**University of Alberta**

# The distribution and abundance of amphibians across land-use types in Alberta's Aspen Parkland

by

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# ABSTRACT

Alteration and loss of habitat are likely major causes of declining amphibian populations worldwide. The objective of this study was to assess amphibian habitat-use in the highly modified Aspen Parkland of central Alberta, Canada. Small ponds, classified as crop, pasture, residential or "natural" based on surrounding land-use, were surveyed for amphibians using auditory call surveys and live traps. Local, pond-level and landscape-level habitat features were also measured. Relative abundances of wood frog and boreal chorus frog were lowest in crop and pasture ponds, western toad abundance was greatest at "natural" and pasture ponds, and tiger salamander abundance was greatest within crop ponds themselves. The Canadian toad was extremely rare. Several landscape and some local habitat features were strongly associated with relative abundances of frogs and the tiger salamander. Results suggest that land-use types vary in their suitability as amphibian habitat and landscape-level features significantly influence amphibian abundance.

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# CHAPTER 1: GENERAL INTRODUCTION

Recent evidence suggests that, worldwide, populations of a variety of amphibian species are declining (Barinaga 1990; Blaustein and Wake 1990: Wake 1991: Houlahan et al. 2000; Green 2003). For example, the western toad (*Bufo boreas*) appears to be declining in some parts of its North American range (Carey 1993; Fisher and Shaffer 1996), and tiger salamander (*Ambystoma tigrinum*) populations in southwestern United States and isolated populations in southern British Columbia are now considered endangered (Cannings et al. 1999; Fish and Wildlife Service 2003). There are 43 species of amphibians in Canada, 18 of which are currently classified as endangered, threatened or of special concern (COSEWIC 2003).

In the Beaverhillls region of central Alberta, there were historically 6 species of amphibians: tiger salamander, wood frog (*Rana sylvatica*), boreal chorus frog (*Pseudacris maculata*), northern leopard frog (*Rana pipiens*), western toad, and Canadian toad (*Bufo hemiophrys*). Tiger salamander, wood frog and boreal chorus frog populations are currently considered "secure" in Alberta (i.e. not at risk of extinction; Alberta Environment 2000). The northern leopard frog was present in the Beaver Hills, but severe declines over the past few decades have greatly reduced its range in Alberta (Wagner 1997; Russell and Bauer 2000), probably eliminating it from the Beaver Hills region. The northern leopard frog is currently "at risk" of extinction in Alberta (i.e. populations have declined, or are believed to have declined, to non-viable levels; Alberta Environment 2000). The western toad, which only occurs in the central and southwestern portion of Alberta, has recently been listed as "sensitive" due to population declines in some parts of its North American range (i.e. not currently at risk of extinction, but may require special attention or protection to prevent it from becoming at risk; Alberta Environment 2000). The Canadian toad has also largely disappeared from the central and southern portions of its provincial range, and now "may be at risk" of extinction in Alberta (i.e. particularly vulnerable because of non-cyclical declines in population or habitat, or reductions in provincial distribution; Hamilton et al. 1998; Alberta Environment 2000).

Although the exact causes of global amphibian declines are unknown, a variety of explanations exist. These include habitat loss and alteration, ultraviolet radiation, pathogens, pollution from acid precipitation, fertilizers, herbicides and pesticides, introduction of exotic species, and the harvesting of amphibians for scientific supply, the pet trade, and human consumption (Harte and Hoffman 1989; Johnson 1992; Carey 1993; Blaustein et al. 1994; Fisher and Shaffer 1996; Duellman 1999; Adams 2000; Hayes et al. 2002). The synergistic effect of one or more of these factors may also be a cause of population declines (e.g. Kiesecker et al. 2001; Christin et al. 2003). In many cases, the reality and severity of declines cannot be substantiated due to the lack of long-term data and the significant natural fluctuations in population size documented in "healthy" amphibian populations (Pechmann et al. 1991; Pechmann and Wilbur 1994).

Amphibians are considered good indicators of their environment (Wake 1991). The permeable nature of their skin makes them particularly sensitive to changes in their environment (Duellman and Trueb 1994), such as the introduction of contaminants or changes in climatic conditions. Furthermore, unlike the majority of other vertebrates, many species of amphibians are dependent on both freshwater and terrestrial environments. As a result, variations in amphibian distribution, both spatially and temporally, may be indicative of changes in the distribution of other wildlife species relying on these same aquatic and terrestrial ecosystems.

The Beaver Hills region is located within the Aspen Parkland Ecoregion of central Alberta. The Aspen Parkland is a transition zone between the moister forested Boreal Plains Ecozone to the north and the drier grasslands of the Prairies Ecozone to the south (Environment Canada 1996). The Beaver Hills region lies at the northern edge of the Aspen Parkland Ecoregion and is defined by an area of greater elevation owing to glacial activity that formed a moraine. Due to the unique climatic and vegetation characteristics of the Beaver Hills, this region has also been classified as an isolated patch of Dry Mixedwood more typical of the Boreal Forest Natural Region (Zelt and Glasgow 1976; Alberta Environmental Protection 1997a). Since the Dry Mixedwood classification does not reflect current vegetation conditions (due to extensive clearing in the region) but rather expected conditions given the climate, topography and soils (Zelt and Glasgow 1976), we will identify the Beaver Hills as Aspen Parkland. This same Aspen Parkland vegetation classification is also used by Environment Canada (1996).

The dominant vegetation in the Beaver Hills consists of trembling aspen (*Populus tremuloides*), and balsam poplar (*Populus balsamifera*; Alberta Environment Protection 1997b). The soil types include black and dark brown chernozems and dark gray luvisols (Alberta Environment Protection 1997b). The chernozems, and to a lesser extent the luvisols, have a high organic content, and thus are excellent for agricultural production (Alberta Environment Protection 1997a). In this region, the mean annual temperature is 2°C with an average of 95 frost-free days, and the total annual precipitation is approximately 350 to 450 mm (Alberta Environmental Protection 1997b).

Over the last several hundreds of years, the Beaver Hills region has undergone extensive modifications. Prior to European settlement, 3 factors influenced this landscape: (i) a large number of beavers (*Castor canadensis*) that manipulated streams and waterbodies, (ii) large ungulates, particularly bison (*Bison bison*) that created large open meadows through extensive browsing, and (iii) indigenous people, who used fire to maintain open areas to attract bison (Parks Canada 1999). In the 1890's, Europeans settled in the Beaver Hills and further contributed to the modification of this landscape by removing trees (for fuel, building supplies and agricultural purposes), suppressing fire, reducing beaver populations and eliminating bison (Kemper 1976).

Today, some of the primary land-uses in the Beaver Hills include livestock grazing and crop production. In Strathcona County - the county comprising the largest area within the Beaver Hills - 62% of the land area is in crop production (64,600-ha) and 29% of the land is used as pastures (30,000-ha; Toma and Bouma Management Consultants and Stantec Consulting 2003). An increase in the population of this region has also led to the development of numerous rural residential estates, particularly in Strathcona County where the rural population increased almost 14% between 1993 and 2001, and is projected to increase another 9% by 2006 (Strathcona County 2002). There are also a number of protected areas within the Beaver Hills including Elk Island National Park (EINP) and Ministik Lake Game Bird Sanctuary. EINP is a 19,400-ha federal reserve with a large population of ungulates, notably bison, wapiti (*Cervus canadensis*) and moose (*Alces alces*). Ministik Lake Game Bird Sanctuary is a smaller, 7,350-ha provincial reserve established to provide protection and habitat for birds (Kemper 1975). The sanctuary is used primarily for hiking and snowmobiling, and restricted access has limited human disturbance within the reserve (Alberta Environmental Protection 1997c).

The alteration of the Beaver Hills landscape by humans has affected both aquatic and terrestrial ecosystems. There are increasingly fewer wetlands in the Aspen Parkland Ecoregion. Between 1970 and 1990, 21 to 48% of wetlands were lost, largely due to drought and drainage for agricultural purposes (Alberta Environmental Protection 1996). Terrestrial systems are also being altered by such factors as forest removal and the loss of natural grasslands. It is estimated that 85 to 95% of the original Aspen Parkland has been lost due to agriculture and urbanization (Alberta Environmental Protection 1997b). The Aspen Parkland is now viewed as an endangered ecosystem owing to extensive fragmentation, alteration and loss (Rowe 1987).

This thesis consists of 2 additional chapters: Chapter 2, which is the main focus of the thesis, and Chapter 3, which provides a general summary of the thesis. Chapter 2 addresses the following questions regarding habitat use by pond-breeding amphibians in the Beaver Hills:

(i) What species are currently present in the Beaver Hills landscape and what is the relative abundance of these species?

(ii) How does amphibian abundance differ over a gradient of land-uses that vary in the extent and nature of disturbance to native vegetation?

(iii) What features of the terrestrial and/or aquatic habitat at the local and landscape level are most important in influencing amphibian abundance?

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# CHAPTER 2: AMPHIBIAN HABITAT USE

## Introduction

Alteration and loss of habitat are likely major causes of declining amphibian populations worldwide (Johnson 1992; Blaustein et al. 1994a; Alford and Richards 1999). A variety of other factors, such as ultraviolet radiation, pathogens, pollution, and non-native species have also been suggested as playing a role in population declines (Harte and Hoffman 1989; Carey 1993; Blaustein et al. 1994b; Fisher and Shaffer 1996; Adams 2000; Kiesecker et al. 2001; Hayes et al. 2002). In much of North America and Europe, amphibians exist in fragmented human-altered landscapes (e.g. Baker and Halliday 1999; Kolozsvary and Swihart 1999; Guerry and Hunter 2002). Such altered landscapes may represent unsuitable habitat for some amphibians, notably pond-breeding species. Pond-breeding species often have widely fluctuating populations (Marsh 2001) and may rely on dispersing individuals for persistence in the landscape. As a result, they may be more susceptible to population declines in human-fragmented landscapes, where dispersal is difficult (Green 2003). The conservation of amphibians in such modified landscapes depends on assessing their patterns of abundance and understanding how anthropogenic disturbances are affecting amphibian habitat use.

Characteristics of the "local" pond habitat (i.e. the aquatic environment and area immediately surrounding it) are important for some amphibian species due to the necessity of ponds for breeding. Many of these pond-breeding species are further dependent on this local habitat because they are philopatric, returning to the same pond (for some species, their natal pond) to breed in subsequent years (Sinsch 1990; Pough et al. 2001). Amphibians will often migrate between areas to find appropriate sites for hibernation, breeding, and summer use (Sinsch 1990). Movements between these areas may be especially restricted in highly altered and fragmented landscapes (Rothermel and Semlitsch 2002), increasing the utilization and importance of the breeding pond and its immediate surroundings.

Specific local habitat features of the pond and area immediately surrounding it may influence the distributional patterns of pond-breeding amphibians. Species may select habitat characteristics that provide favourable conditions for breeding and/or foraging. For example, physical attributes of a waterbody, such as its size and hydroperiod, can affect the growth rate and time to metamorphosis of larval amphibians (Loman 2002a); such features have also been correlated with amphibian abundance and species richness (Laan and Verboom 1990; Richter and Azous 1995; Findlay and Houlahan 1996; Babbitt and Tanner 2000; Lehtinen and Galatowitsch 2001). Some pond-breeding amphibians will favour small, semi-permanent waterbodies because less permanent ponds can limit the successful production of metamorphs whereas large, permanent ponds often contain fish predators (Skelly 1997; Semlitsch and Bodie 1998). Fish can predate directly on amphibians and affect the species richness and abundance of amphibians in a pond (Hecnar and M'Closkey 1997; Smith et al. 1999), or they can compete for similar food resources and affect the growth and activity of some amphibian species (Figiel and Semlitsch 1990). Aquatic vegetation (i.e. macrophytes, phytoplankton) may also be an important habitat feature for some species. Macrophtyes often provide a substrate for egg attachment and protection for developing larvae (Duellman and Trueb 1994; Tarr and Babbitt 2002), and phytoplankton can be a source of food for larvae of some species (Kupferberg et al. 1994). The chemistry of pond water may also influence amphibian distributions (Hecnar and M'Closkey 1996; Bunnell and Zampella 1999), where changes in water chemistry can cause behavioral changes, abnormalities and even death in some species (Marco et al. 1999; Vatnick et al. 1999).

Of particular importance to pond-breeding amphibians in a multi land-use landscape may be the landform surrounding a pond, which in turn may affect many of the previously described local habitat features. Understanding the effects of varying land-use types on amphibian abundance and distribution is poorly understood. This may be due to the diversity of landscapes that differ in type and intensity of land-uses, and the limited number of studies assessing the effects of various land-use types on amphibian species occurrence, abundance and/or richness (see Anderson et al. 1999; Toral et al. 2001; Woinarski and Ash 2002).

The landscape surrounding a pond may also represent important habitat for some amphibians due to their dependence on these areas for food, shelter and hibernation. Many amphibians can migrate up to 1-km in the landscape (Sinsch 1990); however, these distances can be greater and vary widely between species (e.g. up to 15-km/year for *Bufo marinus*; Easteal and Floyd 1986). Furthermore, habitat at a landscape level may be particularly important for populations of some species due to their structure as metapopulations (Sjogren 1991; Alford and Richard 1999). A metapopulation is defined as a population comprised of several unstable sub-populations that inhabit discrete habitat patches (Hanski 1998). (For pond-breeding amphibians, these sub-populations exist at spatially discrete ponds, where breeding occurs.) Although sub-populations are unstable, migration between patches results in regional stability for the species (Hanski 1998).

As such, certain characteristics of the landscape may be affecting distributional patterns of pond-breeding amphibians. For example, the density of waterbodies in the landscape has been identified as an important characteristic affecting some species (Laan and Verboom 1990; Kolozsvary and Swihart 1999; Lehtinen et al. 1999). This may be because the alteration or loss of waterbodies reduces population size and thus the number of dispersing individuals. Fewer waterbodies in the landscape also increases the distance between waterbodies, which limits the interaction of sub-populations existing at discrete ponds (Semlitsch 2002). Another factor potentially influencing the abundance and distribution of species is the amount of forest in the landscape, a feature that can be positively related to amphibian species richness (Findlay and Houlahan 1996; Hecnar and M'Closkey 1998; Findlay et al. 2001). For some species, forests may provide suitable terrestrial habitat for hibernation or migration between adjacent ponds (Semlitsch 2000; Marsh and Trenham 2001). Amphibian distribution and abundance may also be influenced by the amount and type of land-use within the landscape, such as cropland, pastures (Pearman 1997; Mensing et al. 1998; Ray et al. 2002) or urban areas (Richter and Azous 1995; Knutson et al.1999; Lehtinen et al. 1999). Roads in particular may influence patterns of distribution by acting as barriers to dispersal (Gibbs 1998a; deMaynadier and Hunter 2000).

This study was conducted in the Beaver Hills region of central Alberta, an area that has been extensively modified by human activities and contains a diversity of land-use types. The Beaver Hills is located within the Aspen Parkland Ecoregion, where 85 to 95% of the native vegetation has been lost due to agriculture and urbanization (Alberta Environmental Protection 1997). Furthermore, this area has also experienced major loss of wetlands; it is estimated that the number of small wetlands in the Canadian prairies has been reduced by 70% (Alberta Environmental Protection 1997). The Beaver Hills supports a mosaic of different land-uses, including crop and livestock production, rural residential acreages, as well as recreational and wildlife areas. Despite increasing modification of this landscape, the Beaver Hills is recognized as providing important habitat for a variety of wildlife due to the remaining patches of undisturbed upland area and high density of small waterbodies. These waterbodies have been identified as essential for a significant number of both breeding and staging waterfowl (Kemper 1976; Alberta Environmental Protection 1997). For example, 283 avian species have been recorded in this landscape, 57 of which are considered of special status (Bilyk et al. 1998). In general, small waterbodies are extremely important for maintaining a diversity of plant and animal species (Gibbs 1993; Semlitsch and Bodie 1998).

Five species of amphibians currently occur within the Beaver Hills: wood frog, boreal chorus frog, western toad, Canadian toad and tiger salamander. [The northern leopard frog was historically present in this region, but severe declines over the last several decades have greatly reduced its range (Wagner 1997; Russell and Bauer 2000) and likely eliminated it from the Beaver Hills.] The 5 species that currently occur in the Beaver Hills have different ranges throughout Alberta and North America. The wood frog and boreal chorus frog occur in most parts of Alberta and large portions of North America. The western toad ranges from Alaska south to California and into the western half of Alberta, and the Canadian toad occurs in the eastern half of Alberta and ranges throughout Saskatchewan and southern Manitoba, Canada, as well as north central regions of the United States. The tiger salamander ranges from southern Alberta south through much of the United States and into Mexico (Russell and Bauer 2000). All 5 of these species have a biphasic life cycle, in which an aquatic site is required for breeding and terrestrial areas are used for foraging and hibernation.

The objectives of this study were to address the following questions:

(i) What species are currently present in the Beaver Hills landscape and what is the relative abundance of these species? There has been limited research on amphibians in Alberta, and only a few studies have specifically evaluated populations in the Aspen Parkland (see Burns 1986; Cottonwood Consultants Ltd. 1986; Fisher and Roberts 1994; Puchniak 2002). Aside from an inventory of amphibians in Elk Island National Park by Burns (1986), there have been no previous investigations of amphibians in the Beaver Hills region. Moreover, a general lack of research on amphibians in the past has resulted in a deficiency of baseline data, which is absolutely necessary for understanding amphibian population dynamics and potential future declines (Pechmann et al. 1991; Blaustein et al. 1994a).

(ii) How does the relative abundance of amphibians differ over a gradient of land-use disturbance, and do population characteristics (i.e. body size) differ between land-use types? An *a priori* disturbance framework was used in this study, where amphibians were surveyed over a hypothesized gradient of disturbance based on land-use categories. "High" disturbance was represented by crop, "medium" disturbance was represented by pasture, and "limited" disturbance was represented by rural residential acreages (i.e. residences in relatively unaltered plots of vegetation). "Natural" reference sites were represented by undeveloped private property, Elk Island National Park and Ministik Bird Sanctuary. Land-use types were classified into these various disturbance categories based on the frequency and extent to which natural vegetation had been removed (in terms of both composition and structure), and the perceived effect on amphibian breeding and abundance. The relative abundance across land-use types was assessed for the 5 species of amphibians present in the Beaver Hills.

For all 5 amphibian species, it was expected that relative abundance would increase with decreasing land-use disturbance intensity - i.e. lowest abundance in cropland, followed by pasture, residential and "natural" reference areas. Ponds in fields of crop were hypothesized to support the lowest number of individuals due to likely increased nutrient levels within the ponds (from greater fertilizer use), extensive clearing of natural vegetation, and drier conditions resulting from the open habitat immediately surrounding crop ponds (i.e. lack of woody vegetation). Pasture ponds were expected to provide slightly more suitable habitat due to likely reduced fertilizer use (although still high nutrient inputs from livestock waste), and greater amount of woody vegetation in the upland area around pasture ponds (in the study area, there was a general tendency to leave more woody vegetation on pastures compared to crops). Overall, agricultural practices are known to increase freshwater nutrient levels, as well as reduce aquatic and surrounding terrestrial vegetation (De Solla et al. 2002; Scrimgeour and Kendall 2002), factors that may reduce population size of some amphibians by affecting hatching success and survival to metamorphosis. Residential ponds were expected to support more amphibians than crop and pasture ponds due to the patches of natural vegetation remaining around residential ponds. However, these ponds would contain fewer individuals than ponds in ‘natural’ areas due to the removal of vegetation for residences, lawns and gardens, the use of fertilizers on lawns, and roadside pest spraying.

Body size was expected to decrease with decreasing disturbance intensity since body size has been related to the density of larvae in a pond, where high larval densities can result in smaller individuals (Warner et al. 1991; Loman 2002b).

(iii) What habitat features (i.e. terrestrial and/or aquatic) at the local and landscape level are most important in influencing amphibian abundance? Regression models of habitat use were developed for the wood frog, boreal chorus frog and tiger salamander using data collected from call surveys and pitfall trapping.

Relative to local pond features, habitat features measured at the landscape level were expected to be strongly associated with the relative abundance of all 3 amphibian species. This is because populations of some amphibian species are often structured as metapopulations (Alford and Richards 1999), each comprised of spatially discrete sub-populations existing over a relatively large spatial scale. More specifically, it was hypothesized that the amount of water in the landscape would be significantly associated with relative abundance of all 3 species in our study due to the necessity of multiple waterbodies for maintaining metapopulation dynamics. It was also hypothesized that relative abundance of amphibians would be negatively associated with open cover types such as crop and pastures. Amphibians require suitable terrestrial habitat that facilitates movement between breeding, foraging and hibernation sites, as well as between ponds themselves (Semlitsch 2000). Relative to more closed-canopy forested areas, crop and pasture areas likely provide less suitable habitat due to such factors as increased air temperature and reduced soil moisture (thereby affecting body temperatures; Duellman and Trueb 1994), and reduced leaf litter (used as refugia, and source of invertebrate prey; Semlitsch 2000).

The distribution and habitat requirements of pond-breeding amphibian species in northern grassland environments are relatively understudied and poorly understood. Furthering our understanding of amphibian species' distributions and habitat-use patterns in a highly modified landscape such as the Beaver Hills is especially useful and relevant due to the continued alteration of landscapes in North America and the unknown effects on amphibian distribution and abundance. Furthermore, this study's identification of critical habitat components will provide land managers with essential information necessary for planning and implementing conservation strategies for amphibians in the Beaver Hills and in similar multi-use landscapes.

## Methods

### Study area

All ponds were located in a 196,600-ha area within the Beaver Hills region of the Aspen Parkland Ecoregion, approximately 25-km east of Edmonton, Alberta, Canada (Figure 2-1). The surveyed ponds were within the counties of Beaver, Lamont, Leduc and Strathcona. A distinguishing feature within the Beaver Hills study area is its glacial moraine, a knob and kettle terrain resulting from till deposited at a higher elevation than the surrounding plains (Zelt and Glasgow 1976). There are also a large number of small isolated waterbodies scattered throughout the Beaver Hills (Kemper 1976).

## Site selection criteria

A total of 213 ponds were surveyed over 2001 and 2002 (n = 134 in 2001, n = 150 in 2002, n = 71 in both years). GPS locations in combination with digital air-photos were used to determine the exact location of all surveyed ponds (Appendix A). Ponds were selected based on analysis of air-photos and property maps, ground-level investigations, pond accessibility and landowner permission. Many of the surveyed ponds were located near roads, so that a large number of ponds could be surveyed in a limited period of time.

Selected ponds were isolated (no inflows or outflows), permanent or semi-permanent (holding water until at least July) waterbodies ranging in size from 0.01 to 5.26-ha (mean = 0.85-ha). Naturally formed waterbodies were desired. However, communication with landowners revealed that some ponds (< 5%), although "natural" in appearance, were in fact constructed. Thus, this study included mostly natural ponds but some artificially created ponds that were at least 25 years old.

Based on vegetation surveys at 24 of the 213 ponds, common vegetation in the open water (floating or submerged) included common duckweed (*Lemna minor*), pondweed (*Potamogeton* spp.) and hornwort (*Ceratophyllum demersum*; Johnson et al. 1995). Dominant emergent vegetation species included common cattail (*Typha latifolia*), common great bulrush (*Scirpus lacustris*) and narrow-leaved bur-reed (*Sparganium angustifolium*). Species common around the shorelines included marsh ragwort (*Senecio congestus*), marsh willowherb (*Epilobium palustre*), leafy arnica (*Arnica chamissonis*), narrow-leaved dock (*Rumex salicifolius*), pale persicaria (*Polygonum lapathifolium*), Bebb's sedge (*Carex bebbii*), green sedge (*Carex viridula*), Kentucky bluegrass (*Poa pratensis*), northern reed grass (*Calamagrostis inexpansa*), northern manna grass

(*Glyceria borealis*), reed canary grass (*Phalaris arundinacea*), rough hair grass (*Agrostis scabra*), slough grass (*Beckmannia syzigachne*), tufted hair grass (*Deschampsia caespitosa*), wool-grass (*Scirpus cyperinus*), timothy (*Phleum pratense*), foxtail barley (*Hordeum jubatum*), meadow horsetail (*Equisetum pratense*), Canada thistle (*Cirsium arvense*), stinging nettle (*Urtica dioica*), prickly rose (*Rosa acicularis*) and willow (*Salix* spp.).

In order to capture the range of habitat variability within the Beaver Hills landscape, ponds were selected within a variety of land-use types. Ponds were initially selected and then classified into one of 4 land-use categories: crop, pasture, residential and "natural" (i.e. relatively unaltered reference sites). This classification was based on the dominant land-use type (i.e. greatest area coverage) within a 100-m radius surrounding the pond. Classifications were assigned during initial site selection visits or while conducting call surveys. Ponds that could not be classified during visits were later classified based on air photos.

Of the 134 ponds surveyed in 2001, there were 12 in cropland, 24 in pasture, 11 in rural residential acreages, and 87 in "natural" areas. Of the 150 ponds surveyed in 2002, there were 33 in cropland, 33 in pasture, 30 in rural residential acreages, and 54 in "natural" areas (Appendix A). In 2001, there were relatively fewer ponds surveyed in crop and residential areas due to difficulties in finding suitable ponds within these land-use types. In both years, there were relatively more "natural" ponds surveyed because these ponds were being sampled as part of a secondary study concerning toad populations in EINP.

The primary criterion for selection of crop ponds was that there were crop fields surrounding the ponds. Selected ponds within croplands had crop production during the year the survey was conducted (although likely longer). The surrounding cropland consisted of hayfields and row crops (primarily alfalfa, barley, wheat, and canola). Crop ponds generally had a buffer of natural vegetation (i.e. cattail, bulrush) around their margins. Due to a drought in 2002, 4 of the 33 crop ponds had intermittent livestock grazing between late June and August 2002 as crops were abandoned.

Selection criteria for ponds located in pastures were that (i) there was an area at least 1-ha in size around the pond where cows and/or horses were currently or had recently (within the year) been grazing on the vegetation, and (ii) there were no fences immediately surrounding the ponds to exclude livestock. The grazing intensity around these ponds was estimated to range from 0.4 to 6 animals / ha (where grazing intensity = estimated livestock herd size / pasture area). Livestock herd size was estimated while surveying ponds and pasture area was estimated from air photos.

Rural residential ponds were located within quarter section residential estates (64-ha), which were usually subdivided into several 1 to 2-ha property units. Although the location within a residential estate was the primary criterion for pond selection, residential ponds generally had at least 50% natural aquatic and upland vegetation around the pond edge (the other 50% was usually comprised of lawns, gardens or roads/ditches). In general, the nearest house was located approximately 50-m from each surveyed pond.

Ponds in "natural" areas were located throughout the Beaver Hills in protected areas within EINP and Ministik Bird Sanctuary (69%) and on undeveloped private property (31%). These latter ponds on private property were not located within residential estates (as previously described) and the closest house was at least 150-m away. "Natural" ponds had relatively unaltered, aquatic and upland vegetation for at least 15 to 20-m surrounding the pond.

## Amphibian surveys

To properly assess all life stages, detect all amphibian species at a site and accurately estimate amphibian abundance, a combination of sampling techniques was employed (Parris 1999). In this study, amphibian assemblages were surveyed in 2001 and 2002 using (i) auditory call surveys at 213 ponds, and (ii) live trapping techniques at 24 of these 213 ponds.

### *i. Call surveys*

To estimate the relative abundance of breeding male anurans, call surveys were conducted at a total of 213 waterbodies over both years: 134 ponds in 2001, and 150 ponds in 2002. A total of 71 ponds were sampled in both years. These 71 resurveyed ponds included all 24 trapping ponds as well as 47 ponds that were randomly selected from the 134 ponds surveyed in 2001. The goal was that a minimum of 10 to 13 ponds per land-use type be selected for resurveying. However, some ponds that were randomly selected prior to the field season could not be resurveyed in 2002 due to destruction of ponds for residential developments, inaccessibility due to road closures, and drying of ponds. Thus, the total number of resurveyed ponds in each land-use type was 10 crop ponds, 13 pasture ponds, 11 residential ponds, and 37 "natural" ponds. Relatively more "natural" ponds were resurveyed in 2002 because these ponds were being sampled as part of a secondary study concerning toad populations in EINP.

All ponds were surveyed 3 to 4 times for anurans from 2 May to 29 June 2001, and 8 May to 13 June 2002. These surveys encompassed the duration of the period of male vocalizations for all 4 anuran species in the study area. Preliminary surveys at a few ponds were conducted to identify when to start call surveys. Call surveys at all ponds were initiated when wood frogs (which are the first species to start breeding in the study area) were heard at 3 or more ponds. Call surveys were terminated when western toads were no longer heard over 2 to 3 successive nights.

All 213 ponds were surveyed for wood frogs, boreal chorus frogs, western toads and Canadian toads. However, only a subset of the 213 ponds (total = 180 ponds) was included in wood frog analyses (n = 78 in 2001, n = 148 in 2002, n = 46 both years). This is because in 2001, surveys began on 2 May after wood frogs had already begun calling and due to the large number of sites, some ponds were not surveyed for the first time until late May, when vocalizations of wood frogs may have ended (this was not likely a problem for any other species since boreal chorus frogs call throughout May and June, and the 2 toad species only begin vocalizing around the beginning of June). In 2001, a few ponds in EINP that were first surveyed at the beginning of May were used as "barometers" of wood frog calling activity and visited every 7 to 10-days. During visits around 21 May 2001, calling activity at these ponds had decreased substantially and thus all ponds surveyed after this date were excluded from wood frog analyses. At some ponds retained in analyses, however, it is possible that surveys falsely indicated reduced or no wood frog calling activity because vocalizations at these ponds may have been initiated earlier in the season and thus ended earlier, or had a shorter seasonal duration than “barometer” ponds. For this reason, and because a greater number of ponds were surveyed in 2002, call data from 2002 was considered more reliable than data from 2001.

Call surveys followed the guidelines outlined by the Alberta Amphibian Monitoring Program, where the number of calling males of each species was recorded over a 5-min period (Takats and Kendell 2000). In order for the amphibians to become adjusted to the presence of observers, 5-min was allowed to elapse between arrival at a site and the start of the survey. A numerical rating system was used to rate the density of individual calls, where “0” = no calls heard, “1” = individuals can be counted, (*i.e.* there is space between calls), “2” = calls of individuals can be distinguished, but there is some overlapping of calls, and “3” = full chorus, calls are constant, continuous and overlapping (Bishop et al. 1997; Shirose et al. 1997; Takats and Kendell 2000). On a given evening, surveys were typically conducted by 2 teams (each composed of 2 observers), and each team surveyed approximately 20 to 25 ponds per evening.

All sites were surveyed within a 4-hr period in the evening, 2-hr before and 2-hr after sunset. To reduce potential effects resulting from differences in the time at which a survey was conducted, the order that ponds were visited within the 4-hr survey period was reversed with each subsequent visit (i.e. a pond visited early in the evening during survey round 1, was visited later in the evening during survey round 2). During each visit, air temperature, sky conditions, and wind speed (using the Beaufort Wind Scale; World Meteorological Organization 1970) were recorded. Surveys were not conducted during heavy rains or strong winds.

### *ii. Pitfall & minnow trapping surveys*

Pitfall traps were used at 24 ponds to survey adult and terrestrial young-of-the-year (YOY) amphibians of all species (Heyer et al. 1994). Three pitfall-drift fencing arrays were located at equidistant points around each pond, approximately 20-m upland from the water's edge, depending on the suitability of the area for trap installation (Figure 2-2). Each pitfall array consisted of 4 pitfall traps (12 pitfall traps / pond); 1 trap at the intersection of a Y-shaped arrangement of partially buried polyethylene plastic fence (~ 45-cm high), and the other 3 traps at the end of each 5-m arm of drift fencing. Each pitfall trap (black plastic buckets, 11-L) was topped with a plastic polyethylene funnel with a ~15-cm wide opening. Sponge cubes and water were placed inside to prevent dehydration of captured amphibians. A twig was placed vertically, running from the trap bottom to the funnel mouth, to provide an escape route for small mammals.

