University of Alberta

The use of small ephemeral wetlands and streams by amphibians in the mixedwood forest of boreal Alberta

by

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A thesis submitted to the Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of

Master of Science

in

Ecology

Biological Sciences

Spring 2011
Edmonton, Alberta

DEDICATION

- To my darling wife Seun and baby Chiwetel for encouragement.

ABSTRACT

Identifying amphibian habitats within a landscape provides a tool for managing their populations. I identified if and how amphibians used small ephemeral wetlands (≤ 0.1ha) and streams within the mixedwood forest area managed by Daishowa Marubeni International Ltd. near Peace River, north-western Alberta. Twenty-seven wetlands and their riparian zones were sampled for all life stages of amphibians in 2008 using timed visual encounter surveys. The riparian zones of 11 small streams were sampled with pitfall traps within 120 m of their beds from 2006 to 2008. Habitat features were also measured. *Lithobates sylvaticus*, *Anaxyrus boreas* and *Pseudacris maculata* used small ephemeral wetlands and the riparian zones of ephemeral, intermittent and permanent streams at different life stages. Water temperature and canopy cover influenced amphibian presence and abundance in wetlands. Coniferous and deciduous tree density were associated with *L. sylvaticus* abundance at the stream sites. I conclude that small waterbodies are amphibian habitats in the mixedwood forest of boreal Alberta.

ACKNOWLEDGEMENT

My sincere gratitude goes to my supervisor Cindy Paszkowski, for accepting me as a graduate student under her supervision. Her thorough guidance, many corrections, objective criticisms, and patience with my many flaws, contributed to the improvement of my analytic ability and the completion of this thesis. Brian Eaton (Alberta Innovates -Technology Futures) and Jim Witiw (Daishowa-Marubeni International Ltd.) were instrumental in the development and success of this project, and their involvement is gratefully acknowledged.

Many thanks to Charmaine Ferguson for keeping me focused in the field, Tara Andrusiak, Len Peleshok, Luke Nolan for help in the field through encouragement and information during the project. Special thanks to Michelle for her critical assistance in this project. I am indeed very thankful to my supervisory committee, Ellen MacDonald, Suzanne Bayley, and Brian Eaton whose contributions improved the quality of the thesis. Thanks to my examining committee led by an able chairman, Heather Proctor. With a deep sense of appreciation to the members of Pasz-Thonn lab group, I wish to express my gratitude for the food, constructive comments, ideas and laughters that we shared.

Great thanks to the University of Alberta, Alberta Research Council (now Alberta Innovates -Technology Futures), Daishowa-Marubeni International Ltd., the Forest Resource Improvement Association of Alberta, the North American Waterfowl Management Plan, Alberta Sport Recreation Parks and Wildlife Foundation, Circumpolar/ Boreal Alberta Research, for the funding and in-kind support provided in the course of the project.

Gratitude to the staff and co-inhabitants of the Ecological Management Emulating Natural Disturbance (EMEND) camp for the delicious food and shelter support during this project. Finally, to my wife Seun Omole and new baby Chiwetel who kept me on my feet for so many nights during the final stages of the thesis, you are deeply appreciated.

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CHAPTER 1 GENERAL INTRODUCTION AND BACKGROUND OF THE STUDY

1.1 Amphibian population decline

Populations of amphibian species are experiencing declines at local, regional and global scales (Davidson et al., 2001, Marsh et al., 2001; IUCN, 2004; Stuart et al., 2004), increasing concern about the survival of populations and focusing awareness on the need to study and document the distribution and abundance of amphibians at a range of temporal and spatial scales (Pechmann et al., 1991; IUCN, 2004). Amphibians are an important part of global biodiversity contributing to terrestrial and aquatic ecosystems. Amphibians can also be valuable indicators of environmental conditions because they utilize both aquatic and terrestrial habitats, so their population status can indicate the combined consequence of many environmental disturbances within an ecosystem (Blaustein and Kiesecker, 2002). Environmental conditions that characterize a particular region, such as climate, influence how strongly amphibians populations are impacted by changes in or loss of habitat (Carey and Alexander, 2003). Changes in the environment contribute to declines which occur at different rates in different regions around the world. Within Alberta, for example, studies of amphibian populations are required at a regional scale because some species are clearly experiencing pressures that are reducing their populations at a local scale (Russell and Bauer, 2000; Wind et al., 2002; ASRD, 2005).

Declines in amphibian populations are part of the current global reduction in animal diversity which has been associated with factors like predation by introduced fish (Kats et al., 2003; Lundkvist, 2003; Dunham et al., 2004; Knapp, 2005). According to IUCN (2004), invasive species have affected 11% of threatened amphibian species globally. Some other factors associated with amphibian declines include chemical contamination of aquatic habitats (Beebee and Griffith, 2005; Hayes et al., 2002; Blaustein et al., 2003), higher levels of ultraviolet-B radiation (Carey and Alexander, 2003; Lundkvist, 2003; Blaustein et al., 2005), infectious diseases (e.g. chytridiomycosis), malformations and deformities (Daszak et al., 2003). However, the single most important factor causing amphibian decline is habitat loss due to anthropogenic activities, especially those related to resource extraction or conversion of native vegetation to other uses (CBD, 2001; Lundkvist, 2003; IUCN, 2004). Globally, habitat destruction is the main cause of population declines and affects 88% of threatened amphibian species (1641 species) (IUCN, 2004). Active land use, such as logging, agriculture and urbanization, recreational activities, and oil and gas exploration, results in fragmentation and destruction of amphibian habitat (Wake, 1991; Blaustein et al. 1994; deMaynadier and Hunter, 1995; Lundkvist, 2003; IUCN, 2004; Stuart et al., 2004; ASRD, 2005).

1.2 General Habitat Use Patterns of Pond-breeding Amphibians in Alberta

In Alberta, all amphibians breed in aquatic habitats (Russell and Bauer, 2000). Amphibians also depend on standing water for hydration and on adjacent terrestrial habitats for foraging, refuge from solar radiation and predators, and hibernation. Because of their permeable integument, which aids gaseous exchange and osmoregulation, amphibians are sensitive to moisture conditions. Thus the need to access wetlands and the associated terrestrial habitat is key to a complete amphibian life cycle (Semlitsch, 1998; Marsh and Trenham, 2001; Semlitsch, 2002). Most amphibians in Alberta have a biphasic life pattern, with adults migrating to ponds to breed in the spring and returning to terrestrial habitat to forage and overwinter (Russell and Bauer, 2000; Semlitsch, 2008). Many species also exhibit philopatry, with a large proportion of adults returning to breed at the pond where they were hatched (Skelly, 1996; Dodd and Cade, 1998). However, the degree of philopatry varies within and between species, as well as the environmental characteristics of the breeding pond and presence of other suitable ponds within the local area (Berven and Grudzien, 1990; Semlitsch, 2008). If the natal pond is an ephemeral wetland, and desiccation of the pond occurs, alternative breeding ponds within the same general area can be accessed for breeding, thus helping to maintain the local population (Mann et al., 1991; Dodd and Cade, 1998; Skelly, 2005).

The metamorphs of amphibian species in Alberta will usually disperse to the fringes of their natal pond following transformation, then eventually into the surrounding terrestrial habitat. Because of their small size, lower locomotor ability and higher moisture requirements compared to adults, some newly emerged young-of-the-year (YOY) may remain in terrestrial areas around their natal pond for weeks or the entire summer. Many amphibians have been observed to have relatively poor dispersal abilities (Marsh and Trenham 2001), limiting their ability to recolonize sites after local extinctions. However, other species may disperse to surrounding terrestrial uplands to forage and even inhabit non-natal ponds (Gamble, 2007). During dispersal, because of their high requirement for moisture, YOY may require a functional corridor for movement between key habitats (natal pond and terrestrial upland).

A functional corridor for movement provides required resources for juvenile and adult amphibians as they migrate or disperse, including food, shelter (from predators) and hydration (Semlitsch, 2008). Some small water courses and their riparian zones may act as corridors (Dupuis et al., 1995; Rosenberg et al., 1997; Perkins et al., 2006). Consequently, disturbance of these water courses may result in loss of connectivity between aquatic habitats and other critical habitats used for foraging or hibernation, which increases the risk of population decline and local extinction of amphibian populations (Gibbons, 2003). Multiple habitat use characterizes the life cycles of amphibians in the boreal mixedwood forest of Alberta, the site of research described in this thesis. Attempts to protect amphibian populations in this region, as well as others, are targeted at habitat protection, amongst other approaches. One of the major challenges to the conservation of amphibian species is our inability to identify features within landscapes that function as amphibian habitats to ensure their protection (Calhoun et al., 2003; IUCN, 2004; Baldwin et al., 2006).

1.3 Characteristics of the boreal mixedwood forest of Alberta and its amphibian fauna

The boreal mixedwood forest is the largest ecoregion in Alberta and forms part of the boreal forest which covers about 58% of the province. The boreal forest covers about 552 million hectares in Canada (Global Forest Watch Canada, 2002; Natural Regions Committee, 2006). It constitutes the largest forest region in Canada, comprising 35% of total land area and 77% of the total forest land, and extends across Canada from Newfoundland to the Yukon. The boreal mixedwood forest is characterized by elevations that range from about 150 m in the northern mixedwood natural sub-region near the Alberta–Northwest territories border to over 1100 m in the upper boreal highlands natural sub-region near the Alberta–British Columbia border. The common landforms observed are level to undulating till and lacustrine plains combined with various wetland types. The boreal mixedwood forest is dominated by trembling aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), white birch (*Betula papyrifera*), and conifers like white spruce (*Picea glauca*), black spruce (*Picea mariana*), jack pine (*Pinus banksiana*) and tamarack (*Larix laricina*) (ASRD, 2005; Natural Regions Committee, 2006). The common soils found in this region are luvisolic on uplands and mesisols in wetlands. The region experiences high variation in mean monthly temperature (-30 to 20^{o}C) and precipitation (0 to 120 mm) (Natural Regions Committee, 2006).

Common amphibians species found in the boreal mixedwood forest region are the wood frog (*Lithobates sylvaticus,* formerly *Rana sylvatica*), boreal chorus frog (*Pseudacris maculata*) and boreal toad (*Anaxyrus boreas,* formerly *Bufo boreas*) (Russell and Bauer, 2000; Hannon et al., 2002; Eaton, 2004). Wood frog is the most widely distributed anuran across Canada and North America. Adults are 30-60 mm when sexually mature and are generally believed to display a high degree of philopatry to breeding ponds (Berven and Grudzien, 1990). Breeding in northern Alberta occurs in standing water bodies as soon as snow melts between April and early June, with a single female producing up to 2000-3000 eggs (ASRD, 2005). Eggs hatch within 3 weeks and transformation into metamorphs occurs in 6 to 12 weeks (June to early September) depending on water temperature, pH and dissolved oxygen content of the pond (Russell and Bauer, 2000; Egan, 2004; ASRD, 2005). Wood frog tadpoles feed on periphyton, while YOY and adults feed on a variety of arthropods and other small invertebrates. Wood frogs hibernate underneath leaf litter on land and are freeze tolerant (Storey and Storey, 1986.

Boreal chorus frog is the smallest amphibian in Alberta, reaching up to 20-40 mm in length, and is distributed across most of the province (ASRD, 2005). Tadpoles feed on algae, while YOY and adults feed on a variety of small invertebrates (Russell and Bauer, 2000; ASRD, 2005). Breeding and development of boreal chorus frog is similar to that of the wood frog, except females lay 500 to 1500 eggs which hatch within 14 days, and larvae metamorphose after 40 to 90 days (late June to August) (Harding, 1997; ASRD, 2005). Like wood frogs, boreal chorus frogs appear to be philopatric to their natal ponds (Smith, 1987). The boreal chorus frog is a semi-arboreal frog that climbs shrubs, herbs and hibernates under rocks and detritus and in animal burrows (Harding, 1997; Russell and Bauer, 2000). They are freeze tolerant and can hibernate under logs, leaf litter and similar places as wood frogs (Storey and Storey, 1986).

The boreal toad is the largest toad in Alberta, with an adult length of 55-125 mm. Its range is primarily in boreal forest and subalpine environments in western and central Alberta, where it occurs at elevations up to 3,600 m (ASRD, 2005). Toads are less common in the boreal mixedwood forest landscape than wood frogs and boreal chorus frogs. In Alberta, boreal toads are active between April and September, and are observed in close proximity to streams, ponds and lakes. Tadpoles feed on algae and detritus, while adults feed on slugs, earthworms and insects (Russell and Bauer, 2000). Boreal toads breed between April and June, and a female can produce over 5000 eggs. Eggs hatch within 3 to 10 days, and tadpoles metamorphose into juveniles within 3 to 8 weeks (June to August). Boreal toads exhibit a high rate of philopatry to breeding ponds (Wind and Dupuis, 2002). Western toads hibernate in terrestrial burrows or cavities where they can escape freezing as they are not freeze tolerant (Browne and Paszkowski, 2010).

