water body dries up every year but does not dry up in less than two months. The poorest condition for wood frog habitat during its breeding season is if the hydroperiod is less than two months because the eggs and larvae will die from dessication (Vasconcelos and Calhoun, 2006; Egan and Paton, 2004; Kolozsvary, 1988).

Boone et al. (2006) found that it takes an average of 87 days from eggs being deposited to larvae reaching metamorphosis, while Brooks (2004) found that it takes between 53-135 days for wood frog eggs to hatch and for the larvae to metamorphose into juveniles. Both of these averages are around 3 months, and Brook's minimum is almost two months; therefore, it has been assumed that a site that dries up in less than two months is poor wood frog habitat. Intermediate ponds (ponds that dry some years) have also been found to support high numbers of wood frogs, most likely because predators are unable to establish large permanent populations during the drier seasons (Baldwin, 2005; Skelly, 1999).

Figure 3. Suitability index of hydroperiod for the wood frog. A temporary water body is a water body that dries up every year and an intermediate water body is a water body that dries up some years.

The third variable for the wood frog HSI model is water movement. Standing water, including ponds, marshes of lakes, and dug-outs are good habitats for wood frogs. Wood frogs can also live in obstructed streams, but they have not been found to live in streams that are not obstructed (Stevens et al. 2006). An obstructed stream refers to a flowing body of water being obstructed by some source, like a beaver dam, so that the water body primarily consists of standing water.

Stevens et al. (2006) found that wood frogs prefer standing water bodies for breeding compared to non-standing water bodies. They found that beaver ponds were a primary source of stream obstruction. They have suggested that beaver ponds have a synergistic relationship with wood frogs by obstructing streams and providing wood debris for female wood frogs to attach their eggs to. Although, they have also suggested that beaver ponds could be a potential problem if there are floods. Floods occurring within an amphibian habitat that is created by beaver dams could allow fish to invade the habitat. Fish presence in a beaver-created wetland mosaic would have to be managed to sustain a healthy amphibian population.

Like the fish presence variable, only two values were determined. If a selected site primarily consists of standing water, then the condition for this habitat variable is ideal and the suitability index value is 1. Wood frogs have not been found to be present in flowing bodies of water, so if the selected site is a stream that is not obstructed so that the water is constantly flowing, the condition for the habitat is very poor and the suitability index value is 0. No research has been found that has compared the gradient of water flow with wood frog population dynamics, so a suitability index gradient for standing water could not be developed.

Road density is believed to negatively impact wood frog populations by limiting the amount of available habitat and providing geographic barriers between wood frog populations (Egan and Paton, 2004; Findlay, 2001; Findlay and Bourdages, 2000). Roads acting as barriers can limit the amount of gene flow between populations and can also act as a mechanism for killing amphibians due to traffic (Cushman, 2006). It has been suggested that road closures should be used as a conservation technique to prevent

mortality during amphibian migration periods (Timm et al. 2007). It is also possible that roads are simply a surrogate for urbanization and reflect the amount of habitat fragmentation in the area. It may be difficult to suggest that, other than road-kills, roads impact amphibian populations by causing habitat loss and fragmentation. More research is needed to confirm that roads are a source of habitat fragmentation for amphibian populations. There is a very limited body of research that has quantified the negative impact of roads for this particular species; the suitability index for road density was derived only from one source: Rubbo and Kiesecker (2005), so the suitability index for road density may yield a broad output. As more evidence becomes available, more data can be integrated into the suitability index.

The suitability index for road density is in the form of a graph (Figure 4). The first three suitability indexes already discussed can be represented in the form of histograms; the road density suitability index is in the form of a graph because the study that was used to develop the index did not use road density categories (Rubbo and Kiesecker, 2005). Based on the study by Rubbo and Kiesecker (2005), the suitability index values for the model are derived by assigning a suitability index value of 1 to the road density with the highest wood frog population in the study: 3.90 km within 1 km of the wetland. Rubbo and Kiesecker (2005) measured the total length of roads within a 1-km radius of each site. Rubbo and Kiesecker's (2005) observation was converted from 1 km to 1.2 km to get a suitability index value of 4.68 km of road within 1.2 km of the wetland. The suitability index value uses a 1.2-km radius because researchers have found that wood frogs can migrate up to 1.2 km (Porej et al. 2004). The suitability index value was rounded to 5 km of road within 1.2 km of the wetland, since Rubbo and Kiesecker's

(2005) results reflected their specific sample area. The other suitability index value was derived from dividing the wood frog population value by the highest population value of the road density category that received a suitability index value of 1 (Division of Ecological Services, 1981: 3-1 – 3-54). In Rubbo and Kiesecker's (2005) study, 11% of the sites occupied by the wood frog had an average road density of 23 km of road within 1 km of the wetland, and 86% of the sites occupied by the wood frog had an average road density of 3.90 km of road within 1 km of the wetland. Dividing 11% by 86% gives a suitability index value of 0.13; however, the value was rounded to 0.1. The road density that had 11% of the sites occupied by the wood frog was also converted to 1.2 km radius and rounded to the nearest whole number. If the road density is 5 km of road within 1.2 km of the wetland or less, then the suitability index value is 1; if the road density is 28 km of road within 1.2 km of the wetland or more, then the suitability index value is 0.1 (Rubbo and Kiesecker, 2005). Road density can be measured from the center of a wetland, or if the water body is a lake or has quite a large area, then the road density can be measured from the area where the amphibians are found (Robinson, 2001).

Figure 4. Suitability index of road density for the wood frog.

Forest cover has been suggested as an important habitat variable for the wood frog, since it is known to be a component of the terrestrial environment (Patrick et al. 2006; Rubbo and Keisecker, 2005; Porej et al. 2004). Other research has found that forest cover is not a significant habitat variable for wood frog populations (Stevens et al. 2006; Vasconcelos and Calhoun, 2006; Skelly, 2004). Since the relationship between forest cover and amphibian population dynamics is controversial, forest cover was not selected for a habitat variable and was not measured in this study.

Taking the four variables, a HSI model was developed:

$$HSI_{\text{Wood Frog}} = (V_F * V_H * V_S * V_R)^{1/4} \quad [2]$$

V_F = Fish Presence Suitability Index

V_H = Hydroperiod Suitability Index

V_S = Standing Water Suitability Index

V_R = Road Density Suitability Index

The model shows a compensatory relationship, where the relationship is controlled by a geometric mean. A compensatory relationship is when variables with high suitability index values are offset by variables that have low suitability index values. The geometric mean takes into account the lowest suitability index value among the habitat variables. If one of the variables has a suitability index value of 0, then the model output is 0. Even though the model is quite general and approximate, it should reflect most environments; it can become more precise as more research on wood frog habitat is conducted in the sample area (Division of Ecological Services, 1981: 3-1 – 3-54). The general amount of available habitat for the wood frog is the total sample area; however, to be more specific, the specific amount of available habitat can be determined by calculating the areas of the cover types only used by the wood frog (Division of

Ecological Services, 1980b: 4-1). The areas of the cover types only used by the wood frog were not determined in this study.

3:5 Boreal Chorus Frog Habitat Suitability Index Model

The objective for the boreal chorus frog HSI model was to determine key habitat variables that can be integrated into an equation where the output represents the baseline or future conditions of boreal chorus frog habitat during its breeding season. Like the wood frog, the model represents the entire range of the boreal chorus frog and not the sample area of this study. The ideal output for this model is 1 and the acceptable output could not be determined, since the carrying capacity of the boreal chorus frog within the sample area was not measured. The carrying capacity of the boreal chorus frog in the geographic area will need to be measured in the future.

Based on available literature that investigated habitat characteristics of the boreal chorus frog, four key habitat variables and their suitability indexes were determined for the boreal chorus frog during its breeding season. Habitat variables were selected only if the sources agreed upon the variables' relationship between the population dynamics of the boreal chorus frog. If a variable's relationship with the population dynamics of the boreal chorus frog populations was controversial among the sources consulted, the variable was not selected for the model (Division of Ecological Services, 1981: 3-27).

The first variable considered was fish presence. There is very little research available relating boreal chorus frog populations and fish presence. Since fish presence has been found to have a negative impact on other amphibian populations (Marsh and Trenham, 2001), it is assumed that fish presence will also have a negative impact on boreal chorus frog populations. Like the wood frog, only two suitability index values can

be selected. If there are no fish present at a selected site, then the suitability index is 1; if there are fish present at the selected site, the condition for boreal chorus frog habitat is very poor and the suitability index value is 0.

The second variable is water movement. Stevens et al. (2007) found no calling boreal chorus frog males on their sites that were unobstructed streams. Also in their study, boreal chorus frogs were also found to have a positive association with beaver presence; the positive association is believed to occur due to the creation of standing water and wood debris for egg deposits, although there is the possibility that beaver dams can also create habitat for predatory fish. Like the fish presence variable, only two suitability index values can be selected. If a selected site is composed of standing water, the suitability for boreal chorus frog habitat is ideal and the suitability index value is 1. If the selected site consists of a constant flow of water, the suitability for boreal chorus frog habitat is very poor and the suitability index value is 0.

The third variable for the HSI model of the boreal chorus frog is dominant vegetation. Its suitability index is derived from Burton's (2001) study on breeding occurrence of amphibians found in the Western Ranger District of the Caribou National Forest in southeast Idaho (United States). Burton (2001) compared amphibian breeding occurrence with the dominant type of vegetation found at the sample sites. Four main vegetation types were found at his sites: none (unconsolidated material bed), emergent (sedges and rushes), aquatic (submerged or floating vegetation), and shrub (willows). Burton (2001) found that boreal chorus frogs prefer environments dominated by emergent vegetation, and smaller populations of boreal chorus frog were also found in environments dominated by aquatic, shrub, or no vegetation. It is surprising that Burton

(2001) found boreal chorus frogs on sites that were dominated by no vegetation because other researchers have found that sites with no vegetation do not provide a suitable medium for boreal chorus frogs to deposit their eggs on or provide shelter from predation (Stevens et al. 2007; Stevens et al. 2006). Only four suitability index values can be selected for this variable; emergent vegetation is ideal for boreal chorus frog habitat during the breeding season (Figure 5). The suitability index values for the aquatic, shrub, and no vegetation independent variables were derived by dividing their corresponding boreal chorus frog population values by the population value for emergent vegetation found in Burton's (2001) study. The values were then rounded, since Burton's values were specific to his sample area.

Figure 5. Suitability index of dominant vegetation for the boreal chorus frog.

The last variable for the boreal chorus frog HSI model is pond isolation. Only three suitability index values can be selected for the pond isolation variable (Figure 6). The three suitability index values are derived from Burton's (2001) study. Burton (2001) looked at the impact of pond isolation on the boreal chorus frog and found that sites with the highest populations were an average of 663.80 m (SE = 112.20) from the nearest ten

ponds. This average value was rounded to 650 m and was selected as the ideal condition for boreal chorus frog habitat and has a suitability index value of 1. Burton had twenty-five boreal chorus frog breeding sites within his sample area. Standard error (SE) is an estimate of variance around the population mean. 1 SE gives us a region where 68.26% of the sample means will be found, and 2 SE will give us a region where approximately 95% of the sample means will be found (Gould and Gould, 2002: 126-129). Using ± 2 SE of Burton's standard error for the average distance to the closest ten ponds ($+SD = 663.80m + 112.20$, $-SD = 663.80m - 112.20m$), two other suitability index values were determined; the two other conditions and their suitability index values were rounded. If a selected site has an average distance to the closest ten ponds around 400 m or 900 m, then the suitability index value is 0.7.

Figure 6. Suitability index of pond isolation for the boreal chorus frog.

A HSI model has been developed taking into consideration the four habitat variables:

$$HSI_{\text{Boreal Chorus Frog}} = (V_F * V_V * V_S * V_P)^{1/4} \quad [3]$$

V_F = Fish Presence

V_V = Vegetation

V_S = Standing Water

V_P = Pond Isolation

Like the wood frog HSI model, the model for the boreal chorus frog shows a compensatory relationship where the relationship is controlled by a geometric mean. The geometric mean takes into account the lowest suitability index value between the habitat variables. If one of the suitability index values is 0, then the model output is 0. The amount of available habitat for the boreal chorus frog is the total sample area; however, to be more specific, the amount of available habitat can be subdivided by calculating the areas of the cover types used only by the boreal chorus frog (Division of Ecological Services, 1980b: 4-1). The areas of the cover types used only by the boreal chorus frog within the selected geographic area were not determined in this study. The model may be modified as more research on boreal chorus frog habitat is conducted (Division of Ecological Services, 1981: 3-1 – 3-54). Since there is very little research on boreal chorus frog habitat, the model may most likely yield a very approximate output (Nussbaum et al. 1983: 143). More research is needed to make the model more precise.

Developing HSI models based on the literature is a preliminary step. After a model is developed, it needs to be verified by conducting field tests on the selected species. Fieldwork verification will provide a measure of accuracy and better reflection of the geographic area of interest. Fieldwork can be conducted to help determine if

certain habitat variables have the same significant relationship as the relationships found in the literature. The incorporation of modification into the models can continue to occur as more habitat studies on the wood frog and boreal chorus frog are conducted (Division of Ecological Services, 1981: 3-1 – 3-54).

Chapter 4: Fieldwork Methodology

4:1 Introduction

This chapter and the following two chapters represent the remaining three phases of developing a habitat suitability index (HSI) model: model construction, model documentation, and model verification. Model documentation involves recording the steps taken to develop the model, how each habitat variable is justified, and how each variable is measured in the field. Model verification involves validating the model by using sample data to generate acceptable outputs, having a species authority review the model, and testing the model with field data (Division of Ecological Services, 1981: 3-52).

4:2 Study Area

Sampling was conducted north of Cochrane, Alberta. The sample area is part of the Foothills Parkland Natural Sub-region, one the three sub-regions that make up the Parkland Natural Region. The sample area was selected because it is near the expanding city of Calgary, Alberta that could have a negative environmental impact on the sample area in the future (Government of Alberta, 2007: 25). The sub-region has a total area of 3921 km². The geographic area is dominated by rolling to hilly grasslands. Dominant vegetation includes trembling aspen (*Populus tremuloides*) and willow shrublands, where the dominant willow is beaked willow (*Salix bebbiana*). Dominant soils are Black Chernozems and Gray Chernozems. There is a very limited amount of open water (approximately 1%); however, there are many small saturated drainage areas. Native fish found in the Parkland Natural Region include northern pike (*Esox lucius*), yellow perch

(*Perca flavescens*), brook stickleback (*Culaea inconstans*), and fathead minnow (*Pimephales promelas*) (Natural Regions Committee, 2006: 106, 109-110).

The sub-region has a short growing season and cool summer, so intensive agriculture does not take place, and there is a high amount of native vegetation. Dominant crops are hay and feed grains. The most popular use of the land is ranching; over sixty percent of the land is used for ranching. Oil and gas exploration, and hunting and camping occur in the area. Overall, it is a rural area with a low population density (Natural Regions Committee, 2006: 110-111).

In order to reflect more specific habitat characteristics for the species of interest, the sample area was made smaller by looking at sample sites that are part of the Foothills Parkland Natural Sub-region but also the third reach of the Bow River Sub-basin (Figure 7). Reach 3 is between the eastern boundary of Banff National Park and Bears paw Dam. Bears paw Dam is outside the western boundary of Calgary, Alberta. The sample area is within a greater area of 735 km² that makes up the Foothills Parkland Natural Sub-region and Bow River Sub-basin (Bow River Basin Council, 2005: 77).