At all 6 pasture ponds (and 4 of the crop ponds in 2002), barbed wire was placed around each pitfall array to prevent cattle from destroying the traps. Three large fence posts (2-m tall), set back 1 to 2-m from each of the 3 exterior pitfall traps, were used to support 2 strands of barbed wire that encircled each array.

Minnow traps were installed at the 24 ponds in order to survey amphibians in open water habitat (primarily larval anurans, and both adult and larval tiger salamanders). Three Gee-minnow traps were placed between pitfall arrays along the perimeter of the pond, approximately 1 to 3-m from shore (Figure 2-2). Minnow traps had a 6-mm$^2$ wire mesh. Nylon pantyhose were placed over the sides of the minnow traps to prevent smaller tadpoles from escaping. Styrofoam floats (4 per trap, each 10-cm wide and 15-

cm long) were attached to the sides of the traps so that only ¾ of the trap was submerged in water.

Individual amphibians captured from pitfall and minnow traps were weighed and measured from snout to vent (i.e. snout-vent length, SVL). Captured wood frogs were classified as "adult" (> 25-mm SVL, or ≤ 25-mm if captured before 10 July 2001 and 16 July 2002), "YOY" (having a tail bud, or ≤ 25-mm and captured on or after 10 July 2001 and 16 July 2002) or "larva" (non-metamorphosed individuals restricted to an aquatic environment). Western toads were also classified as either "adult" (> 21-mm SVL), "YOY" (≤ 21-mm and caught on or after 10 August 2001 and 1 Aug 2002) or "larva". These dates that were used to define age classes were determined by examining trapping data of smaller individuals (< 30-mm SVL for wood frogs, < 25-mm for western toads) and taking the average date across all sites where large numbers of these individuals first appeared in pitfall traps. For the wood frog and western toad, "adult" referred to all individuals ≥ 1 year old that may or may not be sexually mature. Due to difficulties in distinguishing between age classes for boreal chorus frogs and tiger salamanders, these species were not classified by age.

All individuals captured had one toe clipped and preserved for future skelotochronological assessment of population demographics. Toes were clipped to include the distal phalangeal joint, and Polysporin antibiotic cream was applied to the digit before releasing the individual. Although trapping ponds were more than 1-km apart, individuals captured from distinct sites had a different toe clipped to determine if migration had occurred between surveyed ponds. No marked animals were ever caught at ponds other than where they were originally clipped and thus movement between trapping ponds was not likely a factor in this study.

Traps were checked every 4 to 10-days, depending on capture rates. During periods when large numbers of YOY were emerging from ponds, sites were checked every 1 to 3-days. Traps were open from 1 June to 28 August 2001, and 16 May to 23 August 2002. Some traps were closed periodically due to destruction by animals in both years, and flooding in July 2001. A pitfall trap was considered closed for half of the trap nights since last being checked if it was crushed, pulled out of the ground or flooded. Similarly, a minnow trap was considered closed for half of the possible trap nights if it was crushed or the 2 trap holes were not completely submerged in water. If the drift fence of a pitfall array was knocked down, then both pitfall traps at either end of the damaged fence were considered closed for half of the trap nights since the last inspection. The catch-per-unit-effort (CPUE) of traps was calculated by dividing the number of amphibians caught by the number of trap nights (1 undisturbed trap open for 24-hrs) multiplied by 100.

### Habitat features

Characteristics of the habitat were measured at both a local and landscape level at 163 of the 213 ponds surveyed for amphibians (35 crop ponds, 39 pasture ponds, 29 residential ponds and 60 "natural" ponds). Only 163 of the 213 ponds were included in analyses because some of the 213 ponds were located relatively close to each other (200-m or more), and thus would have had overlapping landscape buffers. To minimize this overlap, only ponds that were 300-m or more from the nearest surveyed pond were included in analyses (thus, total = 163 ponds). During selection of these 163 ponds, specific criteria were used. When a group of 2 or more ponds less than 300-m apart were present, certain ponds were excluded so that the number of remaining surveyed ponds would be maximized. Ponds were also excluded based on their land-use classification (e.g. residential ponds were always retained due to their rarity in the study). If these criteria were not relevant, ponds were randomly selected. Local habitat features were measured only at 24 of the 163 sites (i.e. the 24 trapping ponds), with the exception of pond area, perimeter, estimated upland vegetation height and estimated cattail/bulrush width, which were measured at all 163 ponds (Table 2-1).

### *i. Landscape features*

The classification of habitat variables was done at the University of Alberta using ArcMap 8.2 (ESRI Inc. 2002). Digital orthophotos of Strathcona county and Elk Island National Park (1:20,000) taken in May 2001 were used when digitizing and classifying the land cover (Appendix A). Scanned air-photos of the remaining landscapes within Beaver, Lamont and Leduc counties were georeferenced using road intersections from a vector road layer as control points (root mean square error ≤ 6.5). These georeferenced air photos were taken in either 1998 (1:30,000) or 2001 (1:20,000; Appendix A).

For each surveyed pond, a buffer was created 1-km from the pond edge using ArcMap 8.2 (ESRI Inc. 2002). The area within each buffer ranged from 314 to 433-ha depending on the pond size. This 1-km buffer was selected to encompass proposed migration distances of all 5 species found in the study area. In general, most anurans will not migrate more than 1-km (Sinsch 1990). Although there has been limited research on migration distances of the species in our study, it is believed that wood frogs migrate an average of 1 to 2-km (Berven and Grudzien 1990), and western toads may migrate an average of 218-m (for males) and 721-m (for females; Muths 2003). With respect to the boreal chorus frog, other species of the same family (Hylidae) are known to migrate at an average rate of 1.2 to 2-km/yr (Kramer 1973; Reimchen 1991). It has been suggested that tiger salamanders will usually not move more than 300-m from an aquatic breeding habitat (Madison and Farrand 1998). Data compiled from 6 species of adult *Ambystoma* salamanders suggested a mean migration distance from the edge of a waterbody to be 125-m (Semlitsch 1998).

The composition of habitat features within each 1-km landscape buffer was evaluated by examining the proportion of 7 cover types of interest. These 7 features, which were digitized and classified from air-photos, were as follows: crop, pasture (grazed or natural grasslands), residential areas (houses/farm buildings and area up to 0.8-ha immediately surrounding them), shrub (vegetation of relatively low height, usually located in agricultural fields or around waterbodies), forest (stands of trees, including fencerows, perceived as taller than 3-m, and > 0.01-ha in size – i.e. the minimum detectable size based on air-photo resolution), and water (lakes, ponds, and dugouts ≥ 0.002-ha in size – i.e. the minimum detectable waterbody based on the air-photo resolution). When digitizing and classifying, a scale of 1:5,000 was not exceeded since the resolution of air-photos varied between the scanned georeferenced air-photos and the digital orthophotos. When the cover type for a particular area was unclear (e.g. pasture versus crop), the land cover classification specified by a satellite-based land cover map of the Beaver Hills was used (Young and Sanchez unpubl. data). This 25-m pixel, raster-based land cover map that was recently classified from a 1998 Landsat image of the area, was not extensively used in our analyses due to the relatively coarse grain size of 25-m and unclassified features potentially important for amphibians. Of particular importance to amphibians are small waterbodies (Semlitsch and Bodie 1998), which are difficult to detect from such a coarse resolution land cover map.

Roads were not digitized because an existing line vector layer of roads was available (Sanchez unpubl. data). The road class included paved roads, gravel roads and rail lines. A new road layer was created from the existing line vector data, in which divided 4-lane paved roads were specified as 20-m wide and all other roads and rail lines were specified as 10-m wide.

Configuration of the landscape was also assessed using nearest neighbour indices, including distance between the surveyed pond and (i) the nearest neighbouring waterbody of ≥ 0.002-ha (size was limited by air photo resolution and the smallest detectable waterbody), (ii) the nearest forest patch ≥ 0.1-ha in area (perceived as a size where conditions of the forest patch would be sufficiently different from conditions in surrounding open-canopy cover types, i.e. pasture, crop), and (iii) the nearest road (paved, gravel or rail line). Nearest neighbour indices were measured from the edge of the surveyed pond to the edge of the nearest waterbody, forest or road within the 1-km radius using the measuring tool in ArcView 3.2 (ESRI Inc. 1996). For 2 ponds, where there was either no forest or road within the landscape buffer, a maximum distance of 1-km was used. For both these sites, the actual distances to the nearest forest/road were only slightly greater (at 1.1-km) than the maximum 1-km distance used, and thus results were not likely affected.

### *ii. Local features*

Features of the surveyed pond and area immediately surrounding the pond (i.e. the local habitat) may be important factors influencing amphibian abundance and distribution. For this reason, local physical, chemical and biological habitat features were assessed, including morphometric characteristics of the pond, water chemistry variables, vegetation characteristics, and the presence of fish.

The area and perimeter of all ponds was determined by first digitizing surveyed ponds from scanned and digital orthophotos and then using the X-tools toolbar in ArcMap 8.2 to calculate the area and perimeter (ESRI Inc. 2002). For the 24 trapping ponds, maximum depth was estimated once per year, from 2 to 5 July 2001 and 10 to 13 June 2002, by sampling the center of the pond using a weighted marked rope (note that the center of the pond may not have been the deepest location in all cases, but was used in this study as a standardized estimate of maximum depth). Also at the 24 trapping ponds, changes in water depth were determined using an upright pole (marked in cm intervals) that was installed approximately 5-m from the shoreline, where it was deep enough to avoid zero readings if the pond diminished in size before the next reading. Depth readings were recorded every 2 to 10-days from 2 July to 28 August 2001, and 2 July to 23 August 2002. Fish were sampled using the same 3 minnow traps used for sampling amphibians. Minnow traps were sufficient for surveying fish in this study since there are only small-bodied fish in the Beaver Hills, the fathead minnow (*Pimephales promelas*) and the brook stickleback (*Culaea inconstans*). All captured individuals were counted and identified to species.

Vegetation characteristics for each pond that are potentially important to amphibians were assessed. An estimate of the average width of cattail and/or bulrush around the edge of the pond was visually approximated in June 2002 for all 163 sites (including ponds surveyed for amphibians in 2001 only). At the 24 trapping ponds, from 5 to 13 August 2002, the actual width of cattail and/or bulrush was measured at 4 equidistant points around the pond using a measuring tape. The average of these 4 measurements was used in data analyses. Based on knowledge of the ponds and the similarity of cattail/bulrush width over both survey years, these same measurements of cattail/bulrush width were used in both 2001 and 2002 analyses. The maximum height of upland vegetation (i.e. grasses, shrubs) located 10-m from the pond edge (i.e. starting where the cattail/bulrush ended) was also visually estimated in June 2002 using an index of 0 to 3, where "0" = 0 to 10-cm, "1" = 10 to 30-cm, "2" = 30 to 60-cm and "3" = > 60-cm. If there were trees in the surveyed region, a code of "3" was used. At the 24 trapping ponds, intensive surveys of upland plant height were also conducted from 13 to 18 August 2001 and 5 to 13 August 2002. Plant height was estimated using Robel pole readings (Robel et al. 1970). Four readings were taken around the pond, 10-m upland from the pond edge in each cardinal direction. The average vegetation height from the 20 measurements for each pond was used in data analyses (each of 4 readings is composed of 5 measurements, thus 20 measurements/pond).

Limnological information was collected twice during each summer: 2 to 5 July and 24 to 28 August 2001, and 10 to 13 June and 29 July to 1 August 2002 at all 24 trapping sites. All samples were taken from the center of the pond, approximately 10-cm below the water's surface by an investigator wearing latex gloves. All samples were analyzed for pH, conductivity, chlorophyll-a, total nitrogen and phosphorus concentrations (University of Alberta Limnology Laboratory). During the first sampling period of 2001 only, conductivity was measured in the field using an Omega PHH-500 Series meter (OMEGA Engineering Inc., Stamford, CT). An estimate of water transparency was also determined using a Secchi disk, with the reading taken at the center of the pond.

For each year, the average value of each limnological variable over both sampling periods was used in the analyses. Averages were used because (i) most variables had means that did not differ significantly between sampling periods (student t-test, $p > 0.05$), and (ii) only a limited number of variables could be included in later regression analyses. Several ponds dried up before the second sampling period (site no. 83 in 2001, site nos. 26, 55 and 70 in 2002), and thus values from the first sampling period were used in analyses. For the 3 ponds that were dry during both sampling periods in 2002 (site nos. 52, 82, and 83), values were derived for these sites by regressing values for each of the 5 habitat variables against all local habitat variables from 2002 (where $n = 21$ ponds) using multivariate regression analyses. The resulting regression equations were then used to derive missing values (see Appendix E Table 3 for values). In 2001, pH for all sites was based on the second sampling period readings since pH was only recorded once that year. For pond no. 83, which had dried up during the second sampling period of 2001, a pH of 8.97 was used based on the results of multivariate regression analysis.

## Data analysis

### *i. Species composition & abundance*

All analyses of amphibian assemblages used one of 2 response variables as a measure of relative abundance: (i) the maximum calling code recorded over the 3 to 4 survey periods for each of the call survey sites (for each year, n = 78 to 150 ponds depending on the species and year; total over both years = 213 ponds), and (ii) the CPUE from each of the 24 pitfall and minnow trapping sites. The maximum calling code recorded for each species was used in analyses rather than the mean because breeding activity for some species may only last for 1 to 2-weeks (Russell and Bauer 2000; personal observation); thus, some species may have vocalized during only one of the 3 to 4 surveys that were conducted over the 6 to 7-week period. Therefore, the mean calling code would have underestimated the abundance of calling males.

All analyses involving call survey data were conducted for each of the 4-anuran species recorded (wood frog, boreal chorus frog, western toad and Canadian toad; Appendix B). Analyses involving trapping data were conducted separately for pitfall and minnow traps, and for each of the 4 species caught (wood frog, boreal chorus frog, western toad, and tiger salamander). Analyses of trapping data were also performed for each age class, where relevant (Appendix B). For example, adults and YOY of both wood frogs and western toads captured from pitfall traps were always analyzed separately due to the relatively large number of YOY captured at some ponds. Wood frogs adults and YOY/larvae captured from minnow traps were also analyzed separately. For the boreal chorus frog and tiger salamander, analyses were conducted for all age classes combined because it was too difficult to distinguish between adult and YOY of these 2 species. Distributions of CPUE for each species and age class were assessed using P-P plots and Shapiro-Wilk normality tests (SPSS 10.1, SPSS Inc. 1999). Data were not normally distributed and thus non-parametric tests were used.

To determine whether trapping data from both years should be combined for analysis, differences in abundance between years were assessed using Wilcoxon's signed rank test (SPSS 10.1, SPSS Inc. 1999). Two species differed significantly in abundance between years at the trapping sites: adult wood frogs ($Z = -3.17$, $p = 0.002$ in pitfall traps) and tiger salamanders ($Z = -2.49$, $p = 0.013$ in pitfall traps). Wood frogs also differed significantly at the call survey sites, $Z = -0.85$, $p < 0.000$, although this was likely due to reduced calling intensity scores in 2001 associated with a later start date. Pitfall and minnow trapping data were thus analyzed separately for each year due to the significant annual variation in capture rates for some species, and because trapping and call surveys began earlier in 2002 than in 2001 (resulting in a more robust dataset for 2002). Separation of datasets between years was also advantageous since it aided in determining whether observed trends were consistent between years.

***Comparison of survey techniques:*** The relationship between relative abundance of wood frogs from the 3 different survey techniques used in this study was examined to address several objectives.

Firstly, was the relative abundance of adults (and thus breeding activity) associated with recruitment of metamorphs? To address this, 3 different linear regression analyses were conducted (i) calling code index was regressed against YOY caught in pitfall traps at the 24 trapping ponds surveyed in 2002 only (call survey data for wood frogs recorded in 2002 was more robust than 2001 data), (ii) calling code index was regressed against YOY/larvae caught in minnow traps at the 24 trapping ponds surveyed in 2002, and (iii) pitfall trap captures of adults were regressed against pitfall trap captures of YOY at all 48 trapping ponds surveyed over 2001 and 2002. (It should be noted that "adults" caught in traps may not necessarily have been sexually mature and able to breed.)

Another reason for comparing survey techniques was to determine whether calling code index was an indicator of the relative abundance of adults at a site. To assess this, the maximum calling code index was regressed against adult pitfall trap captures at the 24 trapping ponds surveyed in 2002.

A third objective was to determine if there was a relationship between aquatic versus terrestrial captures of YOY, and whether hatching success was related to successful emergence of YOY onto land. This was done by regressing pitfall trap captures of YOY against minnow trap captures of both metamorphosing YOY and less developed, fully aquatic larvae. For all of these regression analyses, CPUE data was transformed using ln [CPUE + 0.5].

### *ii. Habitat characteristics*

In total, 3 ordination datasets were analyzed: landscape habitat variables from 163 call-surveyed ponds, landscape habitat variables from 24 trapping ponds, and local habitat variables from 24 trapping ponds in 2001. Ordination techniques were employed to assess (i) if the assigned 4 land-use categories were distinct based on characteristics of the landscape habitat, and (ii) whether ponds within different land-use types differed with respect to local pond habitat features. Analyses to address the first objective used landscape habitat features measured from both the 24 trapping sites and the 163 call-surveyed sites (only 163 of the 213 call survey ponds were included in landscape level analyses due to the minimum 300-m distance between ponds). Analyses for addressing the second objective employed local habitat data measured in 2001 from the 24 trapping ponds.

Environmental variables were assessed for normality using P-P plots and Kolmogorov-Smirnov normality test (for the 163 call sites) and Shapiro-Wilk test (for the 24 trapping sites). Where necessary, habitat variables were transformed to reduce variation and approximate normal distributions necessary for improving the outcome of the ordination (James and McCulloch 1990). Habitat variables were transformed using square root [variable], or ln [variable] (in some cases, ln [variable + 0.5] or ln [variable + 1] was used; SPSS 10.1, SPSS Inc. 2000; Table 2-1). The habitat variables used in the landscape habitat ordinations were: CROP, FOREST, PAST, SHRUB, ROAD, RESID, WATER, NEARWTR, NEARFRST, and NEARRD (see Table 2-1 for definitions). The habitat variables used in the local habitat ordinations were: AREA, PERIM, MAXDEPTH, Δ DEPTH, SECCHI, COND, PH, TP, TN and CHLA.

Detrended Correspondence Analysis (DCA) was conducted on all 3 datasets using PC-ORD 4.17 (MjM Software 1999). Transformed values of SHRUB, RESID, and WATER for some of the ponds were negative, and because there can be no negative values when conducting DCA, all values of SHRUB, RESID, and WATER were further transformed as follows: SHRUB + 4.0, RESID + 1.0 and, WATER + 0.6 (these were the minimum values needed to make data positive). Resulting gradient lengths were less than 2.0 (see Appendix C), indicating that Principal Component Analysis (PCA) was the appropriate ordination technique to use (ter Braak and Šmilauer 1998).

PCA, based on a correlation matrix, was then conducted for all 3 datasets on the original transformed data since values can be negative for PCA (PC-ORD 4.17, MjM Software 1999). Multi-Response Permutation Procedures (MRPP), based on a Euclidian (Pythagorean) distance measure, were used to test for pairwise differences between land-use categories. MRPP is a non-parametric t-test that derives a p-value based on the average of pairwise distance measures between response values (Zimmerman et al. 1985). MRPP analyses were conducted on the raw data matrices. Data was considered significant at $p < 0.05$ and results will be discussed primarily with respect to this significance level. However, a Bonferroni correction was also included to provide a more stringent result by accounting for the number of comparisons made for each land-use type (3), where the adjusted alpha was 0.016 (i.e. $0.05 / 3 = 0.016$).

Ordination is particularly useful because it provides a graphical summary of multivariate data (ter Braak 1995). A biplot was created in SYSTAT 10 (SPSS Inc. 2000) using the scores of the first two ordination axes. Confidence ellipses that enclosed ponds within the same land-use category were then drawn. Ellipses were specified to a default size of $p = 0.683$ and the major axes were determined using the unbiased sample standard deviation of the x and y values (SYSTAT 10, SPSS Inc. 2000). The orientation of the ellipse was based on the sample covariance between x and y values (SYSTAT 10, SPSS Inc. 2000). Each vector of the biplot was derived from the correlation between the habitat variable and scores from each of the two ordination axes. The angle and length of the vector represents the direction and strength of the relationship, respectively. Vector arrows were created using PC-ORD (PC-ORD 4.17, MjM Software 1999) and transposed onto the biplots created in SYSTAT 10 (SPSS Inc. 2000).

To determine whether there were differences in vegetation characteristics (i.e. cattail/bulrush width and upland vegetation height around the pond) among the 4 land-use types, Kruskal-Wallis test was used (SPSS 10.1, SPSS Inc. 2000). Pairwise comparisons of significant results ($p < 0.05$) were made using Nemenyi's test (Zar 1999). Vegetation analyses were conducted on 2001 data only for the 24 trapping ponds.

### *iii. Amphibian-habitat relationships:*

#### *Differences across land-use types*

***Abundance of species:*** To determine whether amphibian abundance differed with land-use type, the calling code and CPUE of each amphibian species was compared across the 4 land-use types using Kruskal-Wallis test (SYSTAT 10, SPSS Inc. 2000). Multiple comparisons of significant results ($p < 0.05$) from the call survey sites were made using Dunn's test for unequal sample sizes (Zar 1999). For the 24 trap sites, pairwise comparisons were made using Nemenyi's test (Zar 1999).

***Annual variation:*** To determine if there was annual variation in amphibian abundance for each of the 4 land-use categories based on trapping results, Wilcoxon's signed rank test was used (SPSS 10.1, SPSS Inc. 1999). Analyses were only conducted for species that differed significantly in overall abundance between years (i.e. wood frog and tiger salamander).

***Body size:*** Further analyses were conducted to explore potential differences in the body size (using SVL) of adult and YOY wood frogs captured across the 4 land-use types in 2001 and 2002. Wood frogs were the only species included in size analyses due to the abundance of this species and its widespread occurrence across all 4 land-use types.

The distribution and normality of SVL was assessed using P-P plots and Kolmogorov-Smirnov test (SPSS 10.1, SPSS Inc. 1999). Data were not normally distributed and thus differences in wood frog SVL captured across land-use categories were analyzed using Kruskal-Wallis test (SYSTAT 10, SPSS Inc. 2000). Pairwise comparisons of significant results ($p < 0.05$) were made using Dunn's test (Zar 1999).

Differences in relative abundance and body size across land-use types were considered significant at $p < 0.05$ and results will be discussed primarily with respect to this significance level. However, a Bonferroni correction was also included to provide a more stringent result by accounting for the number of comparisons made for each land-use type (3), where the adjusted alpha was 0.016.

### *Models of amphibian habitat use*

Regression analyses were used to develop models that identify the most important habitat features influencing patterns of distribution of 3 amphibian species found in the study area. Regressions were conducted for the dataset from the 163 call-survey ponds and from the 24 trapping ponds.

All landscape variables and a subset of local habitat variables were included in regressions of the 163 call-survey ponds (Table 2-1). All local and landscape habitat variables were used for the 24 trapping pond regression models. Where necessary, habitat variables were transformed using the same method as was described for the ordinations. Transformation was not necessary for the $\text{UPVEG}_{\text{MEAS}}$, $\text{CAT/BUL}_{\text{EST}}$, and $\text{CAT/BUL}_{\text{MEAS}}$ (which were not included in ordinations; Table 2-1). To reduce multicollinearity, highly correlated habitat variables with pairwise Pearson correlation coefficients greater than 0.75 ($p < 0.05$) were excluded from regression analyses (Gunst and Mason 1980). This resulted in the exclusion of PERIM, SECCHI, TN and FOREST from regression analyses (Table 2-1). FOREST was highly correlated with CROP (-ve); PERIM was highly correlated with AREA (+ve); SECCHI was highly correlated with MAXDEPTH (+ve), TN (-ve) and TP (-ve); TN was highly correlated with SECCHI (-ve), COND (+ve) and TP (+ve).

***Call survey ponds:*** Ordinal logistic regression using the proportional odds model (McCullagh 1980) was employed to identify important habitat components influencing species abundance based on the calling code recorded at the 163 call-surveyed ponds (SPSS 10.1, SPSS Inc. 1999). In this type of model, the last call code category ("3") was used as a reference category to which each of the intercepts related (there is a separate intercept for each of the comparisons and one coefficient term for each of the independent variables; Kleinbaum and Klein 2002). Analyses were conducted for both the wood frog and boreal chorus frog. The western and Canadian toad could not be analyzed due to their rarity in this study (> 87% of ponds had calling codes of "0"; Appendix D Table 1).

Regression analyses of calling wood frogs used data collected in 2002 only. Data from 2001 was not analyzed here because of the reduced calling intensity of wood frogs likely associated with the later seasonal start to call surveys during that year. For boreal chorus frogs, data from both years was combined using a binary YEAR independent variable. Sites that were sampled in both years were omitted from YEAR02 data and only included as YEAR01 to compensate for the sampling of fewer ponds in 2001.

The proportional odds assumption was assessed using the test of parallel lines (Kleinbaum and Klein 2002), and was found to hold for both anuran species. Model fitting was evaluated using the likelihood ratio test, goodness of fit test and evaluation of Cox and Snell $R^2$. Important habitat variables were determined by assessing coefficient values and associated significant levels.

***Trapping ponds:*** For the 24 trapping ponds, important habitat variables influencing amphibian abundance were identified using forward stepwise multiple regression (SPSS 10.1, SPSS Inc. 1999). The all-possible-regression procedure, although superior in finding the best model, was not used due to the large number of independent variables in our study (Kleinbaum et al. 1988). Regressions were conducted for wood frogs (adults) captured from pitfall traps and tiger salamanders (of all age classes) captured from minnow traps (Appendix B). The trap type was selected based on which trapping method (pitfall or minnow) had the greatest capture rates. Trapped boreal chorus frogs were not analyzed due to their low abundance, and western toads were also not included because they only occurred at a few ponds (n = 4 ponds in 2001, n = 5 ponds in 2002; Appendix D Tables 2, 3). For wood frog and tiger salamander models, dependent variables were transformed as ln [CPUE + 0.5].

Regression analyses of trapping abundance incorporated data from both years (i.e. n = 48 ponds) using a binary YEAR variable, which in turn was recoded as a dummy variable. Analyses were conducted using both years in order to increase the sample size and produce a model that identified important habitat variables over both years.

Resulting models were checked for influential cases using standard regression diagnostics, and although most models had 1 to 3 influential cases, regressions without these cases did not sufficiently change model coefficient values to warrant their removal. The assumption of no multicollinearity was assessed using variance inflation factor (VIF) and tolerance statistics (=1/VIF; Kleinbaum et al. 1988). Assumptions of homoscedasticity and normality among residuals in the model were assessed using histograms and P-P plots (Kleinbaum et al. 1988). Independence of residuals was assessed using the Durbin-Watson test statistic (Kleinbaum et al. 1988). Comparison of adjusted $R^2$ was used to select for the best model for each species. Important habitat variables for each species were determined using coefficient values and significance levels of each independent variable.

The regression models for species abundance using both the trapping dataset and the call-survey data were not validated. This is because the models in this study were developed to identify important habitat features influencing amphibian abundance, and as such are more exploratory rather than confirmatory. Thus, models in this study are specific for amphibians in the Beaver Hills and further research would be required to confirm whether results could be generalized for other populations.

## Results

### Species composition & abundance

#### *i. Call surveys*

Five species of amphibians were detected in this study: wood frog, boreal chorus frog, western toad, Canadian toad and tiger salamander. The wood frog and boreal chorus frog were the most common species detected during call surveys (Figure 2-3). Call surveys in 2001 indicated relatively low wood frog abundance (i.e. 76% of ponds had maximum calling codes of "0" or "1", whereas 24% of ponds had maximum calling codes of "2" or "3"; Appendix D Table 1) compared to wood frog abundance in 2002 (where 45% ponds had maximum call codes of "0" or "1", and 55% ponds had maximum call codes of "2" or "3"). In both years, there was a higher percentage of ponds with boreal chorus frog calling codes of "2" or "3" (60% in 2001, 63% in 2002) than ponds with calling codes of "0" or "1". Western toads were much less common and Canadian toads were heard calling only in 2001. When present, western and Canadian toads were recorded at a calling code of only "1".

### *ii. Trapping surveys*

Wood frogs were the most widespread species at the 24 trapping ponds in both years (Figure 2-3). Tiger salamanders were slightly less widespread, followed by boreal chorus frogs and western toads. No Canadian toads were captured in traps.

In 2001, a total of 3,663 individuals were caught in pitfall and minnow traps (3,488 wood frogs, 23 chorus frogs, 36 western toads and 116 tiger salamanders; Appendix D Table 2). In 2002, a total of 2,245 individuals (2,044 wood frogs, 28 chorus frogs, 97 western toads and 76 tiger salamanders) were captured (Appendix D Table 3). In both years, no Canadian toads were caught and western toads were caught only in pitfall traps.

### *iii. Comparison of survey techniques:*

For wood frogs, there was clear agreement between a variety of measurements of abundance and reproductive activity. Regressions of relative abundance of adult wood frogs from pitfall trapping indicated significant positive relationships with both YOY pitfall trap captures and calling code index (Table 2-2). The relative abundance of YOY from pitfall trapping was also significantly correlated with relative abundance of

YOY/larvae from minnow traps. There was also a positive association between maximum calling code index and the relative abundance of YOY from pitfall and minnow traps, although results were not significant.

## Habitat characteristics

### *i. Landscape features*

The ordination plot of landscape variables from the 163 sites indicated relatively good separation of crop, residential and "natural" ponds from each other, whereas pasture ponds did not appear to be distinct from the other land-use categories (Figure 2-4). However, MRPP results indicated all 4 land-use categories to be significantly different from each other (Table 2-3). These MRPP results were also significant at the Bonferroni corrected p-value of 0.016.

Ordination of the 24 trapping sites indicated that crop, residential and "natural" sites were each tightly clustered and separated from each other, but only "natural" ponds were well separated from pasture ponds based on landscape habitat features (Figure 2-5). MRPP results indicated all land-use types were significantly different from each other with the exception of pasture versus residential ponds (Table 2-3). However, when considering a Bonferroni correction, there were also no differences between pasture and crop ponds, and likewise between residential and "natural" ponds (Table 2-3). Results from both the ordination plot and MRPP tests indicated that "natural" ponds were distinct from crop, pasture and residential ponds.

Ordination biplots of both the 24 and 163 pond datasets indicated that crop, residential and "natural" ponds were each characterized by different important landscape habitat features (Figures 2-4, 2-5). Relative to other land-use types, crop ponds were located far from a forest patch and had large amounts of cropland in the surrounding landscape, pasture ponds had large amounts of pasture in the surrounding landscape (although this was only observed in the 163 pond ordination plot), residential ponds were surrounded by large amounts of road and residential areas (i.e. houses/farms), and "natural" ponds had large amounts of forest, shrub and water in the landscape.

The dominant habitat features in the 1-km landscapes differed among land-use types. Landscapes around crop ponds were composed primarily of cropland (53%), landscapes around pasture ponds were composed primarily of both forest (33%) and pasture (30%), whereas landscapes around residential and "natural" ponds were each composed primarily of forest (42% and 52%, respectively; Table 2-4).

### *ii. Local features*

Overall, ponds were small, shallow, somewhat basic, and slightly brackish (conductivity = 500 to 2,000-μS/cm; Steward and Kantrud 1971; Table 2-4). On average, surveyed ponds were hypereutrophic in both years based on total phosphorus (>100-μg/L) and total nitrogen concentrations (> 1,500-μg/L). However, chlorophyll-a readings indicated ponds in 2001 were eutrophic (7 to 40-μg/L) and in 2002 were hypereutrophic (> 40-μg/L; Forsberg and Ryding 1980; Wetzel 1983; Table 2-4). At the 163 call survey ponds, the average height of upland vegetation was ranked as 1.74 (i.e. between 10 to 60-cm), and for the 24 trapping ponds the average maximum height of upland vegetation was 39-cm and 54-cm in 2001 and 2002, respectively (Table 2-4). All ponds supported several meters of cattail/bulrush vegetation around the shoreline, with values ranging widely for both the 163 and 24 pond datasets (Table 2-4). A total of 14 fathead minnows were captured in each year at the same pond (site no. 89, a pasture pond); all other ponds were fishless.