In Alberta, populations of wood frogs and boreal chorus frogs are considered to be relatively secure whereas the boreal toad is listed as "sensitive" by the province and a "species of special concern" nationally by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC, 2005). However, these amphibian species may soon be under increasing pressure in northern Alberta due to habitat alteration and destruction (Wind and Dupuis, 2002; ASRD, 2005; Environment Canada, 2006). Over 75% of the boreal mixedwood forest in Alberta is leased to forestry and energy companies (Prepas et al., 2002). Currently, oil and gas activities, logging for extraction of pulp and soft wood, road construction and recreational activities are some of the major impacts occurring in the boreal mixedwood forest in northwest Alberta (Natural Regions Committee, 2006). These activities could lead to destruction of small ephemeral wetlands and streams, which are potential amphibian habitats (Calhoun et al., 2003; Gibb, 2003; Semlitsch et al., 2003).

Because of their small size and temporary nature, most small ephemeral wetlands and streams are not reliably detectable on contour maps, aerial photographs or hydrological maps (Gibbs, 1993). In Alberta, most relatively large and permanent water bodies have received some form of protection, while smaller, less permanent water bodies are mostly ignored. In the guidelines for habitat protection during forestry activities in Alberta, ephemeral wetlands less than 4 ha (ASRD, 2004), receive no protection. Small intermittent and ephemeral streams are also generally not protected through the creation of treed buffers during timber harvesting (ASRD, 1994; 2005). For small permanent streams, 30 m undisturbed buffers on either side of the stream channel are recommended by Alberta ground rules. When selective timber removal is approved within 30 m buffers, machinery is not allowed within 20 m of the stream's high water mark. When fish spawning is observed, special crossings are required (ASRD, 1994). Inadequate protection of small water bodies, which are common features within the boreal landscape (Eaton, 2004), poses a problem for amphibian protection and conservation generally. What follows is a more detailed review of the attributes of these overlooked amphibian habitats in boreal Alberta.

1.4 Small ephemeral wetlands in the boreal mixed-wood forest

Generally, wetlands are low-lying areas inundated by water long enough to support various life stages of aquatic or hydrophilic plants and wildlife, including amphibians (Euliss et al., 2004). They are often part of a complex hydrological network, and are maintained by precipitation, groundwater or both (Winter et al., 2003), and provide essential services such as flood control, erosion prevention, and retention of nutrients. Wetlands are common features in the boreal mixedwood forest landscape of northwest Alberta (ASRD, 2005; Natural Regions Committee, 2006). Common wetland types, described based on water source and surficial soil geology, include bogs, fens and marshes, swamps and shallow open water ponds (Woo *et al*., 1993; Natural Regions Committee, 2006). Based on the duration of inundation by water, these wetlands can also be described as ephemeral, intermittent, seasonal, semi-permanent or permanent (Gibb, 1993; Euliss et al., 2004; ASRD, 2005). The research described in this thesis focused on ephemeral wetlands.

Ephemeral wetlands are temporary, with precipitation, snow melt and spring run-off as sources of water, often drying at the peak of summer, although a few may persist for longer periods till August/September (Zedler, 2003; Euliss et al., 2004). The source of water for these wetlands influences their hydroperiod, physico-chemical characteristics, and vegetation composition and structure, which in turn influences presence and abundance of amphibians that use the wetlands and associated riparian zones (Burt and Haycock, 1996; Semlitsch and Bodie, 1996; Hayashi et al., 1998; Moore et al., 2003). Some of the common characteristics that influence amphibian utilization of wetlands include temperature, pH, conductivity/salinity, hydroperiod, and canopy cover (Glooschenko et al., 1992; Snodgrass et al., 2000; Olsson and Uller, 2002; Skelly, 2005; Karraker, 2007). Amphibian species such as wood frog, boreal chorus frog, American toad (*Anaxyrus americanus*, formerly *Bufo amercianus*), and pickerel frog (*Lithobates palustris* formerly *Rana palustris*) are associated with ephemeral wetlands and their terrestrial riparian zones for parts of their lifecycle in other regions (Wiggins et al., 1980; Semlitsch and Bodie, 1996; Briston and Kissel, 1996; Kenny *et al.*, 2000), as well as within the mixedwood forest of boreal Alberta (Eaton, 2004; Browne and Paszkowski, 2010).

Riparian zones are terrestrial areas immediately surrounding or adjacent to water bodies, and are primarily characterized by moist to saturated soils and hydrophilic plant species (Burt and Haycock, 1996). Such riparian areas are typically associated with high diversity and abundance of organisms, including amphibians that utilize them for foraging and to move between breeding ponds and terrestrial upland habitat (Semlitsch, 1998; Houlahan et al., 2003; Euliss et al., 2004). In the boreal mixedwood forest, ephemeral wetlands are often less than 0.1 ha in size, and with smaller riparian areas than large permanent wetlands. These wetlands and associated riparian zones are typically smaller than the sizes of water bodies protected during forestry management activities in most parts of North America (Calhoun et al., 2003).

1.5 Small streams in the boreal mixed-wood forest

Small streams in the boreal mixedwood of Alberta are categorized based on water permanence and channel width. I focused on ephemeral, intermittent or small permanent streams based on hydroperiod, channel width and vegetation in the stream channel (Kocher and Harris, 2007). Small ephemeral streams have flowing water only during or shortly after precipitation events, and they are usually dry by June or July. Their stream beds are located above the water table, the centres of theses streams are vegetated. Ephemeral streams are shallow (< 30 cm), have no distinct channel, and are usually absent from topographic maps. Small intermittent streams have distinct non-vegetated channels which may be sporadic and up to 0.5 m in width. Their water flow continues for longer periods than ephemeral streams, though water typically disappears by August/September. Small permanent streams hold water persistently except during severe drought conditions, and they freeze completely during winter. These streams are fed by precipitation and groundwater (Burt and Haycock, 1996). Their channels are continuous with a width of 0.5 to 5 m and their centre's are not vegetated (DMI/ARC Classification; AEP, 1994; Kocher and Harris, 2007). Stream depth can be between 30 cm and 45 cm, but less than 50 cm in May and June. By August/September, the water depth in small permanent streams can be reduced to only 5 to 15 cm (personal observation).

Small streams are important to the hydrology of any landscape because they constitute more than 50% of the total channel length in most watersheds (Hansen, 2001). Despite the small physical dimensions of these streams, they have been shown to be very important ecosystem elements (Mazorelle, 2005). Small streams and their riparian zones serve as movement corridors for amphibian species dispersing and migrating between key habitats (Dupuis et al., 1995; Rosenberg et al., 1997; Johnson et al., 2002; Mazorelle, 2005; Perkins and Hunter, 2006; Semlitsch, 2008). They act as functional corridors by playing three major roles in supporting amphibian populations: (1) providing foraging areas, (2) supplying water for hydration (Rosenberg et al., 1997; Moore et al., 2003) and (3) their riparian vegetation provides shade and cover from predators (Kocher and Harris, 2007). Some amphibians avoid terrestrial areas with open canopy (deMaynadier and Hunter 1999; Rothermel and Semlitsch 2002; Chan-McLeod 2003). Small streams are likely to provide better refugia than larger, wider streams based on higher canopy cover above smaller stream channels.

Small streams are also an important source of sediment and woody debris feeding into wetlands. They exhibit high floral and faunal diversity (e.g. insect larvae) (Muchow and Richardson, 1999), which can be beneficial to amphibians. As small streams flow, they aid the breakdown of leaf litter and organic debris, providing energy and nutrients along the stream's riparian zone and downstream (Kocher and Harris, 2007). Riparian vegetation hanging over the stream also provides some level of shade for the water, helping to maintain a lower water temperature (Kocher and Harris, 2007) which can promote suitability of sites for amphibian hydration during warm periods in the boreal forest. The removal of trees from the riparian zone of small streams can increase the volume of run-off into the streams due to reduced evapotranspiration (Euphrat, 1992), and reduce canopy closure resulting in elevated stream temperatures (Rayne et al., 2008). These factors may affect the utility of streams for amphibians due to increased risk of predation and higher water temperatures (Steedman, 1998; Ice, 2000).

1.6 Thesis organization

This thesis consists of four chapters focused on amphibians and some of their terrestrial and aquatic habitats in the boreal mixedwood of northwest Alberta. This first chapter is a general introduction to amphibian conservation and provides background on the study region and habitats. The second chapter addresses the use of small ephemeral wetlands and their surrounding terrestrial areas by amphibians as breeding and foraging habitat in the mixedwood boreal forest, and identifies what habitat factors influence amphibian presence and abundance. The third chapter deals with amphibian use of small streams and their riparian zones during dispersal and migration, and what habitat features of the streams themselves and adjacent terrestrial habitats influence use. The last chapter consists of general conclusions and recommendations generated by the study concerning the conservation of boreal amphibian populations and their habitats in light of forestry and energy development.

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CHAPTER 2 AMPHIBIAN USE OF SMALL EPHEMERAL WETLANDS IN THE MIXEDWOOD FOREST OF BOREAL ALBERTA

2.1 INTRODUCTION AND BACKGROUND

Human activities often reduce available habitat for amphibian breeding, foraging and overwintering (Semlitsch et al., 2003; Wells, 2007). In the mixedwood boreal forest of Canada, increasing demand for natural resources has resulted in expanded forest harvest and oil and gas extraction (Global Forest Watch Canada, 2002; Schneider et al., 2003; Timoney and Lee. 2009), resulting in pressures on wildlife and their habitats, including wetlands used by amphibians. Identifying amphibian habitats within the boreal forest will aid conservation of their populations. Therefore, understanding the importance of small ephemeral wetlands as potential amphibian habitat may enhance protection through informed management (Gibbs, 1993; Calhoun et al., 2003). At present most wetland protection guidelines in North America are primarily based on size and water permanence (Snodgrass et al., 2000; Babbitt, 2005), so relatively small ephemeral wetlands are not favored for protection (Burne and Griffin, 2005).

In the mixedwood forest of boreal Alberta, ephemeral wetlands are not protected during timber harvest operations under the Forest and Range Practices Act (ASRD, 2005). In the Alberta guidelines for wetland protection, small wetlands considered for protection are at least 4 ha in size (ASRD, 2004), suggesting that the wetlands in my study have no formal protection. This is in part due to difficulty in detection of these wetlands (as they are rarely captured with aerial photography or represented on hydrological maps), their ephemeral nature, and a poor understanding of their function as habitat for wildlife, including amphibians. The importance of these ephemeral wetlands cannot be overemphasized as they have been identified as common features in the mixedwood forest of boreal Alberta (ASRD, 2005; Natural Regions Committee, 2006). Eaton (2004), using Alberta Vegetation Index (AVI) data for a 504.2km^2 area within the boreal mixedwood forest near Athabasca, Alberta, found small water bodies (< 1 ha) constituted about 35% of the wetlands detected.

In some parts of North America relatively small wetlands have been documented as amphibian habitat. Moler and Franz (1987) found 14 species of frogs breeding in small temporary ponds in north central Florida. On the south-eastern Atlantic coastal plains of Georgia, 20 amphibian species were recorded breeding at five small ephemeral ponds (0.38 to 1.06 ha in size) (Cash, 1994). Studies at the Savannah River site facility on the coastal plains of South Carolina recorded 19 to 22 amphibian species at wetlands ranging from 0.08 to 1.0 ha in size (Gibbon and Semlitsch, 1981). Another study in South Carolina recorded 19 to 21 species at wetlands from 0.08 ha to 1.0 ha in size (Semlitsch et al., 1998). Twenty-seven anuran species and caudates were encountered at another small (<0.5 ha) South Carolina wetland over a period of 16 years; these included an estimated 11,000 breeding males and 216,251 metamorphosing juveniles for several amphibian species combined (Semlitsch et al., 1996).

The number of young-of-the-year (YOY) produced at this single wetland suggests that relatively small ephemeral wetlands can contribute considerably to local amphibian populations (Semlitsch et al., 1996). In a study of 17 non-permanent wetlands in north-eastern Connecticut, Skelly et al. (2005) found eight amphibian species, including wood frogs. In visual surveys of small wetlands (area = 0.005 to 0.18 ha; n=33) in the boreal mixedwood forest of Alberta, Eaton (2004) encountered wood frogs and other amphibian species at least once in over 70% of the sites sampled.