Figure 7. Foothills Natural Sub-region and Bow River Sub-basin. Sample area is within the geographic area (Bow River Basin Council, 2005).

Eight properties in the area north of Cochrane were sampled. Each property had a wetland complex, and up to six wetland sites were sampled on a property. The lowest amount of sites sampled on a property was two. Six properties belonged to landowners: Erik Butters, Andrea Deeves, Monterra Estates, Richard Harding, Garnet and Cheryl Ovans, and Clio Smeeton. The other two properties were Alberta Crown land: Big Hill Springs Provincial Park, and Winchell Coule. In total, twenty-eight sites were sampled during the sampling period. The exact locations of each sample site and their general location are shown in Table 2. Sample sites were determined from topographic maps and the most recent aerial photographs of the area. Aerial photographs were collected from the Alberta Air Photograph Interpretation Library. Marshes, swamps, dug-outs, ponds, lakes, and streams were identified in the maps and photographs and visited before the sampling period. Sample sites were selected if the landowner(s) granted permission to conduct sampling and if they were not too far from a road (Heyer et al. 1994: 42). Sites that were too far from a road were not selected for safety purposes. It would have been better to have more sample sites, but it was difficult to obtain permission from other landowners. Sampling was conducted between April 21, 2007 and May 9, 2007.

4:3 Frog Population Sampling

Male frogs are capable of producing mating calls that are unique to each species. During the breeding season, acoustic signals from calling males can be heard in the frog's territory. Male frogs use these calls to attract females and to compete with other males for a mate (Kelley, 2004). Because each call is unique to the species, calling surveys can be conducted to determine the general population of the species of interest at a particular site by measuring the calling intensity of the males (Takats and Priestley, 2002: 1). This

monitoring technique is not as accurate as other monitoring techniques, such as the mark-recapture technique, because the exact population can not be determined, especially if calls are overlapping or if there is a full chorus of calling males at the site; however, it is a reasonably easy technique and requires few resources (Pellet and Schmidt, 2005). Nevertheless, calling surveys are a very common monitoring technique for many frog species, especially when it comes to relying on volunteers to complete a comprehensive survey of an ecosystem (Davis and Verrell, 2005; Ford and Hampton, 2005; Schmidt and Pellet 2005; Pierce and Gutzwiller, 2004).

The calling surveys followed the protocol for the northern leopard frog developed by the Ministry of Sustainable Resource Development of the Alberta Government. Calling surveys were conducted during the optimum monitoring time between late April and early May, from April 21, 2007 to May 9, 2007, which is during the breeding season of each species (Alberta Conservation Association and Alberta Sustainable Resource Development, 2001: 28-29, 35-36). Calling surveys were started after dark at each site. Each calling survey lasted ten minutes: five minutes to allow disturbance from arrival to subside and five minutes for the actual calling survey. Wind speed and air temperature were taken at each site using a Kestrel 3000 weather meter, since a fast wind speed can dampen the calling sound and the optimum air temperature for male calling is equal to or above 10°C (Kendell, 2002b: 16). Each site was monitored using calling surveys three times during the sampling period to take into account measurement error and outliers (Zolman, 1993: 98-99, 138).

Calling intensity is based on a categorical ranking system: rank 1 = none heard, rank 2 = one frog heard, rank 3 = individuals counted, rank 4 = several individuals heard

with some overlap, and rank 5 = full continuous chorus (Kendell, 2002b: 16). A more accurate population can be determined from the first three ranks by taking into consideration the sex ratio of the species. The sex ratio for wood frogs is 1:1. A less accurate population can be determined from the last two ranks (Stevens et al. 2007). There is no literature that reveals the sex ratio for the boreal chorus frog, so a conservative sex ratio of 1:1 was used.

4:4 Habitat Characteristics

Water chemistry was measured at each site using a multi-parameter field probe. Water chemistry was measured to get a better ecological perspective of each site (Brower et al. 1998: 73-74), and the water parameters were correlated with amphibian populations. The probe model was a Hanmet HI9828 multi-parameter water quality probe. Parameters for water chemistry that were measured using the field probe were pH, dissolved oxygen, temperature, and conductivity. Water chemistry measurements were taken from at least three points at each site to get a mean value for each water chemistry parameter.

Dominant vegetation was estimated at each site using visual surveys. Dominant vegetation types were emergent and shrub. Sites that had primarily bare ground were classified as having no vegetation. The presence of fish and whether the site was obstructed to prevent the continuous flow of water were determined using visual surveys and through consultation with landowners.

Road density was measured using the most recent aerial photographs that were available from the Alberta Air Photograph Interpretation Library and topographic maps. Using aerial photographs and topographic maps, unpaved, paved, and total road density were measured within a 1.2-km radius for each site, since wood frogs have been known

to migrate up to 1.2 km (Porej et al. 2004). There is no information on migrating distances for the boreal chorus frog, so a 1.2-km radius was assumed. A transparency circle with a radius of 1.2 km was placed over each site on an aerial photograph or topographic map. The radius of the circle matched the scale of each photograph or map. Placing the center of the circle over the water body, the total lengths of unpaved and paved roads were measured that were within the circle. If the water body was quite large, such as a lake, the center of the circle was placed on the bordering wetland where amphibians were found calling. Also, using a transparency with a 1.2-km radius, the number of wetlands was measured (Robinson, 2001). The area of each site and average distance to the closest ten ponds were also measured using aerial photographs (Burton, 2001).

4.5 Statistical Analysis of Habitat Variables

Correlation analysis was used to investigate relationships and how strong the relationships were between the maximum rank of each species found at each site and the number of wetlands, area, unpaved road density, paved road density, total road density, the average distance to the ten closest ponds, pH, dissolved oxygen, conductivity, water temperature, and air temperature. The ranking system for the calling surveys categorical; the data are ordinal and non-parametric; therefore, the Spearman rank correlation coefficient was used (Gould and Gould, 2002: 16; Zolman, 1993: 156-157). Correlation analysis was performed using the computer program SPSS 16.0 for Windows (SPSS Inc. 2007).

Chi-square analysis was used to determine relationships between frog populations of each species and dominant vegetation, fish presence, and water movement. These

habitat variables were in the form of categorical data that do not have divisible numbers, so correlation analysis could not be performed (Gould and Gould, 2002: 16, 190). In order to complete the analysis, the population of each species was estimated. For sites that had a maximum rank of 1 and 2, the number of calling males for each species was simply added. For sites that had a maximum rank of 3, the maximum number of calling males between the sites was averaged, and then the average number of calling males was multiplied by the number of sites that had a maximum rank of 3. If there were 8 sites that had an average number of 6 calling male wood frogs, then the total would be 48 calling male wood frogs. The same process was done for sites that had a maximum rank of 4. Unfortunately, the exact number of calling males found at sites that had an amphibian call survey rank of 5 could not be determined, so the number of calling males for rank 5 had to be estimated following Pellet and Schmidt (2005). The number of calling males for rank 5 was double the maximum number of calling males for rank 4. The maximum number of calling male wood frogs for sites that had a rank of 4 was 8, so the estimated number of calling males for sites that had a rank of 5 was 16. For the boreal chorus frog, the maximum number of calling males at sites with a rank of 4 was also 8, so the estimated number of calling males at sites with a rank of 5 was 16. This estimation was made in order to keep statistical analysis less complicated because there were only two to three sites that had a rank of 5 for each frog. For each species, the number of sites that had achieved a maximum rank of 5 was multiplied by 16; e.g. 3 sites with maximum rank $5 \times 16 = 48$ calling males). Adding the totals from ranks 1, 2, 3, 4, and 5 together gave the total number of calling males for each frog within the sample area.

There is uncertainty in estimated populations, since there are few sites and calling surveys do not result in an exact population count (Heyer et al. 1994: 92, 96); however, it was not expected to have a large number of sites that had a rank of 5 for either species, so the method is adequate for this study. A more accurate number for rank 5 can be determined as more research is conducted on this particular population measurement problem. It is possible to have a better estimation of calling males for ranks 3 and 4 by combining results from egg-mass surveys and mark-recapture surveys. The results from this combination technique can give a more accurate number of calling males for ranks 3 and 4 that can be used for future calling surveys (Stevens, 2006). In this study, egg-mass surveys or mark-recapture surveys were not conducted.

Once the total number of males was determined for each species, the population was doubled to account for the number of females present. The conservative sex ratio was used because there was not enough research to suggest a different ratio (Stevens, 2006). Chi-square analysis was then performed on wood frog and boreal chorus frog populations in relation to dominant vegetation, fish presence, and water movement.

The first chi-square analyses investigated an equal ratio between the expected variables. There were three null hypotheses: dominant vegetation, water movement, and fish presence has no effect on the population of wood frogs or boreal chorus frogs during the breeding season within the sample area. If the null hypothesis for dominant vegetation was rejected, then a new hypothesis would be made: the population of wood frogs or boreal chorus frogs does not follow the dominant vegetation ratio of 1:0.1:0.2 (emergent, shrub, and no vegetation). The ratio was taken from Burton's (2001) results. If the null hypothesis for water movement was rejected, then a new hypothesis was made:

the population of wood frogs and boreal chorus frogs does not follow the ratio 100:1 (stream obstructed: stream not obstructed). The ratio is based on the suitability indexes for water movement in the preliminary models. If the null hypothesis for fish presence was rejected, then a new hypothesis was made: the population of wood frogs or boreal chorus frogs does not follow the ratio of 100:1 (no fish present: fish present). The ratio is based on the suitability indexes for fish presence in the preliminary models. For the first null hypothesis of each variable, it is expected that they will be rejected for each amphibian species. For the second null hypothesis of each variable, it is expected the chi-square analysis for these comparisons will result in a failure to reject for each amphibian species, as the ratios reflect the expected ratios based on the literature review for each species.

Table 2. Locations of sample sites.

Landowner	Site	Meridian	Township	Range	Section	Latitude (N)	Longitude (W)
Andrea Deeves	1	W5	27	4	17	51° 18' 75"	114° 32' 42"
	2	W5	27	4	17	51° 18' 75"	114° 32' 12"
	3	W5	27	4	17	51° 18' 78"	114° 32' 42"
Big Hill Springs Provincial Park	1	W5	26	3	29	51° 15' 07"	114° 23' 10"
	2	W5	26	3	29	51° 15' 07"	114° 23' 10"
Cleo Smeeton	1	W5	27	5	35	51° 21' 25"	114° 35' 90"
	2	W5	27	5	35	51° 21' 23"	114° 35' 90"
	3	W5	27	5	35	51° 21' 12"	114° 37' 85"
	4	W5	27	5	35	51° 21' 25"	114° 35' 50"
	5	W5	27	5	35	51° 21' 50"	114° 35' 45"
	6	W5	27	5	35	51° 21' 50"	114° 35' 40"
Erik Butters	1	W5	27	6	8	51° 17' 70"	114° 49' 12"
	2	W5	27	6	18	51° 18' 08"	114° 49' 30"
	3	W5	26	6	18	51° 18' 09"	114° 49' 30"
Garnet and Cheryl Ovans	1	W5	27	5	29	51° 19' 76"	114° 32' 00"
	2	W5	27	5	29	51° 19' 77"	114° 32' 00"
	3	W5	27	5	20	51° 19' 68"	114° 32' 42"
	4	W5	27	5	20	51° 19' 73"	114° 32' 70"
	5	W5	27	5	30	51° 19' 80"	114° 33' 00"
	6	W5	27	5	30	51° 19' 81"	114° 32' 78"
Monterra Estates	1	W5	26	4	27	51° 14' 82"	114° 28' 25"
	2	W5	26	4	27	51° 14' 82"	114° 28' 70"
	3	W5	26	4	27	51° 14' 75"	114° 29' 24"
Richard Harding	1	W5	28	5	19	51° 22' 60"	114° 37' 78"
	2	W5	28	5	19	51° 22' 58"	114° 37' 80"
Winchell Couleé	1	W5	29	5	2	51° 27' 10"	114° 35' 88"
	2	W5	29	5	2	51° 27' 25"	114° 36' 48"
	3	W5	29	5	1	51° 26' 75"	114° 34' 77"

Chapter 5: Results

5:1 Calling Surveys

The maximum rank and maximum estimate of calling males of each species at each site are shown in Table 3. The maximum estimate of calling males could not be determined for sites that had a rank of 5. Out the twenty-eight sites, wood frogs were found at fifteen sites and boreal chorus frogs were found at nineteen sites. As Table 3 shows, wood frogs and boreal chorus frogs were both present at twelve sites. Obviously, this reveals that the wood frog and the boreal chorus frog have overlapping cover types within the sample area. The northern leopard frog was not found at any of the sample sites, even though, based on literature, its range overlaps with the wood frog and the boreal chorus frog.

5:2 Habitat Variables

The area varied greatly among the sample sites. The smallest area was 18 m² and the largest area was 3360 m². Road density, the number of wetlands, and average distance to the closest 10 ponds also varied. All of the sites had unpaved roads, but some sites did not have paved roads within a 1.2-km radius. The most isolated site was the third site of Monterra Estates; where there were only three wetland sites within 1.2 km, and the average distance to the closest ten ponds was 1220 m. These data can be found in Tables 4a and 4b. The most dominant vegetation was emergent vegetation (Table 5). The emergent vegetation was composed mostly of herbaceous grasses and cattails. Some sites had no vegetation or not enough to be dominant. The majority of the vegetation found at the sites was dead because at the beginning of the sample period, some sites still had frozen water or there was snow still on the riparian area. This supports the short

growing season of the Foothills Parkland Natural Sub-region (Natural Regions Committee, 2006: 109-110). Since the majority of the vegetation was dead, a vegetation species inventory was not conducted because it would be difficult to identify the vegetation. Fish were found at only one site. There were only four sites that were streams and only two of them were unobstructed. The two sites that were obstructed were obstructed by beaver ponds. The rest of the sites were ponds, marsh, dug-outs, and drainage areas.

The mean pH of the water at the sites ranged between slightly acidic and slightly alkaline. The lowest mean pH was 6.757 (SE = 0.084) and the highest mean pH was 8.718 (SE = 0.025). The mean pH of all the sites was 7.92 (SE = 0.05). When comparing the mean pH and maximum ranks of the wood frog, the pH drops as the number of wood frogs increases (Figure 8). The dissolved oxygen of the water at the sites ranged greatly as did the conductivity, but both decreased as number of wood frogs increased (Figures 9 and 10), and the dissolved oxygen dropped as the number of boreal chorus frogs increased (Figure 11). The lowest mean dissolved oxygen measurement was 0.990 ppm (SE = 0.387) at site 5 of Clio Smeeton's property and the highest was 11.540 (SE = 1.470) at site 1 at Big Hill Springs Provincial Park. The lowest mean conductivity measurement was 64 $\mu\text{S}/\text{cm}$ (SE = 5.9) at site 5 on Clio Smeeton's property, and the highest was 2681 $\mu\text{S}/\text{cm}$ (SE = 416.3) at site 3 of Monterra Estates. These data can be found on Table 6.

The air temperature range was between -0.3°C and 15.8°C . The mean water temperature range was 7.2°C (SE = 0.3) and the air temperature range was 18.3°C (SE = 0.4). Mean air and water temperature measurements can be found on Table 7.

Table 3. Maximum rank and maximum estimate of calling males of each frog at each site.