There were differences in local pond features between years. Both the mean and range of conductivity, phosphorus, nitrogen and chlorophyll-a concentrations were greater in 2002 compared to 2001 (Table 2-4). In 2002, the chlorophyll-a values of some ponds in particular (sites nos. 55 crop and 43 "natural") were substantially greater (by > 300-ug/L) compared to 2001 readings (Appendix E Tables 2,3). Similarly in 2002, phosphorus concentrations were much higher at crop ponds nos. 55 and 26, and nitrogen concentrations were higher at crop ponds nos. 57 and 26. Mean values for maximum depth and change in depth were similar between years (Table 2-4). The mean value for maximum upland vegetation height was 15 cm shorter in 2002 compared to 2001 (Table 2-4).

Graphical representation of ordination results indicated crop sites to be tightly clustered and well separated from pasture and "natural" ponds (Figure 2-5). MRPP tests of pairwise comparisons indicated that crop and pasture ponds differed significantly from each other (however, this result was not significant with Bonferroni correction; Table 2-3). When considering both ordination and MRPP results, only crop and pasture ponds differed from each other based on local habitat features.

Specific local habitat features were strongly associated with the clustering of certain land-use categories (Figure 2-5). High levels of total phosphorus, nitrogen and conductivity were strongly associated with crop ponds. "Natural" ponds, and to a lesser extent pasture ponds, were deeper and more transparent (i.e. greater Secchi depths) relative to the other land-use types. Although residential ponds were not strongly associated with any particular habitat variable, these ponds did have relatively high phosphorus, nitrogen and chlorophyll-a levels (Table 2-4).

As seen in Table 2-4, there were also differences between land-use types with respect to vegetation features (which were not evaluated in ordinations). At the 24 trapping ponds in 2001, there was a significant difference among land-use types for both the width of cattail/bulrush around the pond ($H = 15.031$, $p = 0.002$) and upland vegetation height ($H = 9.287$, $p = 0.026$). The cattail/bulrush width at crop ponds was significantly greater than at pasture ponds ($q = 3.87$, $p < 0.05$) and "natural" areas ($q = 4.908$, $p < 0.01$). Similarly, the upland vegetation height was significantly greater in residential ponds compared to ponds located in pastures ($q = 3.81$, $p < 0.05$).

In general, ponds within the various land-use categories were more different from each other based on habitat features measured at the landscape level than at the local level.

### Amphibian-habitat relationships: Differences across land-use types

#### *i. Abundance of species*

***Wood frog:*** The relative abundance of calling male wood frogs increased as the intensity of disturbance decreased (Figure 2-6). Overall significant differences between land-use types during call surveys were recorded in both 2001 ($H = 12.06$, $p = 0.007$) and 2002 ($H = 33.62$, $p < 0.000$). Pairwise comparisons of land-use types indicated that in both years, wood frogs were significantly less abundant in crop than "natural" ponds (Table 2-5). In 2002, calling wood frogs were also significantly less abundant in crop compared to residential ponds, and pasture relative to "natural" ponds.

Pitfall trapping results indicated that relative abundance of adult wood frogs tended to increase as disturbance intensity decreased (Figure 2-7). There were significant differences in relative abundance across the 4 land-use types for wood frog adults in 2002 ($H = 15.56$, $p = 0.001$; results were not significant in 2001 although patterns were similar, $H = 6.89$, $p = 0.075$). Pairwise comparisons indicated adult wood frogs in 2002 were significantly less abundant in crop and pasture ponds relative to "natural" ponds (Table 2-5). For wood frog YOY, relative abundance was lowest in crop and pasture ponds, and greatest in residential and "natural" ponds, where overall differences across land-use types were significant in both years ($H = 8.41$, $p = 0.038$ in 2001, $H = 12.71$, $p = 0.005$ in 2002). Pairwise comparisons indicated YOY wood frogs in both years were significantly less abundant only in crop relative to "natural" ponds (Table 2-5).

Minnow trapping results found that in both years, relative abundance of adult and YOY wood frogs was greatest in "natural" ponds relative to the other land-use types (Figure 2-8). Relative abundance only differed significantly between land-use types for YOY/larval wood frogs captured in minnow traps in 2001 ($H = 9.90$, $p = 0.019$), where capture rates were significantly greater in "natural" ponds versus crop ponds (Table 2-5). Similar trends between land-use types were also observed for YOY/larval wood frogs captured in 2002, although differences were not significant ($H = 6.73$, $p = 0.080$). In both years, no YOY or larval wood frogs were caught in minnow traps within crop ponds.

***Boreal chorus frog***: The boreal chorus frog differed significantly in mean calling code across land-use types in both 2001 ($H = 25.82$, $p < 0.000$) and 2002 ($H = 34.41$, $p < 0.000$), where relative abundance increased as the intensity of disturbance decreased (Figure 2-6). In both years, the boreal chorus frog was significantly less abundant in crop versus “natural” ponds; this pairwise comparison also yielded the most significant difference in both years for this species (Table 2-5). In 2001, the boreal chorus frog was also significantly less abundant in crop relative to pasture ponds, and in 2002, less abundant in crop relative to residential, and pasture relative to “natural” ponds.

Pitfall and minnow trap captures of boreal chorus frogs were greatest in “natural” ponds and absent in crop ponds during both years (Figures 2-7, 2-8). However, differences between land-use types were only significant in pitfall traps in 2002 ($H = 7.89$, $p = 0.048$), where relative abundance was significantly less in crop compared to “natural” ponds (Table 2-5).

***Western toad:*** Occurrence of calling western toads differed significantly across land-use types ($H = 8.95$, $p = 0.030$ in 2001 and $H = 9.50$, $p = 0.023$); however, pairwise comparisons between land-use types were not significant. This species was only heard in “natural” areas in 2001 (mean call code ± S.E. = $0.17 \pm 0.040$, $H = 8.95$, $p = 0.030$), and in both “natural” ($0.15 \pm 0.048$), and pasture ponds in 2002 ($0.13 \pm 0.059$, $H = 9.50$, $p = 0.023$).

Pitfall capture rates of adult western toads did not differ significantly between land-use types ($H = 6.64$, $p = 0.084$ in 2001, and $H = 4.85$, $p = 0.183$ in 2002; Figure 2-7). However, adults were consistently more abundant in both years at ponds located in “natural” areas, and to a lesser extent pastures relative to the other 2 land-use types (Figure 2-7). There were also no significant differences between land-use types with respect to pitfall capture rates of YOY western toads ($H = 4.00$, $p = 0.260$ in 2001, and $H = 3.00$, $p = 0.392$). The large numbers of newly metamorphosed western toads present in pasture ponds in 2002 were all caught at one pond (no. 35). Western toads were never heard or caught in crop ponds in either year.

***Canadian toad:*** Canadian toads were heard only at 2 pasture ponds in 2001 (mean call code ± S.E. = 0.09 ± 0.063, H = 9.81, p = 0.020). Pairwise comparisons between land-use types for Canadian toads did not yield significant results.

***Tiger salamander:*** There was no significant difference across land-use types in relative abundance of tiger salamanders captured in either pitfall traps (H = 0.15, p = 0.985 in 2001, and H = 0.68, p = 0.879) or minnow traps (H = 4.80, p = 0.187 in 2001 and H = 5.50, p = 0.139; Figure 2-7). No consistent trend was observed in relative abundance from pitfall traps (Figure 2-7); however, tiger salamander capture rates in minnow traps were greatest in crop ponds and lowest in "natural" ponds during both years of the study (Figure 2-8).

### *ii. Annual variation*

The relative abundance of adult wood frogs caught in pitfall traps was significantly lower in 2002 than in 2001 within crop (Z = -2.02, p = 0.043) and pasture ponds (Z = -2.02, p = 0.043). Capture rates of adult wood frogs in residential and "natural" ponds were also lower in 2002 relative to 2001 although differences were not significant (Z = -1.57, p = 0.116 for residential, Z = -0.73, p = 0.463 for "natural").

Although not statistically significant, pitfall capture rates of wood frog YOY in residential and "natural" ponds were lower in 2002 relative to 2001, whereas minnow trap capture rates of YOY/larvae in residential and "natural" ponds were similar between years (Figures 2-7, 2-8). Tiger salamander pitfall capture rates did not differ significantly between years for any of the land-use types.

### *iii. Body size*

Body size of wood frog adults and YOY differed significantly among the 4 land-use types in both years (adults: $H = 16.63$, $p = 0.001$ in 2001, $H = 36.63$, $p < 0.000$ in 2002; YOY: $H = 333.17$, $p < 0.000$ in 2001, $H = 10.07$, $p = 0.006$ in 2002; Figure 2-9). Pairwise comparisons indicated that adults in 2001 were significantly larger in crop ponds relative to pasture and residential ponds; adults in 2002 as well as YOY in 2001 were significantly larger in crop ponds compared to individuals from any other land-use type (Table 2-6; note that no YOY were captured within crop ponds in 2002). Wood frog YOY were also significantly larger in pasture relative to both residential and "natural" ponds in both years.

## Amphibian-habitat relationships: Models of amphibian habitat use

Multiple regression models were only conducted for frogs and tiger salamanders. Results indicated that the abundance of calling male wood frogs was negatively associated with both the amount of crop in the landscape and the occurrence of short upland vegetation around the pond, and positively associated with the width of the emergent vegetation zone around the pond (Table 2-7). Adult wood frog relative abundance from pitfall traps was positively associated with the amount of water in the landscape, and negatively associated with both the amount of pasture in the landscape and change in pond depth. (Regressions also indicated a year effect, where abundance was significantly greater in 2001 than in 2002.)

Abundance of calling breeding male boreal chorus frogs was strongly negatively related to the amount of crop and pasture in the landscape (Table 2-7). Tiger salamander relative abundance from minnow traps was significantly negatively associated with the amount of water in the landscape, while positively related to the amount of residential area around the pond, the distance to the nearest road and the concentration of chlorophyll-a in the pond.

Overall, regression models of trapped wood frogs and tiger salamanders, in which all local and landscape habitat features were included, indicated that the majority of significant habitat features were measured at the landscape level.

## Discussion

### Species composition & abundance

The wood frog was extremely widespread in the Beaver Hills and based on trapping results, it was the most abundant species. Call surveys indicated that the boreal chorus frog was also widespread and abundant in this region. Other studies agree that these 2 species are common in the Aspen Parkland and are believed to be maintaining healthy populations (Burns 1986; Cottonwood Consultants Ltd. 1986; Fisher and Roberts 1994). The low capture rates of boreal chorus frogs in traps does not represent rarity but was likely a result of this species' ability to climb out of pitfall traps (personal observation) due to its adhesive toe pads (Russell and Bauer 2000).

In this study, western toads were neither widespread nor abundant across surveyed ponds. Similarly, no western toads were recorded during amphibian surveys conducted in other regions of the Aspen Parkland (Fisher and Roberts 1994; Puchniak 2002) suggesting that in the Beaver Hills, this species may be geographically isolated from other portions of its range in Alberta. The closest recorded locations of the western toad are ~ 35-km west of the Beaver Hills, in Edmonton, and ~ 70-km north of the Beaver Hills, in an area south of Lac La Biche (Russell and Bauer 2000). In our study, western toads were found to be largely concentrated in the northern portion of Elk Island National Park, with a few individuals heard and caught in 2002 at ponds located in the southwestern region of the study area. Western toads may have recently colonized the Beaver Hills region, since this species was not recorded during a 1986 inventory of amphibians in the Park and there are no historical records indicating that it occurred there in the past (Burns 1986). The first record of western toads in the Beaver Hills was in 1999, in Elk Island National Park (Paszkowski, pers. comm.) although this species was likely present earlier (Takats, pers. comm.).

Canadian toads were extremely rare in the Beaver Hills, where only 1 individual was heard calling in 2001 at a pasture pond located just east of Elk Island National Park. (Although not included in analyses, 2 to 3 Canadian toads were also heard at Astotin Lake in Elk Island National Park on a single evening in both 2001 and 2002.) Other recent surveys indicated similar results, where no Canadian toads were encountered during surveys of amphibians in Elk Island National Park (1999-2000; Paszkowski, pers. comm.) and at numerous sites ~ 40-km south of the Beaver Hills study area (Fisher and Roberts 1994; Puchniak 2002). Historical records indicate that Canadian toads were once present at several sites in the Beaver Hills region (Hamilton et al. 1998) including Elk Island National Park, where they were described as being fairly widespread before the mid-1980's (Burns 1986). Up until 1986, Canadian toads were believed to be maintaining healthy populations in the province (Cottonwood Consultants 1986). Populations of this species are now likely declining, although a lack of historical data makes this hard to determine (Roberts 1992; Hamilton et al. 1998). The lack of Canadian toad records in the Beaver Hills during our study and again in 2003 (Browne, unpublished data) further supports claims of declining populations. It should be noted that although Canadian toads are uncommon in this landscape at present, their extreme rarity in the present study may be compounded by difficulties in detecting this species. Males often call in scattered small groups of 2 to 3 individuals (Cook 1983).

The tiger salamander was the second most widespread species across the 24 trapping sites, although they were much less abundant relative to the wood frog. Puchniak (2002) recorded similar capture rates of tiger salamanders at other wetlands in the Aspen Parkland. Other studies in this region have found few or no tiger salamanders (Burns 1986, Fisher and Roberts 1994), although this was likely due to unsuitable survey techniques. In general, tiger salamanders are considered widespread and common throughout most of their southeastern Alberta range (Cottonwood Consultants Ltd. 1986; Butler and Roberts 1987).

The northern leopard frog was not observed in this study. Other surveys conducted during the past two decades in various regions of the Aspen Parkland also did not record this species (Burns 1986; Fisher and Roberts 1994; Puchniak 2002). The nearest historical record of the northern leopard frog to one of our surveyed ponds was approximately 10-km (Russell and Bauer 2000), indicating that this species was historically present in this region. Our study's findings provide supporting evidence that northern leopard frog populations have declined in Alberta (Wagner 1997; Russell and Bauer 2000).

***Comparison of survey techniques*:** Results indicated that various survey techniques used in this study for measuring relative abundance of wood frogs were in agreement. For example, the significant positive relationship noted between the calling index of adult males and the pitfall capture rates of adults suggests that calling code is a good indicator of the number of adults at a site (Table 2-2). Furthermore, the strong positive correlation between adult pitfall trap captures and YOY pitfall trap captures suggests that the number of adults at a pond is a good indication of future recruitment. However, the relationship between calling code index and YOY abundance was not as strong, implying that calling rank may be too crude a measure of YOY activity. Interestingly, a study of beaver ponds in west-central Alberta found wood frog calling code index to be positively associated with the number of egg masses (Stevens and Paszkowski 2003, in preparation). Thus, the poor relationship between calling code and YOY abundance in my study may imply that breeding occurs but hatching of eggs and/or development of tadpoles is unsuccessful. The significant positive correlation between pitfall trap and minnow trap captures of larvae/YOY suggests that hatching success is related to successful emergence onto land. Although an analysis of trap captures through time was not performed, in general YOY wood frogs were present in large numbers first in minnow traps followed by pitfall traps 1 to 2-weeks later.

## Habitat characteristics

### *i. Landscape features*

Ponds within the various land-use types were distinct based on features measured in the surrounding landscape. This confirms the underlying "subjective" categorization of land-use types in this study, such that the 4 assigned land-use categories were in fact distinct from each other.

The landscapes surrounding ponds of different land-use types varied in the composition and type of important habitat features, which reflects the extent of human modification in these areas. For example, landscapes around crop ponds have been extensively cleared for agriculture, as indicated by the limited amounts of forest in these areas relative to landscapes around "natural" ponds. The relatively large amounts of water in "natural" landscapes likely reflects the drainage of ponds within the other 3 land-use categories (particularly crop); however, this may also be due to greater beaver activity in "natural" areas, and/or the higher density of waterbodies in Elk Island National Park and Ministik Bird Sanctuary where a large number of "natural" ponds were surveyed.

### *ii. Local features*

With the exception of crop ponds, there was little difference between land-use types with respect to local habitat features (Table 2-3, Figure 2-5). This result implies that pasture, residential and "natural" land-use types immediately surrounding a pond have little effect on features of the pond itself. However, crop ponds were distinct relative to pasture and "natural" ponds because of their hypereutrophic and highly saline pond conditions (Table 2-4). These conditions in crop ponds were comparable to water chemistry results from surveys of other small ponds surrounded by cultivated fields in the Aspen Parkland of Alberta, in which ponds also had similarly high conductivity and phosphorus concentrations (Anderson et al. 2002). The relatively greater nutrient and phytoplankton concentrations in our crop ponds, (and to a lesser extent in residential ponds; Table 2-4), may have been due to greater fertilizer use in these areas. Fertilizers enter the pond via surface runoff and groundwater flow and can greatly alter surface water nutrient levels. Over 1.4-million tones of fertilizer are sold annually to farmers in Alberta; nitrogen-containing fertilizers are the most commonly used (primarily urea, anhydrous ammonia and ammonium sulphate), followed by phosphorus fertilizers (primarily monoammonium phosphate), and lastly potassium fertilizers (muriate of potash; Korol and Rattray 2001).

### Amphibian-habitat relationships: Differences across land-use types

#### *i. Abundance of species*

***Wood frog and boreal chorus frog:*** Results suggest that ponds within cropland, and to a lesser extent pastures, are relatively poor habitat for both the wood frog and boreal chorus frog. These land-use types had fewer individuals of both these species than ponds in "natural" areas and to a lesser extent, residential areas, thereby supporting the hypothesis that land-use disturbance intensity affects the relative abundance of these species.

Results suggest that crop ponds in particular do not provide appropriate breeding habitat for the wood frog. Trapping results indicated that no successful breeding of wood frogs (i.e. recruitment of metamorphs) occurred in crop ponds since larvae and locally produced YOY were never caught there (Figures 2-7, 2-8). A total of 73 wood frog YOY were caught in pitfall traps at crop ponds in 2001, but were all from one site (no. 83) and likely did not originate in this pond. There were no signs of breeding at this particular pond; eggs and tadpoles were absent, and 33 of the 39 "adult" wood frogs caught were small (26 to 29-mm) and probably hatched the previous year (and thus were too young to breed). Furthermore, the majority of YOY frogs (51 of 73) were caught during a short 2-week period in mid-August, much later than the period in mid-July when large numbers of YOY were emerging from other trapping ponds. The wood frogs that were captured in this crop pond may have been migrating from nearby ponds following metamorphosis and emergence onto land. Interestingly, wood frogs (and boreal chorus frogs) were heard calling in crop ponds in both years suggesting that males still come to these ponds in the spring but do not find a mate, or alternatively, breeding occurs but eggs fail to hatch.

There have been limited studies examining the effects of agricultural land-use patterns on amphibians, with most of this research assessing the influence of grazing on species richness and abundance. Contrary to our results, abundances of other ranid (R*ana luteiventris*, found in or near riparian areas) and hylid species (*Litoria caerulea*, which prefers moist forested areas) have been reported to be the same on grazed and "natural" ungrazed sites (Bull and Hayes 2000; Woinarski and Ash 2002). This lack of agreement between these studies and ours may be due to differences in the grazing intensity between study areas, or perhaps the wood frog and boreal chorus frog are more terrestrial and/or more sensitive to grazing activity than these other aquatic-breeding species.

***Western toad:*** The hypothesis that western toad relative abundance would increase with decreasing disturbance intensity was partially supported. Relative abundance was lowest in crop ponds and highest in "natural" ponds, however, pasture ponds supported more individuals than residential ponds (Figure 2-7). This result suggests that crop ponds, and to a lesser extent residential ponds, do not provide suitable habitat whereas "natural" areas, and to a lesser extent pastures, provide better habitat for western toads. Interestingly, ponds in both pasture and "natural" areas were deeper with lower nutrient and phytoplankton levels relative to crop and residential ponds (Table 2-4), suggesting that these may be important characteristics of western toad breeding habitat.

Relative to the other land-use types, "natural" areas may have supported a greater number of individuals due to unique features associated with the northern portion of Elk Island National Park where the majority of western toads were both heard and caught. This area is recognized as unique due to the high density of waterbodies and boreal mixedwood vegetation (in contrast to the more typical Aspen parkland in the southern portion of the park and the rest of the Beaver Hills study region; Parks Canada 1999). It is possible that these waterbodies had specific features associated with them that were preferable for breeding (e.g. greater prey source, unique vegetation types, etc.), or likewise boreal mixedwood vegetation resulted in unique conditions preferred by western toads (perhaps greater canopy cover, more ground litter).

Soil type may have also affected western toad abundance. One pond in particular (pasture no. 35) had a high abundance of western toads and was the only pasture pond surveyed with traps where toads were present. This site was unique among trap survey sites because of the sandy soil surrounding the pond, which may have provided the western toad with an optimal substrate for digging burrows. Other toad species (*Scaphiopus holbrookii holbrookii*) have been shown to dig burrows more easily in sand than other substrates (i.e. soil, gravel; Jansen et al. 2001). Soil type may have also affected the amount of moisture in the microhabitat, which may have explained differences in western toad distribution in the study area. Based on the combination of sandy soil and relatively high abundance of western toads at this pond, it is possible that a communal hibernation site for western toads was nearby (such sites have been recorded for Canadian toads; Kuyt 1991).

Factors other than habitat characteristics, such as predation effects, may have affected capture rates of western toads. Studies have indicated that tiger salamanders prey on larval western toads (Petranka et al. 1994). Thus, the relatively low abundance of tiger salamanders within "natural" ponds relative to other land-use types (Figure 2-8) may have explained the greater capture rates of western toads in this land-use type (Figure 2-7). Tiger salamanders may also have been predators of larval boreal chorus frogs but, due to difficulties in trapping boreal chorus frogs in this study, it was difficult to assess the impact of predation.

***Tiger salamander:*** Tiger salamander abundance did not differ significantly between land-use types but, contrary to the hypothesis, this species showed a trend toward greater abundance within crop ponds than ponds in the other land-use types (Figure 2-8). However, these results were only observed with minnow trap captures, suggesting that either there are certain characteristics associated with the aquatic habitat of ponds within cropland that make them preferred by tiger salamanders, or the terrestrial habitat of cropland is less preferable causing tiger salamanders to confine their activity to the aquatic environment. Other studies indicate that, contrary to our results, ponds in agricultural areas do not provide suitable breeding habitat relative to non-agricultural reference waterbodies for other ambystomids (e.g. decreased hatching success; De Solla et al. 2002). These different results are likely due to differences between study species, or differences between study sites and reference pond conditions.

The relative abundance of tiger salamanders in pitfall traps was not high in crop ponds contrary to what might be expected based on minnow trap capture rates in this land-use type. This may be because individuals were remaining in the ponds to avoid drier terrestrial conditions, or were seeking refuge in underground burrows when on land. Although tiger salamanders are able to dig their own burrows (Semlitsch 1983), they are also known to use pre-existing burrows created by small mammals (Trenham 2001; Kolbe et al. 2002), notably northern pocket gophers (*Thomomys talpoides*; Kristensen 1981). Differences in the prevalence of northern pocket gopher burrows across land-use types may have affected pitfall capture rates; in our study, the total number of northern pocket gophers incidentally captured in pitfall traps were greatest during both years in ponds within pasture (2001 = 16, 2002 = 21) and cropland (2001 = 15, 2002 = 17), followed by residential (2001 = 9, 2002 = 9), and "natural" areas (2001 = 0, 2002 = 4).

***Canadian toad:*** Due to the rarity of Canadian toads in this study, we were unable to assess whether abundance differed across land-use types, and specifically what habitat features were strongly associated with the presence of this species. It has been suggested that Canadian toads utilize a variety of habitats for breeding including lakes, ponds, ditches, borrow pits, and streams, and are often found in moist areas adjacent to waterbodies (Roberts and Lewin 1979; Cook 1984; Russell and Bauer 2000). It is possible that western and Canadian toads have similar breeding and/or terrestrial habitat preferences, and competition for suitable habitat has resulted in the geographical separation of these 2 species. Sites containing individuals of both species have only been recorded at a few localities north of Edmonton (Cook 1984; Eaton et al. 1999).

In general, there were significant differences in amphibian relative abundance across the 4 land-use types, strongly reflected by calling and trapped wood frogs and boreal chorus frogs. Since there were also significant differences across land-use types with respect to terrestrial landscape habitat features, this may imply that in the Beaver Hills, the terrestrial habitat is more important than the aquatic pond habitat in determining amphibian distributional patterns.

### *ii. Annual variation*

The lower rates of wood frog captures in all land-use types in 2002 was likely due to extremely low water levels during that year. Low water levels were the result of a hot dry summer in 2001 and reduced snow cover over the winter of 2001/2002. Furthermore, between May – July, when the majority of surveys were conducted, total precipitation was lower in 2002 (51-mm) than in 2001 (127-mm; Elk Island National Park weather station, National Climatic Data Center, http://www.ncdc.noaa.gov/oa/ncdc.html, accessed 8 July 2003). In general, both study years were dry (total annual precipitation was 202-mm in 2001, and 224-mm in 2002) relative to average annual levels of precipitation for this region, which range from 350 - 450 mm (Alberta Environmental Protection 1997).

It is not clear why the same trend of lower abundance in 2002 was not recorded for calling wood frogs. Although pond levels in spring 2002 were low due to lack of precipitation over summer 2001/winter 2002, the onset of relatively warmer weather was later in 2002 (mid-June) relative to 2001 (beginning of May). [Mean monthly temperatures were 11°C and 13°C in May and June 2001, respectively, compared with 8°C and 16°C in May and June 2002; Elk Island National Park weather station, National Climatic Data Center). This may have resulted in comparable pond water levels in May and June of both years, and thus calling activity did not differ substantially between years. Furthermore, the lack of difference in calling wood frogs between years may also have been due to the later seasonal start to call surveys in 2001 and peak wood frog breeding activity possibly being missed at some ponds.

The significantly lower abundance of adult wood frogs in pitfall traps in crop and pasture in 2002 relative to 2001 suggests that these land-use types provide less suitable habitat for adult wood frogs during periods of drought relative to residential and "natural" ponds. Decreased abundance in 2002 in crop ponds may have been due to the lack of water in these landscapes (at the 24 trapping ponds, crop = 2.4%, pasture = 5.6%, residential = 6.4%, "natural" = 10.8%). This may be due to such factors as tile drainage, in which subsurface pipes remove excess water from the land to improve crop yields. Another feature that may have affected wood frog survival in both crop and pasture ponds during drought conditions was the amount of forest cover in the landscape, which was lower in crop (9.5%) and pasture landscapes (28.4%), relative to residential (42.9%) and "natural" landscapes (55.4%). The increased shade, moisture and leaf litter associated with forests relative to open-canopy crop and pastureland may have provided necessary cool and moist conditions not found elsewhere during dry conditions. A study by Rothermel and Semlistch (2002) found that some amphibians (*Ambystoma* sp.) dehydrate more rapidly in agricultural fields than in forested areas.

With respect to larval and YOY wood frogs, it is unclear why capture rates in minnow traps within residential and "natural" areas were similar between years, despite a decrease in pitfall capture rates (Figures 2-7, 2-8). It is possible that the dry conditions in 2002 (i) did not affect wood frog recruitment in residential and "natural" areas, and metamorphs simply stayed closer to the shoreline where there was more moisture, or (ii) hatching success of larvae was unaffected, but the survival of metamorphs emerging from the ponds was reduced (as evidenced by the low relative abundance of YOY in terrestrial traps in 2002). It is likely that low capture rates were due to the former explanation of reduced activity levels in the terrestrial environment since other studies have also indicated that dry conditions can reduce the number of active wood frogs (Bellis 1962).

### *iii. Body size*

Wood frog adults in both years and YOY in 2001 captured from crop ponds were larger than individuals from any other land-use type (Figure 2-9). Mazerolle (2001) also found differences in body size between land-use types, where wood frogs were larger in fragmented bogs undergoing peat mining than individuals in "natural" bogs.

Although this study did not directly investigate the cause of these differences, there are numerous possible explanations for how individuals in crop ponds reached their larger size. Firstly, conditions were likely warmer both within crop ponds (shallower; Table 2-4) and in the surrounding terrestrial landscape (less forest cover; Table 2-4) relative to the other land-use types. Warmer water temperature is known to increase growth and development rates in some amphibian species (Marian and Pandian 1985), and may have caused individuals from crop ponds to attain larger body sizes more quickly. Secondly, it is also possible that crop ponds represent riskier habitat (i.e. fewer breeding ponds, greater exposure thus greater threat of predation, desiccation, less shelter, etc.) and thus there were fewer individuals inhabiting these areas. With fewer individuals there is less competition for resources, more available food, thereby allowing individuals to attain larger overall body sizes. It may also be suggested that the larger size of YOY wood frogs caught from crop ponds in 2001, and from pasture ponds (relative to residential and "natural" ponds) in both years, may have been related to the number of breeding individuals and subsequently, the number of larvae produced in these ponds. Studies show that high densities of larvae decrease the size of resulting metamorphs, likely due to greater competition for resources among developing larvae (Warner et al. 1991; Loman 2002b). In our study, however, densities of young did not likely explain differences in body size since there was no significant relationship between the mean body sizes of newly metamorphosed wood frogs and capture rates across all ponds ($r = -0.218$, $p = 0.247$ for both years combined). In general, it is not clear whether the mean body sizes of adults in cropland were larger because younger adult frogs were absent at these ponds (due to lower or lack of breeding at these sites, or possibly greater predation) or whether the absolute size of individuals (adult or YOY) was in fact larger than in other land-use types.

It is important to note that larger adults captured in cropland may not necessarily represent older individuals. Body size is often used as an indication of age; however, this may not be a valid association. A review of 93 studies by Halliday and Verrell (1988) found that body size (measured using SVL) was often correlated with age (measured using skeletochronology); however, these relationships were often weak and there were large variances in body sizes within age classes, suggesting that body size is not an accurate index of age.

## Amphibian-habitat relationships: Models of amphibian habitat use

Results suggest that both local and landscape-level terrestrial habitat features influence amphibian patterns of abundance. The majority of habitat variables significantly associated to catch-per-unit-effort of tiger salamanders and wood frogs occurred at the landscape level (Table 2-7), thus partially supporting the hypothesis that relative abundance of these species would be strongly related to landscape (versus local) habitat features. However, 2 of the 3 habitat variables strongly associated with calling wood frog abundance were measured at the local level. (Although all habitat variables significantly associated with calling boreal chorus frog abundance were landscape features as well, regression analysis for this species only included a subset of local habitat variables). The predominance of landscape level features from trapping results indicate that the terrestrial environment may be more important than the aquatic habitat in influencing wood frog and tiger salamander patterns of abundance. Furthermore, these species may be more influenced by habitat at a more regional scale than by features of the breeding pond itself.

For both the wood frog and boreal chorus frog, landscapes with large amounts of crop and pasture may not provide the most suitable habitat. Similar to these results, the occurrence of both these species has been strongly associated with dense ground cover and moist soil conditions (Roberts and Lewin 1979; Constible et al. 2001), factors that are not likely related to conditions in open-canopy habitat types such as crop and pasture. In fact, these microhabitat conditions are likely to occur in more forested areas. In our study, the amount of forest was negatively correlated with the amount of cropland ($r = -0.881$, $p < 0.000$, and thus not included in regression analyses), suggesting that landscapes with large amounts of forest cover may provide important habitat for wood frogs and boreal chorus frogs. Previous studies have also indicated that wood frogs tend to occupy landscapes with extensive forest cover (Gibbs 1998b; Knutson et al. 2000; Guerry and Hunter 2002). Wood frogs likely rely on forested areas for summer foraging and shelter use, winter hibernation, and migration corridors connecting breeding ponds with foraging areas, overwintering sites, and other waterbodies. Although distance to a forest patch was not a significant habitat variable in our models, it was negatively correlated with the relative abundance of wood frog adults in pitfall traps ($r = -0.521$, $p = 0.000$). Breeding ponds that are located near a forest patch may be particularly important for YOY wood frogs, which have been shown to preferentially emigrate towards closed-canopy habitat immediately upon metamorphosis (deMaynadier and Hunter 1999).