Amphibian use of small ephemeral wetlands can be influenced by pond characteristics. Small shallow wetlands generally do not support populations of fish and large invertebrates that are predators of amphibian eggs, larvae and adults, thus providing safe habitat (Gibb, 2003; Kats and Ferrer, 2003; Lundkvist, 2003; Knapp, 2005). Eaton et al. (2005) demonstrated that abundance of wood frog tadpoles was reduced by the presence of small-bodied fish like fathead minnow (*Pimephales promelas)* and brook stickleback (*Culaea inconstans*). Some fish species may prey directly on the eggs and tadpoles of amphibian species, or impact amphibians indirectly by preying on insects and plankton which are food for amphibians (Smith, et al., 1999; Russell and Bauer, 2000; Petranka, 2006). A number of abiotic factors may influence wetland use by amphibians as well (Petranka, 1998; Skelly et al., 2002; Schiesari, 2006). Amphibian survival is often higher in ephemeral wetlands with longer hydroperiods (i.e. length of time the wetland contains standing water). Larvae face the risk of density dependent competition due to crowding and death from desiccation in ephemeral wetlands, so some species adapt through behavioral thermoregulation and accelerated metamorphosis (Dodd, 1992; Griffith, 1997; Dodd and Cade, 1998; Pabst et al., 1998; Loman, 2002; Zedler, 2003). Temperature affects locomotor performance, feeding, metabolism and developmental rates of all life stages of amphibians (Bradford, 1990; Gatten et al., 1992; Rome, 1992; Witter and Sievert, 2001). For example, Olsson and Uller (2003) found that tadpoles of *Rana temporaria* displayed faster growth and development at higher temperatures in temporary wetlands, which is an important adaptation in ephemeral environments.

Another pond habitat factor linked to amphibians in wetlands is the degree of shade or canopy cover created by tree crowns (Skelly et al., 2005). In Connecticut, Skelly et al. (2002) found that canopy cover had an effect on temperature, with an average of 5^{o}C temperature difference between open (< 25% cover) and closed canopy (> 75% cover) wetlands. They found that tadpoles of wood frog and spring peeper (*Pseudacris crucifer)* grew faster in open than in closed canopy ponds (Skelly et al., 2005). Adult boreal toads are also encountered more often in clear cuts than forested areas suggesting they prefer open canopy to closed canopy habitats (Wind and Dupuis, 2002). High canopy cover heavily shades ponds resulting in lower temperatures, primary productivity (low food quality for tadpoles) and dissolved oxygen concentrations (Skelly et al., 2005; Schiesari, 2006; Wind et al., 2008). Adult amphibians in the boreal forest may recognize areas of open canopy as breeding spots earlier in the season, because snow melts faster in open canopy areas compared to closed canopy basins (Metacalfe and Buttle, 1998). Another shade-related factor is the percent pond surface cover (PSC) consisting of trees, shrubs, downed woody material, snags, graminoids and herbs. Pond surface cover materials provide hiding spots from predators, heat and direct light, attachment sites for eggs (Egan and Paton, 2004) and habitat for insect food for adult amphibians.

Pond water chemistry, such as pH values below 5.0 or above 8.0, can induce physiological stress, loss of body sodium, delayed metamorphosis and reduced size at metamorphosis, deformities and death in anurans, including wood frog, American toad, and spring peeper (Cummins, 1989; Freda et al., 1991; Glooschenko et al., 1992; Beebee et al., 2005; Schiesari, 2006). High pond electrical conductivity is negatively correlated with abundance of anurans (Glooschenko et al., 1992; Stephen and M'Closkey, 1996; Stumpel and Van der Voet, 1998). Wood frog larvae do not survive or grow well in waters with conductivity above 3000 μS (Karraker, 2007). In the terrestrial environment, most amphibians also require riparian and upland habitat characterized by vegetation and leaf litter appropriate for foraging and summer refuge from predators and solar radiation (Steven et al., 2002; Baldwin et al., 2006). Riparian vegetation aids survival during dispersal and migration across the landscape and can be used as hibernation sites (Semlitsch 1998; Zedler, 2003; Semlitsch, 2008).

This study is aimed at understanding if and how small ephemeral wetlands are used by amphibians, and what biotic and abiotic habitat parameters can be used to predict amphibian presence/abundance in these wetlands within the mixedwood forest of boreal Alberta. The objectives of this work were to (1) document the use of small ephemeral wetlands (< 0.1 ha) by amphibians, (2) estimate abundance of amphibian species at small wetlands, (3) examine habitat features characteristic of small wetlands and relate these features to amphibian presence and abundance, and (4) provide information on the role of small ephemeral wetlands in supporting amphibian populations through their role as breeding sites. My ultimate goal was to provide data to guide management actions that would protect small wetlands used by amphibians during forestry activities. Overall, I predicted that a unique suite of physico-chemical and vegetation signatures would distinguish wetlands used by amphibians from wetlands not used by amphibian. Specifically I predicted that amphibians were more likely to occur and in higher abundances at ephemeral wetlands with longer hydroperiods, higher water temperatures, and less canopy cover.

2.2 METHODOLOGY

2.2.1 Study area and site selection

Study Area: The study was carried out in collaboration with Alberta Innovates – Technology Futures (AITF, formerly Alberta Research Council) on the Forest Management Agreement (FMA) area managed by Daishowa Marubeni International Ltd. (DMI) in northwest Alberta. The study area is within the mixedwood boreal forest natural region of Alberta, near Peace River (Figure 2.1). The forest in this area is characterized by mixed coniferous and deciduous stands with an understory of shrubs, and numerous herbs and grasses. Common tree species in the region are listed in Chapter One. Common wetland vegetation in the area includes black spruce, shrubs (e.g. Labrador tea *Rhododendron groenlandicum* and willows *Salix spp.*), peat mosses (*Sphagnum spp.*), cattail (*Typha spp.*), sedges (*Carex spp.*), reeds *(Phalaris spp.)* and rushes (e.g. *Juncus spp.*). Forest harvesting and oil and gas extraction are common activities in the area (ASRD, 2005).

Site selection: A total of 27 small ephemeral wetlands (< 0.1 ha) were located in the study area early in summer 2008. Six sites were located to the east of the town of Peace River (56° 19´ N, 116° 35´ W), while 21 sites were west of Peace River (56° 46´ N, 118° 25´ W; Figure 2.1). Sizes of wetlands were determined with a measuring tape in May 2008. Areas with standing water above substrate were used to define wetland extent (wetland proper). These wetland sizes were used throughout the study. Wetlands ranged from 0.01 to < 0.07 ha in area and were too small for detection on aerial photographs, thus they were located using ground searches. I visually classified the study wetlands into three types at the start of the study (see section 2.3.2). The wetlands were further classified following the Canadian wetlands classification system (National Wetlands Working Group, 1997).

2.2.2 Amphibian sampling

Presence of amphibians at study wetlands was defined as detection of at least one life-stage (egg, larva, YOY or adult). Amphibian breeding was defined by presence of eggs or tadpoles, and successful breeding by the presence of all life stages (Griffiths, 1997). Wetlands were sampled once every two weeks from May 15^{th} to August 24^{th}, 2008, thus each wetland was visited seven times during the study period. Data on amphibians and some habitat features (pH, water temperature, conductivity, water depth) were collected at each visit to each study site. Pond canopy cover, percent pond surface cover were collected once a month in July and August, and riparian vegetation data were collected once during the study in July.

To assess amphibian presence, time-constrained visual encounter surveys were used; to estimate relative abundance of amphibians, we enumerated all terrestrial life stages (YOY and adults) encountered during visual surveys at each site. Two observers walked systematically in and around each wetland, searching the water, shoreline, and riparian zone (Figure 2.2) for 30 minutes. Eggs and tadpoles were identified and recorded when seen. Adults and YOY were collected by hand at the water's surface, under submerged debris, at the shoreline, and in riparian zones (25 m from the waterline toward the upland). Body size of captured animals was measured as snout-to-urostyle length (SUL) or total length if the animal still had a tail, using a ruler. Animals were weighed with a calibrated spring scale (Pesola). All anurans captured before July 1 were considered adults. After July 1 wood frogs with SUL < 27 mm, boreal chorus frogs with SUL < 19 mm, and boreal toad with SUL < 30 mm were considered YOY. Animals that still had tails were considered YOY regardless of date.

2.2.3 Sampling habitat factors

Three wooden stakes were placed 3 m from the shore for consistent depth measurement. Water depth was measured at the three wooden stakes in each wetland after every visual survey, and measurements were averaged for analysis. Hydroperiod was estimated as the number of days that a wetland had surface water from the first sampling date (May 15th) to last visit date (August 28th). During each visit, water samples were collected 3 m into the pond from the shoreline with bottles rinsed once with de-ionized water. Pond water was analyzed for electrical conductivity, pH, and water temperature using a conductivity meter at each site visit. Water temperature was measured at every visit with a thermometer 3 m into the wetland (Olson et al., 1997) to validate the reading recorded by the conductivity meter.

Prior to sampling, canopy cover by trees was categorized as closed or open; less than 40 % cover of the pond by trees was defined as open. Tree canopy cover $\geq$ 60 % was defined as closed, and between 41 % and 59 % cover was defined as intermediate canopy cover. Canopy cover for each wetland was later measured from 0.3 m above water level at three different points 3 m into the wetland with a convex spherical densiometer. At each point, four canopy measurements were taken, each facing a different cardinal direction and the 12 measurements were averaged. Pond surface cover was visually estimated for the entire surface of the pond. Vegetation in the riparian zone (defined as an area 25 m from waterline into the adjacent terrestrial upland; Figure 2.3) of each wetland was sampled. Vegetation sampled included tree and shrub layers, and herb cover. For riparian vegetation sampling, our goals was to collect data from four 25 x 4 m transects, one on each side of each pond (see Figure 2.3) in July 2008. However, only 15 sites had complete data from four transects, so two transects were randomly selected from these for analysis. The remaining 11 sites had complete data from only two transect and these were used for analysis for 26 wetlands. Each quadrant was divided into five smaller 5 x 4 m quadrants, and each was sampled for trees and shrubs. The number of trees (identified as conifers or deciduous) and shrub stems were counted. Four herb plots (0.5 x 0.5 m) were set up at random spots in each 5 x 4 m quadrat, and percent ground cover by graminoids (grasses, sedges, reeds, and rushes), all forbs, and mosses combined was visually estimated.

2.2.4 Analysis

Within pond analysis: Relative abundance of all amphibians species combined was calculated as catch per unit effort (CPUE) for terrestrial life stages only (adults and YOY), i.e. the number of animals captured relative to length of time spent searching. Mean CPUE was standardized to number of animals caught per hour for each sampling session. The CPUE for each sampling session was used to derive a mean CPUE for each wetland representing all animals combined for the seven sample dates (Fellers and Freel, 1995). Mean values were also calculated for each wetland for pH, temperature, canopy cover, conductivity, hydroperiod and PSC over the study period. (Table 2.1). Normality of data was determined by the skewness and kurtosis after plotting a distribution graph for each variable. Parametric and non-parametric tests where used to analyze normally distributed and skewed capture data, respectively. For the two major wetland types (see section 2.3.2; Figures 2.5 and 2.6), amphibian occurrence was compared using a chi-square contingency test and a Mann-Whitney test was used to determine if there was a difference in CPUE for all three species combined. Analysis was done with STATISTICA version 7 and statistical significance was set at $P = 0.05$.

Pond-based habitat variables for wetlands with and without amphibians were compared using the Wilcoxon rank sum test to identify variables associated with amphibian presence. Forward-selection stepwise multiple regression was used to determine specific wetland habitat features (size, pH, water temperature, hydroperiod, canopy cover, percent pond surface cover and conductivity) that can be used to predict relative abundance (CPUE) of the three amphibian species combined. A normal probability plot of the regression residuals was used to check for normality of the data and an identified outlier WWO4 (Cooks distance > 1.0: based on CPUE) was removed from subsequent analysis. Multicollinearity between habitat features was checked before the stepwise multiple regressions with an auto-correlation matrix and its effect on the model tested with Durbin Watson d analysis. When two habitat variables were significantly correlated, the variable that had no or less significant effect on the regression model was discarded before the final stepwise-regression model was run.

Riparian analysis*:* T-tests assuming unequal variance were used to compare each vegetation variable (deciduous/coniferous tree density, shrub density, and percent ground cover by graminoids, forbs and moss) between the two major wetland types (see section 2.3.2) in order to determine if types could be differentiated based on vegetation signature and to determine if identification of wetland type was consistent. T-tests assuming unequal variance were used to compare vegetation variables between wetlands where amphibians were present versus absent to see if amphibian presence can be associated with specific vegetation signatures. I used Spearman's correlation analysis to identify associations between riparian vegetation features and relative abundance of amphibians among wetlands based on CPUE. This was based on the fact that most animals (> 95%) were caught at the wetlands 9within the ponds), and the assumption that riparian zone vegetation had an indirect effect on amphibian occurrence at the ponds, so may be associated with movement of amphibians, but cannot be used to predict correctly amphibian CPUE or wetland use in my study.