Landowner	Site	Maximum Ranks of Wood Frog	Maximum Calling Males Of Wood Frog	Maximum Ranks of Boreal Chorus Frog	Maximum Calling Males of Boreal Chorus Frog
Andrea Deeves	1	1	0	4	5
	2	1	0	1	0
	3	2	1	3	5
Big Hill Springs Provincial Park	1	1	0	3	2
	2	1	0	3	5
Clio Smeeton	1	3	4	4	6
	2	1	0	3	2
	3	5	-	3	3
	4	1	0	3	2
	5	4	8	4	-
	6	3	3	1	0
Erik Butters	1	4	-	4	-
	2	1	0	1	0
	3	3	4	1	0
Garnet and Cheryl Ovans	1	4	8	4	6
	2	1	0	5	-
	3	1	0	1	0
	4	1	0	1	0
	5	1	0	4	8
	6	3	2	3	4
Monterra Estates	1	3	4	4	-
	2	1	0	1	0
	3	3	2	5	-
Richard Harding	1	1	0	3	3
	2	3	3	2	1
Winchell Coulé	1	5	-	5	-
	2	3	2	1	0
	3	3	3	3	2

- Maximum estimate of calling males could not be determined for sites classified with a maximum rank of 5.

Table 4a. Area of wetland, unpaved road density, paved road density, total road density, number of wetlands, and average distance to the closest ten ponds at each sample site.

Landowner	Site	Area of Wetland (m ²)	Unpaved Road Density (m of road within 1200 m of the sample wetland)	Paved Road Density (m of road within 1200 m of the sample wetland)	Total Road Density (m of road within 1200 m of the sample wetland)	Number of Wetlands within 1200 m of the sample wetland	Average Distance to Closest 10 Ponds (m)
Andrea Deeves	1	150	1800	0	1800	14	543
	2	558	1900	0	1900	13	489
	3	72	1800	0	1800	16	501
Big Hill Springs Provincial Park	1	18	250	1300	1550	5	1015
	2	180	250	1300	1550	5	1015
Clio Smeeton	1	63	1600	2240	3840	14	453
	2	30	1600	2240	3840	21	453
	3	1407	1400	2200	3600	15	485
	4	28	1480	1780	3260	16	453
	5	240	1880	1580	3460	15	537
	6	78	2040	1580	3620	21	552
Erik Butters	1	240	6480	1800	8280	9	565
	2	388	6020	940	6960	11	472
	3	42	6020	940	6960	11	472

Table 4b. Area of wetland, unpaved road density, paved road density, total road density, number of wetlands, and average distance to the closest ten ponds at each sample site.

Landowner	Site	Area of Wetland (m ²)	Unpaved Road Density (m of road within 1200 m of the sample wetland)	Paved Road Density (m of road within 1200 m of the sample wetland)	Total Road Density (m of road within 1200 m of the sample wetland)	Number of Wetlands within 1200 m of the sample wetland	Average Distance to Closest 10 Ponds (m)
Garnet and Cheryl Ovans	1	39	2680	0	2680	15	657
	2	24	2580	0	2580	15	639
	3	2520	2760	0	2760	11	525
	4	3360	2880	0	2880	12	396
	5	120	2720	600	3320	15	519
	6	900	2740	0	2740	16	465
Monterra Estates	1	8760	2000	3980	5980	9	520
	2	2880	2460	4860	7320	7	925
	3	720	2760	4580	7340	3	1220
Richard Harding	1	1440	1600	1860	3460	9	705
	2	40	1600	1860	3460	9	705
Winchell Coulée	1	1800	4020	0	4020	12	789
	2	720	4500	0	4500	6	1105
	3	60	6060	0	6060	6	1530

Table 5. Dominant vegetation, fish presence, and water movement observations at each sample site.

Landowner	Site	Dominant Vegetation	Fish Presence	Water Movement
Andrea Deeves	1	Shrub	Not Present	Unobstructed Stream
	2	None	Present	Not a stream
	3	None	Not Present	Not a stream
Big Hill Springs Provincial Park	1	Emergent	Not Present	Not a stream
	2	Emergent	Not Present	Not a stream
Clio Smeeton	1	Emergent	Not Present	Not a stream
	2	Emergent	Not Present	Not a stream
	3	Emergent	Not Present	Not a stream
	4	Emergent	Not Present	Not a stream
	5	Emergent	Not Present	Not a stream
	6	Shrub	Not Present	Not a stream
Erik Butters	1	Emergent	Not Present	Not a stream
	2	None	Not Present	Unobstructed Stream
	3	Emergent	Not Present	Obstructed Stream
Garnet and Cheryl Ovans	1	Emergent	Not Present	Not a stream
	2	Emergent	Not Present	Not a stream
	3	Emergent	Not Present	Not a stream
	4	Emergent	Not Present	Not a stream
	5	Emergent	Not Present	Not a stream
	6	Emergent	Not Present	Not a stream
Monterra Estates	1	Emergent	Not Present	Not a stream
	2	None	Not Present	Not a stream
	3	Emergent	Not Present	Not a stream
Richard Harding	1	Emergent	Not Present	Not a stream
	2	Emergent	Not Present	Not a stream
Winchell Couleé	1	Emergent	Not Present	Not a stream
	2	Emergent	Not Present	Not a stream
	3	Emergent	Not Present	Obstructed Stream

Figure 8: pH and rank for the wood frog.

Figure 9: Dissolved oxygen and rank for the wood frog

Figure 10: Conductivity and rank for the wood frog.

Figure 11. Dissolved oxygen and rank for the boreal chorus frog.

Table 6. Mean pH, mean dissolved oxygen, and mean conductivity measurements at each sample site and their standard error.

Landowner	Site	Mean pH and Standard Error	Mean Dissolved Oxygen (ppm) and Standard Error	Conductivity (μ S/cm) and Standard Error
Andrea Deeves	1	8.400 (0.031)	7.963 (0.175)	479 (1.2)
	2	8.340 (0.012)	9.510 (0.225)	473 (1.5)
	3	8.157 (0.103)	6.247 (0.663)	734 (26.7)
Big Hill Springs Provincial Park	1	8.613 (0.078)	11.540 (1.470)	870 (29.5)
	2	7.738 (0.143)	7.763 (3.351)	1102 (40.1)
Clio Smeeton	1	7.258 (0.102)	5.780 (0.699)	133 (1.7)
	2	6.950 (0.056)	8.587 (3.058)	170 (22.8)
	3	7.423 (0.190)	8.015 (1.121)	94 (6.9)
	4	7.803 (0.213)	8.490 (1.650)	212 (14.3)
	5	6.757 (0.084)	0.990 (0.387)	64 (5.9)
	6	7.567 (0.041)	1.770 (0.980)	187 (0.7)
Erik Butters	1	7.583 (0.201)	6.068 (1.233)	455 (13.9)
	2	8.315 (0.013)	8.695 (0.187)	457 (0.9)
	3	8.030 (0.132)	9.207 (0.817)	542 (85.2)
Garnet and Cheryl Ovans	1	7.867 (0.098)	5.197 (0.773)	375 (44.2)
	2	7.480 (0.119)	3.273 (0.485)	894 (225.3)
	3	8.287 (0.009)	6.937 (0.621)	377 (0.9)
	4	7.645 (0.119)	4.613 (1.115)	1100 (291.9)
	5	8.197 (0.119)	7.447 (0.845)	258 (20.2)
	6	8.263 (0.103)	7.495 (0.733)	303 (5.6)
Monterra Estates	1	8.718 (0.025)	7.463 (1.129)	1122 (66.3)
	2	8.630 (0.006)	9.550 (0.934)	474 (0.3)
	3	8.645 (0.178)	6.543 (1.051)	2681 (416.3)
Richard Harding	1	7.513 (0.037)	6.263 (0.102)	118 (9.2)
	2	7.560 (0.302)	6.650 (0.425)	132 (3.6)
Winchell Coule��	1	8.025 (0.168)	8.100 (0.664)	282 (33.5)
	2	7.825 (0.070)	4.853 (0.584)	234 (24.5)
	3	8.053 (0.152)	7.540 (0.811)	322 (55.3)

Table 7. Mean air temperature and mean water temperature and their standard error at each sample site.

Landowner	Site	Mean Air Temperature (°C) and Standard Error	Mean Water Temperature (°C) and Standard Error
Andrea Deeves	1	7.33 (1.25)	7.19 (0.17)
	2	7.73 (1.39)	9.40 (0.45)
	3	11.9 (0.00)	17.06 (0.45)
Big Hill Springs Provincial Park	1	8.67 (2.29)	13.07 (0.79)
	2	7.76 (1.39)	9.46 (0.33)
Clio Smeeton	1	6.09 (1.27)	15.03 (0.69)
	2	7.66 (1.28)	15.45 (0.97)
	3	6.33 (2.12)	18.29 (0.37)
	4	6.82 (1.91)	17.13 (0.93)
	5	7.76 (1.49)	15.55 (0.60)
	6	6.84 (1.91)	13.50 (0.45)
Erik Butters	1	8.33 (0.57)	13.10 (0.95)
	2	8.66 (0.57)	7.15 (0.31)
	3	8.33 (0.90)	11.01 (0.23)
Garnet and Cheryl Ovans	1	9.13 (2.08)	7.87 (0.10)
	2	9.45 (3.25)	7.48 (0.12)
	3	8.54 (1.71)	8.29 (0.01)
	4	8.54 (1.71)	7.65 (0.12)
	5	7.93 (2.41)	8.20 (0.19)
	6	8.54 (1.71)	8.26 (0.10)
Monterra Estates	1	8.1 (1.50)	14.20 (0.52)
	2	8.1 (1.50)	9.94 (0.09)
	3	9.2 (2.00)	13.17 (0.96)
Richard Harding	1	8.3 (0.94)	10.84 (0.84)
	2	8.3 (0.94)	14.58 (0.59)
Winchell Coulecé	1	8.17 (2.46)	8.82 (1.02)
	2	10.10 (3.35)	7.66 (0.79)
	3	10.10 (3.35)	7.92 (0.77)

5:3 Statistical Analysis

Spearman rank correlation analysis was used to compare relations between the maximum ranks of each amphibian and the habitat variables from Table 4a, Table 4b, Table 6, and Table 7 (Tables 8a and 8b). Habitat variable correlations were classified as significant if their probability value (p) was below a significance level (α) of 0.05. For the wood frog, total road density surprisingly had a strong positive relationship ($r_s = 0.412$, $p = 0.029$). Other significant habitat variables were pH ($r_s = -0.231$, $p = 0.023$),

dissolved oxygen ($r_s = -0.252$, $p = 0.0013$), and conductivity ($r_s = -0.352$, $p = 0.000$) for the wood frog and dissolved oxygen for the boreal chorus frog. The number of wetlands for the wood frog was one habitat variable that was not classified as significant but had a probability value below 0.10 ($r_s = 0.346$, $p = 0.072$); this habitat variable should still be looked at in future studies. Another habitat variable that did not have a significant relationship but could be significant in future studies was unpaved road density.

Two habitat variables had significant correlations with boreal chorus frog populations: dissolved oxygen ($r_s = -0.325$, $p = 0.001$) and water temperature ($r_s = 0.253$, $p = 0.013$). No other habitat variable had a significant correlation with a probability below 0.10. The average distance to the closest ten ponds could have a significant relationship with boreal chorus frog populations in the future.

Table 8a. Spearman rank correlation coefficients comparing maximum ranks of the wood frog and certain habitat variables at each site. Significant correlations are circled.

Habitat Variable	r_s	p (2-tailed)
Area	0.096	0.625
Unpaved Road Density	0.256	0.188
Paved Road Density	0.091	0.644
Total Road Density	0.412	0.029
Number of Wetlands	0.346	0.072
Average Distance to Closest 10 Ponds	0.100	0.614
pH*	-0.231	0.023
Dissolved Oxygen*	-0.252	0.013
Conductivity*	-0.352	<0.001
Water Temperature*	0.161	0.116
Air Temperature**	0.070	0.558

n = 28

* n = 96

** n = 73

Table 8b. Spearman rank correlation coefficients comparing maximum ranks of the boreal chorus frog and certain habitat variables at each site. Significant correlations are circled.

Habitat Variable	r_s	p (2-tailed)
Area	-0.163	0.406
Unpaved Road Density	-0.082	0.679
Paved Road Density	0.103	0.602
Total Road Density	-0.026	0.896
Number of Wetlands	0.114	0.563
Average Distance to Closest 10 Ponds	0.190	0.333
pH*	-0.084	0.415
Dissolved Oxygen*	-0.325	<0.001
Conductivity*	0.047	0.650
Water Temperature*	0.253	0.013
Air Temperature**	0.179	0.135

n = 28

* n = 96

** n = 71

Chi-square analyses were performed on estimated total populations of each amphibian with dominant vegetation, fish presence, and water movement. In all of the chi-square analysis tables, the values for each part of the chi-square process are shown. If the total $D^2/\text{Expected}$ is larger than the critical value, then the null hypothesis is rejected. For both amphibians, the chi-square analyses supported that wood frogs and boreal chorus frogs do not randomly go to sites dominated by emergent vegetation, shrub vegetation, or no vegetation during the breeding season; the null hypotheses were rejected (Tables 9a and 10a). Having different results than Burton (2001), the wood frogs and boreal chorus frogs were not distributed over the same ratio for dominant vegetation; the new hypotheses were rejected (Tables 9b and 10b). A third chi-square analysis was done and used another new hypothesis of 1:0.084:0 (emergent:shrub:none). The chi-square analysis results suggest that the wood frog and the boreal chorus frog follow this pattern; the analysis failed to reject the second new hypotheses (Tables 9c and 10c).

The chi-square analyses supported the same patterns for fish presence and water movement that are shown in the preliminary models; the null hypotheses were rejected. Both frogs breed at sites regardless of whether the site has fish or does not have fish, and they breed at sites regardless if the sites have streams that are obstructed or not obstructed. The analyses also supported the new hypothesis that both frogs follow the expected pattern of 100:1 for fish presence (fish are not present:fish are present) and 100:1 for water movement (stream is obstructed: stream is not obstructed), as there was a failure in the rejection of the new hypotheses. The results from the other chi-square analyses are shown in Tables 11a to 14b.

Table 9a. Chi-square analysis comparing population of wood frog and category of dominant vegetation (null distribution = 1:1:1, equal distribution between each dominant vegetation type).

Dominant Vegetation	Observed	Expected	Observed – Expected	D ²	D ² /Expected
Emergent	160	56.0	104.0	10816.0	193.1
Shrub	6	56.0	-50.0	2500.0	44.6
None	2	56.0	-54.0	2916.0	52.1
Total	168	168.0			289.8

DF = 2

$\alpha = 0.01$

Critical Value = 13.8

Table 9b. Chi-square analysis comparing population of wood frog and type of category vegetation (null distribution = 1:0.1:0.2, emergent:shrub:none).

Dominant Vegetation	Observed	Expected	Observed – Expected	D ²	D ² /Expected
Emergent	160	129.2	30.8	948.6	7.3
Shrub	6	12.9	-6.9	47.6	3.7
None	2	25.9	-23.3	571.2	22.0
Total	168	168.0			33.0

DF = 2

$\alpha = 0.01$

Critical Value = 13.8

Table 9c. Chi-square analysis comparing population of wood frog and category of dominant vegetation (null distribution = 1:0.1:0, emergent:shrub:none).

Dominant Vegetation	Observed	Expected	Observed – Expected	D ²	D ² /Expected
Emergent	160	152.0	8.0	64.0	0.4
Shrub	6	15.0	-9.0	81.0	5.4
None	2	1.0	1.0	1.0	1.0
Total	168				6.8

DF = 2

$\alpha = 0.01$

Critical Value = 13.8

Table 10a. Chi-square analysis comparing population of boreal chorus frog and category of dominant vegetation (null distribution = 1:1:1, emergent:shrub:none).