The amount of water in the landscape was positively associated with wood frog abundance. Amphibians depend on having moisture in their environment because they need to maintain moist skin for gas exchange, and they lose water easily through their permeable skin (Duellman and Trueb 1994). With respect to population structure, the strong association between wood frog abundance and the amount of water in the landscape may indicate that wood frogs in this region exist as metapopulations. Landscapes with large amounts of water may contain a high density of smaller waterbodies, which is important for pond-breeding species because the distance between ponds is relatively small, thus allowing individuals to easily colonize new ponds and/or rescue declining populations at nearby ponds (Semlitsch 2002). However, this needs to be investigated further since this study did not measure the number of discrete waterbodies in the landscape. Also, the distance of the nearest neighboring waterbody was not strongly associated with wood frog abundance as might be expected; this lack of significance may have been because all surveyed ponds were relatively close enough (i.e. within migration distance) to another waterbody (mean = 122-m; Table 2-4).

The relative abundance of tiger salamanders was significantly negatively associated with the amount of water in the landscape, which may be a reflection of this species tolerance of drier conditions (Russell and Bauer 2000). Results also suggested that proximity to a road negatively influenced tiger salamander abundance. Roads may cause high mortality and limit the dispersal capabilities of many amphibian species (Fahrig et al 1995; Gibbs 1998a; deMaynadier and Hunter 2000). Salamanders in particular are strongly affected by the presence and type of roads compared to anurans (deMaynadier and Hunter 2000).

At the local pond level, results suggest that ponds with less fluctuating water levels that have a relatively large zone of emergent vegetation and relatively tall grasses/shrubs around the pond may be preferred breeding habitat for wood frogs. Ponds with greater emergent vegetation, such as cattail and bulrush, may provide protection for developing larvae since wood frog egg masses are frequently found in more sheltered vegetated areas (Seale 1982). The relatively tall grasses and shrubs around the pond may have been associated with greater abundance because they provide better hibernating sites for wood frogs.

Relative abundance of tiger salamanders was strongly positively related to phytoplankton levels. This may be due to tiger salamanders influencing the trophic structure of their aquatic environment, as has been shown by other studies. Holomuzki et al. (1994) found the presence of tiger salamanders to cause a trophic cascade whereby levels of herbivorous zooplankton (on which salamanders feed) were reduced, and phytoplankton levels increased. Likewise, tiger salamanders may also be indirectly affecting waterfowl densities by competing for similar prey resources (Benoy et al. 2002).

## Conclusion

Five species of amphibians were present in the Beaver Hills (wood frog, boreal chorus frog, western toad, Canadian toad and tiger salamander). All species were either widespread or abundant, except the Canadian toad and to a lesser extent, the western toad. There were differences in relative abundance across the 4 land-use types for each of the species surveyed. Results suggest that ponds within cropland are less suitable habitat for the wood frog and boreal chorus frog, whereas they may provide important habitat for the tiger salamander. Pasture and "natural" areas may represent the most suitable habitat for the western toad based on the species' greater abundance at these sites. Several landscape and some local habitat features were strongly associated with wood frog, boreal chorus frog and tiger salamander relative abundance. Results suggest that larger scale features of the terrestrial environment are important in influencing patterns of abundance of frogs and tiger salamanders.

Table 2-1. Description of local and landscape habitat features from 163 ponds surveyed for anurans using call surveys, and 24 ponds surveyed using traps. All ponds were located in the Beaver Hills region of central Alberta. Indicated for each pond group are variables that were measured (•), and those used (✓) in PCA and regression analyses. The type of transformation was either LN = natural log, SQRT = square root, or - = no transformation was necessary. $\chi$ = habitat variable.

| | | | | Variables measured | | Variables used | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | PCA | | regressions | |
| **Habitat variable** | | | **Transf.** | **163** | **24** | **land-** | **local** | **163** | **24** |
| **Abbrev.** | **Description** | **Unit** | **type** | **ponds** | **ponds** | **scape** | | **ponds** | **ponds** |
| ***Landscape variables (within a 1 km radius)*** | | | | | | | | | |
| CROP | proportion of area as crop | % | SQRT [$\chi$] | • | • | ✓ | | ✓ | ✓ |
| FOREST | forest | % | - | • | • | ✓ | | * | * |
| PAST | pasture | % | - | • | • | ✓ | | ✓ | ✓ |
| SHRUB | shrub | % | LN [$\chi$] | • | • | ✓ | | ✓ | ✓ |
| ROAD | road | % | - | • | • | ✓ | | ✓ | ✓ |
| RESID | residential | % | LN [$\chi + 0.5$] | • | • | ✓ | | ✓ | ✓ |
| WATER | water | % | LN [$\chi + 0.5$] | • | • | ✓ | | ✓ | ✓ |
| NRWTR | nearest waterbody | m | LN [$\chi$] | • | • | ✓ | | ✓ | ✓ |
| NRFRST | forest patch | m | LN [$\chi + 1$] | • | • | ✓ | | ✓ | ✓ |
| NRRD | road | m | LN [$\chi$] | • | • | ✓ | | ✓ | ✓ |
| ***Local variables*** | | | | | | | | | |
| AREA | pond area | ha | - | • | • | | ✓ | ✓ | ✓ |
| PERIM | pond perimeter | m | - | • | • | | ✓ | * | * |
| MAXDEPTH | maximum depth | cm | - | | • | | ✓ | | ✓ |
| Δ DEPTH | change in depth | cm | - | | • | | ✓ | | ✓ |
| SECCHI | secchi depth | cm | - | | • | | ✓ | | * |
| COND | conductivity | µS/cm | LN [$\chi$] | | • | | ✓ | | ✓ |
| PH | pH | - | - | | • | | ✓ | | ✓ |
| TP | total phosphorus | µg/L | LN [$\chi$] | | • | | ✓ | | ✓ |
| TN | total nitrogen | µg/L | LN [$\chi$] | | • | | ✓ | | * |
| CHLA | chlorophyll a | µg/L | LN [$\chi$] | | • | | ✓ | | ✓ |
| $\mathrm{UPVEG}_{\mathrm{MEAS}}$ | upland vegetation height, measured | cm | - | | • | | | | ✓ |
| $\mathrm{UPVEG}_{\mathrm{EST}}$ | upland vegetation height, estimated | (rank, 0-3) | - | • | | | | ✓ | |
| $\mathrm{CAT/BUL}_{\mathrm{MEAS}}$ | cattail/bulrush width, measured | m | - | | • | | | | ✓ |
| $\mathrm{CAT/BUL}_{\mathrm{EST}}$ | cattail/bulrush width, estimated | m | - | • | | | | ✓ | |
| FISH | presence/absence of fish | (0,1) | - | | • | | | | |

* Excluded from regression analyses due to multicollinearity

Table 2-2. Comparison of relative abundance of wood frogs (either adults or YOY) between 3 survey techniques, call surveys (call), pitfall trapping (PT), and minnow trapping (MT), using linear regression analyses. All surveys were conducted in 2001 and 2002 at 24 ponds located in the Beaver Hills region of central Alberta. See text for explanation of objectives. * $p < 0.01$

| **Objective** | **Survey technique comparison** | | | **Year** | **n** | **R** | **p value** |
|---|---|---|---|---|---|---|---|
| 1 | adult male (call) | vs. | YOY (PT) | 2002 | 24 | 0.398 | 0.054 |
| | | vs. | YOY & larvae (MT) | 2002 | 24 | 0.329 | 0.117 |
| | adult (PT) | vs. | YOY (PT) | 2001-2002 | 48 | 0.628 | 0.000 * |
| 2 | adult male (call) | vs. | adult (PT) | 2002 | 24 | 0.552 | 0.005 * |
| 3 | YOY (PT) | vs. | YOY & larvae (MT) | 2001-2002 | 48 | 0.697 | 0.000 * |

Table 2-3. Results of three Principal Components Analyses (PCA), and corresponding Multi-Response Permutation Procedures (MRPP) comparing ponds within 4 different land-use types based on local and landscape habitat features. Ponds were located in the Beaver Hills region of central Alberta. Three datasets were analyzed, each differing in the number of ponds and/or the scale at which habitat features were measured (landscape or local). * $p < 0.05$,
** $p < 0.016$ (Bonferroni adjusted)

| | **Landscape (n=163 ponds) Axis** | | | **Landscape (n=24 ponds) Axis** | | | | **Local (n=24 ponds) Axis** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **1** | **2** | **3** | **4** | **1** | **2** | **3** | **4** |
| Eigenvalue | 3.66 | 1.78 | 1.13 | 3.34 | 2.61 | 1.33 | 1.10 | 4.47 | 2.31 | 1.24 | 1.05 |
| % of variance | 36.59 | 17.81 | 11.33 | 33.36 | 26.10 | 13.30 | 10.97 | 37.22 | 19.27 | 10.29 | 8.77 |
| Cumulative % of variance | 36.59 | 54.40 | 65.73 | 33.36 | 59.45 | 72.73 | 83.70 | 37.22 | 56.48 | 66.77 | 75.54 |

| **Land-use comparison** | | **t** | **p value** | **t** | **p value** | **t** | **p value** |
|---|---|---|---|---|---|---|---|
| crop vs. | pasture | -18.44 | < 0.000 ** | -2.65 | 0.026 * | -2.13 | 0.040 * |
| crop vs. | residential | -22.37 | < 0.000 ** | -4.85 | 0.002 ** | -0.24 | 0.291 |
| crop vs. | "natural" | -50.61 | < 0.000 ** | -6.85 | 0.001 ** | 0.60 | 0.677 |
| pasture vs. | residential | -6.160 | < 0.001 ** | -1.69 | 0.067 | -0.31 | 0.312 |
| pasture vs. | "natural" | -35.91 | < 0.000 ** | -6.20 | 0.001 ** | 0.02 | 0.374 |
| residential vs. | "natural" | -11.76 | < 0.000 ** | -2.20 | 0.038 * | 0.41 | 0.560 |

Table 2-4. Summary of local and landscape habitat features collected from ponds within 4 land-use types in the Beaver Hills region of central Alberta. Unmarked variables were measured at all 163 ponds; marked variables (*) were measured only at the 24 trapping ponds. Refer to Table 2-1 for definition of habitat variables. Sampling for water chemistry was done from 2 July - 28 August 2001, and 10 June - 1 August 2002. Vegetation measurements were taken in June and August 2001 and 2002. n/a = data derived from air photos taken in 1998 or 2001.

| | | | | | Crop | | Pasture | | Residential | | "Natural" | | Overall | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | | Unit | Year | N | Mean | S.E. | Mean | S.E. | Mean | S.E. | Mean | S.E. | Mean | S.E. | Range |
| ***Landscape*** | CROP | % | n/a | 163 | 53.36 | 3.41 | 20.62 | 3.10 | 15.17 | 2.53 | 4.32 | 1.51 | 20.68 | 1.903 | 0 - 85.47 |
| | FOREST | % | n/a | 163 | 13.22 | 1.59 | 32.64 | 2.67 | 41.87 | 2.98 | 52.15 | 1.37 | 37.29 | 1.538 | 1.05 - 68.78 |
| | PAST | % | n/a | 163 | 20.33 | 2.26 | 30.22 | 1.79 | 19.11 | 1.71 | 9.48 | 1.21 | 18.49 | 1.043 | 0 - 62.10 |
| | SHRUB | % | n/a | 163 | 0.07 | 0.01 | 0.08 | 0.01 | 0.07 | 0.01 | 0.22 | 0.01 | 0.13 | 0.008 | 0.02 - 0.52 |
| | ROAD | % | n/a | 163 | 1.19 | 0.06 | 1.18 | 0.07 | 2.04 | 0.14 | 0.97 | 0.05 | 1.26 | 0.048 | 0 - 3.69 |
| | RESID | % | n/a | 163 | 2.55 | 0.39 | 2.84 | 0.35 | 10.90 | 1.17 | 1.20 | 0.22 | 3.61 | 0.368 | 0 - 28.60 |
| | WATER | % | n/a | 163 | 2.36 | 0.34 | 4.88 | 0.75 | 4.19 | 0.52 | 9.94 | 0.92 | 6.08 | 0.466 | 0.07 - 29.94 |
| | NRWTR | m | n/a | 163 | 159.71 | 25.61 | 146.35 | 23.88 | 107.34 | 11.89 | 92.08 | 9.59 | 122.3 | 9.125 | 9.12 - 798.89 |
| | NRFRST | m | n/a | 163 | 154.52 | 28.21 | 126.78 | 34.18 | 30.09 | 7.20 | 23.59 | 2.32 | 77.66 | 11.203 | 0 - 1,017.73 |
| | NRRD | m | n/a | 163 | 49.42 | 14.96 | 76.51 | 20.78 | 33.57 | 6.83 | 68.59 | 19.53 | 60.26 | 9.473 | 0 - 119.20 |
| ***Local*** | AREA | ha | n/a | 163 | 0.82 | 0.16 | 0.77 | 0.17 | 0.41 | 0.09 | 1.13 | 0.16 | 0.85 | 0.08 | 0.01 - 5.26 |
| | PERIM | m | n/a | 163 | 407.17 | 33.29 | 419.28 | 47.83 | 404.19 | 77.72 | 845.57 | 95.39 | 570.91 | 43.07 | 45.21 - 3,357.89 |
| | MAXDEPTH * | cm | 2001 | 24 | 39.50 | 8.49 | 97.30 | 17.76 | 65.08 | 13.83 | 95.42 | 21.36 | 74.3 | 9.21 | 20.0 – 175.0 |
| | | | 2002 | 24 | 31.00 | 7.87 | 90.17 | 23.40 | 61.12 | 14.75 | 102.33 | 22.45 | 71.16 | 10.47 | 1.0 - 190.0 |
| | ΔDEPTH * | cm | 2001 | 24 | 26.50 | 4.59 | 37.33 | 5.41 | 20.83 | 2.93 | 18.00 | 1.93 | 25.7 | 2.41 | 10 - 58 |
| | | | 2002 | 24 | 11.17 | 7.33 | 12.17 | 3.21 | 9.50 | 2.63 | 11.83 | 1.78 | 26.1 | 2.10 | 1 - 46 |
| | SECCHI * | cm | 2001 | 24 | 26.30 | 8.19 | 73.33 | 21.49 | 45.17 | 4.91 | 70.97 | 14.79 | 53.9 | 7.64 | 10.8 - 142.0 |
| | | | 2002 | 21 | 19.83 | 4.42 | 70.05 | 11.74 | 37.17 | 11.20 | 60.72 | 12.41 | 46.94 | 6.37 | 4.0 - 104.5 |
| | COND * | µS/cm | 2001 | 24 | 3,199.62 | 384.27 | 798.54 | 305.36 | 524.43 | 33.44 | 261.01 | 55.13 | 1,195.9 | 270.33 | 125.15 - 4,381.5 |
| | | | 2002 | 21 | 4,038.75 | 953.17 | 873.74 | 362.58 | 663.58 | 65.22 | 285.14 | 66.05 | 1,465.3 | 393.58 | 158.60 - 7,596.20 |
| | PH * | - | 2001 | 23 | 8.55 | 0.15 | 8.11 | 0.35 | 8.12 | 0.56 | 7.93 | 0.28 | 8.18 | 0.18 | 7.00 - 9.91 |
| | | | 2002 | 21 | 8.57 | 0.15 | 9.13 | 0.23 | 8.14 | 0.23 | 8.62 | 0.22 | 8.61 | 0.12 | 7.59 - 9.63 |
| | TP * | µg/L | 2001 | 24 | 1,030.50 | 480.85 | 313.65 | 114.77 | 723.74 | 362.82 | 186.00 | 57.75 | 563.47 | 159.67 | 58.00 - 3,429.40 |
| | | | 2002 | 21 | 1,786.95 | 952.43 | 320.87 | 137.51 | 1,051.26 | 549.82 | 280.60 | 101.65 | 859.92 | 289.59 | 76.20 - 6,451.50 |
| | TN * | µg/L | 2001 | 24 | 9,805.09 | 2,889.78 | 3,655.85 | 1,290.22 | 6,232.38 | 2,039.49 | 2,756.71 | 409.74 | 5,612.5 | 1,051.19 | 1,228.04 - 23,261.68 |
| | | | 2002 | 21 | 11,249.58 | 3,682.23 | 3,508.73 | 1,328.52 | 6,481.05 | 2,130.52 | 3,018.87 | 420.47 | 6,064.5 | 1,247.02 | 1,377.30 - 27,762.00 |
| | CHLA * | µg/L | 2001 | 24 | 72.31 | 50.85 | 13.91 | 4.18 | 27.35 | 10.39 | 11.65 | 2.74 | 31.3 | 13.18 | 1.30 - 324.40 |
| | | | 2002 | 21 | 130.57 | 56.02 | 17.43 | 4.71 | 62.03 | 24.66 | 101.41 | 79.29 | 77.89 | 25.00 | 4.42 - 496.23 |
| | UPVEG$_{meas}$* | cm | 2001 | 24 | 58.37 | 8.06 | 29.78 | 8.51 | 63.68 | 6.52 | 64.57 | 7.59 | 54.1 | 4.66 | 3.90 - 92.60 |
| | | | 2002 | 24 | 35.5 | 9.09 | 16.98 | 3.89 | 57.71 | 4.76 | 47.42 | 4.76 | 39.4 | 4.21 | 8.90 - 70.50 |
| | UPVEG$_{est}$ | 0-3 | 2001 | 163 | 1.11 | 0.18 | 0.67 | 0.16 | 1.97 | 0.21 | 2.68 | 0.08 | 1.74 | 0.10 | 0 - 3 |
| | CAT/BUL$_{meas}$* | m | 2002 | 24 | 19.66 | 6.12 | 3.63 | 2.43 | 9.38 | 2.92 | 0.26 | 0.26 | 8.23 | 2.28 | 0 - 49.88 |
| | CAT/BUL$_{est}$ | m | 2002 | 163 | 6.24 | 1.43 | 3.03 | 0.78 | 3.40 | 0.59 | 4.18 | 0.73 | 4.21 | 0.47 | 0 - 37.0 |

Table 2-5. Pairwise comparisons of amphibian abundance at ponds differing in land-use type (crop, pasture, residential and "natural" areas). All ponds were located in the Beaver Hills region of central Alberta, and sampled in 2001 and 2002 using call surveys (n = 78 - 134 ponds), pitfall traps (n = 24 ponds) and minnow traps (n = 24 ponds). Comparisons were conducted only for species whose abundance differed significantly between land-use types (Kruskal-Wallis test, $p < 0.05$, see Figures 2-6, 2-7 and 2-8). Pairwise comparisons were made using either Dunn's test (call data) or Nemenyi's test (trapping data). * $p < 0.05$, ** $p < 0.016$ (Bonferroni adjusted)

| | | | **Call surveys** | | | | **Pitfall trap surveys** | | | | **Minnow trap surveys** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Species** | **Age class** | **Year** | **land-use comparison** | | **S.E.** | **Q** | **land-use comparison** | | **S.E.** | **q** | **land-use comparison** | | **S.E.** | **q** |
| ***wood frog*** | ***adult*** | 2001 | crop vs. | "natural" | 7.06 | 3.29 * | n.s. | | | | n.s. | | | |
| | | 2002 | crop vs. | residential | 10.81 | 2.90 * | crop vs. | "natural" | 17.321 | 4.59 ** | n.s. | | | |
| | | | | "natural" | 9.506 | 5.09 ** | | | | | | | | |
| | | | pasture vs. | "natural" | 9.597 | 3.86 ** | pasture vs. | "natural" | 17.321 | 4.13 * | | | | |
| | ***YOY*** † | 2001 | n/a | | | | crop vs. | "natural" | 17.321 | 3.81 * | crop vs. | "natural" | 3.000 | 3.70 * |
| | | 2002 | n/a | | | | crop vs. | "natural" | 17.321 | 4.85 ** | n.s. | | | |
| ***boreal chorus frog*** | ***adult*** | 2001 | crop vs. | pasture | 14.14 | 2.77 * | n/a | | | | n/a | | | |
| | | | | "natural" | 11.96 | 4.50 ** | | | | | | | | |
| | | 2002 | crop vs. | residential | 11.06 | 3.12 * | n/a | | | | n/a | | | |
| | | | | "natural" | 9.566 | 5.33 ** | | | | | | | | |
| | | | pasture vs. | "natural" | 9.566 | 3.39 * | | | | | | | | |
| | ***all age classes*** | 2001 | n/a | | | | n.s. | | | | n.s. | | | |
| | | 2002 | n/a | | | | crop vs. | "natural" | 17.321 | 3.67 * | n.s. | | | |

n/a: Particular age class(es) was not sampled using listed survey technique

n.s.: Kruskal-Wallis test results were not significant, thus pairwise comparisons were not made.

† : For minnow trap surveys only, includes YOY and larvae

Table 2-6. Pairwise comparisons of mean body size of adult and YOY wood frogs caught from 24 ponds differing in surrounding land-use type (crop, pasture, residential and "natural" areas). All ponds were located in the Beaver Hills region of central Alberta, and sampled in 2001 and 2002 using pitfall and minnow traps. Pairwise comparisons were made using Dunn's test. See Figure 2-9 for mean body sizes within each land-use types. * $p < 0.05$, ** $p < 0.016$ (Bonferroni adjusted)

| Species | Age class | Year | land-use comparison | | S.E. | Q |
|---|---|---|---|---|---|---|
| ***wood frog*** | ***adult*** | 2001 | crop vs. | pasture | 34.60 | 3.43 * |
| | | | | residential | 29.48 | 3.67 ** |
| | | 2002 | crop vs. | pasture | 49.55 | 3.33 ** |
| | | | | residential | 43.43 | 3.62 ** |
| | | | | "natural" | 42.55 | 5.26 ** |
| | | | residential vs. | "natural" | 18.16 | 3.68 ** |
| | ***YOY*** | 2001 | crop vs. | pasture | 55.38 | 3.82 ** |
| | | | | residential | 51.12 | 11.70 ** |
| | | | | "natural" | 47.94 | 13.65 ** |
| | | | pasture vs. | residential | 38.21 | 10.11 ** |
| | | | | "natural" | 33.83 | 13.08 ** |
| | | 2002 | pasture vs. | residential | 31.90 | 2.49 * |
| | | | | "natural" | 28.68 | 3.11 ** |

Table 2-7. Results of regression analyses of amphibian relative abundance with local and landscape habitat variables from ponds located in the Beaver Hills region of central Alberta. Only significant ($p < 0.05$) habitat variables are included. Refer to Table 2-1 for definition of habitat variables. Analyses were done using data from both survey years combined (2001 and 2002) except analyses of call-surveyed wood frogs where only 2002 data was used. Call = call surveys, PT = pitfall traps, MT = minnow traps.

| | **wood frog** | | | | **boreal chorus frog** | | **tiger salamander** | |
|---|---|---|---|---|---|---|---|---|
| | **2002 (Call)<br>n = 132<br>adult males** | | **2001-2002 (PT)<br>n = 48<br>adults** | | **2001-2002 (Call)<br>n = 163<br>adult males** | | **2001-2002 (MT)<br>n = 48<br>all age classes** | |
| **Variable** | **β** | **p** | **β** | **p** | **β** | **p** | **β** | **p** |
| Intercept | | | | | | | | |
| trap | | | 0.682 | 0.047 | | | -0.689 | 0.073 |
| call Code = 0 | -1.712 | 0.213 | | | -3.228 | 0.016 | | |
| Code = 1 | 0.528 | 0.698 | | | -1.823 | 0.169 | | |
| Code = 2 | 1.659 | 0.224 | | | -1.083 | 0.413 | | |
| YEAR = 01 | | | 0.554 | 0.011 | | | | |
| YEAR = 02 | | | | | | | | |
| ***Landscape*** | | | | | | | | |
| CROP | -0.322 | 0.001 | | | -0.323 | 0.000 | | |
| PAST | | | -0.018 | 0.038 | -0.031 | 0.037 | | |
| SHRUB | | | | | | | | |
| ROAD | | | | | | | | |
| RESID | | | | | | | 0.288 | 0.010 |
| WATER | | | 0.672 | 0.000 | | | -0.589 | < 0.000 |
| NRWTR | | | | | | | | |
| NRFRST | | | | | | | | |
| NRRD | | | | | | | 0.257 | 0.013 |
| ***Local*** | | | | | | | | |
| AREA | | | | | | | | |
| MAXDEPTH * | | | | | | | | |
| $\Delta$ DEPTH * | | | -0.023 | 0.031 | | | | |
| COND * | | | | | | | | |
| PH * | | | | | | | | |
| TP * | | | | | | | | |
| CHLA * | | | | | | | 0.320 | 0.005 |
| UPVEG$_{meas}$* | | | | | | | | |
| UPVEG= 0 | -0.960 | 0.057 | | | | | | |
| UPVEG= 1 | | | | | | | | |
| UPVEG= 2 | | | | | | | | |
| UPVEG= 3 | | | | | | | | |
| CAT/BUL$_{meas}$* | | | | | | | | |
| CAT/BUL$_{est}$ | 0.064 | 0.035 | | | | | | |
| **Adjusted $R^2$ †** | 0.305 | | 0.505 | | 0.238 | | 0.561 | |
| **Overall p** | - | | < 0.000 | | - | | < 0.000 | |

* Variables not included in call-survey analyses

† Cox and Snell (Pseudo $R^2$) for ordinal regression models of call-surveyed ponds

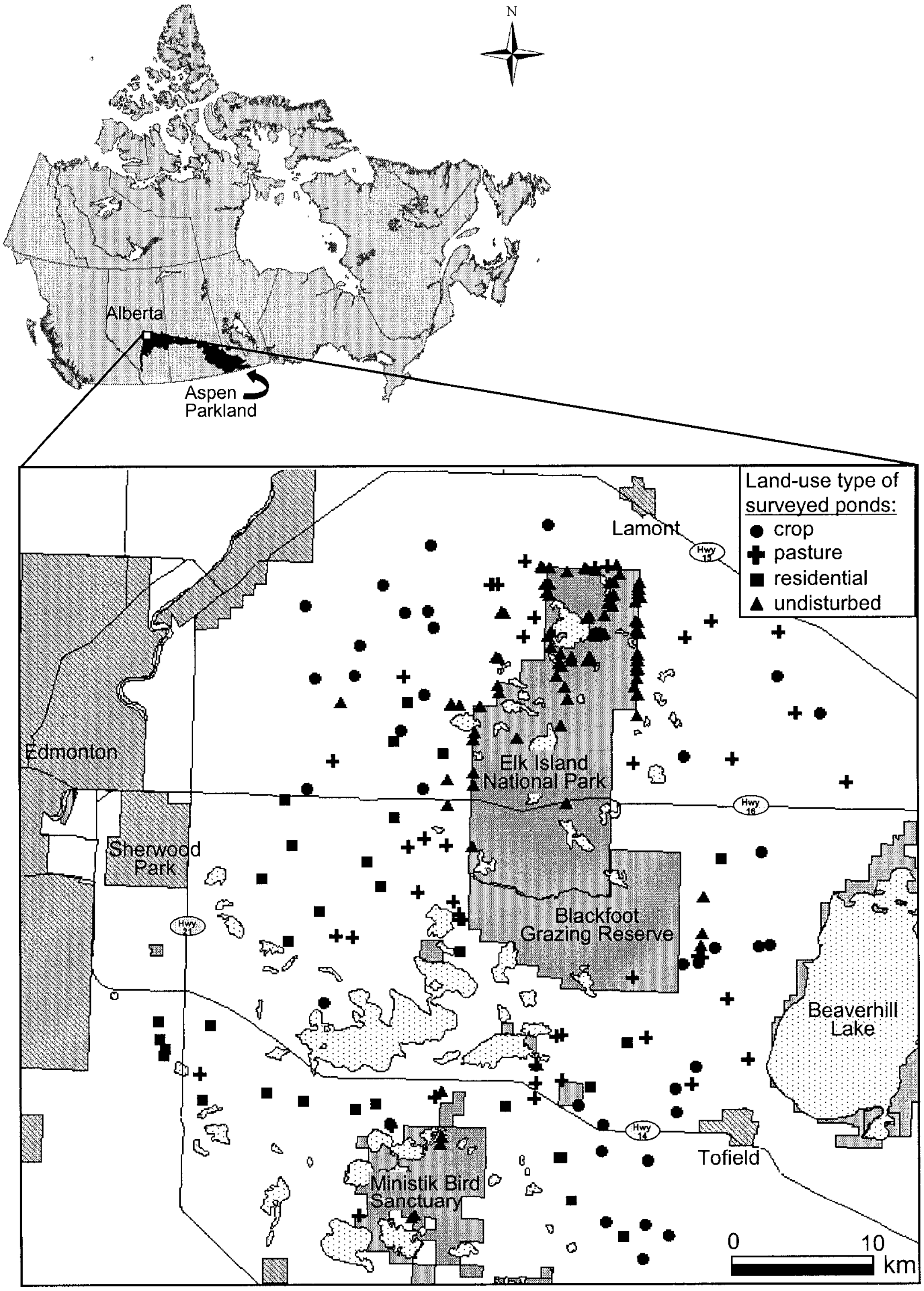


Figure 2-1. The Beaver Hills study area, located in the Aspen Parkland Ecoregion of central Alberta, Canada.