2.3 RESULTS

2.3.1 Occurrence and abundance of amphibians

As expected, all life stages of three species of anurans (boreal toad, wood frog, and boreal chorus frog) were encountered during the surveys (Appendix 2.1). During a total of 94.5 search hours, 1105 amphibians (terrestrial stages only) were captured at the 27 study wetlands (total CPUE = 11.6 amphibians/hour). Mean CPUE, was 14.1 ± 4.7 (Mean ± SE) animals per hour for all species combined in all 27 sites during 94.5 search hours between May and August, 2008. Captures consisted of 835 wood frogs, 230 boreal chorus frogs 36 boreal toads, and 4 unidentified frogs (Table 2.2). Amphibians were encountered at 70% of wetlands sampled (19 wetlands), while 30% (8 wetlands) lacked any evidence of amphibians. All wetlands with amphibians had both wood frogs and boreal chorus frogs, while only two had boreal toads. Successful breeding was confirmed at 14 wetlands (51.8% of the 27 wetlands) whereas five wetlands with amphibians had no confirmed breeding. A majority of the captures (Figure 2.4) were animals produced in the study year (2008). Of the amphibians captured, 83.3% of wood frogs, 71.8% of chorus frogs and 19.2% of boreal toads still had tails (evidence of recent transformation) at the time they were encountered. Excluding WWO4, the number of YOY captured was positively correlated with the number of adults ($r = 0.6$, $P_{value} = 0.01$ Pearsons correlation).

2.3.2 Wetland types and relative amphibian abundance

I identified three types of ephemeral wetlands during my study based on their general characteristics. "Type A" wetlands were mineral wetlands that were marshy and overgrown by emergent vegetation within the standing water. Vegetation within the pond included cattail, graminoids (sedges, reeds, rushes), and forbs. Volumes of downed woody materials were low. When wet, between 50% and 70% of the surface was covered by emergent vegetation (Figure 2.5), but emergent vegetation overgrew 90% of pond when dry. The riparian zone started at a shallow bank (continuous with the surface of the pond, which had low slope), and included flooded areas which supported a high density of willows. Twelve Type A wetlands were surveyed; they can be classified as "mineral marsh wetlands" (National Wetlands Working Group, 1997).

There were 14 "Type B" mineral wetlands characterized by more open water and more shrubs compared to Type A (Table 2.3). The pond edges were dominated by shrubs and snags. They supported a high volume of downed woody material and a few deciduous trees, such as young aspen trees at the pond edges and growing in < 20% of the pond. When dry, the surface of the wetland was bare or covered by decaying leaves. The riparian zone began with a steep and more abrupt bank from the pond edge and was drier than for type A wetlands. The riparian zone contained willows, a few graminoids (usually on only one side of the pond), tall shrubs, conifers and deciduous trees (Figure 2.6). Type B wetlands can be classified as “mineral shallow water wetlands” (National Wetlands Working Group, 1997).

A single “Type C” wetland consisted of an area of open water surrounded by peatland. The riparian zone was continuous with the pond with no distinct bank, wet throughout the 25 m riparian extent, and supported peat mosses, graminoids, and shrubs. The riparian zone was dominated by conifers (over 85 % of the riparian area, based on visual estimate; Figure 2.7). The Type C wetland can be classified as a “treed basin fen” (National Wetlands Working Group, 1997).

Amphibians were encountered at 11 of 12 Type A wetlands, with a mean CPUE of 12.8 ± 2 animals/hr, and seven of 14 Type B wetlands, with a mean CPUE of 11.2 ± 6.7 animals/hr (mean of CPUE means including all wetlands with and without amphibians). Including WW04 (type B), the mean CPUE of wetland Types A and B were not significantly different (P_{value} = 0.67; Mann Whitney U test). Excluding WW04, type A had significantly higher CPUE than type B (P_{value} = 0.03). Occurrence of breeding amphibians was significantly different for wetland types A and B (χ^2 = 27.5, P < 0.001, df = 1; contingency chi-square test), with breeding at nine of the 12 type A wetlands (75%), but at only four of the 14 type B wetlands (28.5%). Of the 13 wetlands with breeding (excluding wetland type C), wetland Type A and B represented 69.2% and 30.8% of the sites with observed breeding, respectively. Analysis of riparian vegetation indicated the mean densities of coniferous and deciduous trees, and percent ground cover, tended to be higher in Type A than Type B wetlands, but differences were not significant (Table 2.3). Shrub density was significantly higher in type B than in type A wetlands (Table 2.3).

2.3.3 Relationship between habitat features and amphibian presence

(i) General description of habitat features

Mean size of the 27 study wetlands was 0.02 ± 0.003 ha (mean ± SE). Mean water temperature of the wetlands was 12.5°C ± 0.83 (range = 7.0 to 16.8°C) between June and August, 2008; mean monthly water temperature increased from

12.1 ^{o}C in June, to 13.1 in July, and 14.9 ^{o}C in August. Mean hydroperiod recorded was 83 ± 0.83 days (range = 47 to 115) and mean pH recorded was 6.3 ± 0.15 (range = 4.7 to 7.4). Mean PSC was 53 ± 4.9%, with about 85% of the sampled wetlands characterized by >30% vegetation coverage of the water's surface. Mean electrical conductivity was 446.1 ± 91.6 µ/cm. There were only two significant correlations between pond habitat variables; wetland size had a significant positive correlation with hydroperiod ($r = 0.4$, $P_{value} = 0.02$) and a negative correlation with PSC ($r = -0.3$, $P_{value} = 0.04$).

(ii) Relationship between habitat variables and amphibian presence/CPUE

Pond habitat variables and amphibian presence: Mean wetland size (area) and electrical conductivity of wetlands with and without amphibians were not significantly different (Table 2.4). Hydroperiod was significantly longer and water temperature was significantly higher in wetlands with amphibians compared to those without amphibians (Table 2.4). Average pH of wetlands with amphibians was significantly higher than wetlands without amphibians (Table 2.4). Canopy cover differed markedly between wetlands with and without amphibians, with significantly higher cover at wetlands without amphibians (Table 2.4)**.** Similarly, wetlands lacking amphibians supported significantly higher PSC (Table 2.4).

Pond habitat variables and CPUE: In examining the relationship between mean of monthly means of CPUE and pond environment variables for the 27 wetlands, Cooks distance identified an outlier (WWO4) which was excluded from the regression analysis. There was no significant multi-colinearity affecting the regression model (Durbin Watson d = 2.016). Based on the normal probability plot of the regression residuals, the data used for the regression had a normal distribution after removal of WW04. Step-wise multiple regressions indicated that two of the six tested variables explained most of the variation in the relative abundance of amphibians. Pond temperature and canopy cover explained about 73.3% of the variance in relative abundance (CPUE) of amphibians (Table 2.5).

The resultant model (equation 2.1) indicates that CPUE of amphibians is positively related to pond temperature and negatively related to canopy cover (Figure 2.8).

$$Y_{(CPUE)} = 1.960 + 0.639(\mathbf{Temp}) - 0.030(\mathbf{Canopy}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

Vegetation variables and amphibian presence/CPUE: Analysis of vegetation in the riparian zone indicated that none of the variables measured differed significantly between wetlands with and without amphibians, although the density of conifer trees tended to be higher and density of shrubs lower around wetlands without amphibians (Table 2.6). CPUE (overall means from each wetland) was also not significantly correlated with most of the vegetation variables (Table 2.7), except for deciduous tree density which was positively correlated with CPUE (Table 2.7; Figure 2.9).

2.4 DICUSSION AND CONCLUSION

Amphibian use of small ephemeral wetlands as habitat

My study identified three types of small ephemeral wetlands commonly found in northern Alberta that can function as amphibian habitats. It provided evidence that amphibians use small ephemeral water bodies (< 0.1 ha) for breeding and foraging in the boreal mixedwood forest. The three species of anuran amphibians studied were able to use these wetlands for breeding and successful development from egg to metamorphosis (Appendix 2.1). Wood frog was the most common of the species encountered, while the boreal toad was the least common, only occurring in two of 27 wetlands. My results are consistent with several studies that have shown small wetlands support populations of a variety of amphibian species in a range of ecological regions (Moler and Franz, 1987; Dodd and Cade, 1998; Russell *et al.*, 2002; Semlitsch, 2002; Zedler, 2003; Eaton, 2004; Liner et al., 2008). Adult frogs usually locate ephemeral wetlands early in the season, breed and disperse to uplands before wetlands dry (Zedler, 2003; David, 2007). If the wetlands lack water in a given year, amphibians may still utilize them in subsequent years because philopatry is a common behavior observed amongst wood frogs and boreal toads (Marsh and Trenham, 2001; Gamble et al., 2007). Vasconcelos and Calhoun (2004) found that 98% and 88% of male and female wood frogs, respectively, were faithful to their original breeding wetlands in a study in Maine.

Observation of successful breeding of large numbers of wood frogs and boreal chorus frogs in the same ponds suggests that my study wetlands support reproduction by both species, despite evidence that these two species compete in their larval stage (Whiting, 2010), likely affecting survival and developmental rates of tadpoles (Vasconcelos and Calhoun, 2006; Hawley, 2009). Factors that make these wetlands attractive to breeding amphibians are their shallow depth and temporary nature, which preclude fish occupancy. Accidental introduction of fish into ephemeral wetlands adversely impacts amphibian populations through increased predation on anuran eggs and larvae (Hecnar and M'Closkey, 1997; Smith et al., 1999; Semlitsch, 2000). Small ephemeral wetlands in the mixedwood forest of Alberta offer advantages as breeding habitat over larger, permanent water bodies because of the absence of fish (Eaton et al., 2005).

Observations of amphibians in some of the wetlands that lacked signs of breeding suggest anurans are also using these wetlands for other requirements like hydration and feeding (Marsh, et al., 2001; Semlitsch, 2002). However, the number of adults seen correlated with YOY encountered, suggesting that breeding may have occurred at some sites but were not captured. All life stages of amphibians were completely absent at some study wetlands. The time constrained visual survey technique that I used, or imperfect detection by observers, may have resulted in failure to detect amphibians at sites where they actually occurred at very low densities or occurred sporadically. However, habitat features are likely to have led to true absence of amphibians from some sites (see section 2.4.3).

Amphibians were more likely to be present and breed in marsh wetlands (type A) than the shallow open water wetlands (type B), but there was no distinct habitat feature clearly associated with this pattern. However, the emergent herbs and leaf litter characteristic of type A wetlands may have provided better attachment for amphibian eggs than the shrubs common in type B wetlands.

Additional sampling of ephemeral wetlands is required to reach conclusions on which wetland type is utilized most by amphibians in northwest Alberta.

Effects of habitat factors on amphibian use of small ephemeral wetlands

My study did not identify a set of unique habitat variables that could predict the relative abundance of amphibians in the small ephemeral wetlands. It did, however, identify temperature and canopy cover as good predictors of amphibian presence and capture rates. Most of the habitat variables that I measured, such as temperature and canopy cover, have been investigated by other studies that indicate these factors affect presence, distribution, breeding success and larval development of amphibians (Gaten, 1992; Grant and Licht, 1993; Wellborn et al., 1996; Stumpel and Van der Voet, 1998; Babbitt et al., 2003; Skelly et al., 2005; Babbitt, 2005). In my study as well, pond temperature and canopy cover were identified as the major factors influencing the presence and relative abundance of amphibians. Water temperature influences almost all physical, chemical and biological processes in an aquatic ecosystem, and usually determines the rate at which processes occur. Temperature also influences the rate of evapotranspiration, influencing the hydroperiod of wetlands. Because amphibians are ectotherms, their physiological responses and behavior are driven by changes in environmental temperature. In temperate areas, this leads to annual cycles of activity, including hibernation. Other functions that can be influenced by temperature are locomotion (Rome et al., 1992), mating (Narins, 1995), and feeding (Witters and Sievert, 2001).

Observations from laboratory and field studies of lakes and ephemeral wetlands in Oregon indicated that boreal toad and Pacific tree frog (*Pseudacris regilla*) tadpoles were more attracted to shallow surface waters of ponds with warmer temperatures during the day than colder deeper areas (Bancroft et al., 2008). Rates of embryonic development and metabolism are temperature dependent in all amphibians, although there is variation in minimum and optimum temperature levels even across temperate species (Bradford, 1990). Low minimum pond temperatures have been implicated as a key factor increasing embryonic mortality in *Rana temporaria* (Beattie et al., 1991). Although amphibian embryos grow faster at warm temperatures compared to colder conditions, very high temperatures also retard growth, and cause desiccation of embryo and tadpoles of boreal toads and other amphibians (Bradford, 1990, Blaustein et al, 2005). Temperature also affects key parts of the amphibian peripheral and central nervous system which is associated with call perception during breeding (Gatten et al., 1992).