Dominant Vegetation	Observed	Expected	Observed – Expected	D ²	D ² /Expected
Emergent	220	80.0	140.0	19600.0	245.0
Shrub	20	80.0	-60.0	3600.0	45.0
None	0	80.0	-80.0	6400.0	80.0
Total	240	240.0			370.0

DF = 2

$\alpha = 0.01$

Critical Value = 13.8

Table 10b. Chi-square analysis comparing population of boreal chorus frog and category of dominant vegetation (null distribution = 1:0.1:0.2, emergent:shrub:none).

Dominant Vegetation	Observed	Expected	Observed – Expected	D ²	D ² /Expected
Emergent	220	184.5	35.5	1260.3	6.8
Shrub	20	18.5	1.5	2.3	0.1
None	0	37.0	-37.0	1369.0	37.0
Total	240	240.0			44.0

DF = 2

$\alpha = 0.01$

Critical Value = 13.8

Table 10c. Chi-square analysis comparing population of boreal chorus frog and category of dominant vegetation (null distribution = 1:0.1:0, emergent:shrub:none).

Dominant Vegetation	Observed	Expected	Observed - Expected	D ²	D ² /Expected
Emergent	220	217.0	3.0	9.0	0
Shrub	20	22.0	-2.0	4.0	0.2
None	0	1.0	-1.0	1.0	1.0
Total	240	240.0			1.2

DF = 2

$\alpha = 0.01$

Critical Value = 13.8

Table 11a. Chi-square analysis comparing population of wood frog with fish presence (null distribution = 1:1).

Fish	Observed	Expected	Observed - Expected	D ²	D ² /Expected
Not Present	168	84.0	84.0	7056.0	84.0
Present	0	84.0	-84.0	7056.0	84.0
Total	168	168.0			168.0

DF = 1

$\alpha = 0.01$

Critical Value = 10.8

Table 11b. Chi-square analysis comparing population of wood frog with fish presence (null distribution = 1:0).

Fish	Observed	Expected	Observed - Expected	D ²	D ² /Expected
Not Present	168	167.0	1.0	1.0	0.0
Present	0	1.0	-1.0	1.0	1.0
Total	168	168.0			1.0

DF = 1

$\alpha = 0.01$

Critical Value = 10.8

Table 12a. Chi-square analysis comparing population of boreal chorus frog with fish presence (null distribution = 1:1).

Fish	Observed	Expected	Observed - Expected	D ²	D ² /Expected
Not Present	240	120.0	120.0	14400.0	120.0
Present	0	120.0	-120.0	14400.0	120.0
Total	240	240.0			240.0

DF = 1

$\alpha = 0.01$

Critical Value = 10.8

Table 12b. Chi-square analysis comparing population of boreal chorus frog with fish presence (null distribution = 1:0).

Fish	Observed	Expected	Observed - Expected	D ²	D ² /Expected
Not Present	240	239.0	1.0	1.0	0.0
Present	0	1.0	-1.0	1.0	1.0
Total	240	240.0			1.0

DF = 1

$\alpha = 0.01$

Critical Value = 10.8

Table 13a. Chi-square analysis comparing population of wood frog with stream obstruction (null distribution = 1:1).

Stream	Observed	Expected	Observed - Expected	D ²	D ² /Expected
Obstructed	168	84.0	84.0	7056.0	84.0
Unobstructed	0	84.0	-84.0	7056.0	84.0
Total	168	168.0			168.0

DF = 1

$\alpha = 0.01$

Critical Value = 10.8

Table 13b. Chi-square analysis comparing population of wood frog with stream obstruction (null distribution = 1:0).

Stream	Observed	Expected	Observed - Expected	D ²	D ² /Expected
Obstructed	168	167.0	1.0	1.0	0.0
Unobstructed	0	1.0	-1.0	1.0	1.0
Total	168	168.0			1.0

DF = 1

$\alpha = 0.01$

Critical Value = 10.8

Table 14a. Chi-square analysis comparing population of boreal chorus frog with stream obstruction (null distribution = 1:1).

Stream	Observed	Expected	Observed - Expected	D ²	D ² /Expected
Obstructed	240	120.0	120.0	14400.0	120.0
Unobstructed	0	120.0	-120.0	14400.0	120.0
Total	240	240.0			240.0

DF = 1

$\alpha = 0.01$

Critical Value = 10.8

Table 14b. Chi-square analysis comparing population of boreal chorus frog with stream obstruction (null distribution = 1:0).

Stream	Observed	Expected	Observed - Expected	D ²	D ² /Expected
Obstructed	240	239.0	1.0	1.0	0.0
Unobstructed	0	1.0	-1.0	1.0	1.0
Total	240	240.0			1.0

DF = 1

$\alpha = 0.01$

Critical Value = 10.8

Chapter 6: Discussion

6:1 Introduction

There were significant relationships between certain habitat variables and populations of the wood frog and the boreal chorus frog. Most relationships supported results found in other studies, and some relationships were not consistent with results found in other research. Also, there were no relationships between certain habitat variables, even though significant relationships were expected. These findings may support the development of HSI models that are different than the preliminary models that were based on results found only in literature.

6:2 Fish

As expected, all the sites that had amphibian species present did not contain fish. Only one site contained fish (site 2 on Andrea Deeves' property), and it did not have any amphibians present. It was difficult to find sites within the sample area that contained fish. In the Government of Alberta trout stocking database, there were no sites found within the sample area (Fisheries Management Information System, 2007). It may be necessary to find more sample sites that contain fish in order to have more sensitive statistical test (Zolman, 1993: 87-88). It is possible to determine if lakes, ponds, or wetlands contain fish using minnow traps (Stevens et al. 2006); however, some water bodies still had some parts frozen and there were not enough personnel and time to discover a sufficient number of sites that contain fish.

Many researchers have found that wood frog populations decrease when sites contain fish (Petranka et al. 2007; Stevens et al. 2006; Egan and Paton, 2004; Porej et al. 2004; Regosin et al. 2003; Thiemann and Wassersug, 2000). Petranka and Holbrook

(2006) tested recolonization success of wood frogs in restored wetland in Graham County, New York (United States). They found that recolonization rates of wood frogs were high until a fish invasion occurred. Egg masses were not found in more than half of the ponds that contained fish; out of those ponds, the egg mass decline was more than 98%. When the fish disappeared, wood frogs recolonized and egg masses were found. This behaviour can be seen in other amphibians as well. Knapp et al. (2007) found that the mountain yellow-legged frog (*Rana muscosa*) inhabited streams once the fish were removed from them.

It still has not been discovered if amphibians choose to breed at a site regardless of fish presence. Eaton (2004) looked at populations of wood frogs at sites before and after fish winterkills in northern Alberta. He found that wood frog populations were higher after a fish winterkill; however, he could not determine if more wood frogs chose to migrate to the site because there were less fish. Wood frogs are known to be philopatric, as adults return to the same water body to breed. If wood frogs return to the same site, they may breed at the site regardless of whether fish are present there or not; the wood frog population may be low at a site that contains fish simply because the fish prey upon wood frog adults and larvae (Eaton, 2004).

There are many conservation efforts that have realized the negative impact of fish and conservationists are trying to create and restore ephemeral wetland or take out the fish found in permanent wetland. Petranka et al. (2003a) and Petranka et al. (2003b) studied the success of amphibian recolonization in created wetland at the Tulula Wetlands Mitigation Bank in North Carolina (United States). The wetland was created because of the loss of natural habitat due to converted golf course ponds. Seven semi-

permanent wetlands and three permanent wetlands were created; all of them were intentionally made fish-free. There are some frogs that do survive in the presence of fish, but since wood frogs are historically known to live in wetlands that do not have fish, the introduction of fish by invasion or for recreational purposes should have a detrimental effect (Stevens et al. 2006; Hazell et al. 2001).

The results comparing boreal chorus frog populations with fish presence also support the negative impact of fish. The results of fieldwork conducted in this project support the general hypothesis that fish presence negatively impacts the presence of amphibians (Marsh and Trenham, 2001). More research is needed to continue to support the negative relationship between the boreal chorus frog and fish presence during the breeding season.

6:3 Standing Water

Both amphibian species seemed to favor habitats that had non-flowing water, since the majority of the sites in this study were non-flowing and only one site that was flowing had boreal chorus frogs present. Other studies have also found that wood frogs tend to avoid unobstructed bodies of water that have a continuous flow (Stevens et al. 2006; Stevens, 2005; Egan and Paton, 2004; Petranka et al. 2003). It is suggested that wood frogs avoid non-obstructed streams in order to avoid predators such as fish (Stevens et al. 2006). It is possible that fish presence interferes with the relationship between standing water and wood frog populations; however, flowing water bodies also negatively impact amphibians by washing away deposited eggs and larvae (Hossack and Corn, 2005). Mesocosms could be used to better determine how unobstructed streams impact amphibians. There are some species that do breed in streams, but in North

America, there are not very many (Semlitsch and Bodie, 2003). Based on the North American Monitoring Program (NAAMP) database, only twenty-four out of five hundred and seventy-three species are stream breeding, and wood frogs are classified as a pond breeding species (Green, 2003).

The boreal chorus frogs tend to follow the same habitat requirement; however, there was one site that was an unobstructed stream but had boreal chorus frogs present. Hossack and Corn (2005) looked at boreal chorus frog presence and stream obstruction. In their study, larvae and calling frogs were occasionally found in streams, but once a heavy rainfall came, the larvae were washed away. The streams were then declared to not be ideal habitat for breeding purposes, since the eggs and larvae could not stay grounded (Green, 2003). Stevens et al. (2006) compared boreal chorus frog presence and the presence of beaver dams. The researchers found a positive relationship with boreal chorus frog populations and beaver dams. They also did not find any boreal chorus frogs on sites that were unobstructed streams or water bodies that had a continuous flow. A beaver dam can stop the flow of a water body and provide suitable habitat for boreal chorus frogs; however, there is the possibility that beaver dams can provide habitat for predatory fish if the area is flooded (Stevens et al. 2006). Boreal chorus frogs have also been classified as pond-breeding amphibians under the Resources Inventory Committee in British Columbia (Hengeveld, 1999: 2).

6:4 Dominant Vegetation

Most of the sites that had wood frogs or boreal chorus frogs present were dominated by emergent vegetation. Other studies have found that the wood frogs favor sites dominated by emergent or woody vegetation (Hokit and Brown, 2006; Stevens et al.

2006; Egan and Paton, 2004). Most of the emergent vegetation found at the sites was herbaceous vegetation that included various grasses and cattails. Emergent vegetation is also the dominant vegetation for other species of frogs, and emergent vegetation can include herbs, grasses, reeds, sedges, and rushes (Parris and Lindenmayer, 2004; Jansen and Healy, 2003). Woody or shrub material that is submerged, such as the roots and branches of willows, can also be suitable vegetation for the wood frog (Stevens et al. 2006).

There is limited research that has investigated the impact of vegetation type and boreal chorus frog presence. Burton (2001) found that 75% of the sites were dominated by emergent vegetation. This study was done in the Western Ranger District of Caribou National Forest in southeast Idaho (United States). The emergent vegetation found during his study included sedges and rushes. Comparing the results from Burton's study and this study and taking into consideration that the boreal chorus frog's range and wood frog's range overlap, it is safe to assume that both the habitats of the wood frog and of the boreal chorus frog in Alberta are primarily dominated by emergent vegetation.

Wood frogs, boreal chorus frogs, and other amphibians use vegetation for ovipositing, shelter from extreme weather, and protection from predators (Parris and Lindenmayer, 2004). Sites with no vegetation at all are poor habitats for these frogs (Hazell et al. 2001); they do not provide suitable material to attach eggs during the breeding season or provide protection. Most of the vegetation found at the sample sites in this research project was dead, but it still can provide the same uses for amphibians as live vegetation. Conservation managers have realized that increasing the vegetation density at a site allows an increase in amphibian populations because of the increased

protection from fish, since there is less open water (Lichtenberg et al. 2006; Hamer et al. 2002).

Researchers are realizing that sites with dense vegetation in the riparian and terrestrial area surrounding a wetland are an important need for amphibian conservation (Lee et al. 2006; Urbina-Cardona et al. 2006; Bulger et al. 2003; Lemckert and Brassil, 2000). The distance to the nearest forest cover and the area of forest cover within the core terrestrial habitat have also been studied because they are believed to have an impact on amphibian population dynamics (Patrick et al. 2006; Rubbo and Kiesecker, 2005; Porej et al. 2004). Future research efforts are required to find out how vegetation and which vegetation types support amphibian populations both in the aquatic and terrestrial environment.

6:5 Water Quality

Wood frog populations had a significant negative correlation with all three water chemistry parameters in this research project. There is limited literature that has studied water chemistry and its relationship with wood frog populations, and observations between the different sources are quite variable. Laposata and Dunson (2000) discovered a significant relationship between pH and wood frog populations, but Campbell et al. (2004) found no significant relationship between water chemistry and wood frog populations.

Wood frog populations had the strongest negative correlation with conductivity ($-0.353, p = <0.001$). Measuring the conductivity of the water determines how much solute is in the water by using an electric current. Pure water has a high resistance to electric current, so if a conductivity probe was immersed into pure water, little electric current

would pass through the water resulting in the water having a very low conductivity. As more solutes are discharged into the water, the water's resistance to electric current is reduced. A high conductivity means that there is a high amount of solute in the water (Wetzel and Likens, 2000: 100). Since the wood frog populations had such a strong negative relationship with conductivity, it is suggested that wood frogs prefer water with less solute during the breeding season. Purer water must be better for larvae and adults. Larvae may need purer water in order to grow healthy, since amphibian eggs have no shell protection and are directly exposed to the particles and toxins found in the water (Stebbins and Cohen, 1997: 162; Beebee, 1996: 16, 137). Adults may need purer water, since they have permeable skin that directly exposes them to toxic solute that could be in the water (Young et al. 2004: 7).

For pH, the evidence suggests that wood frogs prefer slightly acidic to slightly alkaline waters. When comparing the mean pH and maximum ranks, the pH drops as the number of wood frogs decreases; however the results are not significant (Figures 8 and 9). In Alberta, most water is slightly alkaline due to the high amount of bicarbonate found in the sediment. Because of the high buffering capacity of Alberta's surface water, a high amount of acidic material would be needed to bring down the pH of the water to the point where it may harm amphibians that inhabit the water (Mitchell and Prepas, 1990: 23). The pH of the water needs to be fairly acidic in order to harm wood frogs; the LC_{50} (the concentration to kill 50% of the sample population) of pH on wood frog larvae is 4.10 (Sadinski and Dunson, 1992). Laposata and Dunson (2000) compared amphibian presence with natural wetland and wastewater-irrigated wetland. One of the water chemistry parameters they looked at was pH. They found that wood frog populations

were lower in the wastewater-irrigated wetland. The wastewater-irrigated wetland a higher pH than the pH of the natural wetland; however, the mean pH of the wastewater-irrigated wetland was 7.073 (SE = 0.170) and the mean pH of the natural wetland was 5.550 (SE = 0.194). The pH of the natural wetland found in their sample area, Centre County, Pennsylvania (United States), is much lower than the pH of natural wetland and lakes found in Alberta. Also, other parameters they examined, such as nutrients, may have confounded their results. More research is needed to determine how populations of wood frogs change along a pH gradient in Alberta, since the average pH is much higher than in the wetland mentioned in the study by Laposata and Dunson (2000). It may be necessary to use mesocosms to conduct this isolated-variable study.