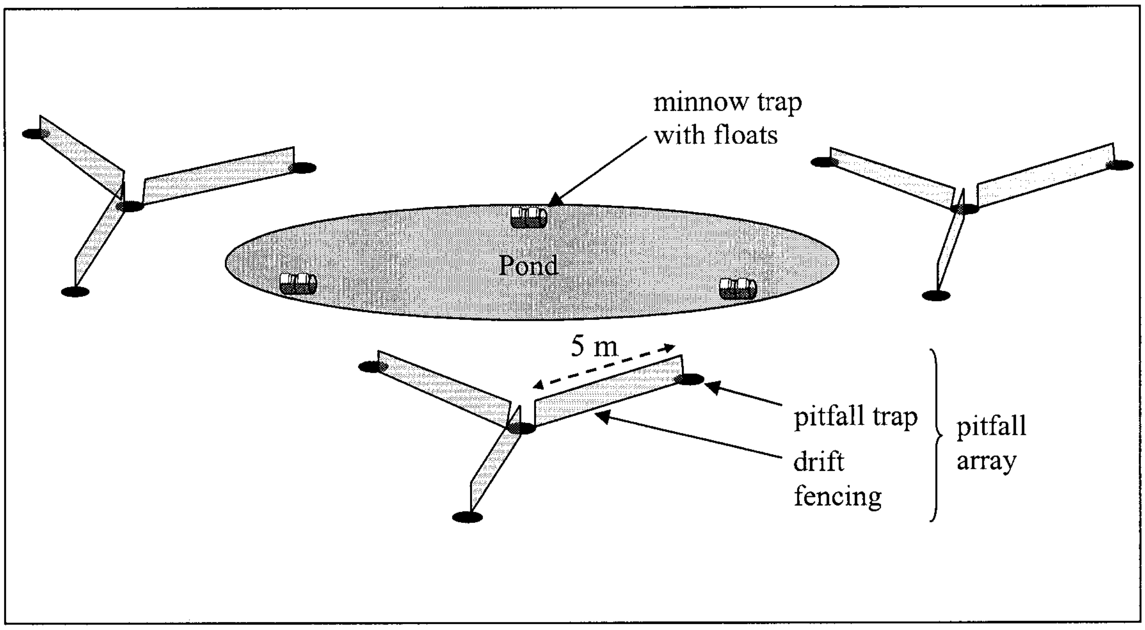
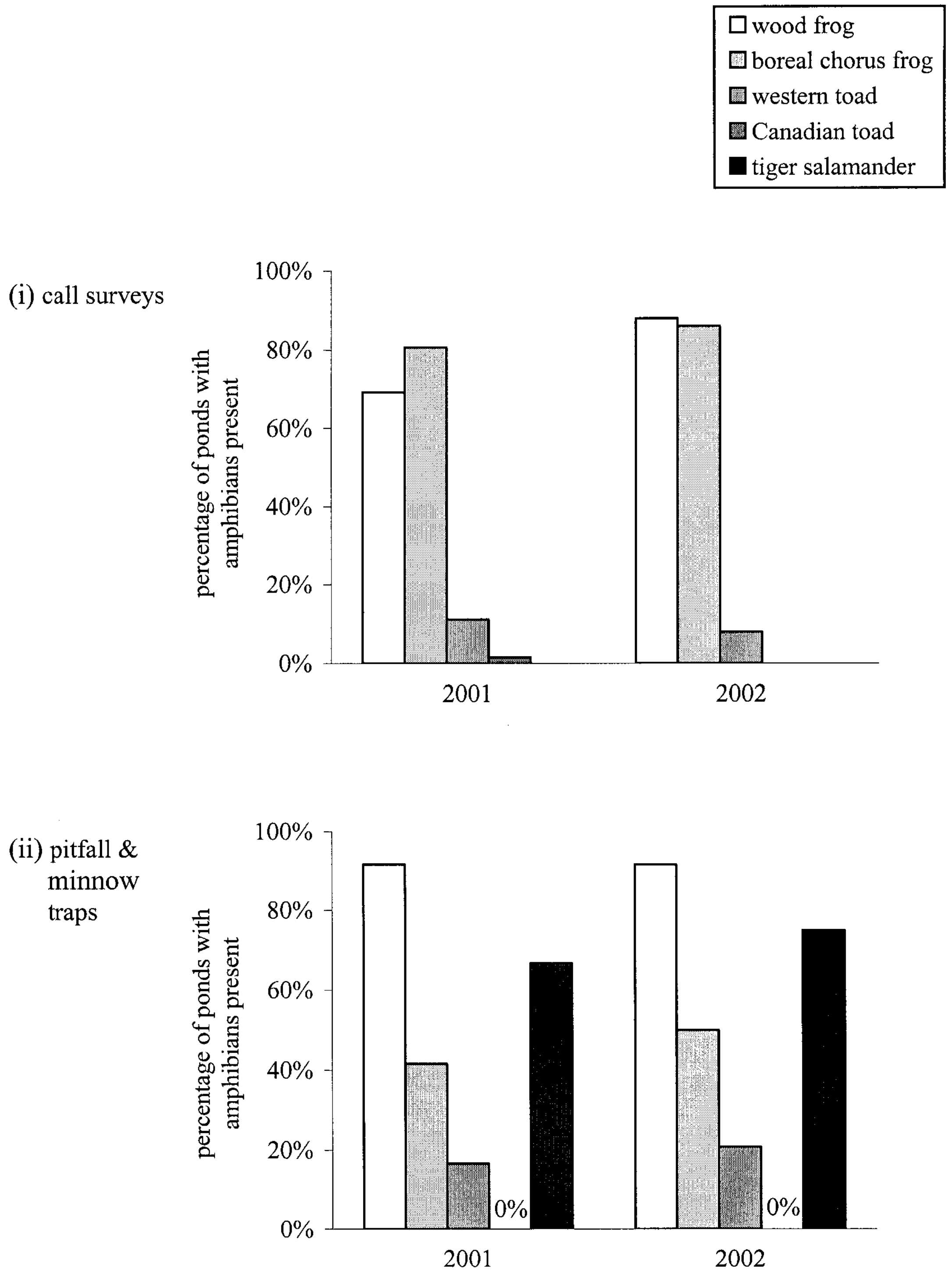


Figure 2-2. Design and deployment of pitfall and minnow traps at the 24 ponds. Each pond had 3 pitfall arrays (4 pitfall traps/array) located approximately 20-m from the pond edge. Three partially submerged minnow traps were placed around the margin of the pond.



(i) call surveys

(ii) pitfall & minnow traps

Figure 2-3. The proportion of ponds in the Beaver Hills regions of central Alberta surveyed in 2001 and 2002 with each amphibian species present, based on (i) call surveys, n = 78-134 ponds in 2001 and n = 148-150 ponds in 2002 (see text), and (ii) pitfall and minnow traps, n = 24 ponds.

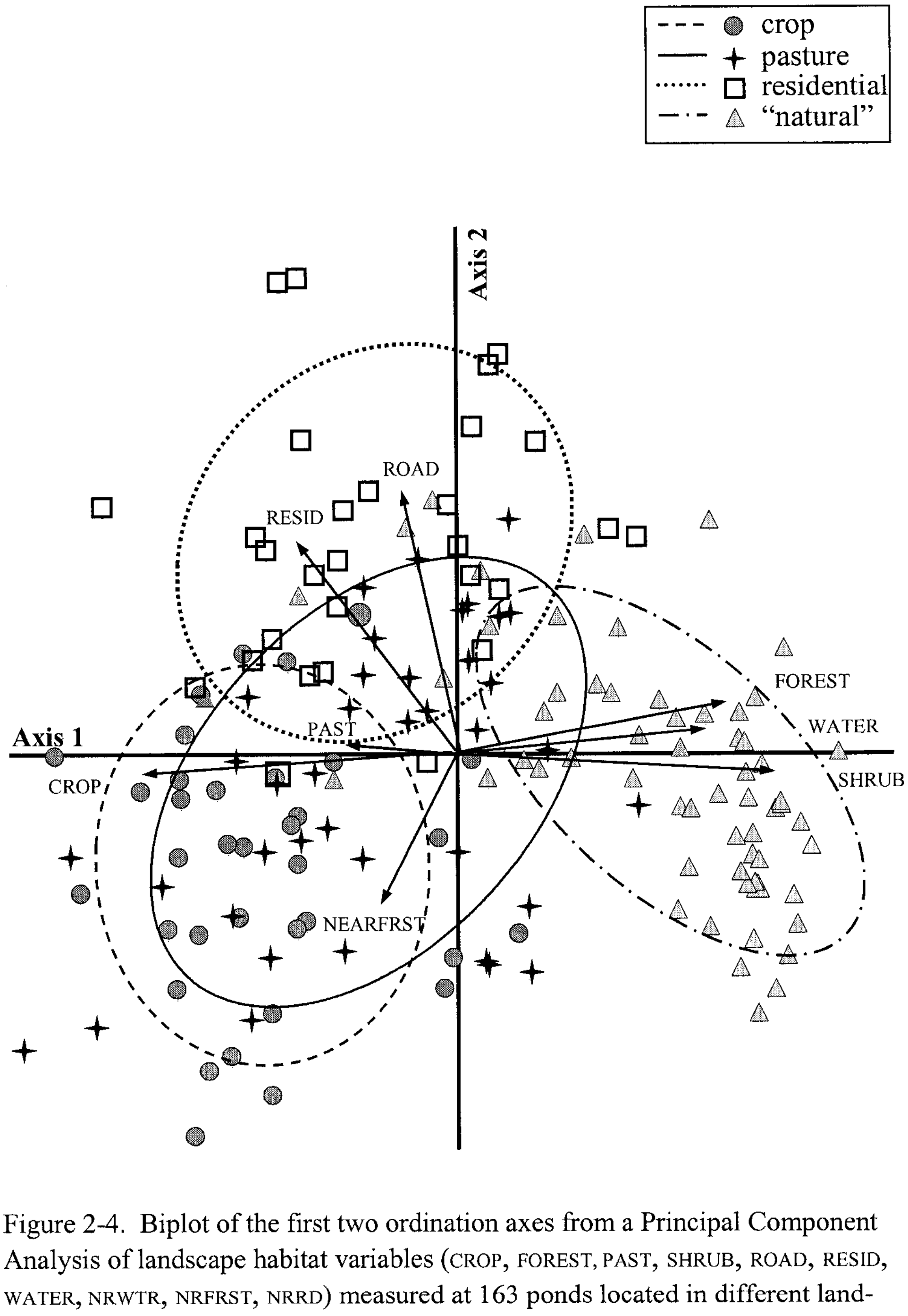


Figure 2-4. Biplot of the first two ordination axes from a Principal Component Analysis of landscape habitat variables (CROP, FOREST, PAST, SHRUB, ROAD, RESID, WATER, NRWTR, NRFRST, NRRD) measured at 163 ponds located in different land-use types (35 crop, 39 pasture, 29 residential, 60 "natural") in the Beaver Hills region of central Alberta. Refer to Table 2-1 for definition of habitat variables. Each symbol represents a pond, and each vector represents the correlation between a habitat variable and the two ordination axes. Confidence ellipses are centered on the means for each land-use type.

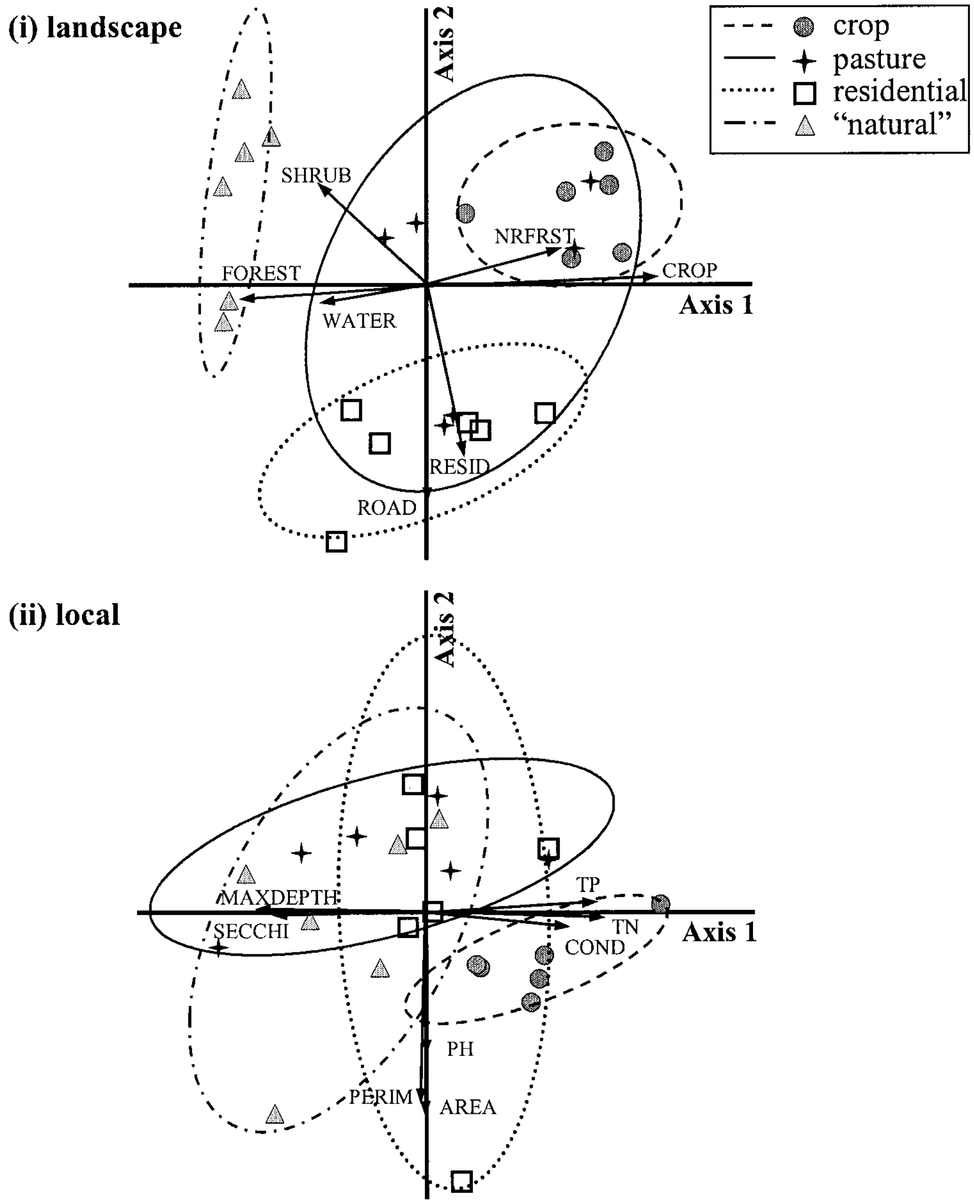


Figure 2-5. Biplots of the first two axes from a Principal Component Analysis of (i) landscape habitat variables (CROP, FOREST, PAST, SHRUB, ROAD, RESID, WATER, NRWTR, NRFRST, NRRD), and (ii) local habitat variables (AREA, PERIM, Δ DEPTH, MAXDEPTH, SECCHI, COND, PH, TP, TN, CHLA) measured at 24 ponds located in different land-use types (6 crop, 6 pasture, 6 residential, 6 "natural") in the Beaver Hills region of central Alberta. Refer to Table 2-1 for definition of habitat variables. Each symbol represents a pond, each vector represents the correlation between a habitat variable and the two ordination axes. Confidence ellipses are centered on the means for each land-use type.

***call surveys :***

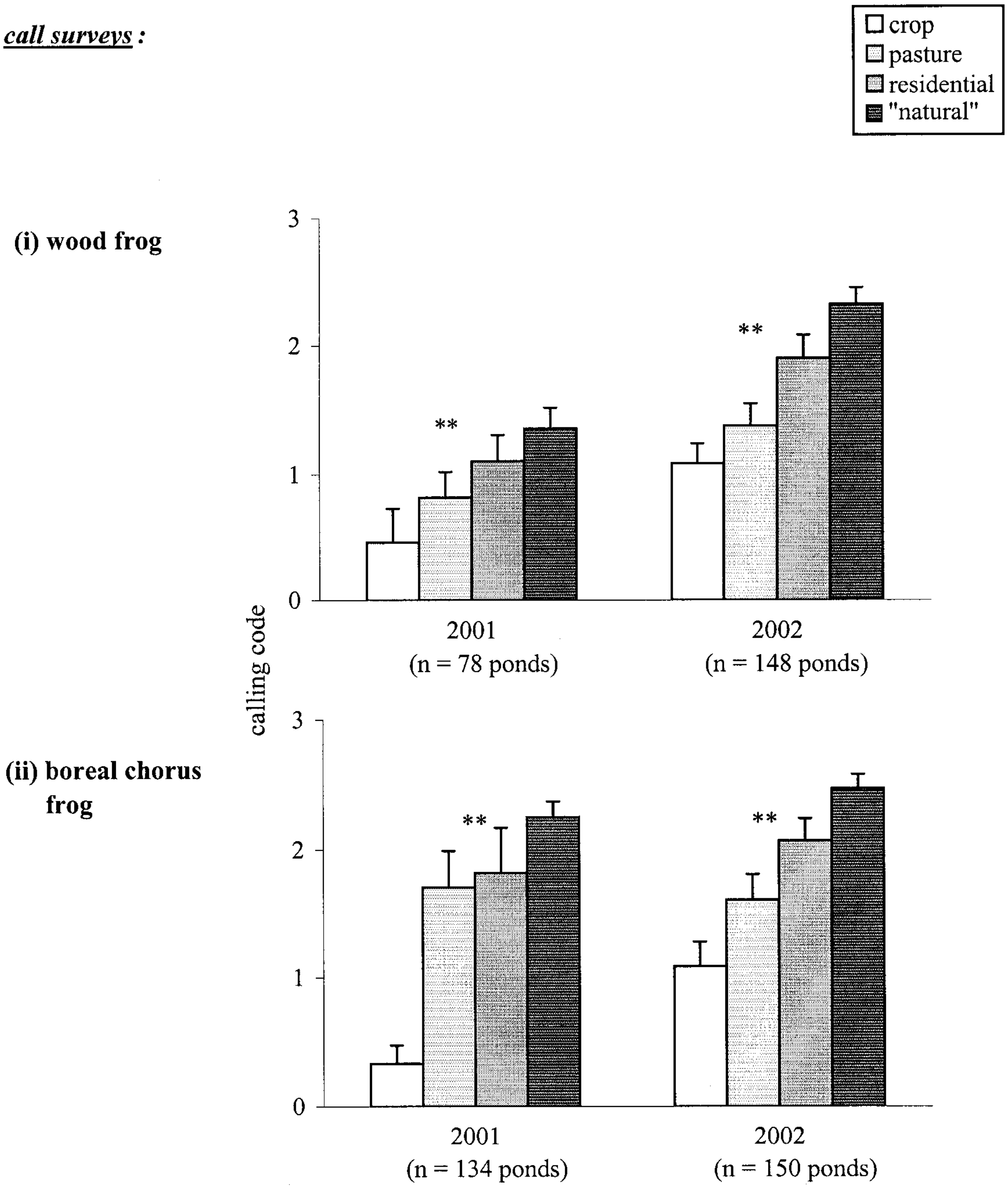


Figure 2-6. Mean calling code of 2 frog species recorded in 2001 and 2002 during evening surveys at ponds within various land-use types in the Beaver Hills region of central Alberta. Bars represent the standard error of the mean. Kruskal-Wallis test was done for each species and year, where overall significant differences are indicated. ** $p < 0.01$

***pitfall traps :***

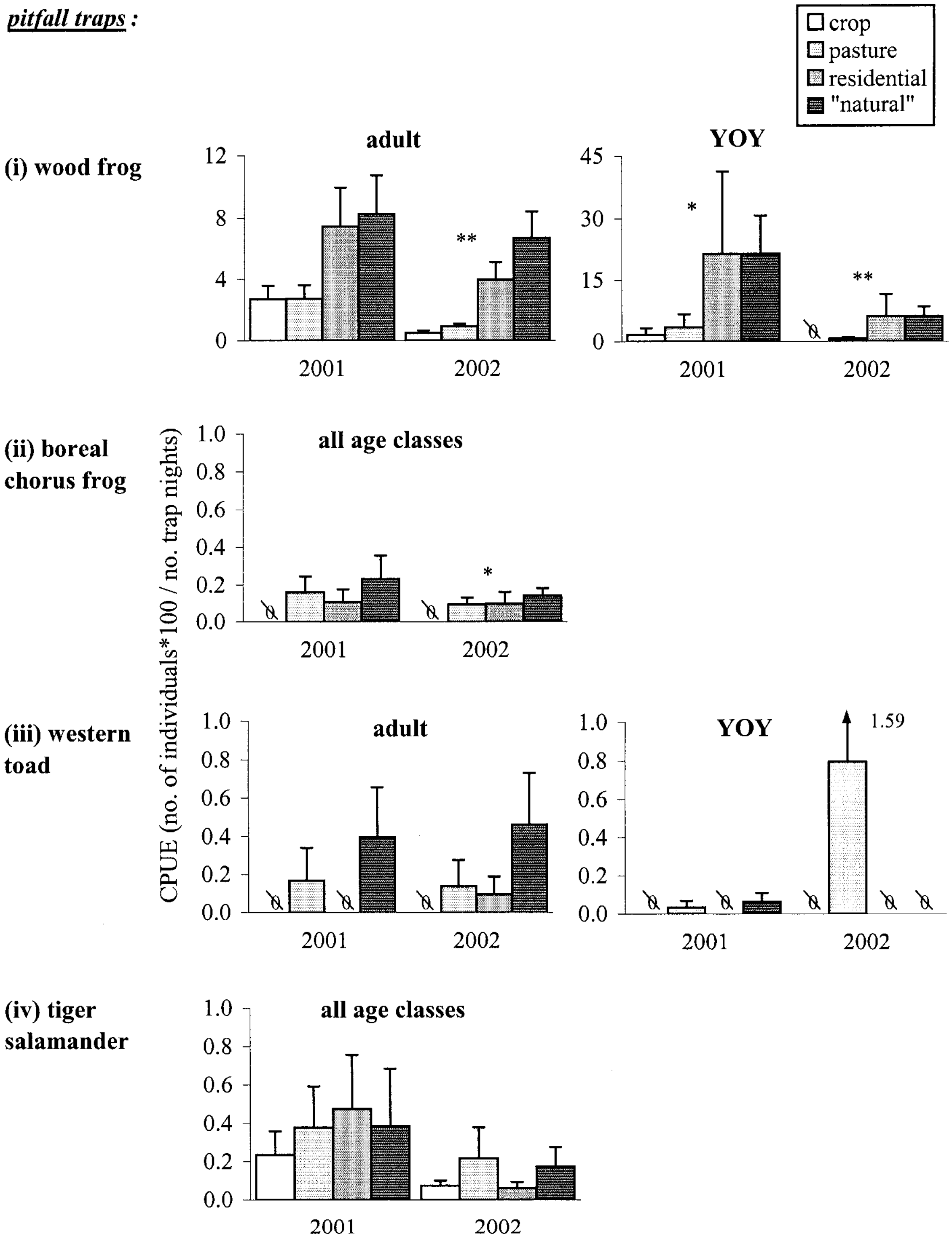


Figure 2-7. Mean catch-per-unit-effort (CPUE) of 4 amphibian species caught in pitfall traps in 2001 and 2002 at 24 ponds located within various land-use types in the Beaver Hills region of central Alberta. Bars represent the standard error of the mean. Kruskal-Wallis test was done for each species and year, and overall significant differences are indicated. * $p < 0.05$, ** $p < 0.01$, ⊘ = zero value.

***minnow traps* :**

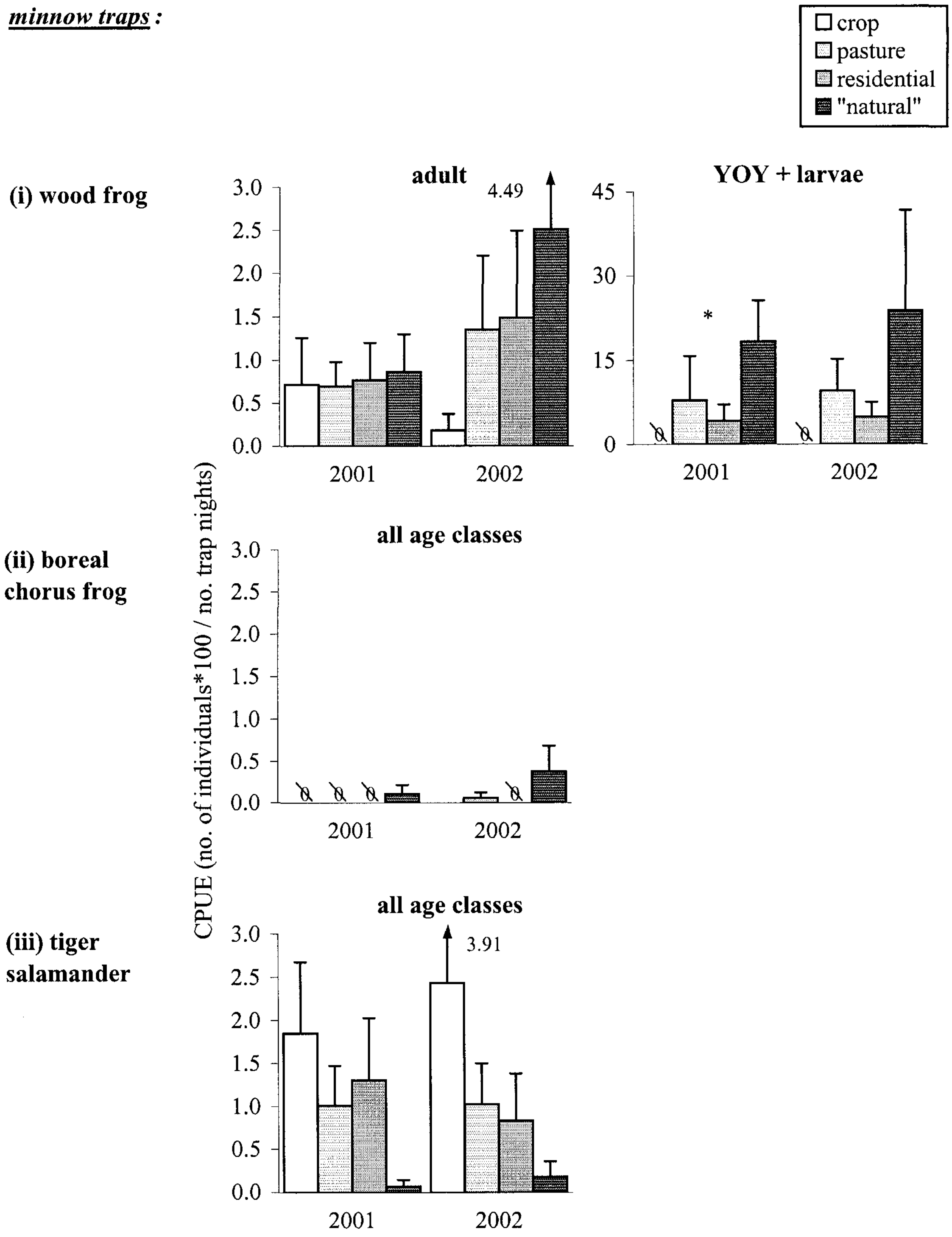


Figure 2-8. Mean catch-per-unit-effort (CPUE) of 3 amphibian species caught in minnow traps in 2001 and 2002 at 24 ponds located within various land-use types in the Beaver Hills region of central Alberta. Bars represent the standard error of the mean. Kruskal-Wallis test was done for each species and year, and overall significant differences are indicated. * $p < 0.05$, ∅= zero value.

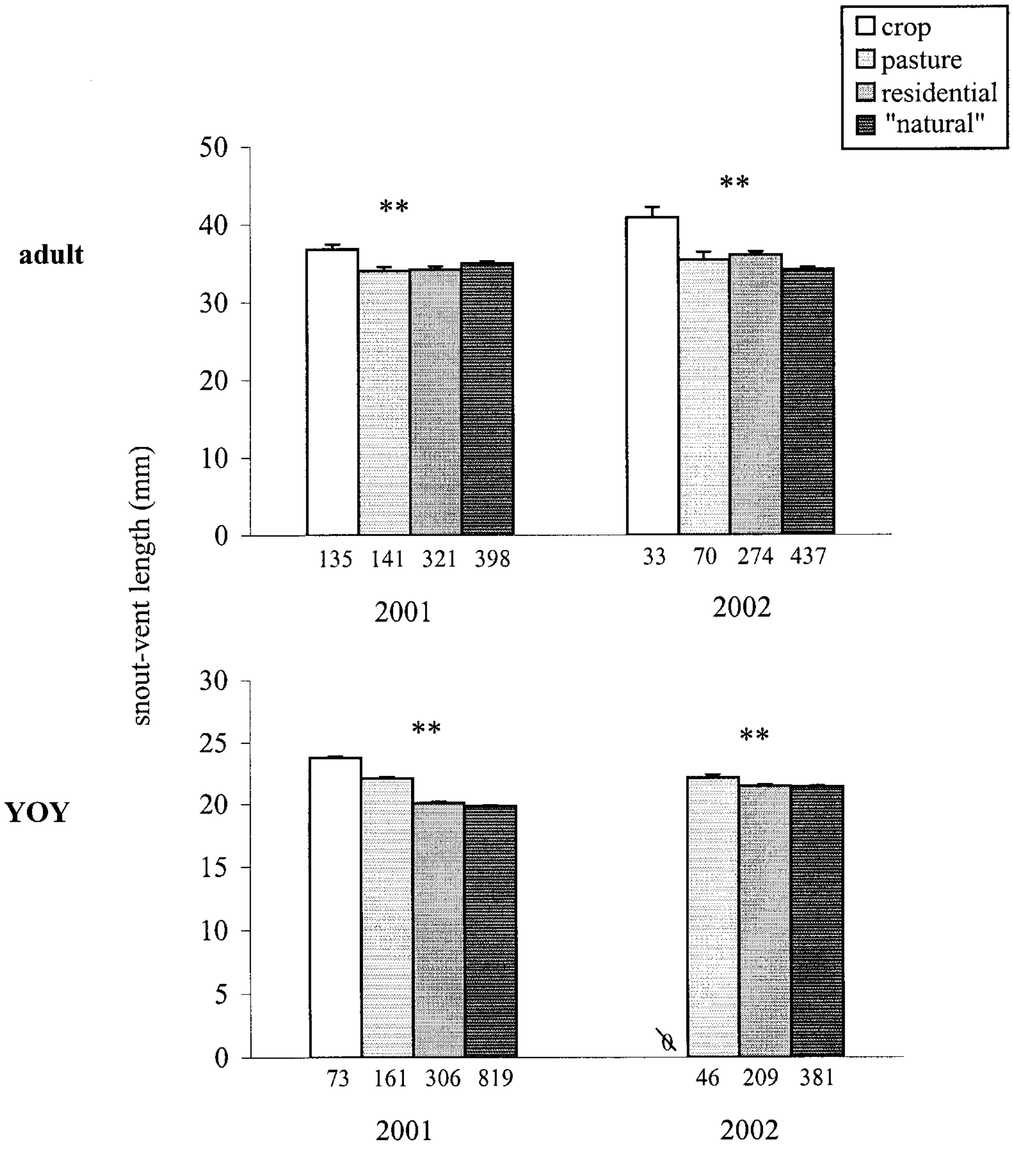


Figure 2-9. Mean body sizes of adult and YOY wood frogs captured in 2001 and 2002 from pitfall and minnow traps at 24 ponds within various land-use types in the Beaver Hills region of central Alberta. Bars represent the standard error of the mean. Kruskal-Wallis test was done for each age class and year, and overall significant differences are indicated. ** $p < 0.01$, ⊗ = zero value, numbers below bars represent total number of individuals measured within each land-use.

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# CHAPTER 3: GENERAL SUMMARY

The purpose of this chapter is to provide a summary of this study's major findings, address limitations of this study, present considerations for future studies, and provide management recommendations based on the results of this study.

## Summary of results

A summary of this study's findings is listed in Table 3-1.

## Limitations of study / Future research

There are various limitations to this study, one of which was the relatively short time frame (2-years) over which it was conducted. Although differences in relative abundance among land-use types were consistent over both study years, there was significant annual variation in relative abundance of trapped individuals. Population sizes of various species of amphibians are known to fluctuate through time, especially those of aquatic-breeding species (Marsh 2001). Thus, a longer-term study (10 to15-yrs) might be required to confirm the results of this study.

There are certain limitations to the survey techniques used in this study, particularly with respect to pitfall trapping and call surveys. For example, pitfall trapping is a costly, time and labour-intensive technique. As a result, relatively few (24) sites could be sampled, thereby reducing the sample size of this study and the power of analyses. When using call surveys, only an index of abundance is generated and it is difficult to set a specific survey time period that will capture all calling species (this study used 4-hrs in the evening) since calling activity can be species-specific with respect to the time of day and/or weather conditions (Mohr and Dorcas 1999; Bridges and Dorcas 2000). Our study used a combination of survey techniques due to the limitations associated with each of these techniques. Future studies of amphibians in the Beaver Hills could also use these same techniques or might consider using other survey techniques (but which also have limitations) such as visual searches (Parris et al. 1999), egg mass counts (Crouch and Paton 2000), or using automated recording systems to assess calling individuals (Bridges and Dorcas 2000).

There may have been potential errors associated with the digitized land cover GIS dataset. Interpretation of air photos is subjective and some misclassification of land cover types may have occurred. Furthermore, amphibian surveys were conducted in 2001-2002 and the land cover classification was based on air photos taken in either 1998 or 2001. Similar studies might consider using satellite imagery (e.g. Landsat-TM) to obtain a landscape image taken during the same year as the study; however, resolution can be compromised with such images and relative to air photos, smaller habitat features may not be detected. The selected scale for landscape-level analyses (1-km) may also have been a limitation of this study since different species can have varying dispersal distances. Future research might consider using a unique scale for each species depending on its dispersal capabilities, or conversely using multiple scales (i.e. 0.5-km, 1-km, 1.5-km) to better assess the scale at which habitat features are most influential.

Other habitat features not measured in our study may have accounted for differences in relative abundance. Such features may have included the type of soil in the landscape (which may differ between land-uses, particularly in cropland, and possibly affect distributions of burrowing species such as the western toad and tiger salamander), the number of waterbodies in the landscape and their individual size, or more detailed classification of cover types (i.e. distinguishing between pasture and native grasslands - differences in vegetation density and type may affect microhabitat conditions, food/shelter resources, etc.). Also not considered in this study were agrichemicals, which in the Aspen Parkland are present in the majority of wetlands within cropland (primarily 2,4-D, MCPA, AMPA and glyphosate; Anderson et al. 2002). Agrichemicals can affect amphibians by altering their behaviour, growth, and development (Briston and Threlkeld 1998; Christin et al. 2003). Although our study found very low deformity rates in wood frogs (at less than 1%; Eaton et al., in revision), it is unclear whether agrichemicals are negatively affecting amphibians in the Beaver Hills.