The attraction of tadpoles to warmer parts of ponds is common (Olson, 1998). For example, boreal toad larvae will aggregate in the warm shallow margins of wetlands to enhance their rate of growth and development (Poll et al., 1984). In a study by Wollmuth et al. (1987), cascade frog *(Rana cascadae)* tadpoles were habitually located in the warmest part of ponds that received the most sunlight. Wollmuth and Crashaw (1988) also found that bullfrog (*Lithobates catesbeianus* formerly *Rana catesbeiana*) tadpoles preferred the warmest parts of ponds. Most of the tadpoles that I encountered in my study wetlands were located near the shore during sunny days. This behaviour is consistent with Bradford's (1984) observations that tadpoles of the yellow-legged frog (*Rana mucos)* occurred frequently near the shore of a wetland during the day, but moved into deeper water in the evening.

Another pond feature, pH was higher in the wetlands with amphibians suggesting that pH plays a role in amphibian presence or absence. pH is influenced by natural processes like nutrient uptake by plants, CO_2 production by roots, oxidation of nitrogen and sulphur compounds, and humification of organic substances (Ulrich, 1980); in turn, pH affects larval amphibians. High acidity (low pH) causes physiological distress, damages eggs, denatures body proteins, and triggers embryonic mortality (Cummins 1989; Sadinski and Dunson, 1992; Freda, 2003; Schiesari, 2006). However, in my study sites there were no noticeable morphological effects of pH on amphibians.

Another pond habitat variable linked to amphibian presence and relative abundance at my study wetlands was the extent of tree canopy cover. Canopy cover of the ponds directly influences key characteristics, such as water and air temperature and hydroperiod, because canopy cover regulates the amount of light that reaches the forest floor and a pond's surface (Russell et al., 2002; Ice, 2000; Zedler and Kercher, 2004; Zulkiflee and Blackburn, 2009). Lower primary production due to lower light levels could affect the amount and type of periphyton and other food sources available to amphibians, which affects growth and survival of larvae, juveniles, and adults (Briston and Kissell, 1996; Skelly et al., 2002). In my study, open-canopy wetlands supported more amphibians compared to heavily shaded, closed-canopy wetlands. This observation is consistent with other studies that have shown canopy cover to be related to amphibian presence and abundance at wetlands (e.g. Skelly et al., 2005). Werner and Glennemeier (1999) suggested that wood frogs are closed canopy specialists; however, my study indicates that higher canopy cover reduces the probability of use of small wetlands by wood frogs, boreal chorus frogs and boreal toads. Open wetlands may offer ice-free water earlier in the spring because melting will occur faster due to higher temperature from more direct sunlight, more through-fall of precipitation (results in higher soil moisture), and less evapotranspiration by trees (Zulkiflee and Blackburn, 2009). This is consistent with laboratory and field studies by Skelly et al. (2002, 2005), who found that the warmer water of open wetlands promotes rapid development of amphibian larvae, affording them the chance of developing before complete desiccation of ponds. Alberta is cold compared to other portions of the range of wood frogs and boreal chorus frogs so thermal relations are particularly important.

The riparian vegetation bordering wetlands plays an important role in affecting water chemistry, and canopy cover (Burt and Haycock, 1996; Zedler and Kercher, 2004). Some studies suggest that riparian areas dominated by deciduous trees support a greater abundance of amphibians than areas dominated by conifers (deMaynadier and Hunter, 1995; Degraaf and Yamasaki, 2001). Surveys of the 25 m riparian zone of my study wetlands indicated a higher proportion of deciduous trees than coniferous trees around wetlands where amphibians were present (Table 2.6). Deciduous trees may be associated with increased abundance of insects (food for adult amphibians; Holly and Hayes, 2008). Studies by Hanlin et al. (2000) in managed forests of South Carolina documented lower occurrence or abundance of amphibians (southern toad, *Anaxyrus terrestris*) in areas dominated by conifers compared to areas dominated by deciduous trees. In boreal Alberta a study by Browne et al. (2009) also showed a negative relationship between cover in conifers and abundance of wood frogs, boreal chorus frogs and boreal toads, though this correlation was at different spatial scales for the different species. Roberts and Lewin (1979), in a study in the boreal forest near Fort McMurray in northeastern Alberta, reported that amphibians were absent from conifer-dominated stands. Because deciduous trees are characterized by broad leaves, they provide cover within riparian zones, but still allow some light to get to the forest floor. Litter associated with deciduous tree leaves is likely more attractive to amphibians than conifer needles.

The pond surface covered (PSC) by emergent plants, submergent plants and downed woody material also was negatively related to the presence of amphibians at the study wetlands. Adult wood frogs and chorus frogs take refuge and lay eggs under and around submergent plants and downed woody materials close to the water surface (Egan and Paton, 2004), so they may have been more difficult to detect during visual surveys. Tadpoles commonly stay in the littoral zones of wetlands where they take refuge around emergent and aquatic macrophytes (Alford, 1999). In a study of ephemeral ponds in an upland forest in the Chicago area, Nuzzo et al. (2000) showed *Pseudacris crucifer, Pseudacris triseriata* and *Lithobates pipens* abundance increased with increasing pond surface cover, which is contrary to my observations. My findings however differ from those of Nuzzo et al. (2000) as these researchers found no animals when PSC < 80%, whereas I found amphibians at PSC < 40%. Despite benefits offered by PSC, when emergent vegetation is of high density and covers a large portion of a wetland's surface area, it becomes a feature that contributes to desiccation of small ephemeral wetlands due to evapotranspiration (Zedler and Kercher, 2004).

It is important to note that in my assessment of amphibian utilization of small ephemeral wetlands, presence or absence appeared to be a more valuable measure of habitat suitability than relative abundance, perhaps because it was a simpler metric that was less biased by the surveyors' ability to detect animals and by weather conditions than CPUE as an estimate of abundance.

Implications for amphibian populations

Most conservation actions aimed at maintaining amphibian populations have involved translocation of eggs, tadpoles and metamorphs (Dodd and Siegel, 1991), captive breeding (Bloxan and Tonge, 1995), or habitat protection (Denton et al., 1997; IUCN, 2004). The first two techniques have been highly variable in terms of success, and habitat protection often requires substantial research on amphibian populations in a particular location. My study contributes information allowing identification of suitable wetland habitats for wood frogs, chorus frogs and boreal toad in the mixedwood forest of boreal Alberta.

Despite the small size and ephemeral nature of the study wetlands, they are functional breeding, hydration and foraging habitats for wood frog, boreal chorus frog, and boreal toad. They also effectively provide connectivity between other small wetlands, larger wetlands, and terrestrial habitats allowing wetland animals to access these areas and linking meta-populations (Gibbs, 1993). My surveys suggest that anthropogenic destruction or degradation of this class of wetlands will reduce habitat for these anuran species, adversely reducing their chances of survival and reproduction. My study also supports calls for protection of small wetlands and their riparian zones for conservation purposes throughout North America (Gibbs, 1993; Semlitsch and Bodie, 1998; Dodd and Cade, 1998; Snodgrass et al., 2000; Calhoun et al., 2003).

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Table 2.1 Habitat variables measured at 27 wetlands and frequency of sampling. Visual surveys for amphibians occurred every two weeks.

Class	**Habitat Variable**	**Frequency**
Physico-chemical	Water temperature	At every visual survey
	pH	At every visual survey
	Canopy Cover	Once a month
	Electrical conductivity	At every visual survey
	Water depth	At every visual survey
	% pond surface cover	Once a month
Biological	Tree density (stem/quadrant)	Once during the study
	Shrub density (stem/quadrant)	Once during the study
	% ground cover	Once during the study

Table 2.2. Summary of captures at study wetlands where amphibians were present (n=19 of the 27 sampled wetlands) between May and August, 2008. Surveys were done twice per month (7 surveys per site).

Amphibian species	**Age class***	**# of animals captured**	**Total # of animals**	**# of wetlands with amphibians**
Wood frog	YOY Adult	594 241	835	19
Boreal chorus frog	YOY Adult	149 81	230	19
Boreal toad	YOY Adult	26 10	36	2
Unidentified anurans	Adult	4	4	3
TOTAL		1105	1105	19

*YOY = Young of the year - animals that emerged from their natal ponds in the same year in which they were first captured; Adults – animals that have survived at least one winter since they metamorphosed.

Table 2.3 Comparison of riparian vegetation [mean ± SE, (range)] between wetlands A and B, using t-tests based on average stem counts from two 25 x 4 m quadrants for each wetland for 25 wetlands (wetland type C excluded).

Vegetation variables	**Wetland type A (n=12)**	**Wetland type B (n=13)**	**t-value)**	**P-value**
Conifer density (stems/quadrant)	34 ± 8.2 (1 - 89)	28.1 ± 8.7 (1 - 104)	0.48	0.06
Deciduous tree density(stems/quadrant)	30.7 ± 9.8 (1- 112.5)	21.6 ± 4.1 (3 - 57.5)	0.86	0.40
Shrub density (stems/quadrant)	34.8 ± 5.3 (15 - 74.5)	57.1 ± 8.5 (28 - 118)	**2.24**	**0.04***
% ground cover	86.3 ± 3.40 (65 – 100)	82.14 ± 3.9 (65-95)	0.78	0.44

*Significance at P-value < 0.05 is indicated by the values in bold

Table 2.4: Comparison of physico-chemical habitat variables of wetlands where amphibians were present versus absent, June to August, 2008; mean ± SE (range).

Habitat variable	Present (n=19)	Absent (n=8)	Wilcoxon rank-sum test
Size (ha)	0.02 ± 0.003 (0.01 - 0.02)	0.01 ± 0.001 (0.01 - 0.02)	Z = -1.75 P = 0.08
Temp (°C)	13.8 ± 0.38 (9.0 - 16.2)	9.5 ± 0.40 (7.5 - 11)	**Z = -3.69 P < 0.001***
pH	6.6 ± 0.14 (5.4 - 7.4)	5.6 ± 0.003 (4.7 - 6.7)	**Z = -2.92 P = 0.001***
Conductivity (μ/cm)	472 ± 107 (43.5 - 1609)	384 ± 185 (54 - 1565)	Z = -1.30 P = 0.19
Canopy cover (%)	19 ± 3.19 (2 - 43)	85.75 ± 3.08 (71 - 97)	**Z = 4.01* P < 0.001**
Pond surface cover (%)	44 ± 4.7 (10 - 80)	73.75± 9.34 (10 - 90)	**Z = 2.77* P < 0.01**
Hydroperiod (days)	90 ± 4.53 (47 - 115)	65 ± 3.42 (47 - 75)	**Z = -3.28* P = 0.001**

* Significance at P-value < 0.05 indicated in bold

Table 2.5: Summary of the step-wise regression model showing relationships between relative abundance (catch per unit effort) and pond habitat environmental variables that were significant in the model; n = 26 sampled wetlands.

Habitat variables	**B**	**Standard error of B**	**t-value**	**P-value**
Intercept	1.95988	0.96099	2.04	0.054
Pond temperature (^{o}C)	0.63877	0.29991	2.13	0.045
Canopy cover (%)	-0.02982	0.00707	-4.22	<0.00
	Regression Summary R = 0.88 Adjusted $R^2 = 0.77$ $R^2 = 0.74$ $F(3,22) = 24.47$ P-value < 0.00001 Standard error of estimate: 0.91 Durbin Watson d = 0.202			

Table 2.6 Comparison of riparian vegetation [mean ± SE, (range)] between (i) wetlands with and without amphibians, based on average stem counts from two 25 x 4 m quadrants for each wetland for 26 wetlands (wetland type C excluded).

Vegetation variables	**Amphibians present (n=18)**	**Amphibians absent (n=8)**	**t-value**	**P-value**
Conifer density (stems/quadrat)	25.8 ± 6.4 (1 - 89)	42 ± 12.6 (2 - 104)	1.27	0.28
Deciduous tree density (stems/quadrat)	29.5 ± 6.6 (4 - 113)	25.3 ± 9.9 (1 - 79)	0.351	0.73
Shrub density (stems/quadrat)	48 ± 7.1 (16 - 119)	44 ± 9.1 (22 - 92)	0.39	0.70
% ground cover	83 ± 3.3 (65 - 95)	85 ± 4.27 (65 - 100)	0.40	0.68

*Significance at P-value < 0.05 is indicated by the values in bold.

Table 2.7 Correlation analysis between relative abundance (mean catch per unit effort across seven sampling sessions) and vegetation of the riparian zone (measured once), using the Pearsons correlation analysis. Based on vegetation data averaged over two 25 x 4 quadrants for each wetland; n = 26 wetlands.