Dissolved oxygen had a negative relationship with wood frog populations. This is most likely because the water bodies had a low mixing capacity. The majority of sites had no flowing water because they were obstructed in some form. Water bodies that have a slow mixing capacity have less oxygen than fast, running streams (Horne and Goldman, 1994: 117, 247). Temperature also affects the amount of dissolved oxygen in the water. The lower the temperature, the more oxygen will dissolve in the water until the maximum saturation point is reached (Kalff, 2002: 226-228). The amount of dissolved oxygen could be related to the degree of mixing; however, the temperature of the water may have confounded the results. Again, mesocosms could be used in order to control water and air temperature (Caquet et al. 1996). Between the sites during the water sampling, the mean temperature of the water ranged from 7.15°C (SE = 0.31) to 19.03°C (SE = 0.58). Based on this study, it is difficult to suggest that the amount of dissolved oxygen directly impacts wood frog amphibian populations.

Wood frogs have very short breeding periods, so the amount of dissolved oxygen may not significantly affect reproduction and larvae growth. Wood frogs are mostly terrestrial organisms; other than breeding and larvae development, they do not need to spend a significant amount of time under water; therefore, they may not rely on a high amount of dissolved oxygen to survive (Campbell et al. 2004). More research is needed to better quantify the relationship between dissolved oxygen and wood frog populations during the breeding season. Like pH, the use of mesocosms may be necessary to successfully look at this relationship.

The boreal chorus frog only had a significant relationship with dissolved oxygen and water temperature. The boreal chorus frog may have a negative relationship with dissolved oxygen for the same reason as the wood frog: a short use of the water for breeding and ovipositing (Alberta Conservation Association and Alberta Sustainable Resource Development, 2001: 28-29). Most of the water bodies had no flowing water, so the dissolved oxygen should be in a low amount (Horne and Goldman, 1994: 117, 247). During the sample study, the mean dissolved oxygen of the sites was 6.9 ppm (SE = 0.3) and the mean dissolved oxygen ranged between 0.990 ppm (SE = 0.387) to 11.540 ppm (SE = 1.470). The tolerance of the wood frog to low oxygen levels is not known (Laposata and Dunson, 2000). The minimum dissolved oxygen level to keep a lake healthy is 5 ppm. If the dissolved oxygen level is between 2 ppm and 5 ppm, most species of fish are stressed. If the dissolved oxygen level is below 2 ppm, then mortality of fish occurs (Big Lake Environment Support Society, 2006: 3). Five sites had mean dissolved oxygen levels below 5 ppm, but how closely the wood frog's tolerance is similar to a fish's tolerance is not known. Also, boreal chorus frogs have a short

breeding period and because boreal chorus frogs do not need to be in the water all year round, they may have adapted to aquatic environments with low amounts of dissolved oxygen.

It is unclear why water temperature has a significant correlation with boreal chorus frog populations. Water temperature may affect the behavior of boreal chorus frog calling males. The optimum water temperature for northern leopard frog calling males is 10°C (Kendell, 2002b: 16), but the source does not explain if this optimum temperature is a behavior limitation or a physiological limitation. There was no significant correlation between water temperature and wood frog populations. One possible reason for this result is that the wood frog can adapt well to cold temperatures, since it is found more north than any other amphibian (Alberta Conservation Association and Alberta Sustainable Resource Development, 2001: 35-36). There was no significant relationship between air temperature and wood frog and boreal chorus frog populations. The temperature of the ambient environment impacts the temperature of the water; therefore, a large range in air and water temperature would make it hard to suggest that either one of these variables has a direct impact on the population dynamics of either frog that was studied.

There is also a very little amount of research that looks at the relationship between water chemistry and boreal chorus frog populations. Muths et al. (2003) found that boreal chorus frogs had no significant relationship with water chemistry. It seems that the boreal chorus frog is highly adapted to broad range of water chemistry parameters. Other amphibians have been found to adapt to aquatic environments with a broad range

of water chemistry parameters; the green and golden bell frog (*Litoria aurea*) in Australia is an example (Hamer et al. 2002).

6:6 Pond Isolation

In this study, the wood frog did not have a significant positive relationship with neighbouring wetlands ($0.346, p = 0.072$), and, it did not have a significant relationship with the average distance to the closest ten ponds. Other studies have found different results. Baldwin (2005) found that wood frogs have a negative relationship with wetland proximity; however, he determined that the wood frog's relationship was most likely irrelevant, since there was a high mean amount of wetlands within 500 m of the breeding pools. The mean number of wetlands within 500 m was 9.2, and there was a mean of 11.5 wetlands within 4.5 km^2 for this study. The high number of wetlands in this study also supports this suggestion.

There are different methods to research pond isolation: mark-recapture (Cushman, 2006) and gene pool analysis (Olson et al. 2007). There are also methods to prevent pond isolation. Cunningham et al. (2007) found that an increase in pond isolation could have a negative impact on wood frog breeding sites. They found that an indirect method to minimize pond isolation is through the management of beaver dams. The creation of beaver dams can create a wetland mosaic for amphibians.

Instead of measuring the number of wetlands within a 1.2-km radius or the average distance of to the closest ten ponds, it may be better to compare the amount of wetland area within a 1.2-km radius. It may also be better to measure the perimeter of the wetlands instead of the area. By changing the parameter to measure, it may change the result of an analysis. The question of whether the species is impacted by pond

isolation is still being looked at; it is just being looked at by measuring a different parameter. Geographic information system (GIS) analysis could be used to accurately measure the perimeter and total wetland area within a 1.2-km radius instead of using topographic maps and aerial photographs; however, this was not done, since the measurement of the distance between the nearest ponds was thought to be adequate for this study. As more research is conducted within the area, a larger data set can be developed that could be used for GIS analysis (Chang, 2002: 2-5).

The relationship in this study between wood frog presence and neighbouring wetland suggests that wood frogs are grouped together in metapopulations within the sample area, but more research is needed to better quantify how wood frogs are organized into metapopulations. Petranka and Holbrook (2006) found no significant results that support that wood frogs are organized into metapopulations at a local level; they suggest that wood frogs need to be investigated at a landscape or regional level to determine if they are organized into metapopulations (Petranka and Holbrook, 2006). The problem with trying to support the metapopulation theory for a particular amphibian species based on fieldwork is that it can be quite expensive because it is hard to have enough data for a landscape-level study (Cushman, 2006). Also, in order to strongly support that a particular amphibian species follows the metapopulation theory, genetic results comparing genetic variability between populations are needed besides pond isolation measurements (Olson et al. 2007; Marsh et al. 1999).

The boreal chorus frog had no significant relationship with the number of wetlands or the average distance to the closest ten ponds. There are no known studies that have looked at the migrating distance of the boreal chorus frog. A 1.2-km migrating

distance was assumed, since the boreal chorus frog shares its habitat with the wood frog. The migrating distance of the boreal chorus frog can be determined in the future by using radio telemetry (Rittenhouse and Semlitsch, 2006).

Burton (2001) found that boreal chorus frogs had a negative relationship with the average distance to the closest ponds. He suggested that the result was because boreal chorus frogs use ponds just for breeding purposes and spend the rest of their time in the surrounding terrestrial environment. Wood frogs also spend most of their time in their terrestrial habitat, but they may have a stronger metapopulation organization than the boreal chorus frog. Since boreal chorus frogs may only use ponds for the breeding season and because they are capable of migrating, it is more likely for a boreal chorus frog to be found in an isolated pond during the breeding season. Boreal chorus frogs may rely more on the hydroperiod of a wetland, so they may breed in more isolated wetlands if there are few surrounding wetlands that have suitable hydroperiods (Baldwin, 2005).

There are some studies that have found strong correlations with the connectivity of ponds and frog presence (Lauck et al. 2005; Matthews et al. 2001). The metapopulation theory, the mechanisms behind the metapopulation theory, and how strongly the metapopulation theory applies for many amphibian species is not well known (Marsh and Trenham, 2001). Boreal chorus frogs may be organized into very weak metapopulations, but as more long-term, landscape-level research is conducted comparing pond isolation data as well as genetic data, a better understanding can be developed.

6:7 Road Density

Surprisingly, the wood frog had a significant positive relationship with total road density. Based on available literature, it was expected that wood frogs would have a negative relationship with road density (Rubbo and Kiesecker, 2005; Egan and Paton, 2004; Findlay et al. 2001). It has been found that roads interfering with frog habitats can negatively impact populations directly by road kills or indirectly by reducing available habitat, increasing fragmentation between neighbouring populations, and increasing the risk of extinction for individual populations. Hels and Buchwald (2001) have even developed a method to quantify the impact of road kills on amphibian populations based on the intensity of traffic. Research on the impact on roads of wood frogs is also controversial, since Petranka et al. (2003b) have found no significant relationship with wood frog populations and road density.

So far, there is no other study that has found a positive relationship with road density. One hypothesis for this result is the small amount of road within the sample area. For total road density, the mean density was 3983 m of road within 1200 m of the wetland (SE = 369 m), the maximum density was 8280 m of road within 1200 m of the wetland, and there were only seven sites that were above 5000 m of road within 1200 m of the wetland. Looking at the suitability index of road density for the wood frog preliminary habitat suitability index model, twenty-one sites meet the ideal condition and have a suitability index value of 1. The other seven sites have a suitability index value between 0.8 and 1. There were no sites that had a high-enough road density to have a low suitability index value. The small amount of road may have affected the correlation coefficient and its significance value. If there were more sites that had a suitability index

value below 0.8 or even below 0.5, the correlation between the wood frog populations and road density within the sample area may change.

Another hypothesis for this result is multicollinearity between another variable. If road density has a strong positive or negative correlation with another independent variable, then the two variables are not mutually exclusive and there is a high level of confounding (Burton, 2001). Genet (2004) compared species presence to road density in southern Michigan (United States). Genet (2004) measured the total road length within a 1000-m radius of each site and correlated the result with species presence. Genet (2004) discovered that there was a positive relationship between wood frog presence and road density, but there was a negative relationship between wood frog presence and the amount of urban area. Genet (2004) also discovered that there was a negative relationship between road density and spring peeper (*Pseudacris crucifer*) and Western chorus frog (*Pseudacris triseriata*) presence. There is the possibility that there was a high correlation between urban area and road density causing the inconsistency between the species. Houlahan (2002) compared species richness with various landscape variables in southeastern Ontario. During his initial bivariate linear regression analysis, he discovered a negative relationship between species richness and road density and he discovered a positive relationship between species richness and forest cover. He also discovered a strong negative correlation the two independent variables. Since forest cover had the strongest bivariate relationship among the landscape variables, he conducted a multi-regression analysis with forest cover. During his multi-regression analysis with forest cover, road density did not have a significant relationship with species richness. He suggested that because of the strong negative correlation between

forest cover and road density, there is confounding between the two variables which resulted in road density having no significant relationship in the multi-regression analysis. He also suggested if road density was looked at differently, such as measuring traffic volume instead of road length, there may have been different statistical results. The other possible hypothesis for this result is statistical error; it is possible the correlation between total road density and wood frog population is a statistical anomaly. It may be that the coefficient and its significance value is a result of chance, since paved road density and unpaved road density had no significant correlation.

The range of road density in this study shows that the sample area is a rural community and not an urban or sub-urban community. Hels and Buchwald (2001) found that amphibians are negatively impacted by road density, but their study site had a traffic intensity of 3200 vehicles/24h. It is most unlikely that this sample area, a rural community dominated by gravel roads, will have a traffic intensity that comes close to this value. As urban development continues in the area, road density may eventually have a significant negative relation with wood frog populations.

The boreal chorus frog had no significant relationship with road density. There are studies that have also found no significant relationship with road density and their amphibian species of interest (Pellet and Schmidt, 2005; Campbell et al. 2004; Petranka et al. 2003b). A possible explanation for this result is the small amount of road. Using the suitability index of road density for the preliminary wood frog habitat suitability index model, there were no sites that had road density measurements high enough to receive a suitability index value below 0.8. Another possible explanation for this result is that the boreal chorus frog has very broad habitat needs. It has one of the greatest ranges,

compared to other amphibians, and is known to adapt to every environment in Alberta other than extreme alpine environments (Alberta Conservation Association and Alberta Sustainable Resource Development, 2001: 28-29).

Road density could still have a negative relationship with these two amphibian species. Road construction and road traffic is a means of habitat destruction and fragmentation (Cushman, 2006). It is possible that roads are simply a surrogate of urbanization and habitat loss; the amount of roads in an area most likely has a positive linear relationship with the amount of urban development. It may be better to combine the number of roads with the amount of urban development in the area and see if this combination impacts amphibian populations. Research is still needed to determine if roads have an affect on amphibian populations. If road density does have a relationship with amphibian populations, then the mechanisms behind the process needs to be determined (Timm et al. 2007). More research that involves more sample sites and long-term monitoring should help determine potential significant contributions of roads on amphibian populations.

Chapter 7: Modifications of the Habitat Suitability Index Models

7:1 Introduction

New models were developed as part of the model verification process for the creation of a habitat suitability index (HSI) model by analyzing the habitat variable relationships with field data (Division of Ecological Services, 1981: 3-52). Results from the field data lead to some habitat variable relationships that were contradictory to the relationships in the literature review, so the models were modified to reflect the field data results.. These modified models will still have to be verified by having a species authority review the models or testing them with field data collected within the sample area (Division of Ecological Services, 1981: 3-52).

7:2 Wood Frog Habitat Suitability Index Model

Based on the field data, the wood frog has three key habitat variables for the HSI model. The first two habitat variables are fish presence and standing water and have the same suitability indexes as the indexes shown for the preliminary HSI model based on literature for the wood frog. The third variable is dominant vegetation. The suitability index is different than the preliminary suitability index for the boreal chorus frog; a site that is dominant with no vegetation receives a suitability index value of 0 (Figure 12). The suitability index is different because no frogs were found at sites that were classified with having no vegetation.

A suitability index could not be developed for conductivity. When comparing the mean conductivity and the ranks from the calling surveys, no distinctive pattern could be determined (Figure 13). It is possible to combine ranks to get a more general pattern,

such as averaging the means of ranks 5 and 4 and averaging the means of ranks 3, 2, and 1; however, this would lead to the suitability index being very subjective.

A suitability index also could not be developed for dissolved oxygen, since no distinctive pattern could be determined when comparing mean dissolved oxygen and rank (Figures 14). Again, it is possible to combine ranks, such as averaging the means between selected ranks, but the suitability index would be very subjective. The pH was also not put into the new model because the pH varied too much among the ranks (Figure 15). The mean pH range between the sites was only 1.961; the mean minimum pH was 6.757 (SE = 0.084); the LC₅₀ for wood frog larvae is 4.12 (Sadinski and Dunson, 1992).

Figure 12. Suitability index of dominant vegetation for the wood frog.

Figure 13. Mean conductivity of each rank for the wood frog. Y bars represent standard error.

Figure 14. Mean dissolved oxygen of each rank for the wood frog. Y bars represent standard error.

Figure 15: Mean pH of each rank for the wood frog. Y bars represent standard error.

Taking the three variables, a final HSI model is developed:

$$HSI_{\text{Wood Frog}} = (V_F * V_S * V_V)^{1/3} \quad [4]$$

V_F = Fish Presence

V_S = Standing Water

V_V = Dominant Vegetation

The model shows a compensatory relationship where the relationship is controlled by a geometric mean. The geometric mean considers the lowest suitability index value. If one of the variables has a suitability index value of 0, then the habitat suitability index is 0. Even though the model is quite general and approximate, it should reflect the particular geographic area and can become more precise as more research on wood frog habitat is conducted within the sample area (Division of Ecological Services, 1981: 3-1 – 3-54).