In general, a goal of this study was to identify important habitat features influencing patterns of amphibian abundance. Future studies should concentrate on determining if there are thresholds at which these habitat features become critically important for amphibians.

## Management recommendations

Results from this study have important implications for management and conservation of amphibians in the Beaver Hills, particularly for organizations with interests within the Beaver Hills, such as Ducks Unlimited Alberta North American Waterfowl Management Plan (NAWMP) and Parks Canada. Our study results suggest that terrestrial habitat features at a landscape-level may be important in influencing amphibian patterns of abundance. Although a terrestrial buffer zone of natural vegetation around ponds may reduce negative effects for some pond-breeding amphibians (164-m zone; Semlitsch 1998), management efforts should perhaps focus on maintaining specific habitat features within the larger, regional landscape (Storfer 2003). For example, if conservation of the wood frog and boreal chorus frog is a priority, then future conversion of forest into crop and pastures should be minimized in landscapes containing potential breeding ponds for these species. Conversely, the construction of new roads (paved and gravel) and rail lines should be minimized when managing for the tiger salamander.

It has been suggested that connectivity at a landscape-level in fragmented landscapes is more of a concern for pond-breeding amphibians than in less developed areas (Marsh and Trenham 2001). In our study, most of the significant associations of habitat features with amphibian relative abundance were linked to increasing the connectivity of the landscape. For example, more water and forest in the landscape may be particularly important in anthropogenically-modified areas such as the Beaver Hills, where dispersal capabilities may be more restricted than in less fragmented and disturbed landscapes. Forested areas may provide corridors for movement between ponds, while increased water in the landscape may decrease the distance between breeding ponds. Increasing such habitat features might facilitate the "rescuing" of local declining populations by source populations.

Because the Beaver Hills landscape is so altered, maintaining existing landscape habitat features may not be sufficient for conserving amphibian populations. Thus, management might include restoring or creating new habitat features (Semlitsch 2002). For example, in agricultural areas within the Beaver Hills where many ponds have been drained, constructing new ponds may be a valuable means of creating suitable amphibian habitat (Baker and Halliday 1999). Furthermore, if amphibian species' populations in the

Beaver Hills are structured as metapopulations, then managers might consider preserving "source" amphibian ponds while allowing future development in areas of amphibian "sink" habitat.

There should be a focus on ensuring that a diversity of ponds that differ in local and surrounding landscape habitat conditions are preserved or managed since this study's results indicated that different amphibian species were strongly associated with different habitat features. For example, ponds located in crop and pastures may not provide the most suitable habitat for frogs; however, preserving such ponds may be essential for conserving tiger salamander and western toad populations.

This study indicated that ponds located in rural residential acreages provide important habitat for frogs. As such, residential landowners should be informed of this and encouraged to manage their land for these amphibians. Education of amphibians and their habitat could be incorporated into new, or pre-existing landowner stewardship initiatives such as Ducks Unlimited Cooking Lake Moraine Stewardship Project, which provides private landowners with the opportunity to actively participate in habitat conservation on their land (Ducks Unlimited 1999).

For rarer species, such as the western and Canadian toads, there needs to be further identification of important habitat features as well as more intensive surveys to assess their abundance and distribution. Management should also include continuous monitoring of all amphibian species in the Beaver Hills. Amphibian monitoring could be incorporated into the recently adopted ecosystem-based management plan developed jointly by Elk Island National Park and the County of Strathcona (Chapman, pers.

comm.). This would identify potential changes in abundance and distribution across the landscape through time, and prevent potential future declines.

Table 3-1. Summary of study results.

| | | |
|---|---|---|
| **Amphibian species present** | | |
| | wood frog | widespread, abundant |
| | boreal chorus frog | widespread, abundant |
| | western toad | not widespread, not abundant |
| | Canadian toad | extremely rare |
| | tiger salamander | widespread, less abundant |
| **Habitat characteristics: Differences across land-use types** | | |
| | Ponds were better separated by land-use type based on landscape-level features than local habitat features. | |
| **Amphibian-habitat relationships: Differences across land-use types** | | |
| Relative abundance | wood frog | “natural”, residential > crop, pasture * |
| | boreal chorus frog | “natural” > crop * |
| | western toad | “natural” > pasture > residential > crop |
| | tiger salamander | crop > 3 other land-use types |
| Annual variation | wood frogs: adults | 2001 > 2002 all land-use types (* = crop, pasture) |
| Body size | wood frog: adults | 2001: crop > pasture, residential * |
| | | 2002: crop > 3 other land-use types * |
| | wood frog: YOY | 2001: crop > pasture > residential, “natural” * |
| | | 2002: pasture > residential, “natural” * |
| **Amphibian-habitat relationships: Models of amphibian habitat use** | | |
| Significant habitat features: | | |
| Landscape level | wood frog (calling) | amount of crop in the landscape (-ve) |
| | wood frog (trapped) | amount of pasture in the landscape (-ve)<br>amount of water in the landscape (+ve) |
| | boreal chorus frog (calling) | amount of crop in the landscape (-ve)<br>amount of pasture in the landscape (-ve) |
| | tiger salamander (trapped) | amount of residential area in the landscape (+ve)<br>amount of water in the landscape (-ve)<br>distance to the nearest road (+ve) |
| Local pond level | wood frog (calling) | width of emergent vegetation around the pond (+ve)<br>upland vegetation height around the pond (-ve) |
| | wood frog (trapped) | change in depth (-ve) |
| | tiger salamander (trapped) | chlorophyll a concentrations in ponds (+ve) |

* significant difference

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Appendix A. The land-use classification, year of survey, GPS location, and year of air photo used for digitizing images of 213 ponds surveyed for amphibians in the Beaver Hills region of central Alberta in 2001 and 2002. All ponds were surveyed using evening call surveys and marked ponds (*) were also surveyed with pitfall and minnow traps. ❖ = the 163 ponds included in amphibian-habitat regression analyses, EINP = Elk Island National Park.

| Site no. | Land-use category | Year 2001 | Year 2002 | UTM Easting | UTM Northing | UTM Zone | County / District | Year of Air Photo | |
|---|---|---|---|---|---|---|---|---|---|
| **25** | crop | X | | 390872.35 | 5927300.38 | 12 | Beaver | 1998 | ❖ |
| **27** | crop | X | | 386613.34 | 5926108.91 | 12 | Beaver | 1998 | ❖ |
| **72** | crop | X | | 365208.87 | 5915015.28 | 12 | Strathcona | 2001 | |
| **203** | crop | | X | 376214.92 | 5956514.72 | 12 | Lamont | 2001 | ❖ |
| **205** | crop | | X | 392181.02 | 5945876.27 | 12 | Lamont | 1998 | ❖ |
| **207** | crop | | X | 395121.10 | 5943360.26 | 12 | Lamont | 1998 | ❖ |
| **210** | crop | | X | 385681.66 | 5940374.75 | 12 | Lamont | 1998 | ❖ |
| **214** | crop | | X | 391051.65 | 5933759.52 | 12 | Lamont | 1998 | ❖ |
| **218** | crop | | X | 384543.72 | 5907116.34 | 12 | Beaver | 1998 | ❖ |
| **219** | crop | | X | 382937.30 | 5907861.82 | 12 | Beaver | 1998 | ❖ |
| **220** | crop | | X | 382785.94 | 5905424.29 | 12 | Beaver | 1998 | ❖ |
| **222** | crop | | X | 380138.74 | 5908069.60 | 12 | Beaver | 1998 | ❖ |
| **224** | crop | | X | 379874.43 | 5913086.00 | 12 | Beaver | 1998 | ❖ |
| **225** | crop | | X | 379963.40 | 5914873.34 | 12 | Beaver | 2001 | ❖ |
| **228** | crop | | X | 367686.27 | 5944632.13 | 12 | Strathcona | 2001 | ❖ |
| **231** | crop | | X | 368165.89 | 5955088.92 | 12 | Strathcona | 2001 | ❖ |
| **232** | crop | | X | 364850.57 | 5952301.40 | 12 | Strathcona | 2001 | ❖ |
| **233** | crop | | X | 359386.85 | 5950811.91 | 12 | Strathcona | 2001 | ❖ |
| **235** | crop | | X | 359503.90 | 5938199.88 | 12 | Strathcona | 2001 | ❖ |
| **250** | crop | | X | 386456.68 | 5918883.32 | 12 | Beaver | 1998 | ❖ |
| **252** | crop | | X | 385005.26 | 5917392.27 | 12 | Beaver | 1998 | ❖ |
| **253** | crop | | X | 385108.37 | 5915792.86 | 12 | Beaver | 1998 | ❖ |
| **254** | crop | | X | 378276.94 | 5916225.37 | 12 | Beaver | 2001 | ❖ |
| **257** | crop | | X | 360616.04 | 5923346.32 | 12 | Strathcona | 2001 | ❖ |
| **261** | crop | | X | 366048.08 | 5942123.36 | 12 | Strathcona | 2001 | ❖ |
| **272** | crop | | X | 367604.38 | 5938170.29 | 12 | Strathcona | 2001 | ❖ |
| **26 *** | crop | X | X | 391564.91 | 5927356.59 | 12 | Beaver | 1998 | ❖ |
| **48** | crop | X | X | 387804.17 | 5927218.14 | 12 | Beaver | 1998 | ❖ |
| **49 *** | crop | X | X | 385640.42 | 5926037.76 | 12 | Beaver | 1998 | ❖ |
| **51** | crop | X | X | 367969.34 | 5950473.57 | 12 | Strathcona | 2001 | ❖ |
| **52 *** | crop | X | X | 368381.84 | 5949279.37 | 12 | Strathcona | 2001 | ❖ |
| **53** | crop | X | X | 366375.10 | 5950349.53 | 12 | Strathcona | 2001 | ❖ |
| **54** | crop | X | X | 363155.84 | 5948115.20 | 12 | Strathcona | 2001 | ❖ |
| **55 *** | crop | X | X | 362832.13 | 5945992.86 | 12 | Strathcona | 2001 | ❖ |
| **57 *** | crop | X | X | 360047.86 | 5945803.75 | 12 | Strathcona | 2001 | ❖ |
| **83 *** | crop | X[b] | X | 383090.84 | 5912378.27 | 12 | Beaver | 1998 | ❖ |
| **8** | pasture | X | | 382052.96 | 5939976.39 | 12 | Lamont | 2001 | ❖ |
| **21** | pasture | X | | 366188.52 | 5945965.52 | 12 | Strathcona | 2001 | ❖ |
| **28** | pasture | X | | 386538.22 | 5926699.07 | 12 | Beaver | 1998 | |
| **29** | pasture | X | | 386845.49 | 5926642.89 | 12 | Beaver | 1998 | ❖ |
| **58** | pasture | X | | 367559.84 | 5934837.57 | 12 | Strathcona | 2001 | ❖ |
| **59** | pasture | X | | 366445.62 | 5934230.72 | 12 | Strathcona | 2001 | ❖ |
| **65** | pasture | X | | 361380.14 | 5928117.51 | 12 | Strathcona | 2001 | ❖ |

| Site | Land-use | Year | | UTM | | | County / | Year of | |
|---|---|---|---|---|---|---|---|---|---|
| no. | category | 2001 | 2002 | Easting | Northing | Zone | District | Air Photo | |
| **71** | pasture | X | | 365227.21 | 5914921.17 | 12 | Strathcona | 2001 | ❖ |
| **90** | pasture | X[a] | | 370149.29 | 5929319.26 | 12 | Strathcona | 2001 | |
| **117** | pasture | X[a] | | 379376.43 | 5953527.81 | 12 | Lamont | 2001 | |
| **118** | pasture | X[a] | | 380220.65 | 5953582.77 | 12 | Lamont | 2001 | ❖ |
| **202** | pasture | | X | 374517.21 | 5953993.93 | 12 | Lamont | 2001 | ❖ |
| **204** | pasture | | X | 392202.41 | 5949075.09 | 12 | Lamont | 1998 | ❖ |
| **206** | pasture | | X | 393340.81 | 5943390.06 | 12 | Lamont | 1998 | ❖ |
| **208** | pasture | | X | 396818.20 | 5938595.43 | 12 | Lamont | 1998 | ❖ |
| **209** | pasture | | X | 388949.96 | 5940276.88 | 12 | Lamont | 1998 | ❖ |
| **211** | pasture | | X | 385658.23 | 5948615.49 | 12 | Lamont | 2001 | ❖ |
| **212** | pasture | | X | 387496.03 | 5949781.61 | 12 | Lamont | 1998 | ❖ |
| **216** | pasture | | X | 389963.57 | 5919455.90 | 12 | Beaver | 1998 | ❖ |
| **226** | pasture | | X | 375247.11 | 5950072.21 | 12 | Strathcona | 2001 | ❖ |
| **234** | pasture | | X | 361183.64 | 5940139.74 | 12 | Strathcona | 2001 | ❖ |
| **239** | pasture | | X | 362566.46 | 5928029.22 | 12 | Strathcona | 2001 | ❖ |
| **247** | pasture | | X | 375109.86 | 5916844.74 | 12 | Strathcona | 2001 | ❖ |
| **248** | pasture | | X | 376674.00 | 5921085.86 | 12 | Strathcona | 2001 | |
| **249** | pasture | | X | 382896.89 | 5920991.73 | 12 | Beaver | 1998 | ❖ |
| **251** | pasture | | X | 386123.44 | 5917725.50 | 12 | Beaver | 1998 | ❖ |
| **259** | pasture | | X | 369114.62 | 5934335.80 | 12 | Strathcona | 2001 | ❖ |
| **267** | pasture | | X | 351852.11 | 5918532.09 | 12 | Strathcona | 2001 | ❖ |
| **268** | pasture | | X | 362904.19 | 5908616.19 | 12 | Leduc | 1998 | ❖ |
| **274** | pasture | | X | 374424.32 | 5948719.30 | 12 | Strathcona | 2001 | ❖ |
| **283** | pasture | | X | 376981.99 | 5918009.36 | 12 | Strathcona | 2001 | ❖ |
| **35 *** | pasture | X | X | 372158.94 | 5952401.55 | 12 | Strathcona | 2001 | ❖ |
| **50 *** | pasture | X | X | 382001.07 | 5925179.25 | 12 | Blackfoot Reserve | 1998 | ❖ |
| **62** | pasture | X | X | 369572.55 | 5930565.74 | 12 | Strathcona | 2001 | ❖ |
| **64** | pasture | X | X | 367053.46 | 5931196.48 | 12 | Strathcona | 2001 | ❖ |
| **73 *** | pasture | X | X | 375216.56 | 5917822.83 | 12 | Strathcona | 2001 | ❖ |
| **74 *** | pasture | X | X | 368203.84 | 5916940.86 | 12 | Strathcona | 2001 | ❖ |
| **82 *** | pasture | X | X | 388603.67 | 5923656.84 | 12 | Beaver | 1998 | ❖ |
| **84** | pasture | X | X | 375169.16 | 5919110.06 | 12 | Strathcona | 2001 | ❖ |
| **86** | pasture | X | X | 377020.90 | 5921153.86 | 12 | Strathcona | 2001 | ❖ |
| **89 *** | pasture | X[a] | X | 369873.20 | 5929692.18 | 12 | Strathcona | 2001 | ❖ |
| **91** | pasture | X[a] | X | 369841.43 | 5929263.66 | 12 | Strathcona | 2001 | ❖ |
| **112** | pasture | X[a] | X | 372282.33 | 5952357.20 | 12 | Strathcona | 2001 | |
| **149** | pasture | X[a] | X[a] | 372609.23 | 5952422.41 | 12 | Strathcona | 2001 | ❖ |
| **213** | residential | | X | 388224.92 | 5933396.40 | 12 | Beaver | 1998 | ❖ |
| **221** | residential | | X | 381274.84 | 5907089.84 | 12 | Beaver | 1998 | ❖ |
| **223** | residential | | X | 377711.27 | 5909650.13 | 12 | Beaver | 1998 | ❖ |
| **227** | residential | | X | 381611.24 | 5920596.15 | 12 | Beaver | 1998 | ❖ |
| **236** | residential | | X | 357858.57 | 5937515.40 | 12 | Strathcona | 2001 | ❖ |
| **237** | residential | | X | 358333.49 | 5934323.07 | 12 | Strathcona | 2001 | ❖ |
| **238** | residential | | X | 360268.64 | 5929910.71 | 12 | Strathcona | 2001 | ❖ |
| **240** | residential | | X | 364533.72 | 5931504.45 | 12 | Strathcona | 2001 | ❖ |
| **241** | residential | | X | 365473.14 | 5936274.66 | 12 | Strathcona | 2001 | ❖ |
| **242** | residential | | X | 352633.29 | 5921892.69 | 12 | Strathcona | 2001 | ❖ |
| **243** | residential | | X | 352071.27 | 5916698.83 | 12 | Strathcona | 2001 | ❖ |
| **244** | residential | | X | 356506.07 | 5917220.96 | 12 | Strathcona | 2001 | ❖ |

| Site no. | Land-use category | Year 2001 | Year 2002 | UTM Easting | UTM Northing | UTM Zone | County / District | Year of Air Photo | |
|---|---|---|---|---|---|---|---|---|---|
| **245** | residential | | X | 364101.43 | 5916426.47 | 12 | Strathcona | 2001 | ❖ |
| **246** | residential | | X | 373130.32 | 5916234.01 | 12 | Strathcona | 2001 | ❖ |
| **255** | residential | | X | 378980.81 | 5917576.45 | 12 | Beaver | 2001 | ❖ |
| **256** | residential | | X | 362692.24 | 5916037.14 | 12 | Strathcona | 2001 | ❖ |
| **258** | residential | | X | 363558.69 | 5933173.06 | 12 | Strathcona | 2001 | ❖ |
| **260** | residential | | X | 365475.50 | 5941519.72 | 12 | Strathcona | 2001 | ❖ |
| **262** | residential | | X | 356242.22 | 5932063.17 | 12 | Strathcona | 2001 | ❖ |
| **20** | residential | X | X | 366396.40 | 5944177.75 | 12 | Strathcona | 2001 | ❖ |
| **60 *** | residential | X | X | 369966.37 | 5927005.74 | 12 | Strathcona | 2001 | ❖ |
| **61 *** | residential | X | X | 368929.30 | 5940687.66 | 12 | Strathcona | 2001 | ❖ |
| **66 *** | residential | X | X | 358011.71 | 5927750.37 | 12 | Strathcona | 2001 | ❖ |
| **67** | residential | X | X | 348979.19 | 5922119.99 | 12 | Strathcona | 2001 | ❖ |
| **68** | residential | X | X | 349117.42 | 5920921.05 | 12 | Strathcona | 2001 | ❖ |
| **69** | residential | X | X | 349396.74 | 5919720.11 | 12 | Strathcona | 2001 | ❖ |
| **70 *** | residential | X | X | 359083.22 | 5916596.12 | 12 | Strathcona | 2001 | ❖ |
| **81** | residential | X | X | 377060.80 | 5912739.32 | 12 | Beaver | 1998 | |
| **93 *** | residential | X[a] | X | 376822.06 | 5912683.37 | 12 | Beaver | 1998 | ❖ |
| **94 *** | residential | X[a] | X | 349420.62 | 5920256.48 | 12 | Strathcona | 2001 | ❖ |
| **3** | "natural" | X | | 376891.09 | 5946831.28 | 12 | EINP | 2001 | |
| **9** | "natural" | X | | 382376.08 | 5943194.91 | 12 | Lamont County | 2001 | ❖ |
| **11** | "natural" | X | | 382438.55 | 5944659.36 | 12 | Lamont County | 2001 | |
| **13** | "natural" | X | | 372923.73 | 5950447.43 | 12 | Strathcona | 2001 | ❖ |
| **14** | "natural" | X | | 372494.72 | 5947347.71 | 12 | Strathcona | 2001 | |
| **16** | "natural" | X | | 370002.91 | 5943957.85 | 12 | Strathcona | 2001 | ❖ |
| **17** | "natural" | X | | 369496.95 | 5944037.89 | 12 | Strathcona | 2001 | ❖ |
| **18** | "natural" | X | | 369488.13 | 5944009.83 | 12 | Strathcona | 2001 | |
| **22** | "natural" | X | | 376235.77 | 5952395.96 | 12 | EINP | 2001 | ❖ |
| **24** | "natural" | X | | 376232.42 | 5953530.58 | 12 | EINP | 2001 | ❖ |
| **30** | "natural" | X | | 386724.62 | 5927433.51 | 12 | Beaver | 1998 | ❖ |
| **31** | "natural" | X | | 386829.21 | 5928216.22 | 12 | Beaver | 1998 | ❖ |
| **32** | "natural" | X | | 386882.15 | 5928206.82 | 12 | Beaver | 1998 | |
| **33** | "natural" | X | | 386889.87 | 5930827.33 | 12 | Beaver | 1998 | ❖ |
| **36** | "natural" | X | | 377481.44 | 5953264.07 | 12 | EINP | 2001 | ❖ |
| **42** | "natural" | X | | 380335.41 | 5951031.80 | 12 | EINP | 2001 | |
| **45** | "natural" | X | | 378917.75 | 5949947.99 | 12 | EINP | 2001 | |
| **46** | "natural" | X | | 378870.32 | 5950007.76 | 12 | EINP | 2001 | |
| **56** | "natural" | X | | 361735.83 | 5944157.04 | 12 | Strathcona | 2001 | ❖ |
| **75** | "natural" | X | | 368725.90 | 5917284.17 | 12 | Strathcona | 2001 | ❖ |
| **85** | "natural" | X | | 375320.14 | 5919111.33 | 12 | Strathcona | 2001 | |
| **97** | "natural" | X[a] | | 372869.85 | 5950384.85 | 12 | Strathcona | 2001 | |
| **98** | "natural" | X[a] | | 376387.28 | 5949079.73 | 12 | EINP | 2001 | |
| **105** | "natural" | X[a] | | 379738.03 | 5949082.88 | 12 | EINP | 2001 | |
| **106** | "natural" | X[a] | | 380038.64 | 5948965.14 | 12 | EINP | 2001 | ❖ |
| **107** | "natural" | X[a] | | 379943.64 | 5948816.02 | 12 | EINP | 2001 | |
| **108** | "natural" | X[a] | | 379184.21 | 5947042.36 | 12 | EINP | 2001 | |
| **111** | "natural" | X[a] | | 378948.29 | 5947176.85 | 12 | EINP | 2001 | |
| **113** | "natural" | X[a] | | 375733.51 | 5953560.27 | 12 | Strathcona | 2001 | |
| **114** | "natural" | X[a] | | 375708.60 | 5953649.34 | 12 | Strathcona | 2001 | ❖ |
| **116** | "natural" | X[a] | | 378751.60 | 5953538.69 | 12 | Lamont | 2001 | |

| Site | Land-use | Year | | UTM | | | County / | Year of | |
|---|---|---|---|---|---|---|---|---|---|
| **no.** | **category** | **2001** | **2002** | **Easting** | **Northing** | **Zone** | **District** | **Air Photo** | |
| **119** | "natural" | X[a] | | 380905.07 | 5953678.03 | 12 | Lamont | 2001 | ❖ |
| **120** | "natural" | X[a] | | 382490.71 | 5952186.78 | 12 | EINP | 2001 | |
| **122** | "natural" | X[a] | | 382500.83 | 5951977.96 | 12 | EINP | 2001 | |
| **127** | "natural" | X[a] | | 382486.06 | 5949748.84 | 12 | Lamont | 2001 | |
| **129** | "natural" | X[a] | | 382396.39 | 5949087.30 | 12 | EINP | 2001 | |
| **130** | "natural" | X[a] | | 382484.28 | 5949076.23 | 12 | Lamont | 2001 | |
| **131** | "natural" | X[a] | | 382538.36 | 5948977.66 | 12 | Lamont | 2001 | |
| **133** | "natural" | X[a] | | 382330.40 | 5947404.90 | 12 | EINP | 2001 | ❖ |
| **134** | "natural" | X[a] | | 382462.20 | 5947387.70 | 12 | Lamont | 2001 | |
| **135** | "natural" | X[a] | | 382352.36 | 5947020.26 | 12 | EINP | 2001 | |
| **136** | "natural" | X[a] | | 382442.10 | 5946999.00 | 12 | Lamont | 2001 | |
| **137** | "natural" | X[a] | | 382333.87 | 5946690.87 | 12 | EINP | 2001 | |
| **139** | "natural" | X[a] | | 382454.51 | 5946424.37 | 12 | Lamont | 2001 | |
| **140** | "natural" | X[a] | | 382351.33 | 5945803.12 | 12 | EINP | 2001 | ❖ |
| **142** | "natural" | X[a] | | 377781.42 | 5947046.49 | 12 | EINP | 2001 | |
| **147** | "natural" | X[a] | | 370849.09 | 5934298.39 | 12 | EINP | 2001 | ❖ |
| **150** | "natural" | X[a] | | 376284.06 | 5951626.63 | 12 | EINP | 2001 | ❖ |
| **151** | "natural" | X[a] | | 376046.32 | 5951781.18 | 12 | EINP | 2001 | |
| **263** | "natural" | | X | 369213.20 | 5938871.80 | 12 | Strathcona | 2001 | ❖ |
| **264** | "natural" | | X | 381086.53 | 5953015.99 | 12 | EINP | 2001 | ❖ |
| **265** | "natural" | | X | 380732.27 | 5952483.06 | 12 | EINP | 2001 | |
| **266** | "natural" | | X | 380614.82 | 5950866.03 | 12 | EINP | 2001 | ❖ |
| **269** | "natural" | | X | 377138.23 | 5946629.71 | 12 | EINP | 2001 | ❖ |
| **270** | "natural" | | X | 377536.96 | 5944356.57 | 12 | EINP | 2001 | ❖ |
| **271** | "natural" | | X | 382508.06 | 5952503.94 | 12 | EINP | 2001 | ❖ |
| **275** | "natural" | | X | 372682.39 | 5947247.39 | 12 | Strathcona | 2001 | ❖ |
| **276** | "natural" | | X | 372671.97 | 5945273.01 | 12 | EINP | 2001 | ❖ |
| **277** | "natural" | | X | 372768.60 | 5944847.36 | 12 | EINP | 2001 | |
| **278** | "natural" | | X | 371353.65 | 5943897.75 | 12 | EINP | 2001 | ❖ |
| **279** | "natural" | | X | 370956.27 | 5941618.49 | 12 | EINP | 2001 | ❖ |
| **280** | "natural" | | X | 370974.73 | 5942097.77 | 12 | EINP | 2001 | ❖ |
| **281** | "natural" | | X | 370915.63 | 5939328.49 | 12 | EINP | 2001 | ❖ |
| **282** | "natural" | | X | 370916.47 | 5938444.79 | 12 | EINP | 2001 | ❖ |
| **284** | "natural" | | X | 369202.38 | 5937134.14 | 12 | Strathcona | 2001 | ❖ |
| **1** | "natural" | X | X | 376319.80 | 5947957.44 | 12 | EINP | 2001 | ❖ |
| **2** | "natural" | X | X | 376998.02 | 5947530.25 | 12 | EINP | 2001 | ❖ |
| **4 *** | "natural" | X | X | 377339.63 | 5945218.07 | 12 | EINP | 2001 | ❖ |
| **5** | "natural" | X | X | 376975.61 | 5942530.62 | 12 | EINP | 2001 | ❖ |
| **6 *** | "natural" | X | X | 373942.23 | 5941662.53 | 12 | EINP | 2001 | ❖ |
| **12** | "natural" | X | X | 373111.08 | 5950370.09 | 12 | Strathcona | 2001 | |
| **23** | "natural" | X | X | 375990.06 | 5952415.53 | 12 | Strathcona | 2001 | |
| **37 *** | "natural" | X | X | 379477.34 | 5953338.93 | 12 | EINP | 2001 | ❖ |
| **38** | "natural" | X | X | 380454.99 | 5952515.22 | 12 | EINP | 2001 | ❖ |
| **40** | "natural" | X | X | 380775.83 | 5951641.63 | 12 | EINP | 2001 | ❖ |
| **41** | "natural" | X | X | 380445.19 | 5951537.33 | 12 | EINP | 2001 | |
| **43 *** | "natural" | X | X | 379029.09 | 5950141.08 | 12 | EINP | 2001 | ❖ |
| **44** | "natural" | X | X | 378967.63 | 5949982.70 | 12 | EINP | 2001 | |
| **77 *** | "natural" | X | X | 368611.65 | 5913688.40 | 12 | Ministk Sanctuary | 2001 | ❖ |
| **78** | "natural" | X | X | 368710.60 | 5914096.43 | 12 | Ministk Sanctuary | 2001 | |

| Site | Land-use | Year | | UTM | | | County / | Year of | |
|---|---|---|---|---|---|---|---|---|---|
| no. | category | 2001 | 2002 | Easting | Northing | Zone | District | Air Photo | |
| **79 *** | "natural" | X | X | 366792.19 | 5908592.95 | 12 | Ministk Sanctuary | 1998 | ❖ |
| **80** | "natural" | X | X | 366622.75 | 5908405.59 | 12 | Ministk Sanctuary | 1998 | |
| **88** | "natural" | X | X | 377369.64 | 5937248.25 | 12 | EINP | 2001 | ❖ |
| **92** | "natural" | X[a] | X | 382335.90 | 5944642.98 | 12 | EINP | 2001 | ❖ |
| **99** | "natural" | X[a] | X | 376177.24 | 5948738.62 | 12 | EINP | 2001 | ❖ |
| **100** | "natural" | X[a] | X[a] | 376707.65 | 5946009.13 | 12 | EINP | 2001 | ❖ |
| **101** | "natural" | X[a] | X | 379317.00 | 5948914.61 | 12 | EINP | 2001 | |
| **102** | "natural" | X[a] | X | 379225.25 | 5948864.48 | 12 | EINP | 2001 | |
| **103** | "natural" | X[a] | X | 379454.34 | 5948783.49 | 12 | EINP | 2001 | ❖ |
| **104** | "natural" | X[a] | X | 379504.61 | 5949059.87 | 12 | EINP | 2001 | |
| **109** | "natural" | X[a] | X | 379069.15 | 5947335.81 | 12 | EINP | 2001 | |
| **110** | "natural" | X[a] | X | 378930.26 | 5947054.50 | 12 | EINP | 2001 | ❖ |
| **115** | "natural" | X[a] | X | 378807.40 | 5953403.09 | 12 | EINP | 2001 | ❖ |
| **121** | "natural" | X[a] | X | 382553.55 | 5952018.52 | 12 | Lamont | 2001 | ❖ |
| **123** | "natural" | X[a] | X | 382489.10 | 5951689.29 | 12 | EINP | 2001 | ❖ |
| **124** | "natural" | X[a] | X | 382628.08 | 5951415.41 | 12 | Lamont | 2001 | |
| **125** | "natural" | X[a] | X | 382231.91 | 5951105.80 | 12 | EINP | 2001 | ❖ |
| **126** | "natural" | X[a] | X | 382289.15 | 5949789.08 | 12 | EINP | 2001 | ❖ |
| **128** | "natural" | X[a] | X | 382404.80 | 5949260.05 | 12 | EINP | 2001 | ❖ |
| **138** | "natural" | X[a] | X | 382334.20 | 5946404.51 | 12 | EINP | 2001 | ❖ |
| **141** | "natural" | X[a] | X | 382181.66 | 5945253.70 | 12 | EINP | 2001 | ❖ |
| **143** | "natural" | X[a] | X | 377780.38 | 5947365.70 | 12 | EINP | 2001 | ❖ |
| **144** | "natural" | X[a] | X | 380075.18 | 5950223.23 | 12 | EINP | 2001 | ❖ |

X[a] : ponds not surveyed for wood frogs

X[b] : ponds not surveyed for boreal chorus frogs, western toads and Canadian toads

Appendix B. Checklist of species and age class datasets included in amphibian-habitat analyses. ✓ = analyses of land-use type differences, ☑ = analyses of amphibian-habitat regression models.