Vegetation Features	**Test**	
	Pearsons correlation	P-value
Conifer density (stems/quadrant)	-0.04	0.83
Deciduous density (stems/quadrant)	**0.48**	**0.01***
Shrub density (stems/quadrant)	-0.30	0.13
Percent ground with vegetation cover	-0.38	0.06

*Significance at P-value < 0.05 is indicated by the values in bold.

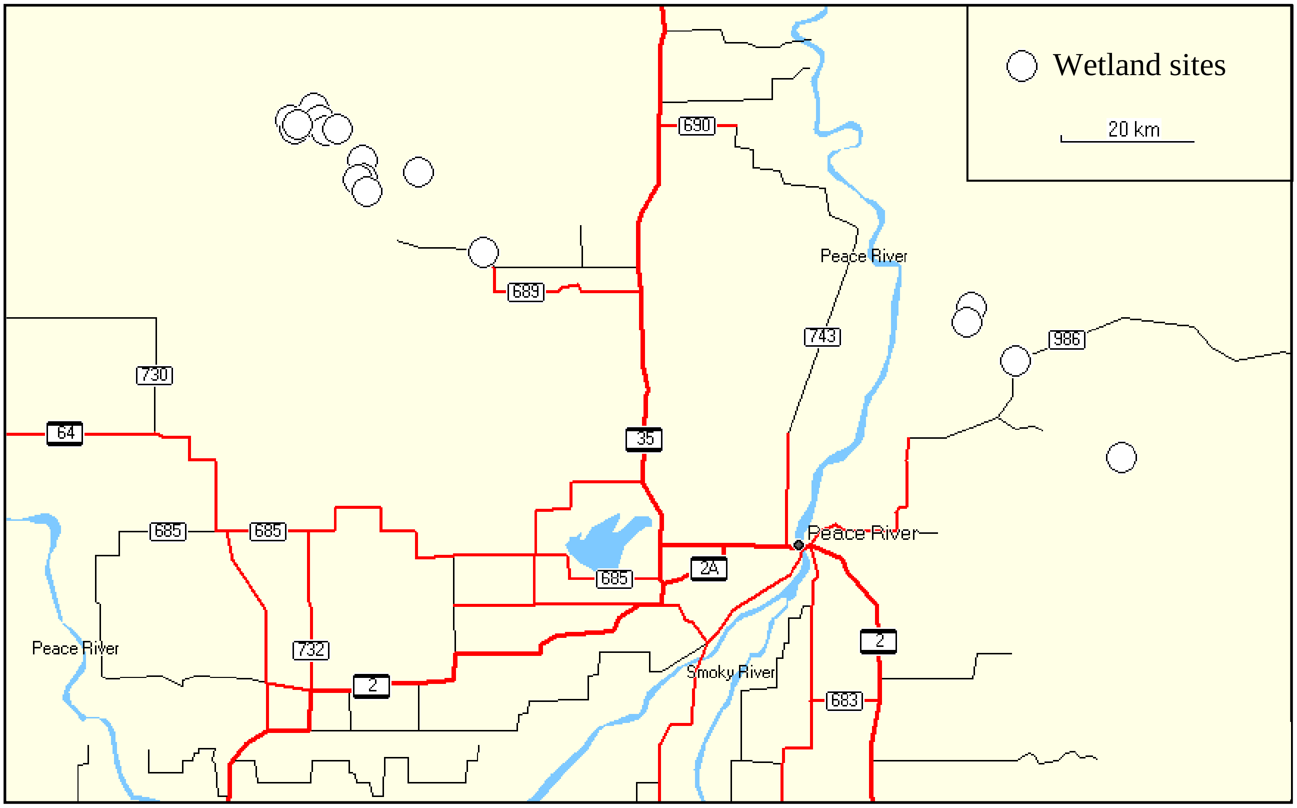


Figure 2.1. Map showing study area in the mixedwood boreal forest of Alberta. Wetland sites were located in two areas, one to the west and the other to the east of the town of Peace River.

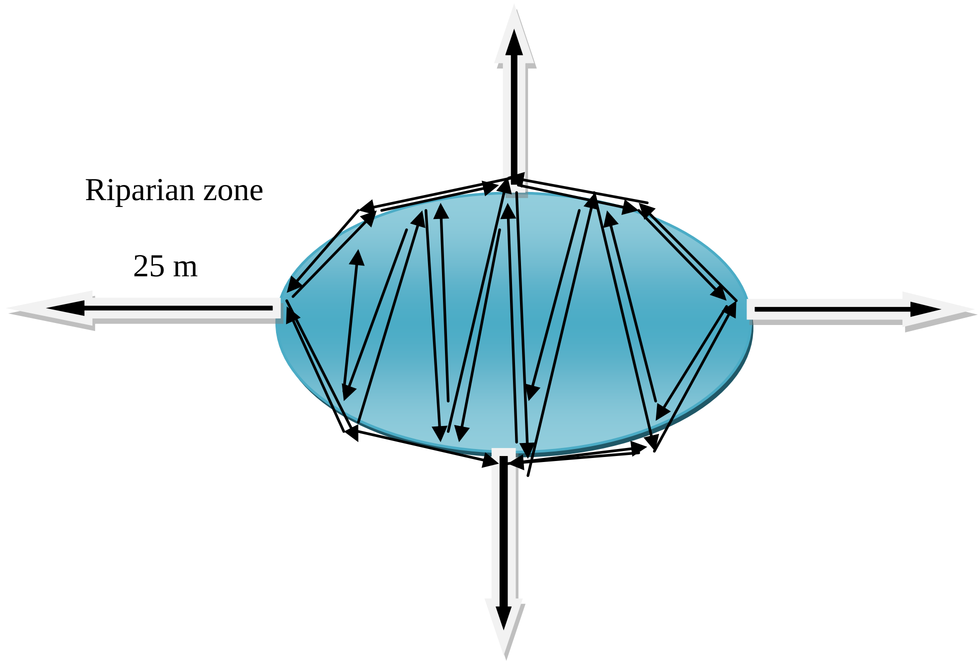


Figure 2.2. Direction of searches during time-constrained visual surveys for amphibians. The search for animals started from within and directly around the pond and moved out along four 25 m transects into the riparian zone.

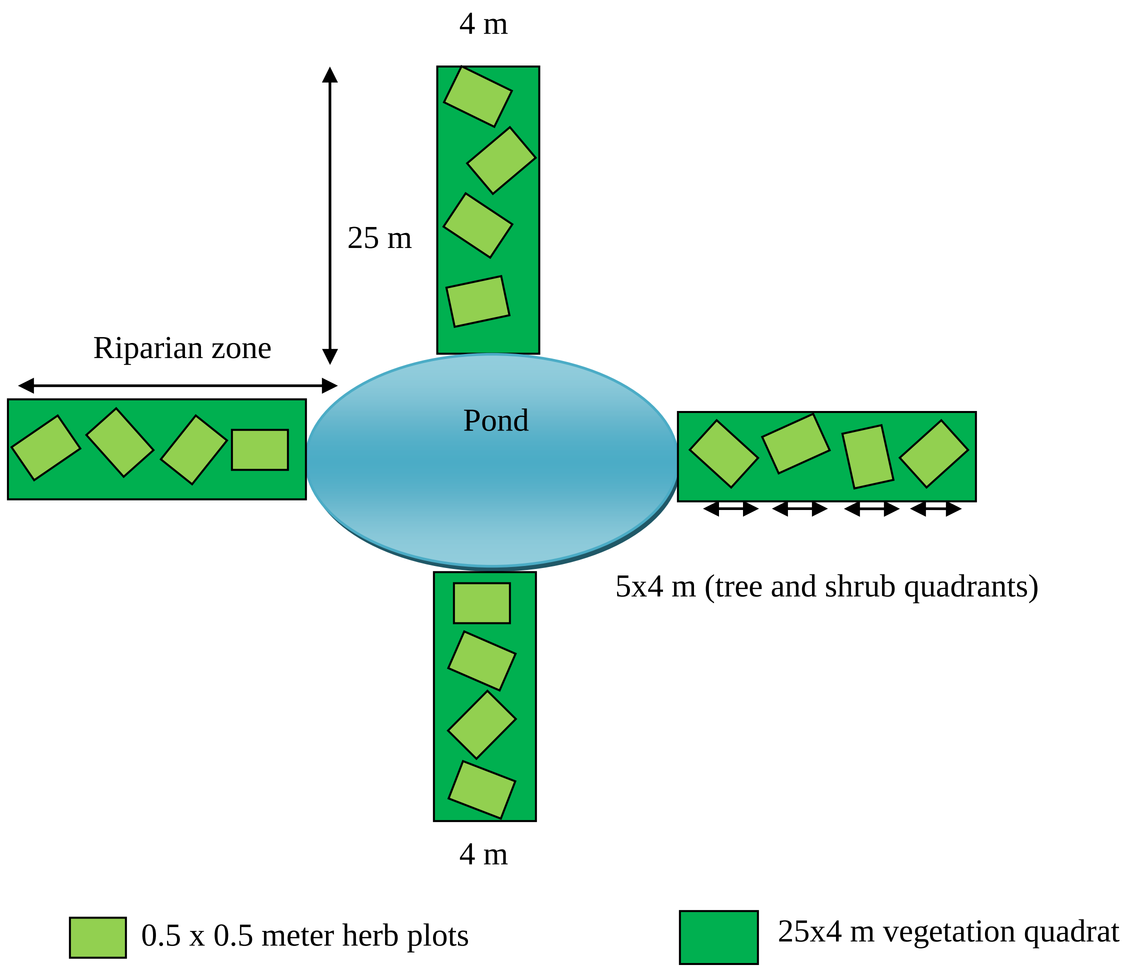


Figure 2.3. Placement of 25 x 4 meter vegetation quadrats and extent of the riparian zone. Quadrants were used to measure vegetation in the riparian zones of wetlands. The 0.5 x 0.5 m plots used to measure % cover of ground surface by herbs, graminoids and moss were randomly placed within the 25 x 4 m quadrats. Data from only two quadrats for each wetland were used for analysis.

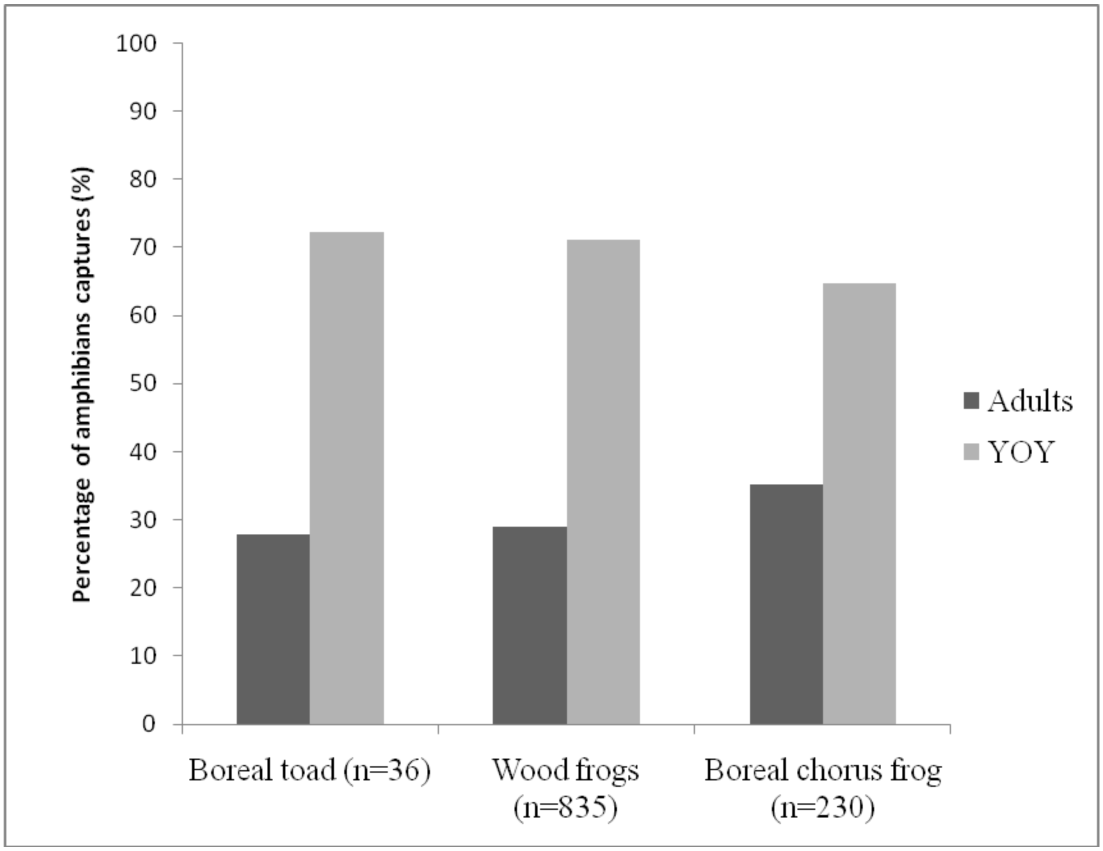
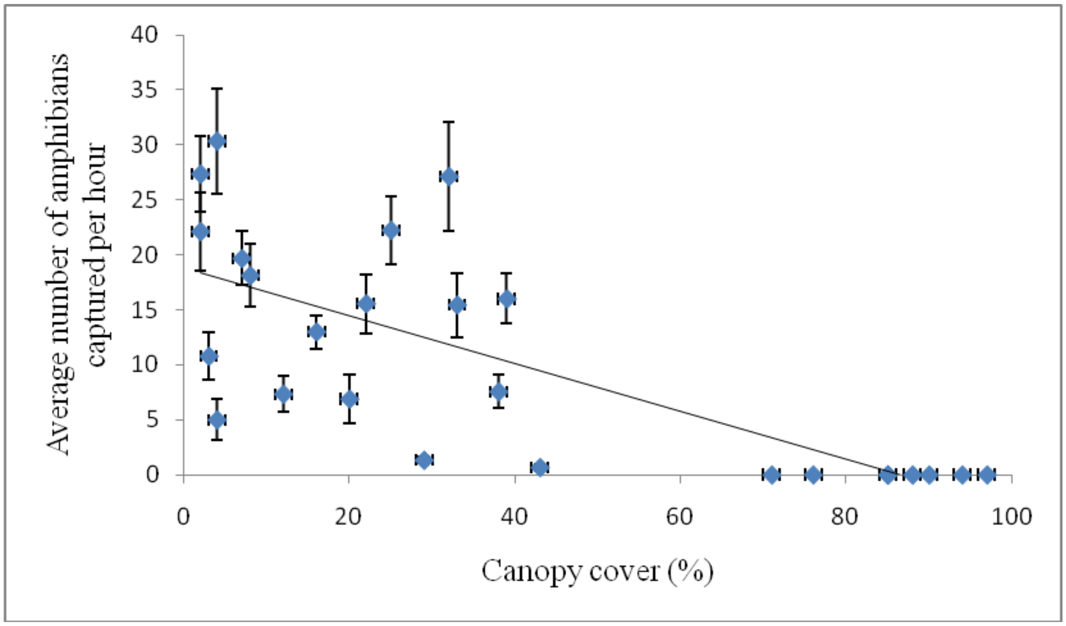