All three habitat variables in the model are non-parametric, categorical data. The problem with non-parametric data is that they are less precise than parametric data and it is more difficult to find significant trends in a non-parametric test. Non-parametric data are difficult to work with because it is difficult to predict the distribution around the mean for a data set; therefore, it takes many parameters to describe the distribution, unlike

parametric data (Gould and Gould, 2002: 16, 139-140). The dominant vegetation habitat variable is based on categorical data and the fish and standing water habitat variables are based on binary data. Both these types of data consist of less information than discrete or continuous data, which are types of parametric data (Zar, 1974: 4, 109). For scientists and conservation managers, it may be difficult to make decisions based on a model that does not require a vast amount of information. A conservation manager may not want to make a difficult conservation decision based on a model that requires data of low complexity and that produces an output of estimation; however, this model may be a more efficient, cost-effective method, since tests and models that use non-parametric data are usually more simple to conduct and easier to calculate (Pagano and Gauvreau, 2000: 312). This model is the original model and should produce an acceptable output that is suitable to act as a guide for conservation managers. It is also acceptable that the acceptable model output is not equal to the ideal output of 1 at this stage of the model development (Gould and Gould, 2002: 16, 139-140).

Compared to the HSI model that was based on available literature, hydroperiod was not included, since hydroperiod was not determined for the sample sites. It is possible to have dominant vegetation represent hydroperiod. Egan and Paton (2004) found that woody vegetation and persistent emergent vegetation is more likely to be found in wetlands with seasonal/temporary hydroperiods and aquatic vegetation is more likely to be found in wetland with permanent hydroperiods. Seasonal hydroperiods allow for emergent vegetation to germinate during water draw-downs (Henning and Schirato, 2006). The hydroperiod suitability index can still be integrated into the HSI model for this geographic area in future conservation efforts; however, it may be necessary to

confirm that hydroperiod does in fact impact wood frog populations found in this sample area.

Road density was also not included, since the range of road density was not large enough to have a strong comparison. Road density could be used as a habitat variable; however, it would only reflect a rural area with very light road traffic. If future urban developments occur within the sample area and change the area into a sub-urban or urban area, then the preliminary road density suitability index can not be used. Fish presence and water movement are the strongest habitat variables in the model. Conductivity, dissolved oxygen, and pH have an effect on wood frog presence, but no non-subjective suitability index could be developed for them and their relationship between wood frog and boreal chorus frog populations are definitely not as powerful or have a strong effect compared to fish presence and water movement.

7:3 Boreal Chorus Frog Habitat Suitability Index Model

For the boreal chorus frog, there are only three key habitat variables for the HSI model. The first three habitat variables are fish presence, water movement, and dominant vegetation. Fish presence and water movement have the same suitability indexes as the suitability indexes in the preliminary model that was based on available literature. For dominant vegetation, the suitability index is the same as suitability index of the wood frog (Figure 12).

A suitability index could not be developed for dissolved oxygen. When comparing mean dissolved oxygen and rank, no distinctive pattern could be determined (Figure 16). It is possible to combine the ranks, such as averaging the mean dissolved oxygen value between selected ranks, but the suitability index would be very subjective.

Figure 16. Mean dissolved oxygen for each rank for the boreal chorus frog. Y bars represent standard error.

A HSI model has been developed by taking into consideration the three habitat variables:

$$HSI_{\text{Boreal Chorus Frog}} = (V_F * V_S * V_V)^{1/3} \quad [5]$$

V_F = Fish Presence

V_S = Standing Water

V_V = Dominant Vegetation

The HSI model shows a compensatory relationship using a geometric mean; the lowest suitability index model is taken into consideration. If one of the suitability index values is 0, then the habitat suitability index is 0. The model can be modified as more research on boreal chorus frog habitat is conducted (Division of Ecological Services, 1981: 3-1 – 3-54). Since there is very little research on boreal chorus frog habitat, the model should most likely yield a very approximate output for the sample area (Nussbaum et al. 1983: 143); however, this is the original model for the species in the selected geographic area and is the first known HSI model for the particular species. Key habitat variables have been identified for the boreal chorus frog, and as more research is conducted in the area,

an acceptable output can be achieved that can be used to make conservation management decisions.

Like the wood frog model, all three habitat variables in the model are non-parametric, categorical data. The problem with non-parametric data is that they are less reliable than parametric data and harder to find significant trends in a non-parametric test. It is easier to reject a null hypothesis with a non-parametric test than with one that is parametric; however, it is easier to have a Type II error (have a significant output when you are not supposed to have a significant error) with a non-parametric test (Pagano and Gauvreau, 2000: 312). Quantitative comparisons can not be made among a non-parametric data set, so less information is conveyed in a data set used for this model (Zar, 1974: 4); therefore, there is a higher chance of error when a scientist or manager makes an important conservation decision. This model is the original model, it is sufficient that the acceptable model output is not equal to the ideal output of 1 (Gould and Gould, 2002: 16, 139-140).

For the boreal chorus frog HSI model, pond isolation was not included, since there were no significant relationships between the boreal chorus frog and pond isolation. More research is needed to determine if boreal chorus frogs are organized into metapopulations and how strongly metapopulation mechanisms affect boreal chorus frog population dynamics. Pond fragmentation along with gene pool studies can be conducted to determine if the boreal chorus frog supports the metapopulation theory (Olson et al. 2007).

Chapter 8: Recommendations for Future Research

8:1 Introduction

In order to make the models more sensitive, further research is needed. There needs to be more research that focuses on the habitat ecology of the wood frog and the boreal chorus frog, especially within the geographic area that the models represent. More research will allow more information to be considered for further development and verification of the models. Based on this study, certain topics have been selected that require more research for further development of the models; required studies and ways on how to conduct them have been suggested.

8:2 Using Mesocosms for Future Fish and Water Quality Studies

More research is needed to study cause-and-effect relationships between fish and wood frog and boreal chorus frog population dynamics, especially within the geographic area. The northern pike, brook stickleback, fathead minnow, and white sucker (*Catostomus commersoni*) are found in the Parkland Natural Region (Natural Regions Committee, 2006: 106). Sites already containing fish can be used for future research; however, if there are a lack of sites that contain fish or if there are too many environmental variables to take into consideration, mesocosms can be used to determine the impact of fish found in the area on amphibian population dynamics (Horne and Dunson, 1995). A mesocosm complex could be constructed within the geographic area. Man-made holes or tanks that are filled with artificial pond water, soil, and plants that are found within the geographic area could be used (Caquet et al. 1996). Amphibians could then be relocated into the mesocosms followed by the introduction of fish. The amphibians during the fish invasion can be monitored to see if fish cause a complete

crash in the amphibian population and whether some amphibians still remain in the mesocosm. By using mesocosms, the type of fish species used in the study can also be controlled to see if non-indigenous fish have a greater negative impact than indigenous fish on the amphibian populations.

There is no known research that has looked at the difference between fish population dynamics and wood frog or boreal chorus frog population dynamics. It is difficult to suggest that every site that has fish present will never be able to support wood frogs. Mesocosms could be used to look at the difference between fish populations on the wood frog. Tanks could be used each containing a different number of fish to determine if there is a difference in the negative impact on wood frog or boreal chorus frog populations.

The impact of the water quality parameters that were looked at in this study can also be looked at using mesocosms. The artificial water used in the man-made holes or tanks can be manipulated to represent conditions that are similar to the conditions of the sites found within the area or to represent conditions that have been selected by the researcher (Horne and Dunson, 1995). The pH can be controlled to represent the conditions that have a sub-lethal effect on the amphibian species, since the range of the pH in this study does not meet the sub-lethal pH level for the wood frog (Sadinski and Dunson, 1992). Dissolved oxygen can be controlled by controlling the temperature of the water and air, and the conductivity can be controlled by controlling the amount of solute that enters the mesocosm (Kalff, 2002: 226-228; Wetzel and Likens, 2000: 100).

8:3 Forest Cover and Vegetation

The two HSI models only represent the breeding season for the two species. Both frogs use the terrestrial environment for foraging and hibernation (Regosin et al. 2003). The terrestrial environment and its characteristics must be taken into consideration in order to produce a HSI model that represents the entire life cycle of each species. Unfortunately, there is lack of sufficient research for the wood frog and barely any research for the boreal chorus frog that looks at terrestrial habitat characteristics.

There is very little research that has looked at wood frogs or boreal chorus frogs success in grasslands and open areas, since wood frogs have been found in these ecosystems (Rittenhouse and Semlitsch, 2007; Vasconcelos and Calhoun, 2006). Only one study has looked at the impact of grassland vegetation on wood frog population dynamics. Eaves (2004) looked at the impact of land use in the Aspen Parkland Natural Sub-region on the wood frog and the boreal chorus frog. She compared four land uses (pasture, crop, natural, and residential) on wood frog and boreal chorus frog population dynamics and found that both of the species had the greatest abundance at sites where the primary land use was natural; however, she did not look at other terrestrial variables, such as the amount of land use area within each of the species migratory distances, the amount of each land use on the perimeter of each site, and the distance to each land use. If a suitability index was developed using Eaves' variables, the suitability index would require ordinal data. The three habitat variables that could have also been looked at would allow a suitability index that would require more sensitive, parametric data.

Research needs to be done in the geographic area to determine how vegetation cover surrounding wetland that is not classified as forest affects wood frog or boreal

chorus frog population dynamics. The amount of area of each vegetation type; the distance to each vegetation type; the amount of area of each vegetation type within the migratory distances of each species; and the status of each vegetation type, such as the grassland being dominated by invasive species are some of the habitat variables that need to be looked at. It may be useful to use GIS to determine the amount of vegetation types that are part of the terrestrial environment that make up the habitat for the sample species (Guerry and Hunter Jr., 2002).

8:4 Conclusion

After further verification, these models can be used to determine the baseline and future quality and quantity of habitat during the breeding season in the Foothills Parkland Natural Sub-region and Bow River Sub-basin for the wood frog and the boreal chorus frog. These models can be used to predict how future changes within this geographic area can change the quality and quantity of habitat for each amphibian species. They can also be used as a guide when managers and scientists want to restore or create wetland to support wood frog or boreal chorus frog populations within the sample area by considering the ideal suitability index values of each variable.

These models are at the stage where they can be used to determine future investigations of habitat-variable relationships with the wood frog and boreal chorus frog within the sample area. More research on these two species within the sample area can help enhance and revise the models so they can be used to make accurate conservation management decisions (Jones et al. 2002). There is very little research that has examined the habitat characteristics of each species and this study helps point out what additional

investigations are needed to help improve conservation efforts and keep populations of both species sustainable for the future.

References

- Adams MS. 2002. Biological Indicators of Aquatic Ecosystem Stress: Introduction and Overview. Adams MS. Editor. Biological Indicators of Aquatic Ecosystem Stress. Bethesda, Maryland (United States): American Fisheries Society.
- Alberta Conservation Association, Alberta Sustainable Resource Development Fish and Wildlife Service. 2001. Alberta Amphibian Monitoring Manual. Edmonton, Alberta: Alberta Sustainable Resource Development.
- Alberta Sustainable Resource Development. 2008. Boreal Chorus Frog. Available at <http://www.srd.alberta.ca/fishwildlife/wildlifeinalberta/amphibiansalberta/woodfrog.aspx> [March 15, 2008].
- Alberta Sustainable Resource Development. 2008. Wood Frog. Available at <http://www.srd.alberta.ca/fishwildlife/wildlifeinalberta/amphibiansalberta/woodfrog.aspx> [March 15, 2008].
- Alberta Sustainable Resource Development. 2003. Status of the Northern Leopard Frog (*Rana pipiens*) in Alberta. Update 2003. Wildlife Status Report No.9. Edmonton, Alberta: Alberta Sustainable Resource Development, Fish and Wildlife Division, and Alberta Conservation Association.
- Baldwin RF. 2005. Pool-Breeding Amphibian Habitat Use and Conservation in Southern Maine's Urbanizing Landscapes. PhD. Orono, Maine (United States): The University of Maine.
- Baldwin RF, Calhoun AJK, deMaynadier PG. 2006. Conservation Planning for Amphibian Species Using Movements and Habitat Selection of the Wood Frog *Rana sylvatica*. Journal of Herpetology 40(4): 442-453.
- Beebee TJC. 1996. Ecology and Conservation of Amphibians. New York, New York (United States): Chapman & Hall.
- Beebee TJC, Griffiths RA. 2005. The Amphibian Decline Crisis: A Watershed for Conservation Biology? Biological Conservation 125: 271-285.
- Big Lake Environment Support Society. 2006. Big Lake Water Quality Monitoring Program. St. Albert, Alberta: Big Lake Environment Support Society.
- Bishop CA, Mahony NA, Struger J, Pettit KE. 1999. Anuran Development, Density and Diveristy in Relation to Agricultural Activity in the Holland River Watershed, Ontario, Canada (1990-1992). Environmental Monitoring and Assessment 57: 21-43.
- Blouin F, Taylor BN, Quinlan RW. 2004. The Southern Headwaters at Risk Project: A Multi-Species Conservation Strategy for the Headwaters of the Oldman River. Volume 2.

Species Selection and Habitat Suitability Index Models. Alberta Species at Risk Report No. 90. Edmonton, Alberta: Alberta Sustainable Resource Management, Fish and Wildlife Division.

Boone RB, Johnson CM, Johnson LB. 2006. Simulating Vernal Pool Hydrology in Central Minnesota, USA. *Wetlands* 26(2): 581-592.

Borin M, Vianello M, Morari F, Zanin G. 2005. Effectiveness of Buffer Strips in Removing Pollutants in Runoff from a Cultivated Field in Northeast Italy. *Agriculture, Ecosystems, and Environment* 105: 101-114.

Borin M, Bigon E. 2002. Abatement of NO₃-N Concentration in Agricultural Waters by Narrow Buffer Strips. *Environmental Pollution* 117: 165-168.

Bow River Basin Council. 2005. Nature, Renew, Protect: A Report on the State of the Bow River Basin. Calgary, Alberta: Bow River Basin Council.

Brinson MM, Malvárez AI. 2002. Temperate Freshwater Wetlands: Types, Status, and Threats. *Environmental Conservation* 29(2): 115-133.

Brodman R, Parrish M, Kraus H, Cortwright S. 2006. Amphibian Biodiversity Recovery in a Large-Scale Ecosystem Restoration. *Herpetological Conservation and Biology* 1(2): 101-108.

Brooks RT. 2004. Weather-Related Effects on Woodland Vernal Pool Hydrology and Hydroperiod. *Wetlands* 24(1): 104-114.

Brower JE, Zar JH, von Ende CN. 1998. Field and Laboratory Methods for General Ecology. Boston, Massachusetts (United States): WCB McGraw-Hill.

Brusnyk LM, Gilbert FF. 1983. Use of Shoreline Timber Reserves by Moose. *Journal of Wildlife Management* 47: 673-685.

Bulger JB, Scott Jr. NJ, Seymour RB. 2003. Terrestrial Activity and Conservation of Adult California Red-legged Frogs (*Rana aurora draytonii*) in Coastal Forests and Grasslands. *Biological Conservation* 110: 85-95.

Burton SR. 2001. Amphibian Declines in Southeast Idaho: Using Modeling to Assess the Habitat Loss Hypothesis. PhD. Pocatello, Idaho (United States): Idaho State University.