| | **Call surveys** | **Pitfall traps** | | | **Minnow traps** | | |
|---|---|---|---|---|---|---|---|
| **Species** | **adult** | **adult** | **YOY** | **ALL** | **adult** | **YOY + larvae** | **ALL** |
| wood frog | ☑ | ☑ | ✓ | | ✓ | ✓ | |
| boreal chorus frog | ☑ | | | ✓ * | | | ✓ * |
| western toad | ✓ | ✓ | ✓ | | n.c | n.c | n.c |
| Canadian toad | ✓ | n.c | n.c | n.c | n.c | n.c | n.c |
| tiger salamander | n/a | | | ☑* | | | ✓ * |

* could not distinguish between age classes
n.c.: no individuals captured
n/a: not applicable

Appendix C. Gradient lengths from 3 separate Detrended Correspondence Analyses (DCA) comparing ponds within 4 different land-use types based on local and landscape habitat features. Ponds were located in the Beaver Hills region of central Alberta. Three datasets were analyzed, each differing in the number of ponds and/or the scale at which habitat features were measured (landscape or local).

| | **Landscape (n=163 ponds) Axis** | | | **Landscape (n=24 ponds) Axis** | | | **Local (n=24 ponds) Axis** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **1** | **2** | **3** | **1** | **2** | **3** |
| Gradient Lengths | 1.604 | 1.438 | 0.671 | 1.401 | 0.979 | 0.951 | 0.619 | 0.153 | 0.425 |
| | 1.596 | 1.447 | 0.666 | 1.400 | 0.983 | 0.959 | 0.626 | 0.152 | 0.405 |
| | 1.583 | 1.458 | 0.664 | 1.398 | 0.984 | 0.960 | 0.633 | 0.154 | 0.348 |
| | 1.576 | 1.458 | 0.664 | 1.396 | 0.985 | 0.962 | 0.636 | 0.152 | 0.315 |

Appendix D

Table 1. Summary of the call survey data from 2001 and 2002, indicating the number of ponds where the same calling code (0-3) was recorded. Ponds were located in the Beaver Hills region of central Alberta and categorized by land-use type.

| Species | Year | Land-use type | No. of ponds | Call code 0 | 1 | 2 | 3 |
|---|---|---|---|---|---|---|---|
| wood frog | 2001 | crop | 13 | 10 | 1 | 1 | 1 |
| | | pasture | 17 | 7 | 6 | 4 | 0 |
| | | residential | 9 | 1 | 6 | 2 | 0 |
| | | "natural" | 39 | 6 | 22 | 2 | 9 |
| | | **Total** | **78** | **24** | **35** | **9** | **10** |
| | 2002 | crop | 33 | 8 | 17 | 5 | 3 |
| | | pasture | 32 | 7 | 10 | 11 | 4 |
| | | residential | 30 | 1 | 12 | 6 | 11 |
| | | "natural" | 53 | 2 | 10 | 10 | 31 |
| | | **Total** | **148** | **18** | **49** | **32** | **49** |
| boreal chorus frog | 2001 | crop | 12 | 8 | 4 | 0 | 0 |
| | | pasture | 24 | 7 | 5 | 0 | 12 |
| | | residential | 11 | 2 | 2 | 3 | 4 |
| | | "natural" | 87 | 9 | 16 | 6 | 56 |
| | | **Total** | **134** | **26** | **27** | **9** | **72** |
| | 2002 | crop | 33 | 12 | 11 | 5 | 5 |
| | | pasture | 33 | 7 | 9 | 7 | 10 |
| | | residential | 30 | 1 | 9 | 8 | 12 |
| | | "natural" | 54 | 1 | 6 | 12 | 35 |
| | | **Total** | **150** | **21** | **35** | **32** | **62** |
| western toad | 2001 | crop | 12 | 12 | 0 | 0 | 0 |
| | | pasture | 24 | 24 | 0 | 0 | 0 |
| | | residential | 11 | 11 | 0 | 0 | 0 |
| | | "natural" | 87 | 72 | 15 | 0 | 0 |
| | | **Total** | **134** | **119** | **15** | **0** | **0** |
| | 2002 | crop | 33 | 33 | 0 | 0 | 0 |
| | | pasture | 33 | 29 | 4 | 0 | 0 |
| | | residential | 30 | 30 | 0 | 0 | 0 |
| | | "natural" | 54 | 46 | 8 | 0 | 0 |
| | | **Total** | **150** | **138** | **12** | **0** | **0** |
| Canadian toad | 2001 | crop | 12 | 12 | 0 | 0 | 0 |
| | | pasture | 24 | 22 | 2 | 0 | 0 |
| | | residential | 11 | 11 | 0 | 0 | 0 |
| | | "natural" | 87 | 87 | 0 | 0 | 0 |
| | | **Total** | **134** | **132** | **2** | **0** | **0** |
| | 2002 | crop | 33 | 33 | 0 | 0 | 0 |
| | | pasture | 33 | 33 | 0 | 0 | 0 |
| | | residential | 30 | 30 | 0 | 0 | 0 |
| | | "natural" | 54 | 54 | 0 | 0 | 0 |
| | | **Total** | **150** | **150** | **0** | **0** | **0** |

Table 2. Summary of amphibians caught with pitfall traps (PT) and minnow traps (MT) from 1 June to 28 August 2001 at 24 ponds within 4 different land-use types. All ponds were located in the Beaver Hills region of central Alberta.

| | | wood frog | | | | | boreal chorus frog | | | western toad | | | | | tiger salamander | | No. of trap nights | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | Land-use | adults | | YOY | | larvae | adults | | larvae | adults | | YOY | | larvae | adults & larvae | | | |
| no. | type | PT | MT | PT | MT | MT | PT | MT | MT | PT | MT | PT | MT | MT | PT | MT | PT | MT |
| 52 | crop | 24 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 10 | 996.0 | 247.0 |
| 55 | crop | 47 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 876.0 | 216.0 |
| 57 | crop | 25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 3 | 876.0 | 192.0 |
| 83 | crop | 37 | 2 | 73 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 756.0 | 189.0 |
| 26 | crop | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 8 | 680.0 | 174.0 |
| 49 | crop | 4 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 612.0 | 153.0 |
| 35 | pasture | 18 | 2 | 10 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 2 | 0 | 0 | 13 | 6 | 982.0 | 239.5 |
| 89 | pasture | 29 | 2 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 910.5 | 210.0 |
| 50 | pasture | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 888.0 | 222.0 |
| 73 | pasture | 17 | 1 | 110 | 36 | 45 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 4 | 576.0 | 171.0 |
| 74 | pasture | 64 | 4 | 8 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 918.0 | 219.0 |
| 82 | pasture | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 516.0 | 129.0 |
| 61 | residential | 68 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 946.5 | 237.0 |
| 60 | residential | 152 | 1 | 959 | 0 | 39 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 2 | 795.0 | 213.0 |
| 66 | residential | 46 | 2 | 7 | 1 | 11 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1008.0 | 252.0 |
| 94 | residential | 24 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 6 | 293.5 | 141.0 |
| 93 | residential | 11 | 5 | 46 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 720.0 | 176.5 |
| 70 | residential | 31 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 5 | 756.0 | 189.0 |
| 37 | "natural" | 85 | 6 | 27 | 0 | 31 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 3 | 1 | 982.0 | 234.0 |
| 43 | "natural" | 32 | 0 | 34 | 0 | 0 | 1 | 0 | 0 | 5 | 0 | 2 | 0 | 0 | 1 | 0 | 720.0 | 180.0 |
| 4 | "natural" | 81 | 3 | 94 | 0 | 47 | 1 | 0 | 0 | 15 | 0 | 1 | 0 | 0 | 0 | 0 | 948.0 | 237.0 |
| 6 | "natural" | 3 | 0 | 5 | 0 | 9 | 5 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 624.0 | 156.0 |
| 77 | "natural" | 161 | 3 | 392 | 10 | 99 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 16 | 0 | 857.0 | 216.0 |
| 79 | "natural" | 51 | 0 | 296 | 24 | 7 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 591.0 | 148.0 |
| **Total** | | 1,023 | 37 | 2,065 | 74 | 289 | 22 | 0 | 1 | 31 | 0 | 5 | 0 | 0 | 67 | 49 | 14,105.5 | 3,570.0 |

**Total no. individuals caught of all species: 3,663**

Table 3. Summary of amphibians caught with pitfall traps (PT) and minnow traps (MT) from 16 May to 23 August 2002 at 24 ponds within 4 different land-use types. All ponds were located in the Beaver Hills region of central Alberta.

| | | wood frog | | | | | boreal chorus frog | | | western toad | | | | | tiger salamander | | No. of | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | Land-use | adults | | YOY | | larvae | adults | | larvae | adults | | YOY | | larvae | adults & larvae | | trap nights | |
| no. | type | PT | MT | PT | MT | MT | PT | MT | MT | PT | MT | PT | MT | MT | PT | MT | PT | MT |
| 52 | crop | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1080.0 | 279.0 |
| 55 | crop | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1081.0 | 279.0 |
| 57 | crop | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | 1083.0 | 279.0 |
| 83 | crop | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1041.5 | 267.0 |
| 26 | crop | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 15 | 1057.5 | 267.0 |
| 49 | crop | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 1056.0 | 264.0 |
| 35 | pasture | 1 | 1 | 6 | 1 | 0 | 2 | 0 | 0 | 9 | 0 | 52 | 0 | 0 | 11 | 3 | 1067.0 | 58.5 |
| 89 | pasture | 35 | 5 | 21 | 7 | 17 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 1152.0 | 92.5 |
| 50 | pasture | 8 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1147.0 | 275.5 |
| 73 | pasture | 2 | 0 | 13 | 2 | 7 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1011.5 | 31.5 |
| 74 | pasture | 16 | 1 | 4 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1041.5 | 155.0 |
| 82 | pasture | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1079.5 | 285.0 |
| 61 | residential | 15 | 1 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1088.0 | 269.0 |
| 60 | residential | 101 | 2 | 360 | 2 | 39 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1093.5 | 288.5 |
| 66 | residential | 23 | 4 | 23 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1011.5 | 266.0 |
| 94 | residential | 42 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 1 | 5 | 965.0 | 266.5 |
| 93 | residential | 23 | 17 | 0 | 0 | 32 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1036.5 | 267.0 |
| 70 | residential | 46 | 0 | 15 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 1061.5 | 31.5 |
| 37 | "natural" | 22 | 3 | 12 | 2 | 2 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 2 | 3 | 1092.0 | 273.0 |
| 43 | "natural" | 53 | 1 | 13 | 0 | 0 | 1 | 0 | 0 | 16 | 0 | 0 | 0 | 0 | 1 | 0 | 991.5 | 270.0 |
| 4 | "natural" | 87 | 0 | 145 | 0 | 5 | 0 | 0 | 0 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 1080.0 | 268.5 |
| 6 | "natural" | 36 | 0 | 119 | 55 | 235 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1056.0 | 264.0 |
| 77 | "natural" | 146 | 3 | 17 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1077.0 | 255.0 |
| 79 | "natural" | 84 | 8 | 32 | 4 | 15 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0 | 1068.0 | 64.5 |
| **Total** | | 772 | 50 | 786 | 73 | 363 | 28 | 0 | 0 | 45 | 0 | 52 | 0 | 0 | 34 | 42 | 25,518.0 | 5,316.5 |

**Total no. individuals caught of all species: 2,245**

Appendix E

Table 1. Local and landscape habitat features measured at 163 ponds in the Beaver Hills region of central Alberta in 2001 and 2002. Refer to Table 2-1 for definition of habitat variables. All ponds were surveyed for amphibians using evening call surveys; marked ponds (*) were also surveyed using pitfall traps and minnow traps.

| | | | | local habitat features | | | | landscape habitat features (within a 1-km radius of surveyed pond) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Site** | **Land-use** | Year | | AREA | PERIM | UPVEG | CAT/BUL | CROP | FOREST | PAST | ROAD | SHRUB | RESID | WATER | NRWTR | NRFRST | NRRD |
| **no.** | **category** | **2001** | **2002** | **(ha)** | **(m)** | **(m)** | **(m)** | **(%)** | **(%)** | **(%)** | **(%)** | **(%)** | **(%)** | **(%)** | **(m)** | **(m)** | **(m)** |
| **25** | crop | X | | 0.20 | 260.03 | 1 | 0.3 | 63.84 | 6.83 | 15.97 | 1.28 | 0.09 | 2.31 | 0.52 | 275.74 | 352.16 | 0.00 |
| **27** | crop | X | | 0.83 | 537.68 | 3 | 20.0 | 48.30 | 16.42 | 11.55 | 0.95 | 0.16 | 0.00 | 7.32 | 93.73 | 4.98 | 95.54 |
| **203** | crop | | X | 0.25 | 239.88 | 1 | 3.0 | 10.02 | 35.98 | 46.74 | 1.23 | 0.04 | 1.16 | 0.86 | 12.01 | 93.95 | 0.00 |
| **205** | crop | | X | 0.05 | 121.43 | 1 | 0.0 | 68.13 | 6.92 | 18.81 | 1.01 | 0.02 | 2.55 | 0.40 | 83.97 | 14.55 | 3.45 |
| **207** | crop | | X | 0.32 | 330.90 | 1 | 0.0 | 48.80 | 3.71 | 40.75 | 1.32 | 0.02 | 3.01 | 0.24 | 370.55 | 8.41 | 1.00 |
| **210** | crop | | X | 2.11 | 629.83 | 0 | 37.0 | 40.52 | 6.92 | 38.66 | 1.21 | 0.09 | 1.40 | 1.88 | 100.44 | 129.35 | 0.00 |
| **214** | crop | | X | 0.17 | 209.43 | 0 | 1.5 | 66.31 | 5.30 | 12.77 | 1.20 | 0.11 | 0.96 | 2.07 | 9.91 | 38.72 | 0.00 |
| **218** | crop | | X | 0.41 | 329.94 | 1 | 4.0 | 61.16 | 13.40 | 20.31 | 0.94 | 0.02 | 0.61 | 1.35 | 101.63 | 0.00 | 14.25 |
| **219** | crop | | X | 0.35 | 303.04 | 0 | 1.0 | 57.90 | 11.16 | 23.01 | 1.24 | 0.05 | 0.46 | 1.04 | 176.56 | 41.89 | 11.36 |
| **220** | crop | | X | 0.77 | 386.22 | 3 | 3.0 | 59.90 | 10.50 | 19.14 | 1.12 | 0.06 | 0.64 | 2.57 | 134.11 | 9.90 | 0.00 |
| **222** | crop | | X | 0.12 | 152.28 | 3 | 0.5 | 21.82 | 24.48 | 46.88 | 1.58 | 0.03 | 1.87 | 0.92 | 249.73 | 12.37 | 14.58 |
| **224** | crop | | X | 2.27 | 684.42 | 2 | 5.0 | 32.21 | 12.17 | 38.59 | 0.75 | 0.11 | 2.72 | 2.63 | 257.25 | 17.67 | 7.28 |
| **225** | crop | | X | 0.21 | 210.22 | 0 | 2.0 | 29.11 | 17.23 | 38.36 | 1.73 | 0.09 | 3.24 | 1.13 | 115.50 | 171.46 | 10.96 |
| **228** | crop | | X | 0.13 | 176.67 | 1 | 1.0 | 32.69 | 34.72 | 18.23 | 1.20 | 0.06 | 5.42 | 2.14 | 196.75 | 172.78 | 25.38 |
| **231** | crop | | X | 0.93 | 595.42 | 1 | 0.5 | 80.14 | 8.09 | 3.69 | 0.60 | 0.04 | 1.94 | 2.04 | 405.85 | 376.64 | 38.07 |
| **232** | crop | | X | 1.58 | 569.54 | 0 | 2.0 | 85.47 | 6.08 | 1.33 | 0.97 | 0.03 | 2.23 | 1.33 | 100.78 | 447.17 | 69.44 |
| **233** | crop | | X | 0.02 | 75.13 | 1 | 0.5 | 84.71 | 2.41 | 5.02 | 1.74 | 0.03 | 3.09 | 0.27 | 181.83 | 268.13 | 21.13 |
| **235** | crop | | X | 0.18 | 379.86 | 1 | 20.0 | 60.99 | 14.08 | 10.54 | 2.23 | 0.06 | 5.26 | 0.95 | 77.62 | 326.40 | 58.57 |
| **250** | crop | | X | 0.42 | 386.84 | 0 | 6.0 | 55.93 | 16.89 | 8.21 | 0.82 | 0.12 | 0.19 | 5.53 | 71.08 | 40.41 | 24.45 |
| **252** | crop | | X | 0.56 | 436.01 | 0 | 3.0 | 41.86 | 10.43 | 35.08 | 1.57 | 0.06 | 2.81 | 2.26 | 90.48 | 377.29 | 2.00 |
| **253** | crop | | X | 2.75 | 904.74 | 3 | 8.0 | 54.67 | 10.63 | 27.17 | 1.10 | 0.06 | 0.12 | 0.78 | 798.89 | 500.77 | 73.16 |
| **254** | crop | | X | 0.28 | 404.71 | 0 | 0.5 | 10.97 | 41.87 | 26.27 | 1.45 | 0.12 | 1.85 | 5.79 | 113.32 | 36.83 | 44.57 |
| **257** | crop | | X | 0.08 | 232.70 | 1 | 1.0 | 43.55 | 22.95 | 8.76 | 1.70 | 0.07 | 8.27 | 7.42 | 18.16 | 61.53 | 6.85 |
| **261** | crop | | X | 0.16 | 375.52 | 3 | 0.5 | 55.35 | 11.42 | 15.17 | 1.14 | 0.05 | 10.39 | 1.78 | 63.46 | 41.15 | 0.00 |
| **272** | crop | | X | 0.52 | 473.84 | 3 | 6.0 | 59.64 | 10.69 | 14.98 | 1.65 | 0.04 | 5.78 | 3.75 | 94.58 | 5.57 | 8.97 |
| **26 *** | crop | X | X | 0.94 | 494.75 | 2 | 13.0 | 61.74 | 7.37 | 18.48 | 1.07 | 0.07 | 3.33 | 0.70 | 86.18 | 252.27 | 40.73 |

| | | | | local habitat features | | | | landscape habitat features (within a 1-km radius of surveyed pond) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site no. | Land-use category | Year 2001 | Year 2002 | AREA (ha) | PERIM (m) | UPVEG (m) | CAT/BUL (m) | CROP (%) | FOREST (%) | PAST (%) | ROAD (%) | SHRUB (%) | RESID (%) | WATER (%) | NRWTR (m) | NRFRST (m) | NRRD (m) |
| **48** | crop | X | X | 0.36 | 325.35 | 0 | 3.0 | 26.62 | 23.73 | 29.67 | 1.56 | 0.12 | 0.31 | 6.13 | 44.27 | 54.39 | 101.19 |
| **49 *** | crop | X | X | 0.77 | 377.66 | 1 | 6.0 | 24.34 | 19.58 | 34.71 | 0.73 | 0.15 | 0.30 | 5.28 | 45.62 | 148.61 | 204.17 |
| **51** | crop | X | X | 0.05 | 146.94 | 1 | 25.0 | 65.29 | 7.54 | 16.84 | 1.27 | 0.05 | 3.36 | 0.90 | 49.69 | 232.14 | 15.90 |
| **52 *** | crop | X | X | 0.54 | 339.23 | 1 | 20.0 | 71.27 | 4.19 | 11.65 | 0.54 | 0.06 | 3.74 | 2.71 | 300.24 | 35.11 | 426.04 |
| **53** | crop | X | X | 1.87 | 566.79 | 0 | 8.0 | 69.47 | 7.03 | 9.45 | 1.36 | 0.08 | 2.99 | 1.27 | 218.44 | 24.96 | 7.57 |
| **54** | crop | X | X | 3.75 | 737.33 | 0 | 6.0 | 80.43 | 6.13 | 1.48 | 1.02 | 0.06 | 2.02 | 3.05 | 332.94 | 8.34 | 71.61 |
| **55 *** | crop | X | X | 0.94 | 614.48 | 1 | 8.0 | 70.57 | 8.91 | 6.26 | 0.98 | 0.08 | 2.34 | 3.34 | 66.54 | 220.56 | 27.96 |
| **57 *** | crop | X | X | 2.98 | 694.01 | 2 | 1.0 | 73.96 | 10.10 | 4.23 | 0.64 | 0.07 | 2.08 | 1.85 | 165.16 | 622.32 | 285.33 |
| **83 *** | crop | X[b] | X | 0.76 | 548.26 | 1 | 2.0 | 49.79 | 6.83 | 32.83 | 0.60 | 0.09 | 0.35 | 0.32 | 86.89 | 259.38 | 18.27 |
| **8** | pasture | X | | 4.09 | 1,210.42 | 2 | 4.0 | 33.60 | 12.51 | 30.31 | 1.19 | 0.15 | 4.25 | 3.57 | 22.82 | 297.48 | 39.50 |
| **21** | pasture | X | | 0.06 | 108.98 | 3 | 0.3 | 27.56 | 32.73 | 31.47 | 0.64 | 0.04 | 2.22 | 1.66 | 171.56 | 25.19 | 13.67 |
| **29** | pasture | X | | 0.12 | 153.02 | 3 | 2.0 | 30.43 | 27.02 | 12.62 | 0.94 | 0.19 | 0.00 | 10.29 | 145.27 | 97.36 | 9.84 |
| **58** | pasture | X | | 1.92 | 899.54 | 0 | 2.0 | 11.59 | 53.67 | 14.89 | 1.42 | 0.09 | 2.29 | 7.33 | 33.21 | 41.22 | 0.00 |
| **59** | pasture | X | | 1.22 | 695.50 | 1 | 3.0 | 0.46 | 57.10 | 19.83 | 1.65 | 0.10 | 6.04 | 4.58 | 126.47 | 116.60 | 48.76 |
| **65** | pasture | X | | 0.25 | 283.17 | 1 | 20.0 | 0.00 | 47.29 | 37.31 | 1.81 | 0.06 | 5.81 | 1.96 | 79.17 | 87.24 | 54.64 |
| **71** | pasture | X | | 1.29 | 576.73 | 1 | 5.0 | 27.55 | 40.63 | 20.78 | 1.09 | 0.04 | 1.37 | 4.91 | 19.48 | 51.27 | 12.20 |
| **118** | pasture | X[a] | | 1.19 | 600.86 | 3 | 0.5 | 0.00 | 49.08 | 29.37 | 1.04 | 0.14 | 0.98 | 5.65 | 364.55 | 16.83 | 0.00 |
| **202** | pasture | | X | 0.02 | 63.58 | 1 | 0.5 | 15.11 | 40.18 | 33.42 | 1.25 | 0.05 | 2.36 | 3.01 | 431.31 | 59.40 | 2.00 |
| **204** | pasture | | X | 0.19 | 189.31 | 1 | 0.5 | 40.90 | 6.53 | 41.13 | 0.81 | 0.04 | 1.18 | 5.41 | 54.62 | 475.92 | 8.23 |
| **206** | pasture | | X | 0.05 | 133.72 | 0 | 0.0 | 49.13 | 4.72 | 40.34 | 1.15 | 0.03 | 1.85 | 0.07 | 681.09 | 863.79 | 33.17 |
| **208** | pasture | | X | 1.12 | 550.36 | 0 | 0.0 | 12.14 | 9.53 | 61.11 | 0.74 | 0.15 | 1.23 | 0.77 | 266.75 | 12.38 | 0.00 |
| **209** | pasture | | X | 0.07 | 115.90 | 1 | 0.0 | 16.05 | 12.79 | 62.10 | 1.34 | 0.05 | 2.98 | 0.10 | 271.45 | 317.28 | 4.00 |
| **211** | pasture | | X | 0.29 | 277.91 | 0 | 4.0 | 20.27 | 32.64 | 38.57 | 0.74 | 0.04 | 0.32 | 3.85 | 81.03 | 51.16 | 8.76 |
| **212** | pasture | | X | 1.13 | 547.89 | 0 | 0.0 | 68.08 | 1.05 | 23.71 | 1.18 | 0.03 | 2.25 | 1.27 | 243.75 | 1,000.00 | 105.40 |
| **216** | pasture | | X | 0.27 | 302.91 | 2 | 3.0 | 53.14 | 8.59 | 29.97 | 1.45 | 0.05 | 1.36 | 0.66 | 231.04 | 81.56 | 8.47 |
| **226** | pasture | | X | 1.54 | 603.94 | 3 | 5.0 | 8.26 | 57.60 | 23.85 | 0.96 | 0.06 | 1.51 | 1.81 | 544.10 | 10.45 | 205.98 |
| **234** | pasture | | X | 0.50 | 382.05 | 0 | 0.0 | 10.85 | 42.29 | 32.27 | 0.95 | 0.06 | 4.71 | 3.24 | 12.04 | 57.48 | 42.52 |
| **239** | pasture | | X | 0.07 | 202.84 | 0 | 2.0 | 0.00 | 45.58 | 36.78 | 1.71 | 0.05 | 5.05 | 5.77 | 66.04 | 35.90 | 5.00 |
| **247** | pasture | | X | 0.10 | 125.52 | 0 | 0.0 | 9.81 | 46.23 | 27.82 | 1.22 | 0.09 | 1.38 | 4.24 | 66.96 | 24.34 | 12.06 |
| **249** | pasture | | X | 0.32 | 251.32 | 0 | 2.0 | 0.00 | 63.66 | 14.18 | 0.91 | 0.18 | 0.49 | 3.25 | 109.69 | 46.11 | 6.49 |
| **251** | pasture | | X | 1.05 | 444.90 | 0 | 1.5 | 46.29 | 9.12 | 23.65 | 1.44 | 0.13 | 1.81 | 4.82 | 13.43 | 63.36 | 1.00 |

| | | Year | | local habitat features | | | | landscape habitat features (within a 1-km radius of surveyed pond) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site no. | Land-use category | 2001 | 2002 | AREA (ha) | PERIM (m) | UPVEG (m) | CAT/BUL (m) | CROP (%) | FOREST (%) | PAST (%) | ROAD (%) | SHRUB (%) | RESID (%) | WATER (%) | NRWTR (m) | NRFRST (m) | NRRD (m) |
| **259** | pasture | | X | 0.11 | 154.02 | 0 | 0.0 | 2.99 | 52.05 | 23.44 | 1.67 | 0.07 | 5.84 | 6.65 | 63.95 | 62.83 | 13.56 |
| **267** | pasture | | X | 0.47 | 500.41 | 0 | 0.5 | 56.26 | 17.63 | 11.55 | 1.48 | 0.07 | 4.58 | 1.55 | 66.80 | 46.26 | 36.00 |
| **268** | pasture | | X | 0.57 | 468.55 | 0 | 7.0 | 2.01 | 45.67 | 34.83 | 0.85 | 0.04 | 2.71 | 9.79 | 23.00 | 59.54 | 5.82 |
| **274** | pasture | | X | 0.27 | 257.97 | 0 | 5.0 | 18.44 | 37.90 | 28.06 | 0.55 | 0.13 | 0.00 | 2.41 | 88.13 | 50.61 | 18.62 |
| **283** | pasture | | X | 0.68 | 491.55 | 0 | 10.0 | 15.56 | 42.37 | 24.15 | 1.53 | 0.10 | 2.30 | 3.88 | 79.96 | 48.25 | 7.51 |
| **35 *** | pasture | X | X | 0.50 | 521.35 | 1 | 0.0 | 47.30 | 24.35 | 20.59 | 0.79 | 0.04 | 2.10 | 0.85 | 58.92 | 157.73 | 583.42 |
| **50 *** | pasture | X | X | 0.53 | 381.92 | 2 | 2.5 | 0.00 | 35.25 | 42.14 | 0.90 | 0.16 | 0.42 | 5.43 | 109.89 | 100.02 | 102.79 |
| **62** | pasture | X | X | 0.03 | 61.44 | 0 | 0.0 | 15.19 | 26.97 | 39.18 | 1.57 | 0.02 | 7.92 | 6.91 | 185.49 | 226.20 | 223.34 |
| **64** | pasture | X | X | 0.61 | 383.87 | 0 | 0.0 | 19.26 | 32.86 | 38.37 | 1.22 | 0.03 | 4.28 | 1.43 | 177.00 | 9.29 | 11.89 |
| **73 *** | pasture | X | X | 0.50 | 345.68 | 0 | 20.0 | 10.57 | 44.76 | 27.95 | 2.06 | 0.06 | 5.05 | 3.32 | 129.14 | 21.02 | 8.08 |
| **74 *** | pasture | X | X | 0.48 | 338.77 | 1 | 7.0 | 22.28 | 32.37 | 30.95 | 0.23 | 0.08 | 0.54 | 5.52 | 81.42 | 17.22 | 392.05 |
| **82 *** | pasture | X | X | 1.15 | 632.91 | 0 | 0.0 | 60.79 | 7.03 | 15.46 | 0.85 | 0.11 | 4.00 | 1.28 | 275.40 | 167.51 | 164.32 |
| **84** | pasture | X | X | 0.62 | 479.29 | 0 | 0.5 | 13.21 | 32.60 | 27.40 | 0.95 | 0.09 | 2.51 | 14.43 | 15.95 | 15.15 | 0.00 |
| **86** | pasture | X | X | 0.18 | 167.73 | 0 | 0.0 | 4.70 | 41.99 | 33.80 | 1.84 | 0.08 | 1.64 | 7.73 | 59.74 | 14.94 | 6.20 |
| **89 *** | pasture | X[a] | X | 1.14 | 791.16 | 0 | 0.5 | 3.05 | 26.86 | 42.00 | 1.48 | 0.03 | 6.93 | 17.03 | 125.64 | 26.68 | 355.34 |
| **91** | pasture | X[a] | X | 5.26 | 1,439.23 | 0 | 10.0 | 0.42 | 35.34 | 28.27 | 1.61 | 0.04 | 7.56 | 22.64 | 9.53 | 17.34 | 232.56 |
| **149** | pasture | X[a] | X[a] | 0.11 | 215.52 | 0 | 0.0 | 31.05 | 36.42 | 24.85 | 0.71 | 0.05 | 1.00 | 1.10 | 121.73 | 71.61 | 200.55 |
| **213** | residential | | X | 0.05 | 133.55 | 0 | 0.5 | 7.46 | 53.62 | 16.58 | 1.67 | 0.13 | 4.24 | 3.76 | 140.95 | 22.42 | 10.14 |
| **221** | residential | | X | 0.03 | 69.73 | 3 | 1.0 | 15.10 | 29.73 | 41.29 | 1.22 | 0.06 | 4.28 | 2.88 | 238.83 | 72.86 | 9.46 |
| **223** | residential | | X | 0.07 | 132.31 | 3 | 0.5 | 5.25 | 43.22 | 36.88 | 1.83 | 0.06 | 2.14 | 4.49 | 79.22 | 0.00 | 35.42 |
| **227** | residential | | X | 0.06 | 129.00 | 3 | 6.0 | 0.00 | 61.79 | 10.82 | 1.84 | 0.19 | 1.50 | 4.70 | 58.12 | 5.59 | 1.00 |
| **236** | residential | | X | 0.08 | 171.93 | 0 | 5.0 | 49.85 | 9.70 | 15.99 | 3.49 | 0.03 | 14.82 | 2.70 | 138.57 | 80.99 | 15.47 |
| **237** | residential | | X | 0.15 | 201.01 | 0 | 1.0 | 18.50 | 31.38 | 18.68 | 3.64 | 0.07 | 19.15 | 2.14 | 11.42 | 10.94 | 25.42 |
| **238** | residential | | X | 0.03 | 131.57 | 0 | 1.0 | 15.89 | 35.15 | 32.51 | 1.08 | 0.04 | 10.21 | 1.68 | 43.20 | 0.00 | 53.11 |
| **240** | residential | | X | 0.26 | 308.22 | 1 | 1.0 | 3.47 | 51.94 | 20.21 | 2.06 | 0.03 | 16.00 | 3.02 | 131.07 | 22.45 | 19.11 |
| **241** | residential | | X | 0.78 | 803.99 | 3 | 7.0 | 18.49 | 48.56 | 18.10 | 1.03 | 0.03 | 9.61 | 1.25 | 198.62 | 13.00 | 11.01 |
| **242** | residential | | X | 0.05 | 145.21 | 1 | 1.0 | 9.29 | 31.92 | 21.50 | 2.53 | 0.07 | 21.87 | 6.02 | 68.28 | 68.63 | 0.00 |
| **243** | residential | | X | 0.13 | 187.62 | 1 | 4.0 | 30.90 | 23.36 | 13.00 | 1.16 | 0.11 | 9.49 | 11.02 | 266.65 | 8.22 | 118.89 |
| **244** | residential | | X | 0.04 | 79.45 | 3 | 1.0 | 4.66 | 63.84 | 11.72 | 1.80 | 0.07 | 7.46 | 3.77 | 146.04 | 19.27 | 13.90 |
| **245** | residential | | X | 1.15 | 1,048.38 | 3 | 2.0 | 13.04 | 61.49 | 9.15 | 1.20 | 0.05 | 8.54 | 1.79 | 21.04 | 0.00 | 0.00 |
| **246** | residential | | X | 0.25 | 409.72 | 3 | 1.0 | 0.16 | 58.69 | 14.45 | 1.26 | 0.15 | 4.58 | 5.49 | 176.40 | 0.00 | 0.00 |