Figure 2.4. Proportion of adult versus newly metamorphosed young-of-the-year (YOY) for amphibians sampled between May and August 2008.

Figure 2.5. Example of wetland Type A. This type is a mineral marsh wetland that is dominated by graminoids, sedges, and various herbs.

Figure 2.6. Example of wetland Type B. This type is a mineral shallow open water wetland that is dominated by shrubs, trees, and snags in and around the pond.

Figure 2.7. Example of wetland type C. This wetland is a treed basin fen associated with peatlands and is characterized by open water. The riparian vegetation consists of mosses, graminoids, sedge, shrubs, living trees (mainly conifers) and snags.



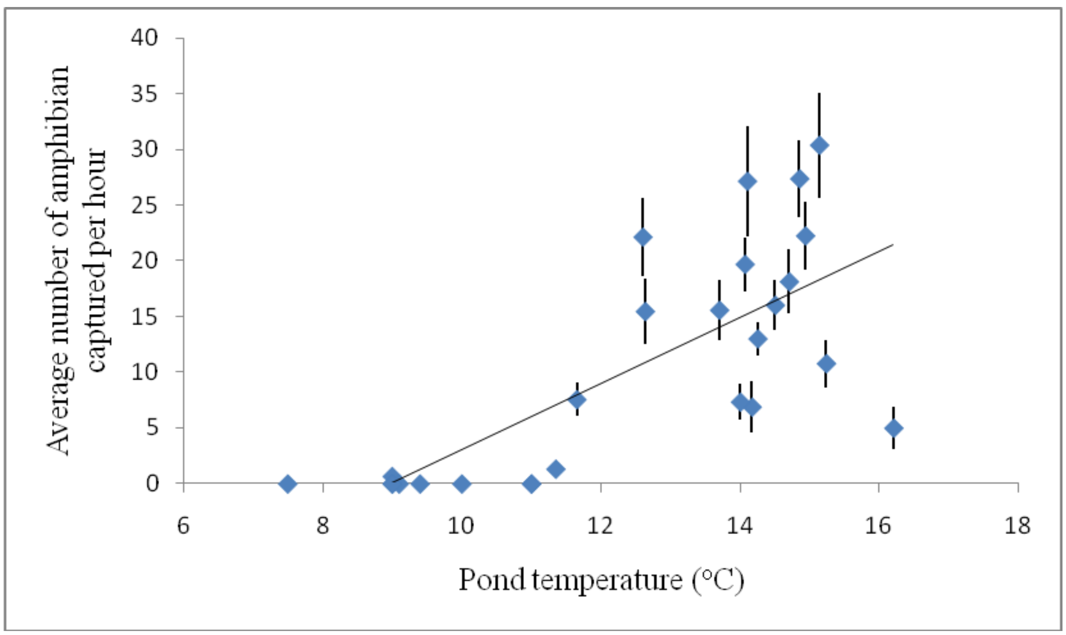


Figure 2.8. Scatter plots showing the relationship between the two significant predictor pond habitat variables (canopy cover and pond temperature) and the average number of amphibians encountered per hour (CPUE ± SE) at the study wetlands (n=26).

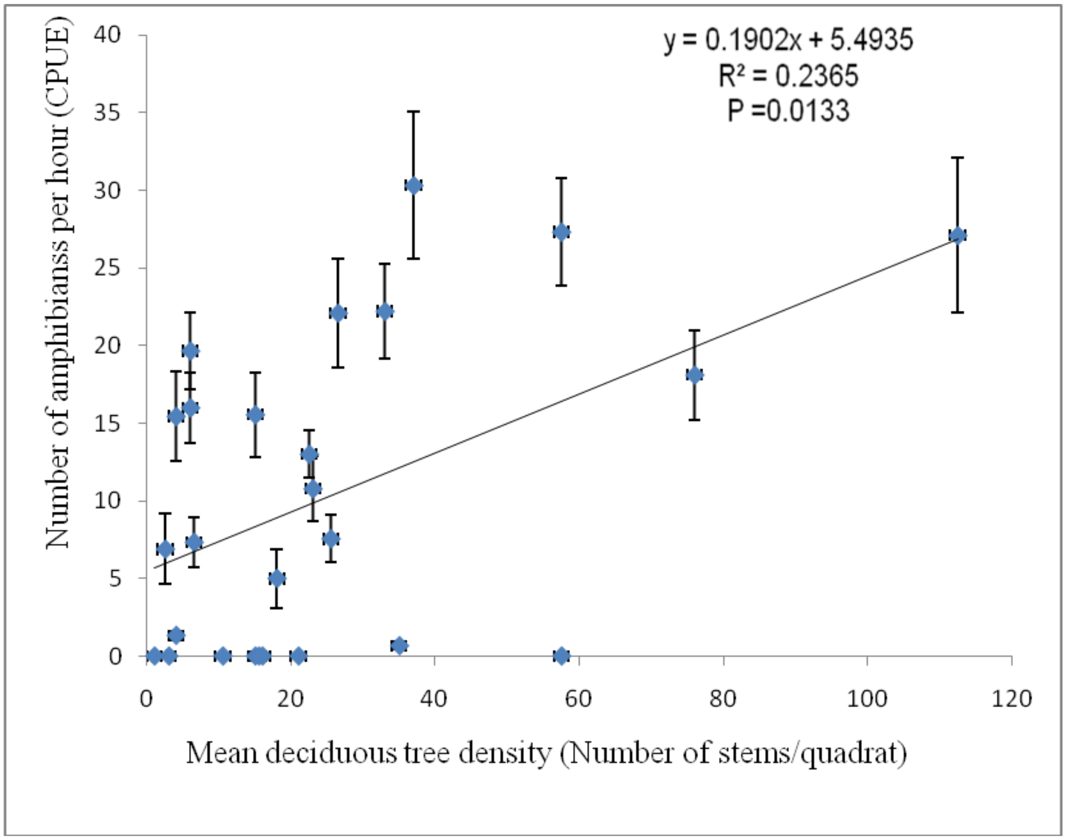


Figure 2.9. Relationship between riparian deciduous tree density (within 25 m of the pond) and relative abundance of amphibians (catch per unit effort; CPUE ± SE; n=26).

CHAPTER 3 AMPHIBIAN USE OF RIPARIAN ZONES OF SMALL STREAMS IN THE MIXEDWOOD FOREST OF BOREAL ALBERTA

3.0 INTRODUCTION AND BACKGROUND OF THE STUDY

3.1 Riparian zones of streams as amphibian habitat

The mixedwood forest in boreal Alberta is currently experiencing logging, and oil and gas exploration and extraction (ASRD, 2005; Natural Regions Committee, 2006), potentially threatening amphibian populations through habitat alteration. Such habitat destruction and degradation have contributed to observed amphibian population declines at local, regional and global levels (Blaustein and Kiesecker, 2002; Houlahan et al., 2000; Corser, 2001; Beebee and Griffith, 2005). Conservation efforts aimed at the protection of amphibian populations have been focused mainly on habitat protection. However, current efforts by forestry managers to define important amphibian habitat are faced with incomplete information on the diverse array of habitats which are important for survival and reproduction of local amphibians.

The common amphibian species in the study area, including boreal toad, wood frog and boreal chorus frog (Hannon et al., 2002; Eaton, 2004), have a biphasic lifestyle, with adults moving to ponds to breed and migrating back to terrestrial upland habitat to forage and hibernate. Similarly, metamorphs disperse from natal ponds to the surrounding terrestrial upland habitat to forage and overwinter (Dupuis *et al*., 1995; Rosenberg et al., 1997; Perkins and Hunter 2006; Semlitsch, 2008). During movement between wetlands and terrestrial upland habitats, amphibians require moist habitat for hydration and foraging; any habitat that meets these requirements aids connectivity between key seasonal habitats (Semlitsch, 2002). As ectotherms, amphibians have physiological limitations related to thermal requirements; their locomotion, feeding, and body metabolism are temperature dependent (Gatten et al., 1992). Their locomotor performance decreases when temperatures are relatively low (Rome et al., 1992) affecting their feeding by reducing their ability to catch prey. Because of their temperature and moisture requirements when moving overland, and the fact that migrating or dispersing individuals expend substantial energy, increasing their body temperature (Semlitsch, 2008) and losing moisture, availability of food and sources of moisture influences the distances travelled and survival of juvenile and adult anurans (Wind and Dupuis 2002; Baldwin et al., 2006; Rittenhouse et al., 2009).

Isolation of breeding ponds by disruption of functional terrestrial corridors that provide conditions for amphibian movement have been associated with increased risk of desiccation to dispersing or migrating individuals, and an increased likelihood of population decline at isolated sites as a result of poor recruitment (Marsh and Trenham, 2001; Rothermel Semlitsch, 2002; Rittenhouse et al., 2008). Riparian zones of small streams are the terrestrial ecosystems immediately surrounding or adjacent to the stream, and are usually characterized by moist soils and hydrophilic plant species (Burt and Haycock, 1996) forming an interface of ecological connections and interactions between the streams and the terrestrial uplands (Gregory et al., 1991). Riparian habitats associated with small streams can connect wetlands to terrestrial upland habitats by providing hydration areas for dispersing or migrating amphibians (Rosenberg et al. 1997; Moore et al., 2003). Riparian habitats support a high biodiversity of macro-invertebrates that are food for amphibians (Sheridan and Olson, 2003; Gibbons, 2003). Stream riparian zones also provide some degree of shade to mitigate desiccation risks, and protection against predators (Rothermel and Semlitsch, 2002; Kocher and Harris, 2007). To what extent small streams provide habitat for amphibians depends on their hydrologic patterns and physical structure. Small streams also have an important hydrological role, in general, as they constitute more than 50% of the total channel length in most watersheds in North America (Hansen, 2001), and are an important source of inputs of sediment and woody debris to larger streams and wetlands (Burt and Haycock, 1996; Gomi et al., 2002; Kocher and Harris, 2007).