Campbell CE, Warkentin IG, Powell KG. 2004. Factors Influencing the Distribution and Potential Spread of Introduced Anurans in Western Newfoundland. *Northeastern Naturalist* 11(2): 151-162.

Caquet TH, Lagadic L, Jonot O, Baturu W, Kilanda M, Simon P, Le Bras S, Echaubard M, Ramade F. 1996. Outdoor Environmental Ponds (Mesocosms) Designed for Long-

term Ecotoxicological Studies in Aquatic Environment. *Ecotoxicology and Environmental Safety* 34: 125-133.

Casagrandi R, Gatto M. 2002. A Persistence Criterion for Metapopulations. *Theoretical Population Biology* 61: 115-125.

Chang K. 2002. *Introducing To Geographic Information Systems*. Boston (United States): The McGraw-Hill Companies, Inc.

Cochran DM, Goin CJ. 1970. *The New Field Book of Reptiles and Amphibians*. New York (United States): G.P. Putman's Sons.

Correll DL. 2005. Principles of Planning and Establishment of Buffer Zones. *Ecological Engineering* 24: 433-439.

Cunningham JM, Calhoun AJK, Glanz WE. 2007. Pond-Breeding Amphibian Species Richness and Habitat Selection in a Beaver-Modified Landscape. *Journal of Wildlife Management* 71(8): 2517-2526.

Cushman SA. 2006. Effects of Habitat Loss and Fragmentation on Amphibians: A Review and Prospectus. *Biological Conservation* 128: 231-240.

Dahl TE. 2000. *Status and Trends of Wetlands in the Conterminous United States 1986 to 1997*. Washington, D.C (United States): Department of the Interior, Fish, and Wildlife Service.

Darveau M, Beauchesne P, Belanger L, Huot J, LaRue P. 1995. Riparian Forest Strips as Habitat for Breeding Birds in Boreal Forest. *Journal of Wildlife Management* 59: 67-78.

Davis AB, Verrell PA. 2005. Demography and Reproductive Ecology of the Columbia Spotted Frog (*Rana luteiventris*) Across the Palouse. *Canadian Journal of Zoology* 83: 702-711.

Division of Ecological Services. United States Fish and Wildlife Services. Department of the Interior. 1981. *Standards for the Development of Habitat Suitability Index Models* 103 ESM. Washington, D.C (United States): United States Fish and Wildlife Services.

Division of Ecological Services. United States Fish and Wildlife Services. Department of the Interior. 1980a. *Habitat as a Basis for Environmental Assessment*. 101 ESM. Washington, D.C (United States): United States Fish and Wildlife Services.

Division of Ecological Services. United States Fish and Wildlife Services. Department of the Interior. 1980b. *Habitat Evaluation Procedures*. ESM 102. Washington, D.C (United States): United States Fish and Wildlife Services.

Downey BA, Downey BL, Quinlan RW, Castelli O, Remesz VJ, Jones PF. 2004. MULTISAR: The Milk River Basin Habitat Suitability Models for Selected Wildlife Management Species. Alberta Species at Risk Report No. 86. Edmonton, Alberta: Alberta Sustainable Resource Management, Fish and Wildlife Division.

Dupuis L, Steventon D. 1999. Riparian Management and the Tailed Frog in Northern Coastal Forests. *Forest Ecology and Management* 124: 35-43.

Eaton BR. 2004. The Role of Landscape Factors, Predation, and Demography in the Ecology of Anurans in Boreal Alberta. PhD. Edmonton, Alberta: University of Alberta.

Eaves SE. 2004. The Distribution and Abundance across Land-use Types in Alberta's Aspen Parkland. M.Sc. Edmonton, Alberta: University of Alberta.

Egan RS, Paton PW. 2004. Within-Pond Parameters Affecting Oviposition by Wood Frogs and Spotted Salamanders. *Wetlands* 24(1): 1-13.

Euliss Jr. NH, Mushet DM. 2004. Impacts of Water Development on Aquatic Macroinvertebrates, Amphibians, and Plants in Wetlands of a Semi-arid Landscape. *Aquatic Ecosystem Health & Management* 7(1): 73-84.

Findlay SC. 2001. Land-use Correlates on Anuran Community Richness and Composition in Southeastern Ontario Wetlands. *Ecoscience* 8(3): 336-343.

Findlay SC, Bourdages J. 2000. Response Time of Wetland Biodiversity to Road Construction on Adjacent Lands. *Conservation Biology* 14(1): 86-94.

Fish and Wildlife Service. Alberta Sustainable Resource Development. 2000. The General Status of Alberta Wildlife Species. Edmonton, Alberta: Alberta Sustainable Resource Development.

Fisheries Management Information System. 2007. Stocking Report. Edmonton, Alberta: Alberta Ministry of Sustainable Resource Development.

Ford NB, Hampton PM. 2005. The Amphibians and Reptiles of Camp Maxey, Lamar County, Texas with Comments on Census Methods. *Texas Journal of Science* 57(4): 359-370.

Forman RTT, Godron M. 1986. *Landscape Ecology*. New York, New York (United States): John Wiley & Sons, Inc.

Froom B. 1982. *Amphibians of Canada*. Toronto, Ontario: McClelland and Stewart Limited.

Gardner TA, Barlow J, Peres CA. 2007. Paradox, Presumption and Pitfall in Conservation Biology: The Importance of Habitat Change for Amphibians and Reptiles. *Biological Conservation* 138: 166-179.

Gartshore RG, Purchase M, Rook RI, Scott L. 2006. Bayview Avenue Extension, Richmond Hill, Ontario, Canada Habitat Creation and Wildlife Crossings in a Contentious Environmental Setting: a Case Study (September 2005). Irwin CL, Garret P, McDermott KP. Editors. *Proceedings of the 2005 International Conference on Ecology and Transportation*. Raleigh, North Carolina (United States): Center for Transportation and the Environment, North Carolina State University.

Genet KS. 2004. Status and Distribution of Frogs and Toads in Southern Michigan: Population Trends and the Influence of Habitat and Landscape Characteristics. PhD. East Lansing, Michigan (United States): Michigan State University.

Gibbons JW. 2003. Terrestrial Habitat: A Vital Component for Herpetofauna of Isolated Wetlands. *Wetlands*: 23(3): 630-635.

Gibbs JP. 2000. Wetland Loss and Biodiversity Conservation. *Conservation Biology* 14(1): 314-317.

Gould JL, Gould GF. 2002. *Biostats Basics. A Student Handbook*. New York, New York (United States): W. H. Freeman And Company. pp. 189-194, 260-264.

Government of Alberta. 2007. *Land-Use Framework: Understanding Land Use in Alberta*. Edmonton, Alberta: Government of Alberta.

Government of Canada. 1991. *The Federal Policy on Wetland Conservation*. Ottawa, Ontario: Minister of Supply and Services Canada.

Graham K, Bessie W, Hoover A, Bonar R, Quinlan R, Beck J, Beck B. 1999. Long-toed Salamander Year Round Habitat. Habitat Suitability Index Model. Version 5. Hinton, Alberta: Foothills Model Forest.

Green DM. 2003. The Ecology of Extinction: Population Fluctuation and Decline in Amphibians. *Biological Conservation* 111: 331-343.

Guerry AD, Hunter Jr. ML. 2002. Amphibian Distributions in a Landscape of Forests and Agriculture: An Examination of Landscape Composition and Configuration. *Conservation Biology* 16(3): 745-754.

Gyllenburg M, Hanski I. 1997. Habitat Deterioration, Habitat Destruction, and Metapopulation Persistence in a Heterogeneous Landscape. *Theoretical Population Biology* 52: 198-215.

- Häkkinen J, Pasanen S, Kukkonen JVK. 2001. The Effects of Solar UV-B Radiation on Embryonic Mortality and Development in Three Boreal Anurans (*Rana temporaria*, *Rana arvalis*, and *Bufo bufo*). *Chemosphere* 44: 441-446.
- Hamer AJ, Lane SJ, Mahony MJ. 2002. Management of Freshwater Wetlands for the Endangered Green and Golden Bell Frog (*Litoria aurea*): Roles of Habitat Determinants and Space. *Biological Conservation* 106: 413-424.
- Hazell D, Cunningham R, Lindenmayer D, Mackey B, Osborne W. 2001. Use of Farm Dams as Frog Habitat in an Australian Agricultural Landscape: Factors Affecting Species Richness and Distribution. *Biological Conservation* 102: 155-169.
- Hels T, Buchwald E. 2001. The Effect of Road Kills on Amphibian Populations. *Biological Conservation* 99: 331-340.
- Henning JA, Schirato G. 2006. Amphibian Use of Chehalis River Floodplain Wetlands. *Northwestern Naturalist* 87: 209-214.
- Hengeveld PE. 1999. Amphibian Reconnaissance Surveys in the Williston Reservoir Watershed. May 1998. PFWWCP Report No. 207. Prince George, British Columbia: Peace/Williston Fish and Wildlife Compensation Program.
- Herrmann HL, Babbitt KJ, Baber MJ, Congalton RG. 2005. Effects of Landscape Characteristics on Amphibian Distribution in a Forest-dominated Landscape. *Biological Conservation* 123: 139-149.
- Heyer W, Donnelly MA, McDiarmid RW, Hayek LC, Foster MS. 1994. Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians. Washington, D.C. (United States): Smithsonian Institution Press.
- Hodson J, Henry M, Hewitson S, Quinby P. 2004. Habitat Use by American Marten in Temagami, Ontario: Preliminary Implications for the Marten Habitat Suitability Index Model and Management Guidelines. Forest Landscape Baselines. Brief Progress and Summary Reports. No. 24. Toronto, Ontario: Ancient Forest Exploration & Research.
- Hokit GD, Brown A. 2006. Distribution Patterns of Wood Frogs (*Rana Sylvatica*) in Denali National Park. *Northwestern Naturalist* 87: 128-137.
- Horne MT, Dunson WA. 1995. The Interactive Effects of Low pH, Toxic Metals, and DOC on a Simulated Temporary Pond Community. *Environmental Pollution* 89(2): 155-161.
- Horne AJ, Goldman CR. 1994. Limnology. Second Edition. New York, New York (United States): McGraw-Hill Inc.

Hossack BR, Corn PS. 2005. Lack of Significant Changes in Herpetofauna of Theodore Roosevelt National Park, North Dakota, Since the 1920s. *The American Midland Naturalist* 154: 423-432.

Houlahan JE. 2002. The Effects of Adjacent Land-use on Water Quality and Biodiversity in Southeastern Ontario Wetlands. PhD. Ottawa, Ontario: University of Ottawa.

Jackson WB. Mammals as Indicators of Environmental Water Quality. 1974. King CC, Elfner LE. Editors. *Organisms and Biological Communities as Indicators of Environmental Quality: a Symposium*. Columbus, Ohio (United States): The Ohio State University.

James JD. 1998. Status of the Columbia Spotted Frog (*Rana luteiventris*) in Alberta. Alberta Wildlife Status Report No. 17. Edmonton, Alberta: Alberta Environment Protection, Fisheries & Wildlife Division, and Alberta Conservation Association.

Jansen A, Healy M. 2003. Frog Communities and Wetland Condition: Relationships with Grazing by Domestic Livestock along an Australian Floodplain River. *Biological Conservation* 109: 207-219.

Joly P, Morand C, Cohas A. 2003. Habitat Fragmentation and Conservation: Building a Tool for Assessing Landscape Matrix Connectivity. *Comptes Rendus Biologies* 326: S132-S139.

Jones K, Ellis R, Hott R, MacArthur B, Utzig-Kutenai G. 2002. A Strategy for Habitat Supply Modeling for British Columbia. Volume II: Appendices. Victoria, BC: R. Keith Jones & Associates.

Kalff J. 2002. *Limnology: Inland Water Ecosystems*. Upper Saddle River, New Jersey (United States): Prentice-Hall, Inc.

Kapustka LA. 2005. Assessing Ecological Risks at the Landscape Scale: Opportunities and Technical Limitations. *Ecology and Society* 10(2): 11-19.

Kelley DB. 2004. Vocal Communication in Frogs. *Current Opinion in Neurobiology* 14: 751-757.

Kendell K. 2002a. Northern Leopard Frog Introduction: Year 3 (2001). Alberta Species at Risk Report No. 42. Edmonton, Alberta: Alberta Sustainable Resource Development, Fish and Wildlife Division.

Kendell K. 2002b. Survey Protocol for the Northern Leopard Frog. Alberta Species at Risk Report No.43. Edmonton, Alberta: Alberta Sustainable Resource Development, Fish and Wildlife Division.

Kolozsvary MB. 1998. Hydroperiod of Wetlands and Reproduction in Wood Frogs (*Rana sylvatica*) and Spotted Salamanders (*Ambystoma maculatum*). PhD. Orono, Maine (United States): The University of Maine.

Knapp RA, Boiano DM, Vredenburg VT. 2007. Removal of Nonnative Fish Results in Population Expansion of a Declining Amphibian (mountain yellow-legged frog, *Rana muscosa*). *Biological Conservation* 137: 11-20.

Knapp RA. 2005. Effects of Non-native Fish and Habitat Characteristics on Lentic Herpetofauna in Yosemite National Park, USA. *Biological Conservation* 121: 265-279.

Knapp RA, Matthews KR. 2000. Non-native Fish Introductions and the Decline of the Mountain Yellow-legged Frog from within Protected Areas. *Conservation Biology* 14(2): 428-438.

Kupchella CE, Hyland MC. 1993. *Environmental Science: Living Within the System of Nature*. Third Edition. Upper Saddle River, New Jersey (United States): Prentice-Hall Inc.

Laposata MM, Dunson WA. 2000. Effects of Spray-Irrigated Wastewater Effluent on Temporary Pond-Breeding Amphibians. *Ecotoxicology and Environmental Safety* 46: 192-201.

Lauck B, Swain R, Barmuta L. 2005. Breeding Site Characteristics Regulating Life History Traits of the Brown Tree Frog (*Litoria ewingii*). *Hydrobiologica* 537: 135-146.

LeeY, Kuo Y, Lin Y, Chu W, Wang H, Wu S. 2006. Composition, Diversity, and Spatial Relationships of Anurans Following Wetland Restoration in a Managed Tropical Forest. *Zoological Science* 23(10): 883-391.

Lee P, Smyth C, Boutin S. 2004. Quantitative Review of Riparian Buffer Width Guidelines from Canada and the United States. *Journal of Environmental Management* 70: 165-180.

Lemckert F, Brassil T. 2000. Movement and Habitat Use of the Endangered Giant Barred River Frog (*Mixophyes iteratus*) and the Implications for its Conservation in Timber Production Forests. *Biological Conservation* 96: 177-184.

Lichtenberg JS, King SL, Grace JB, Walls SC. 2006. Habitat Associations of Chorusing Anurans in the Lower Mississippi River Alluvial Valley. *Wetlands* 26(3): 736-744.

MacArthur D. 1982. Physiological Aspects of Overwintering in the Boreal Chorus Frog (*Pseudacris triseriata maculata*). *Comparative Biochemical Physiology* 72A(1): 137-141.