| | | | | local habitat features | | | | landscape habitat features (within a 1-km radius of surveyed pond) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site no. | Land-use category | Year 2001 | Year 2002 | AREA (ha) | PERIM (m) | UPVEG (m) | CAT/BUL (m) | CROP (%) | FOREST (%) | PAST (%) | ROAD (%) | SHRUB (%) | RESID (%) | WATER (%) | NRWTR (m) | NRFRST (m) | NRRD (m) |
| **255** | residential | | X | 1.82 | 973.34 | 3 | 1.0 | 4.93 | 49.82 | 17.47 | 2.56 | 0.15 | 4.36 | 6.11 | 95.28 | 0.00 | 16.20 |
| **256** | residential | | X | 0.05 | 253.05 | 2 | 5.0 | 24.49 | 42.60 | 16.86 | 1.72 | 0.04 | 9.72 | 1.00 | 29.60 | 123.81 | 41.41 |
| **258** | residential | | X | 0.06 | 234.34 | 2 | 2.0 | 11.73 | 45.38 | 27.46 | 1.14 | 0.04 | 8.77 | 1.69 | 42.65 | 68.35 | 32.91 |
| **260** | residential | | X | 0.14 | 191.61 | 1 | 2.0 | 43.48 | 15.95 | 16.37 | 1.67 | 0.04 | 15.35 | 3.54 | 148.90 | 82.87 | 11.01 |
| **262** | residential | | X | 0.13 | 204.00 | 2 | 1.0 | 7.39 | 37.47 | 14.04 | 3.69 | 0.06 | 28.60 | 2.51 | 34.84 | 13.88 | 16.30 |
| **20** | residential | X | X | 0.37 | 490.30 | 3 | 10.0 | 40.77 | 12.29 | 26.03 | 1.83 | 0.05 | 11.23 | 3.29 | 105.32 | 0.00 | 10.68 |
| **60 *** | residential | X | X | 1.22 | 2,006.72 | 2 | 10.0 | 0.41 | 48.28 | 18.04 | 2.88 | 0.06 | 11.93 | 12.70 | 45.25 | 4.13 | 109.57 |
| **61 *** | residential | X | X | 0.62 | 366.93 | 3 | 6.0 | 23.54 | 22.91 | 26.69 | 1.89 | 0.07 | 10.23 | 7.44 | 92.26 | 13.08 | 36.60 |
| **66 *** | residential | X | X | 1.38 | 837.27 | 1 | 10.0 | 34.70 | 25.81 | 15.01 | 2.15 | 0.03 | 11.21 | 8.06 | 160.86 | 138.18 | 45.44 |
| **67** | residential | X | X | 0.74 | 781.84 | 1 | 6.0 | 13.11 | 32.73 | 30.49 | 2.61 | 0.06 | 12.60 | 2.78 | 89.18 | 54.39 | 68.61 |
| **68** | residential | X | X | 0.01 | 45.21 | 3 | 0.5 | 0.61 | 68.78 | 5.91 | 2.30 | 0.05 | 14.95 | 2.48 | 88.56 | 0.00 | 17.87 |
| **69** | residential | X | X | 0.20 | 197.79 | 3 | 6.0 | 15.23 | 47.20 | 12.69 | 2.61 | 0.06 | 11.60 | 4.82 | 169.97 | 11.38 | 19.07 |
| **70 *** | residential | X | X | 0.46 | 260.93 | 3 | 0.0 | 14.29 | 51.21 | 9.70 | 1.84 | 0.03 | 18.70 | 1.10 | 91.28 | 21.21 | 101.70 |
| **93 *** | residential | X[a] | X | 0.90 | 585.93 | 1 | 1.0 | 0.27 | 50.20 | 32.46 | 2.02 | 0.09 | 1.19 | 5.24 | 94.25 | 10.47 | 7.41 |
| **94 *** | residential | X[a] | X | 0.54 | 340.54 | 3 | 6.0 | 12.78 | 59.17 | 4.18 | 2.36 | 0.06 | 11.71 | 4.00 | 106.20 | 6.38 | 125.81 |
| **9** | "natural" | X | | 0.33 | 659.56 | 3 | 2.5 | 0.00 | 39.30 | 38.25 | 0.67 | 0.10 | 1.46 | 10.09 | 31.98 | 15.43 | 5.19 |
| **13** | "natural" | X | | 0.03 | 95.10 | 2 | 1.0 | 61.63 | 22.86 | 6.02 | 1.28 | 0.04 | 3.37 | 0.81 | 39.64 | 0.00 | 0.00 |
| **16** | "natural" | X | | 0.16 | 165.96 | 3 | 5.0 | 4.64 | 50.04 | 21.15 | 1.74 | 0.06 | 5.92 | 10.27 | 115.29 | 9.35 | 21.31 |
| **17** | "natural" | X | | 0.03 | 74.42 | 3 | 0.5 | 10.18 | 56.68 | 15.31 | 1.76 | 0.06 | 7.11 | 2.57 | 80.01 | 18.56 | 0.00 |
| **22** | "natural" | X | | 1.53 | 1,273.27 | 3 | 3.0 | 4.23 | 63.86 | 7.78 | 0.56 | 0.16 | 0.59 | 7.26 | 43.67 | 30.65 | 16.42 |
| **24** | "natural" | X | | 0.54 | 1,190.72 | 3 | 3.0 | 0.00 | 58.79 | 27.03 | 1.20 | 0.10 | 0.63 | 2.10 | 158.58 | 23.22 | 18.25 |
| **30** | "natural" | X | | 0.86 | 872.72 | 3 | 4.0 | 4.45 | 49.80 | 17.10 | 1.40 | 0.18 | 0.11 | 9.21 | 89.04 | 16.52 | 20.55 |
| **31** | "natural" | X | | 0.09 | 201.31 | 3 | 1.0 | 4.48 | 54.96 | 16.85 | 1.62 | 0.16 | 0.48 | 5.93 | 11.72 | 19.60 | 7.86 |
| **33** | "natural" | X | | 0.54 | 190.98 | 3 | 1.5 | 0.00 | 42.16 | 25.62 | 0.88 | 0.25 | 1.70 | 4.82 | 96.56 | 37.49 | 2.27 |
| **36** | "natural" | X | | 1.96 | 1,530.73 | 3 | 8.0 | 0.00 | 60.78 | 11.99 | 0.56 | 0.21 | 0.20 | 5.14 | 165.56 | 25.34 | 185.01 |
| **56** | "natural" | X | | 0.36 | 325.64 | 3 | 8.0 | 56.93 | 15.99 | 11.19 | 1.42 | 0.07 | 2.81 | 4.29 | 60.64 | 34.62 | 22.67 |
| **75** | "natural" | X | | 3.28 | 1,158.58 | 3 | 1.0 | 16.19 | 36.88 | 29.07 | 0.75 | 0.08 | 1.68 | 7.04 | 9.45 | 9.82 | 0.00 |
| **106** | "natural" | X[a] | | 0.69 | 524.63 | 3 | 6.0 | 0.00 | 57.43 | 1.32 | 1.12 | 0.27 | 2.62 | 10.84 | 41.31 | 20.62 | 463.71 |
| **114** | "natural" | X[a] | | 0.25 | 366.10 | 3 | 0.5 | 0.72 | 56.32 | 30.17 | 1.19 | 0.07 | 0.67 | 3.79 | 17.82 | 0.00 | 3.79 |
| **119** | "natural" | X[a] | | 2.47 | 1,238.37 | 3 | 2.0 | 2.02 | 50.60 | 30.93 | 1.16 | 0.13 | 0.89 | 1.75 | 172.94 | 18.71 | 10.84 |
| **133** | "natural" | X[a] | | 0.45 | 364.53 | 3 | 1.0 | 0.00 | 58.87 | 0.00 | 0.61 | 0.26 | 0.00 | 14.56 | 37.59 | 31.62 | 23.95 |

| | | Year | | local habitat features | | | | landscape habitat features (within a 1-km radius of surveyed pond) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Site no.** | **Land-use category** | **2001** | **2002** | **AREA (ha)** | **PERIM (m)** | **UPVEG (m)** | **CAT/BUL (m)** | **CROP (%)** | **FOREST (%)** | **PAST (%)** | **ROAD (%)** | **SHRUB (%)** | **RESID (%)** | **WATER (%)** | **NRWTR (m)** | **NRFRST (m)** | **NRRD (m)** |
| **140** | "natural" | X[a] | | 0.32 | 437.33 | 3 | 0.0 | 0.00 | 58.95 | 6.42 | 0.63 | 0.20 | 0.00 | 14.22 | 175.26 | 25.91 | 15.75 |
| **147** | "natural" | X[a] | | 0.84 | 920.10 | 3 | 1.0 | 5.47 | 43.26 | 13.91 | 1.33 | 0.24 | 3.10 | 9.34 | 27.12 | 18.86 | 104.06 |
| **150** | "natural" | X[a] | | 3.43 | 1,146.30 | 3 | 3.0 | 6.80 | 48.16 | 6.89 | 0.49 | 0.21 | 0.65 | 16.39 | 76.57 | 27.68 | 31.36 |
| **263** | "natural" | | X | 0.29 | 235.34 | 3 | 3.0 | 24.91 | 37.25 | 15.18 | 0.89 | 0.10 | 5.28 | 6.75 | 172.53 | 5.56 | 0.00 |
| **264** | "natural" | | X | 0.65 | 742.99 | 3 | 10.0 | 0.00 | 68.16 | 9.71 | 1.16 | 0.18 | 0.07 | 2.51 | 44.16 | 34.33 | 79.31 |
| **266** | "natural" | | X | 1.71 | 2,394.39 | 3 | 2.0 | 0.00 | 49.92 | 0.00 | 0.63 | 0.37 | 0.32 | 11.87 | 51.28 | 0.00 | 35.35 |
| **269** | "natural" | | X | 0.06 | 164.01 | 2 | 0.5 | 0.00 | 40.29 | 0.00 | 0.99 | 0.52 | 0.00 | 6.50 | 241.12 | 9.57 | 3.92 |
| **270** | "natural" | | X | 1.35 | 886.65 | 2 | 5.0 | 0.00 | 50.83 | 0.16 | 0.59 | 0.40 | 0.13 | 8.34 | 51.06 | 28.24 | 281.28 |
| **271** | "natural" | | X | 0.09 | 299.31 | 3 | 0.5 | 0.69 | 68.09 | 14.18 | 1.04 | 0.13 | 2.31 | 0.67 | 105.42 | 12.04 | 13.23 |
| **275** | "natural" | | X | 0.16 | 407.59 | 3 | 2.0 | 24.56 | 30.66 | 11.95 | 1.11 | 0.13 | 2.36 | 16.01 | 78.03 | 17.45 | 21.53 |
| **276** | "natural" | | X | 0.23 | 296.70 | 3 | 4.0 | 0.00 | 55.33 | 2.74 | 0.91 | 0.20 | 0.00 | 21.03 | 54.00 | 27.61 | 11.73 |
| **278** | "natural" | | X | 1.20 | 789.23 | 3 | 12.0 | 1.36 | 51.20 | 19.30 | 1.64 | 0.11 | 3.11 | 12.70 | 35.35 | 60.02 | 13.06 |
| **279** | "natural" | | X | 0.53 | 430.49 | 3 | 20.0 | 0.00 | 52.85 | 10.23 | 0.92 | 0.15 | 0.26 | 20.61 | 48.84 | 54.36 | 18.07 |
| **280** | "natural" | | X | 0.36 | 329.16 | 3 | 2.0 | 0.00 | 52.33 | 3.48 | 1.14 | 0.15 | 0.00 | 28.57 | 298.11 | 23.71 | 15.01 |
| **281** | "natural" | | X | 0.75 | 613.10 | 3 | 0.5 | 9.06 | 46.26 | 16.65 | 0.62 | 0.16 | 0.55 | 10.84 | 41.50 | 0.00 | 20.25 |
| **282** | "natural" | | X | 1.03 | 1,184.24 | 3 | 0.5 | 1.07 | 60.30 | 11.47 | 1.08 | 0.18 | 1.52 | 6.14 | 101.40 | 18.49 | 16.67 |
| **284** | "natural" | | X | 0.92 | 444.43 | 3 | 17.0 | 16.13 | 43.63 | 16.20 | 1.97 | 0.08 | 6.54 | 7.91 | 19.37 | 33.76 | 2.14 |
| **1** | "natural" | X | X | 1.77 | 2,081.17 | 3 | 0.5 | 0.00 | 39.64 | 4.14 | 1.41 | 0.29 | 0.00 | 25.92 | 104.65 | 0.00 | 1.00 |
| **2** | "natural" | X | X | 0.57 | 422.47 | 2 | 30.0 | 0.00 | 39.27 | 0.00 | 1.53 | 0.39 | 0.00 | 20.45 | 174.83 | 36.95 | 32.38 |
| **4 *** | "natural" | X | X | 1.29 | 588.43 | 2 | 10.0 | 0.00 | 47.77 | 0.16 | 0.65 | 0.48 | 0.00 | 3.34 | 115.67 | 38.95 | 53.29 |
| **5** | "natural" | X | X | 2.16 | 2,385.05 | 2 | 1.0 | 0.00 | 66.21 | 0.00 | 1.05 | 0.22 | 0.11 | 11.13 | 79.63 | 28.42 | 38.47 |
| **6 *** | "natural" | X | X | 0.65 | 975.03 | 2 | 0.5 | 0.00 | 60.60 | 0.08 | 0.48 | 0.36 | 0.00 | 2.68 | 378.81 | 12.77 | 355.71 |
| **37 *** | "natural" | X | X | 2.37 | 1,294.56 | 3 | 0.5 | 0.00 | 53.90 | 18.32 | 0.57 | 0.20 | 1.06 | 6.13 | 89.69 | 0.00 | 25.49 |
| **38** | "natural" | X | X | 2.77 | 820.94 | 3 | 7.0 | 0.00 | 57.34 | 0.83 | 0.87 | 0.29 | 0.33 | 11.98 | 83.08 | 95.79 | 77.27 |
| **40** | "natural" | X | X | 5.16 | 2,444.62 | 2 | 10.0 | 0.00 | 54.04 | 0.00 | 0.58 | 0.34 | 0.02 | 11.90 | 117.43 | 58.26 | 78.97 |
| **43 *** | "natural" | X | X | 1.05 | 659.74 | 2 | 0.5 | 0.00 | 60.00 | 0.00 | 0.88 | 0.14 | 2.96 | 21.74 | 55.24 | 6.71 | 280.09 |
| **77 *** | "natural" | X | X | 1.01 | 690.28 | 3 | 1.0 | 0.00 | 44.88 | 7.73 | 0.00 | 0.22 | 0.61 | 24.59 | 143.21 | 22.27 | 1,000.00 |
| **79 *** | "natural" | X | X | 1.86 | 1,239.51 | 3 | 0.0 | 0.00 | 65.09 | 0.00 | 0.63 | 0.28 | 0.00 | 6.77 | 99.10 | 18.28 | 85.11 |
| **88** | "natural" | X | X | 1.23 | 467.98 | 0 | 0.0 | 0.00 | 55.02 | 1.81 | 1.99 | 0.36 | 0.47 | 4.84 | 163.49 | 28.96 | 25.84 |
| **92** | "natural" | X[a] | X | 0.08 | 155.67 | 3 | 1.0 | 0.00 | 55.81 | 14.74 | 0.64 | 0.17 | 0.00 | 11.67 | 9.12 | 41.92 | 15.61 |
| **99** | "natural" | X[a] | X | 0.05 | 254.04 | 1 | 3.0 | 0.00 | 46.02 | 5.29 | 1.28 | 0.17 | 0.20 | 29.94 | 167.72 | 9.08 | 102.78 |

| | | | | local habitat features | | | | landscape habitat features (within a 1-km radius of surveyed pond) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | Land-use | Year | | AREA | PERIM | UPVEG | CAT/BUL | CROP | FOREST | PAST | ROAD | SHRUB | RESID | WATER | NRWTR | NRFRST | NRRD |
| no. | category | 2001 | 2002 | (ha) | (m) | (m) | (m) | (%) | (%) | (%) | (%) | (%) | (%) | (%) | (m) | (m) | (m) |
| **100** | "natural" | $X^a$ | $X^a$ | 0.79 | 1,506.95 | 2 | 15.0 | 0.00 | 45.45 | 0.00 | 0.60 | 0.48 | 0.00 | 5.55 | 249.64 | 14.02 | 10.93 |
| **103** | "natural" | $X^a$ | X | 0.35 | 564.99 | 3 | 0.5 | 0.00 | 53.20 | 5.17 | 1.54 | 0.16 | 3.44 | 20.71 | 88.43 | 0.00 | 9.95 |
| **110** | "natural" | $X^a$ | X | 0.27 | 383.30 | 3 | 8.0 | 0.00 | 65.83 | 1.51 | 0.65 | 0.25 | 0.08 | 6.73 | 62.28 | 12.07 | 8.70 |
| **115** | "natural" | $X^a$ | X | 0.15 | 207.81 | 3 | 5.0 | 0.00 | 58.20 | 13.88 | 0.63 | 0.23 | 0.30 | 4.10 | 114.79 | 52.62 | 76.11 |
| **121** | "natural" | $X^a$ | X | 0.04 | 184.62 | 1 | 10.0 | 1.95 | 63.81 | 12.49 | 0.75 | 0.17 | 1.63 | 2.10 | 22.88 | 34.54 | 0.00 |
| **123** | "natural" | $X^a$ | X | 0.07 | 129.90 | 2 | 1.0 | 1.50 | 61.10 | 9.04 | 0.76 | 0.23 | 1.63 | 2.72 | 13.39 | 20.39 | 10.78 |
| **125** | "natural" | $X^a$ | X | 4.19 | 2,828.01 | 3 | 2.0 | 0.10 | 66.48 | 0.64 | 0.72 | 0.28 | 0.75 | 3.38 | 11.80 | 19.31 | 119.77 |
| **126** | "natural" | $X^a$ | X | 2.25 | 1,592.14 | 3 | 0.5 | 0.00 | 53.67 | 6.23 | 0.82 | 0.34 | 0.69 | 5.08 | 18.75 | 10.75 | 26.35 |
| **128** | "natural" | $X^a$ | X | 0.24 | 470.52 | 2 | 0.0 | 0.00 | 46.70 | 5.87 | 0.79 | 0.38 | 0.14 | 8.92 | 44.57 | 25.18 | 13.23 |
| **138** | "natural" | $X^a$ | X | 0.87 | 584.33 | 3 | 0.5 | 0.00 | 61.97 | 3.43 | 0.62 | 0.22 | 0.00 | 12.31 | 34.06 | 20.36 | 29.94 |
| **141** | "natural" | $X^a$ | X | 4.30 | 2,041.11 | 3 | 0.5 | 0.00 | 57.72 | 9.31 | 0.54 | 0.19 | 0.00 | 13.72 | 62.85 | 61.65 | 25.18 |
| **143** | "natural" | $X^a$ | X | 0.16 | 449.40 | 3 | 10.0 | 0.00 | 52.87 | 0.00 | 1.39 | 0.36 | 0.07 | 9.45 | 151.03 | 25.99 | 117.90 |
| **144** | "natural" | $X^a$ | X | 4.84 | 3,357.89 | 3 | 1.5 | 0.00 | 63.33 | 0.00 | 0.99 | 0.27 | 1.33 | 7.70 | 75.54 | 10.79 | 9.95 |
| | **range** | **min** | | **0.01** | **45.21** | **0** | **0.0** | **0.00** | **1.05** | **0.00** | **0.00** | **0.02** | **0.00** | **0.07** | **9.12** | **0.00** | **0.00** |
| | | **max** | | **5.26** | **3,357.89** | **3** | **37.0** | **85.47** | **68.78** | **62.10** | **3.69** | **0.52** | **28.60** | **29.94** | **798.89** | **1,000.00** | **1,000.00** |
| | **mean** | | | **0.85** | **570.91** | **1.74** | **4.21** | **20.68** | **37.29** | **18.49** | **1.26** | **0.13** | **3.61** | **6.08** | **122.30** | **77.55** | **60.14** |

$X^a$: ponds not surveyed for wood frogs

$X^b$: ponds not surveyed for boreal chorus frogs

Table 2. Local habitat variables measured between 2 July - 28 August 2001 at 24 amphibian trap ponds located in the Beaver Hills region of central Alberta. Refer to Table 2-1 for definition of habitat variables. Values for other local habitat variables (pond area and perimeter) and all landscape habitat variables are listed in Appendix E Table 1. * = data unavailable due to pond drying, but derived from regression with other variables.

| | | **local habitat features** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **MAX** | **Δ** | | | | | | | | |
| **Site no.** | **Land-use category** | **DEPTH (cm)** | **DEPTH (cm)** | **SECCHI (cm)** | **COND (μS/cm)** | **PH** | **TN (μg/L)** | **TP (μg/L)** | **CHLA (μg/L)** | **UPVEG (cm)** | **CAT/BUL (m)** |
| 52 | crop | 26.0 | 26 | 14.0 | 2,829.10 | 8.05 | 4,101.86 | 585.40 | 42.85 | 53.40 | 49.88 |
| 55 | crop | 25.0 | 20 | 21.0 | 4,381.50 | 8.79 | 7,278.86 | 573.20 | 29.66 | 30.70 | 17.75 |
| 57 | crop | 75.0 | 13 | 61.5 | 3,091.00 | 8.82 | 7,896.96 | 478.25 | 31.51 | 52.20 | 11.63 |
| 83 | crop | 20.0 | 20 | 12.0 | 3,690.00 | *8.97 | 11,415.78 | 449.20 | 3.51 | 51.40 | 11.68 |
| 26 | crop | 40.0 | 40 | 10.8 | 3,585.85 | 8.43 | 23,261.68 | 3,429.40 | 324.40 | 77.60 | 12.00 |
| 49 | crop | 51.0 | 40 | 38.5 | 1,620.25 | 8.21 | 4,875.39 | 667.55 | 1.94 | 84.90 | 15.00 |
| 35 | pasture | 149.0 | 20 | 142.0 | 139.45 | 9.80 | 1,228.04 | 60.90 | 9.20 | 3.90 | 0.00 |
| 83 | pasture | 65.0 | 58 | 31.0 | 217.65 | 7.59 | 3,201.88 | 221.15 | 17.78 | 23.20 | 0.00 |
| 50 | pasture | 143.0 | 27 | 130.5 | 506.10 | 7.72 | 2,046.67 | 200.35 | 10.74 | 46.90 | 0.00 |
| 73 | pasture | 92.0 | 38 | 34.5 | 830.00 | 7.51 | 3,111.67 | 460.00 | 31.70 | 48.10 | 14.00 |
| 74 | pasture | 98.0 | 44 | 79.0 | 911.60 | 7.87 | 2,413.25 | 123.55 | 1.30 | 8.00 | 0.00 |
| 82 | pasture | 37.0 | 37 | 23.0 | 2,186.45 | 8.15 | 9,933.61 | 815.95 | 12.73 | 48.60 | 7.75 |
| 61 | residential | 120.0 | 23 | 63.5 | 556.25 | 7.00 | 3,611.29 | 468.35 | 76.21 | 35.90 | 9.63 |
| 60 | residential | 66.0 | 10 | 40.0 | 629.35 | 7.13 | 3,615.73 | 377.00 | 25.87 | 52.80 | 1.50 |
| 66 | residential | 43.0 | 22 | 39.0 | 457.10 | 9.91 | 5,217.99 | 356.00 | 22.55 | 73.10 | 22.75 |
| 94 | residential | 89.0 | 20 | 57.0 | 400.05 | 7.15 | 3,520.72 | 578.90 | 24.97 | 72.90 | 6.38 |
| 93 | residential | 37.5 | 18 | 37.5 | 554.60 | 9.80 | 5,123.57 | 59.20 | 4.83 | 71.30 | 7.00 |
| 70 | residential | 35.0 | 32 | 34.0 | 549.25 | 7.72 | 16,304.97 | 2,503.00 | 9.66 | 76.10 | 9.00 |
| 37 | "natural" | 47.5 | 15 | 46.8 | 215.35 | 8.84 | 2,758.81 | 112.30 | 17.34 | 63.10 | 0.00 |
| 43 | "natural" | 63.0 | 21 | 56.5 | 221.60 | 7.77 | 2,487.49 | 374.00 | 22.32 | 92.60 | 0.00 |
| 4 | "natural" | 135.0 | 14 | 110.0 | 167.15 | 7.31 | 1,697.64 | 58.00 | 5.44 | 34.70 | 0.00 |
| 6 | "natural" | 47.0 | 25 | 26.5 | 345.15 | 7.25 | 3,746.38 | 357.95 | 7.72 | 66.00 | 0.00 |
| 77 | "natural" | 105.0 | 20 | 67.5 | 125.15 | 7.70 | 1,740.41 | 126.90 | 10.13 | 60.90 | 1.53 |
| 79 | "natural" | 175.0 | 13 | 118.5 | 491.65 | 8.73 | 4,109.55 | 86.85 | 6.93 | 70.10 | 0.00 |
| | **range min** | 20.0 | 10 | 10.8 | 125.15 | 7.00 | 1,228.04 | 58.00 | 1.30 | 3.90 | 0.00 |
| | **max** | 175.0 | 58 | 142.0 | 4,381.50 | 9.91 | 23,261.68 | 3,429.40 | 324.40 | 92.60 | 49.88 |
| | **mean** | 74.3 | 26 | 53.9 | 1,195.90 | 8.18 | 5,612.51 | 563.47 | 31.30 | 54.10 | 8.23 |

Table 3. Local habitat variables measured between 10 June - 23 August 2002 at 24 amphibian trap ponds located in the Beaver Hills region of central Alberta. Refer to Table 2-1 for definition of habitat variables. Values for other local habitat variables (pond area and perimeter) and all landscape habitat variables measured are listed in Appendix E Table 1.
* = data unavailable due to pond drying, but derived from regression with other variables.

| | | **local habitat features** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Site no.** | **Land-use category** | **MAX DEPTH (cm)** | **Δ DEPTH (cm)** | **SECCHI (cm)** | **COND (μS/cm)** | **PH** | **TN (μg/L)** | **TP (μg/L)** | **CHLA (μg/L)** | **UPVEG (cm)** | **CAT/BUL (m)** |
| 52 | crop | 15.0 | 15 | * 11.9 | *2,864.07 | *8.05 | *4,015.83 | *603.05 | *41.14 | 17.80 | 49.88 |
| 55 | crop | 47.0 | 37 | 20.0 | 7,596.20 | 8.28 | 12,772.00 | 815.60 | 333.20 | 24.80 | 17.75 |
| 57 | crop | 46.0 | 46 | 33.0 | 5,851.90 | 8.41 | 10,113.00 | 1,747.60 | 148.31 | 57.20 | 11.63 |
| 83 | crop | 1.0 | 1 | * 12.1 | *2,397.06 | *8.88 | *10,383.78 | *381.08 | *4.78 | 8.90 | 11.68 |
| 26 | crop | 31.0 | 31 | 9.0 | 4,171.60 | 8.67 | 27,762.00 | 6,451.50 | 248.27 | 39.50 | 12.00 |
| 49 | crop | 46.0 | 35 | 33.0 | 1,351.60 | 9.03 | 2,450.90 | 722.80 | 7.76 | 64.80 | 15.00 |
| 35 | pasture | 102.0 | 23 | 92.0 | 213.30 | 9.50 | 1,377.30 | 100.95 | 27.03 | 11.20 | 0.00 |
| 83 | pasture | 73.0 | 39 | 62.5 | 237.90 | 9.50 | 2,717.70 | 224.10 | 5.59 | 11.80 | 0.00 |
| 50 | pasture | 190.0 | 30 | 104.5 | 421.60 | 9.63 | 2,346.50 | 180.70 | 31.47 | 35.40 | 0.00 |
| 73 | pasture | 76.0 | 31 | 74.0 | 831.10 | 8.69 | 2,414.50 | 298.20 | 5.89 | 10.40 | 14.00 |
| 74 | pasture | 86.0 | 43 | 66.0 | 965.15 | 9.24 | 2,109.40 | 127.98 | 24.50 | 18.80 | 0.00 |
| 82 | pasture | 14.0 | 14 | * 21.3 | *2,573.44 | *8.22 | *10,086.97 | *993.27 | *10.13 | 14.30 | 7.75 |
| 61 | residential | 92.0 | 21 | 69.5 | 600.35 | 7.60 | 4,502.60 | 611.70 | 18.15 | 52.70 | 9.63 |
| 60 | residential | 84.0 | 24 | 66.0 | 566.15 | 8.08 | 2,375.50 | 274.70 | 18.42 | 68.00 | 1.50 |
| 66 | residential | 75.0 | 25 | 19.0 | 690.00 | 9.07 | 5,077.10 | 663.50 | 39.61 | 64.30 | 22.75 |
| 94 | residential | 60.0 | 24 | 46.5 | 450.00 | 7.67 | 4,379.20 | 530.80 | 111.02 | 70.50 | 6.38 |
| 93 | residential | 34.0 | 34 | 18.0 | 898.00 | 8.51 | 5,661.90 | 440.85 | 22.98 | 49.80 | 7.00 |
| 70 | residential | 22.0 | 22 | 4.0 | 777.00 | 7.93 | 16,890.00 | 3,786.00 | 162.01 | 41.00 | 9.00 |
| 37 | "natural" | 35.0 | 18 | 26.5 | 259.60 | 9.13 | 3,905.40 | 306.00 | 40.13 | 50.00 | 0.00 |
| 43 | "natural" | 40.0 | 29 | 31.0 | 226.85 | 8.69 | 3,176.40 | 406.60 | 496.23 | 55.00 | 0.00 |
| 4 | "natural" | 134.0 | 21 | 87.5 | 182.85 | 8.82 | 1,824.30 | 76.20 | 13.25 | 32.30 | 0.00 |
| 6 | "natural" | 174.0 | 17 | 58.8 | 281.05 | 7.59 | 3,944.40 | 707.05 | 46.78 | 64.90 | 0.00 |
| 77 | "natural" | 105.0 | 16 | 57.0 | 158.60 | 8.59 | 1,654.40 | 99.73 | 7.62 | 42.00 | 1.53 |
| 79 | "natural" | 126.0 | 30 | 103.5 | 601.90 | 8.88 | 3,608.50 | 88.00 | 4.42 | 40.30 | 0.00 |
| | **range min** | 1.0 | 1 | 4.0 | 158.60 | 7.59 | 1,377.30 | 76.20 | 4.42 | 8.90 | 0.00 |
| | **max** | 190.0 | 46 | 104.5 | 7,596.00 | 9.63 | 27,762.00 | 6,451.50 | 496.23 | 70.50 | 49.88 |
| | **mean** | 71.2 | 26 | 46.94 | 1,465.30 | 8.61 | 6,064.57 | 859.92 | 77.89 | 39.40 | 8.23 |