- MacCulloch RD. 2002. The ROM Guide to Amphibians and Reptiles of Ontario. Toronto, Ontario: Royal Ontario Museum.
- Macdonald SE, Eaton B, Machtans CS, Paszkowski C, Hannon S, Boutin S. 2006. Is Forest Close to Lakes Ecologically Unique? Analysis of Vegetation, Small Mammals, Amphibians, and Songbirds. *Forest Ecology and Management* 223: 1-17.
- Maisonneuve C, Rioux S. 2001. Importance of Riparian Habitats for Small Mammal and Herpetofaunal Communities in Agricultural Landscapes of Southern Québec. *Agriculture, Ecosystems and Environment* 83: 165-175.
- Marsh DM, Fegraus EH, Harrison S. 1999. Effects of Breeding Pond Isolation on the Spatial and Temporal Dynamics of Pond Use by the Tundaru Frog (*Physalaemus pustulosus*). *Journal of Animal Ecology* 68(4): 804-814.
- Marsh DM, Trenham PC. 2001. Metapopulation Dynamics and Amphibian Conservation. *Conservation Biology* 15(1): 40-49.
- Marty JT. 2005. Effects of Cattle Grazing on Diversity in Ephemeral Wetlands. *Conservation Biology* 19(5): 1626-1632.
- Matthews KR, Pope KL, Preisler HK, Knapp RA. 2001. Effects of Nonnative Trout on Pacific Treefrogs (*Hyla regilla*) in the Sierra Nevada. *Copeia* 2001(4): 1130-1137.
- Mitchell P, Prepas E. 1990. Atlas of Alberta Lakes. Edmonton, Alberta: The University of Alberta Press.
- Muths E, Campbell DH, Corn PS. 2003. Hatching Success in Salamanders and Chorus Frogs at Two Sites in Colorado, USA: Effects of Acidic Deposition and Climate. *Amphibia-Reptilia* 24: 27-36.
- National Wetlands Research Center. United States Geological Survey. 2008. Habitat Suitability Index Models Series. Available at <http://www.nwrc.usgs.gov/wdb/pub/hsi/hsiintro.htm> [March 5, 2008].
- National Wetlands Working Group. 1997. The Canadian Wetland Classification System. Second Edition. Waterloo, Ontario: Wetlands Research Centre, University of Waterloo.
- Natural Regions Committee. 2006. Natural Regions and Subregions Of Alberta. Downing DJ, Pettapiece WW. Editors. Edmonton, Alberta: Alberta Ministry of Environment.
- Naylor B, Bellhouse T, Christilaw S. 1994. Development and Validation of a Habitat Suitability Index Model for the American Marten in Central Ontario. Technology Report No. 29. Toronto, Ontario: Ontario Ministry of Natural Resources.

Norris, KC. 2006. The Relationship Between Northern Pike (*Esox lucius*) and Wood Frogs (*Rana sylvatica*) in Boreal Alberta. M.Sc. Edmonton, Alberta: University of Alberta.

Nussbaum RA, Brodie Jr. ED, Storm RM. 1983. Amphibians and Reptiles of the Pacific Northwest. Moscow, Idaho (United States): University Press of Idaho

Olson DH, Anderson PD, Frissell CA, Welsh Jr. HH, Bradford DF. 2007. Biodiversity Management Approaches for Stream Riparian Areas: Perspectives for Pacific Northwest Headwater Forests, Microclimates, and Amphibians. *Forest Ecology and Management* 246: 81-107.

Pagano M, Gauvreau K. 2000. Principles of Biostatistics. Second Edition. Pacific Grove, California (United States): Duxbury.

Parris KM. 2001. Distribution, Habitat Requirements and Conservation of the Cascade Treefrog (*Litoria pearsoniana*, Anura: Hylidae) *Biological Conservation* 99: 285-292.

Parris KM, Lindenmayer DB. 2004. Evidence that Creation of *Pinus radiata* Plantation in South-eastern Australia has Reduced Habitat for Frogs. *Acta Oecologica* 25: 93-101.

Pearson KJ. 2004. The Effects of Introduced Fish on the Long-toed Salamander (*Ambystoma macrodactylum*) in Southwestern Alberta, Canada. M.Sc. Lethbridge, Alberta: University of Lethbridge.

Pellet J, Schmidt BR. 2005. Monitoring Distributions Using Call Surveys: Estimating Site Occupancy, Detection Probabilities and Inferring Absence. *Biological Conservation* 123: 27-35.

Patrick DA, Hunter Jr. ML, Calhoun AJK. 2006. Effects of Experimental Forestry Treatments on a Maine Amphibian Community. *Forest Ecology and Management* 234: 323-332.

Pearson KJ. 2004. The Effects of Introduced Fish on the Long-toed Salamander (*Ambystoma macrodactylum*) in Southwestern Alberta, Canada. M.Sc. Lethbridge, Alberta: University of Lethbridge.

Petranka JW, Harp EM, Holbrook CT, Hamel JA. 2007. Long-term Persistence of Amphibian Populations in a Restored Wetland Complex. *Biological Conservation* 138: 371-380.

Petranka JW, Holbrook CT. 2006. Wetland Restoration for Amphibians: Should Local Sites Be Designed to Support Metapopulations or Patchy Populations? *Restoration Ecology* 14(3): 404-411.

- Petranka JW, Kennedy CA, Murray SS. 2003a. Responses of Amphibians to Restoration of a Southern Appalachian Wetland: Perturbations Confound Post-Restoration Assessment. *Wetlands* 23(2): 278-290.
- Petranka JW, Kennedy CA, Murray SS. 2003b. Response of Amphibians to Restoration of a Southern Appalachian Wetland: a Long-term Analysis of Community Dynamics. *Wetlands* 23(4): 1030-1042.
- Pierce BA, Gutzwiller KJ. 2004. Auditory Sampling of Frogs: Detection Efficiency in Relation to Survey Duration. *Journal of Herpetology* 38(4): 495-500.
- Porej D, Hetherington TE. 2005. Designing Wetlands for Amphibians: the Importance of Predatory Fish and Shallow Littoral Zones in Structuring of Amphibian Communities. *Wetlands Ecology and Management* 13: 445-455.
- Porej D, Micacchion M, Hetherington TE. 2004. Core Terrestrial Habitat for Conservation of Local Populations of Salamanders and Wood Frogs in Agricultural Landscapes. *Biological Conservation* 120: 399-409.
- Puchniak, AJ. 2002. Recovery of Bird and Amphibian Assemblages in Restored Wetlands in Prairie Canada. M.Sc. Edmonton, Alberta: The University of Alberta.
- Rawlasyk KJ. 2004. Habitat Characteristics Associated with Wood Frog (*Rana sylvatica*) Abundance in an Agriculturally Fragmented Landscape. M.Sc. Victoria, British Columbia: Royal Roads University.
- Regosin JV, Windmiller BS, Homan RN, Reed JM. 2005. Variation in Terrestrial Habitat Use by Four Poop-Breeding Amphibian Species. *Journal of Wildlife Management* 69(4): 1481-1493.
- Regosin JV, Windmiller BS, Reed JM. 2003. Terrestrial Habitat Use and Winter Densities of the Wood Frog (*Rana sylvatica*). *Journal of Herpetology* 37(2): 390-394.
- Rittenhouse TAG, Semlitsch RD. 2007. Postbreeding Habitat Use of Wood Frogs in a Missouri Oak-Hickory Forest. *Journal of Herpetology* 41(4): 645-653.
- Rittenhouse TAG, Semlitsch RD. 2006. Grasslands as Movement Barriers for a Forest-associated Salamander: Migration Behaviour of Adult and Juvenile Salamanders at a Distinct Habitat Edge. *Biological Conservation* 131: 14-22.
- Robinson JN. 2001. The Effects of Large Scale Landscape Variables on Amphibian Species at Ponds in Northwestern Ontario. B.Sc. Thunder Bay, Ontario: Lakehead University.

Rodríguez-Prieto I, Fernández-Juricic E. 2005. Effects of Direct Human Disturbance on the Endemic Iberian Frog *Rana iberica* at Individual and Population Levels. *Biological Conservation* 123: 1-9.

Roe JH, Hopkins WA, DuRant SE, Unrine JM. 2006. Effects of Competition and Coal-combustion Wastes on Recruitment and Life History Characteristics of Salamanders in Temporary Wetlands. *Aquatic Toxicology* 79: 176-184.

Romanchuk KA, Quinlan RW. 2006. Magrath Northern Leopard Frog Reintroduction Project: Final Report. Species at Risk Report No. 104. Edmonton, Alberta: Alberta Sustainable Resource Development, Fish and Wildlife Division.

Rubbo MJ, Kiesecker JM. 2005. Amphibian Breeding Distribution in an Urbanized Landscape. *Conservation Biology* 19(2): 504-511.

Sadinski WJ, Dunson WA. 1992. A Multilevel Study of Effects of Low pH on Amphibians of Temporary Ponds. *Journal of Herpetology* 26(4): 413-422.

Semlitsch RD, Bodie JR. 2003. Biological Criteria for Buffer Zones Around Wetlands and Riparian Habitats for Amphibians and Reptiles. *Conservation Biology* 17(5): 1219-1228.

Siegel RA, Dodd Jr CK. 2002. Translocations of Amphibians: Proven Management Method or Experimental Technique? *Conservation Biology* 16(2): 552-554.

Skelly DK. 2004. Microgeographic Countergradient Variation in the Wood Frog, *Rana sylvatica*. *Evolution* 58(1): 160-165.

Skelly DK, Werner EE, Cortwright SA. 1999. Long-Term Distributional Dynamics of a Michigan Amphibian Assemblage. *Ecology* 80(7): 2326-2337.

Smith RL, Smith TM. 2001. *Ecology & Field Biology*. San Francisco, California (United States): Benjamin Cummings.

Squire T, Newman RA. 2002. Fine-Scale Population Structure in the Wood Frog (*Rana sylvatica*) in a Northern Woodland. *Herpetologica* 58(1): 119-130.

Standards and Petitions Working Group. 2006. Guidelines for Using the IUCN Red List Categories and Criteria. Version 6.2. Gland, Switzerland: IUCN – The World Conservation Union.

Statistics Canada. 2007. Portrait of the Canadian Population 2006, 2006 Census: Population and Dwelling Counts, 2006 Census. Census Year 2006. Ottawa, Ontario: Minister of Industry.

Stebbins RC, Cohen NW. 1997. A Natural History of Amphibians. Princeton, New Jersey (United States): Princeton University Press.

Stevens CE, Paszkowski CA, Foote LA. 2007. Beaver (*Castor canadensis*) as a Surrogate Species for Conserving Anuran Amphibians on Boreal Streams in Alberta, Canada. *Biological Conservation* 134:1-13.

Stevens CE, Paszkowski CA, Scrimgeour GJ. 2006. Older is Better: Beaver Ponds on Boreal Streams as Breeding Habitat for the Wood Frog. *Journal of Wildlife Management* 70(5): 1360-1371.

Stevens CE, Paszkowski CA, Stringer D. 2006. Occurrence of the Western Toad and its Use of 'Borrow Pits' in West-Central Alberta. *Northwestern Naturalist* 87:107-117.

Stevens CE. 2005. The Role of Beaver in Amphibian Ecology and Conservation in the Boreal Foothills. PhD. Edmonton, Alberta: University of Alberta.

Storfer A. 2003. Amphibian Declines: Future Directions. *Diversity and Distribution* 9: 151-163.

Stuckey RL. 1974. Submersed Aquatic Vascular Plants as Indicators of Environmental Quality. King CC, Elfner LE. Editors. *Organisms and Biological Communities as Indicators of Environmental Quality: a Symposium*. Columbus, Ohio (United States): The Ohio State University.

Takats L, Priestley C. 2002. Alberta Amphibian Call Surveys. A Pilot Year. Final Report. Alberta Species at Risk Report No. 53. Edmonton, Alberta: Alberta Sustainable Resource Development, Fish and Wildlife Division.

Thiemann GW, Wassersug RJ. 2000. Patterns and Consequences of Behavioural Responses to Predators and Parasites in *Rana* Tadpoles. *Biological Journal of the Linnean Society* 71: 513-528.

Timm BC, McGarigal K, Compton BW. 2007. Timing of Large Movement Events of Pond-breeding Amphibians in Western Massachusetts, USA. *Biological Conservation* 136: 442-454.

Urbina-Cardona JN, Olivare-Pérez M, Reynoso VH. 2006. Herpetofauna Diversity and Microenvironment Correlates across a Pasture-edge-interior Ecotone in Tropical Rainforest Fragments in the Los Tuxtlas Biosphere Reserve of Veracruz, Mexico. *Biological Conservation* 132: 61-75.

Vasconcelos D, Calhoun AJK. 2006. Monitoring Created Seasonal Pools for Functional Success: a Six-Year Case Study of Amphibian Responses, Sears Island, Maine, USA. *Wetlands* 26(4): 992-1003.

- Watt RW, Baker JA, Hogg DM, McNicol JG, Naylor BJ. 1996. Forest Management Guidelines for the Provision of Marten Habitat. Version 1.0. Sault Ste. Marie, Ontario: Queen's Printer for Ontario.
- Wetzel RG, Likens GE. 2000. Limnological Analyses. Third Edition. New York, New York (United States): Springer-Verlag New York, Inc.
- Weyrauch SL, Amon JP. 2002. Relocation of Amphibians to Created Seasonal Ponds in Southwestern Ohio. *Ecological Restoration* 20(1): 31-36.
- Wicknick JA, Anthony CD, Reblin JS. 2005. An Amphibian Survey of Killbuck Marsh Wildlife Area, Ohio. *Ohio Journal of Science* 105(2): 2-7.
- Wiken E, Cinq-Mars J, Padilla M, Latsch C, Moore, H. 2003. The State of Canadian Wetlands: Building a Conservation Strategy. Rubec CDA. Editor. Wetland Stewardship in Canada: Contributed Papers from the Conference on Canadian Wetlands Stewardship. Ottawa, Ontario: North American Wetlands Conservation Council.
- Wilkinson L, Berg G. 2004. Research Amphibian Numbers in Alberta (RANA): 2004 Provincial Summary. Alberta Species at Risk Report No. 95. Edmonton, Alberta: Alberta Sustainable Resource Development, Fish and Wildlife Division.
- Wilhm JL. 1974. Biological Approaches to Water Pollution Problems. King CC, Elfner LE. Editors. *Organisms and Biological Communities as Indicators of Environmental Quality: a Symposium*. Columbus, Ohio (United States): The Ohio State University.
- Wilson S, Griffiths M, Anielski M. 2001. The Alberta GPI Accounts: Wetlands and Peatlands. Report No. 23. Drayton Valley, Alberta: The Pembina Institute.
- Woodford JE, Meyer MW. 2003. Impact of Lakeshore Development on Green Frog Abundance. *Biological Conservation* 110: 277-284.
- Young JE, Sánchez-Azofeifa GA, Hannon SJ, Chapman R. 2006. Trends in Land Cover Change and Isolation of Protected Areas at the Interface of the Southern Boreal Mixedwood and Aspen Parkland in Alberta, Canada. *Forest Ecology and Management* 230: 151-161.
- Young BE, Stuart SN, Chanson JS, Cox NA, Boucher TM. 2004. *Disappearing Jewels: the Status of New World Amphibians*. Arlington, Virginia (United States): NatureServe.
- Zar JH. 1974. *Biostatistical Analysis*. Englewood Cliffs, New Jersey (United States): Prentice-Hill, Inc.
- Zedler JB. 2000. Progress in Wetland Restoration Ecology. *Tree* 15(10): 402-407.

Zielinski WJ, Truex RL, Dunk JR, Gaman T. 2006. Using Forest Inventory Data to Assess Fisher Resting Habitat Suitability in California. *Ecological Applications* 16(3): 1010-1025.

Zolman JF. 1993. *Biostatistics. Experimental Design and Statistical Inference*. New York, New York (United States): Oxford University Press.