Small streams can be easily missed during forest harvest planning as they are poorly captured by aerial photographs and forest cover maps, which record only about 75% of larger perennial streams in forested landscapes (Meyer and Wallace, 2001). During some periods (e.g. winter and at the end of summer), the stream bed may not contain water or any recent sign of flow, making it difficult for forestry operators to demarcate these areas to avoid them. As a result, logging, and other land uses, can adversely affect small streams (Collins and Storfer, 2003; Kocher and Harris, 2007). Very little is known about the use of small stream habitats by vertebrates, especially amphibians in boreal Alberta, which has resulted in poor protection of habitat associated with these small water bodies during forestry and oil and gas activities. A comprehensive approach to conservation of amphibian populations in the boreal mixedwood forest through habitat protection will require basic data on their use of stream habitats.

In the present study, I sampled the riparian zone of three small streams types (ephemeral, intermittent and small permanent) in the mixedwood forest of western boreal Alberta. Ephemeral streams are characterized by little or no channel development, short duration of water flow (about 2.5 months) directly associated with rainfall or snow melt in the immediately surrounding area, and have vegetated stream beds located above the groundwater table (AEP, 1994). Intermittent streams are identified by their distinct non-vegetated channels which may be irregular and measure up to 0.5 m in width (AEP, 1994). Water flow persists longer in intermittent streams than ephemeral streams, and beds dry out towards the end of summer, except during periods of drought, when they may dry earlier. Small permanent streams usually persist throughout the summer through base flow maintained by precipitation and groundwater discharge

(Burt and Haycock, 1996). Their channels are continuous, non-vegetated, and 0.5 to 5 m wide (AEP, 1994; Kocher and Harris, 2007). Ephemeral and intermittent streams typically have low flow velocities, and their riparian vegetation creates dense canopy cover over the ground and their narrow channels (Kocher and Harris, 2007). These features should favor amphibian movement along the riparian zone of ephemeral and intermittent streams compared to small permanent streams.

In Alberta, small streams do not usually receive the same protection as larger streams (Moore and Richardson 2003, Cummins and Wilzbach, 2005), because regulations have centered on larger systems that are more likely to support fish populations. Specifically, intermittent and ephemeral streams are not usually protected by treed buffers during timber harvesting operations (ASRD, 2005). The present Alberta guidelines for small stream protection are not adequate and place more emphasis on hydrological permanence and size of streams than their role as habitat for various animal species like amphibians. Ephemeral streams are protected by ensuring undisturbed vegetation remains in wet gullies. Intermittent streams with brush (dense growth of shrubs) and lesser vegetation such as herbs are left undisturbed along the channel, while small permanent streams are better protected than the other types by ensuring no disturbance or removal of timber occurs within 30 m of the stream (ASRD, 2005).

Based on their morphology, ephemeral and intermittent streams will likely favour use by amphibians as their banks are not as high and steep as permanent streams, making them potentially easier to access for hydration. With higher and steeper banks, more distinct channels and increased water velocity, small permanent streams may not attract as many animals in terms of hydration as ephemeral and intermittent streams, except at the peak of summer when the ephemeral and intermittent streams may be dry. However, the riparian zone of the all three types of small streams will benefit amphibians by providing food and cover. The time of water flow in these small streams mostly coincides with the period of active amphibian movement (April to August) for wood frogs, chorus frogs and boreal toads in the mixedwood boreal forest (ASRD, 2005; personal observation, 2008), so they provide foraging habitat and movement corridors for these animals throughout their active periods. Small ephemeral, intermittent and permanent streams, and their associated riparian zones, are considered vital ecotones between aquatic and terrestrial habitats for numerous amphibian species in other regions (e.g., the mountain tailed frog *Ascaphus montanus* and coastal tailed frog *Ascaphus truei*, boreal toad and wood frog; Naiman and Décamps, 1997; Richardson, 2000; Semlitsch and Bodie, 2003). Disruption of stream riparian zones can hamper the movement of amphibians, exposing them to direct solar radiation and predators (Wind and Dupuis, 2002).

Other habitat features, such as ground vegetation cover and downed woody material, also determine the extent of the riparian zone of small streams that may be utilized as habitat. Wood frog, boreal chorus frog, red-legged frog (*Rana aurora*) and American toad (*Anaxyrus americanus)* have been observed to prefer terrestrial areas with closed canopy during dispersal, perhaps to reduce predation risk (deMaynadier and Hunter 1999; Rothermel and Semlitsch, 2002; Chan-McLeod, 2003). Based on observations of Davies (2000) in British Columbia, species like the boreal toad prefer open habitats during migration, but may seek dense shrub cover to protect themselves from desiccation and predation especially during migration and transformation of YOY (Davies, 2000). While canopy cover provides shade, downed woody material provides refuge habitat for amphibians and for invertebrates that are potential prey.

I surveyed the riparian zones of small streams to determine if they function as habitats for amphibian species in the mixedwood forest of northwestern Alberta. The relative abundance of amphibians using the riparian zones of small streams was documented by sampling for wood frog, boreal chorus frog and boreal toad within 120 m of stream channels.

Vegetation features (tree density and percent ground cover) and other habitat variables were also measured and related to amphibian abundance. The specific research questions I addressed were: (1) Do amphibians use riparian zones of ephemeral, intermittent and small permanent streams? (2) Does utilization differ among stream types? (3) Is there a relationship between amphibian capture rates and proximity to the stream bed? (4) Is there a relationship between vegetation characteristics and amphibian distribution and abundance around streams?

I predicted that amphibians would use the riparian zones of small streams as travel corridors for movement between downstream and upland habitats. I also expected that amphibian abundance would be highest closest to the stream. I predicted that amphibians would be more abundant at small ephemeral and intermittent streams than permanent streams because intermittent streams retain more nutrients and may produce more invertebrate food for amphibians, as some life stages of invertebrates are better adapted for conditions created when streams cease flowing (Naiman and Decamps, 1997; Dieterich and Anderson, 2000; Cummins and Wilzbach, 2005). I expected that increased canopy cover due to smaller width, and downed woody material (Cummins and Wilzbach, 2005) due to less downstream transport in the riparian zones of ephemeral and intermittent streams compared to permanent streams would be associated with increased amphibian abundance. Furthermore, from a logistic viewpoint, weather conditions (e.g. temperature, precipitation and wind speed) were expected to influence amphibian movement, thus affecting capture rates. It is anticipated that the information generated in this study will help formulate a more inclusive management framework for amphibian conservation and protection of their habitat in the boreal mixedwood forest of Alberta.

3.2 MATERIALS AND METHODS

3.2.1 Study area and site selection

This project was conducted in the Forest Management Agreement (FMA) area of Daishowa-Marubeni International Ltd. (DMI), in the mixedwood boreal forest of northwest Alberta (Figure 3.0). Common deciduous tree species in the region include aspen, balsam poplar, and white birch, while dominant conifers are white spruce, black spruce, jack pine and tamarack (Natural Regions Committee, 2006). Common understory vegetation includes shrubs (e.g. Labrador tea and willows), peat mosses, sedges and graminoids. The dominant soil types are luvisols on uplands and mesisols in wetlands (Natural Regions Committee, 2006).

The study was conducted by the Alberta Research Council (now Alberta Innovates -Technology Futures) for the first two years (2006 and 2007), and I continued data collection in the third year (2008). During the first field season in the summer of 2006, 11 streams were chosen as study sites. Of these 11 stream sites, six were on the west side of DMI's FMA (approximate centre of the study area was latitude 56°N and longitude 118°W) and five on the east side (latitude 56°N and longitude 116°W). These sites included three ephemeral, three intermittent, and five small permanent streams.

3.2.2 Sampling Design

Four 30-m long drift fence and pitfall trap arrays were installed at each stream site, perpendicular to the flow of the stream. The first drift fence was situated directly across the stream, and the remaining three fences were sequentially established in a line extending upslope, with 5-m gaps between the ends of each adjacent fence (Figure 3.1). Drift fences functioned to guide amphibians into pitfall traps placed along the fence, indicating movements of amphibians relative to the stream channel. The gaps between fences allowed animals to escape when they did not fall into traps and reduced the possibility that amphibians travelling along one fence would be captured along an adjacent fence, thereby misrepresenting amphibian distribution around a stream.

Drift fences were built of silt fencing, a woven material used in landscaping and erosion control that is UV stable and durable (Heyer et al., 1994; Enge, 1997). The bottom 10 cm of each fence was buried in a narrow trench dug in the ground to prevent amphibians passing underneath. Fences were approximately 40 cm high above the ground, 30 m in length and were numbered as fences 1 to 4 based on increasing distance from the stream bed. Fence 1 was installed across the stream, while fences 2, 3, and 4 were approximately 40 m, 75 m and 110 m from the bed, respectively (Figure 3.1). Pitfall traps consisted of 7.5 L white plastic buckets (25 cm deep, 24 cm diameter) placed in the ground so that the mouth of the bucket was level with the ground's surface. Six buckets were arranged on each side of fence 1 (total =12), so that a total of six buckets were placed at each side of the stream channel (Figure 3.1). For fences 2, 3 and 4, five buckets were placed on each side of the fence, distributed equidistantly along the fence (Figure 3.1). Therefore, fence 1 had a total of 12 buckets, whereas fences 2, 3, and 4 had 10 buckets each. Two pieces of heavy black plastic film were used to make a funnel in each bucket to prevent animals escaping from the trap, and to help maintain a moist environment inside the bucket. Two pieces of sponge were also placed in each trap, and soaked with water each time the traps were checked, to maintain a moist environment. A small stick was placed vertically in each trap to provide an escape route for accidentally captured small mammals.

One extra fence and 10 traps were installed 100 m downstream and parallel to fence 1 at three study sites (one at each stream type) in 2008, and were opened for two days on each of two sampling dates (July 27th and August 23rd, 2008). This was done to determine whether animals were travelling unidirectionally from downstream wetlands to uplands, thus using the stream as a travel corridor, or just making random movements that occasionally carried them in the vicinity of streams.

3.2.3 Amphibian Sampling

Amphibians were sampled from June to August in 2006, and May to August in 2007 and 2008 (Table 3.1). Traps were checked every two days during sampling sessions. Captured amphibians were identified to species, assigned to an age class (adult or YOY), measured (snout-to-urostyle length [SUL]), weighed and marked by the removal of two distal phalanges of a single toe. Thumbs were never removed, as these are used by males during mating. The excision site was treated with Polysporin and the animal monitored briefly before release. Animals were marked using a unique toe for each year/site combination in an area; this allowed an assessment of return rate to a site, movement between sites, and ensured the same animal was not counted multiple times within a trapping session. Animals were released approximately 5 to 10 m from traps, on the opposite side of the drift fence along which the individual was captured. Captured animals were assigned to age classes based on size (SUL), and date of capture. During the spring (April and May), all animals were considered adult (defined as those animals that had survived at least one winter). After mid-June, wood frogs caught with tails not completely absorbed, or with an SUL $\leq$ 27 mm were considered young-of-the-year (YOY; non-breeding animals presumed to have emerged from their natal ponds within the current season).

The number of stream sites sampled and trapping effort varied across years; six sites were sampled in 2006, 11 sites in 2007, and 10 sites in 2008 (Appendix 3.1). There were five trapping sessions in 2006 and 2007, and four in 2008. These sessions were roughly equivalent between years in terms of amphibian trapping dates, especially in the latter part of the field season (Table 3.1). In 2008 trapping effort was reduced to only four trapping sessions to allow time for wetland sampling; no trapping occurred in early July (Table 3.1).

3.2.4 Sampling habitat features

Vertical vegetation structure, deadwood resources (downed woody material and snags) and the forest floor plant community were sampled adjacent to each drift fence. One 25 × 4 m belt transect was established parallel to, and 5 m from each side of each fence. Within the belt transect height classes were assigned for all shrubs, trees and snags; height classes were defined as: 1 =1.3-3 m; 2 = 3-5 m; 3 = 5-10 m; 4 = 10-20 m; and, 5 = +20 m. In addition, snags were assigned a decay class: 1 = recently dead; 2 = only major branches remaining; 3 = bole mostly intact; and, 4 = bole broken, wood soft. The number of stems of trees, shrubs and snags were counted for each belt transect, and stem densities for each of these classes were subsequently derived. Volume of downed woody material (DWM) was determined using the line intersect method (Harmon and Sexton, 1996); the species, diameter and decay class of the woody material was recorded at the point where it intersected the centre of the belt transect; decay classes were: 1 = wood had bark and was still hard (a knife penetrated only a few mm); 2 = wood had bark and was still quite hard (knife penetrated a few cm); 3 = wood had some bark and was soft (knife penetrated several cm); 4 = wood had little bark, some vegetation and was soft (knife penetrated up to handle); and, 5 = wood was covered with vegetation, visible as a hump on the ground, and was very soft. Volume was calculated using the formula: $V= ((9.8696 \times \sum d^2) / 8L) \times 10000$, where V is DWM volume (m^3/ha), d is the diameter (m) of each piece of DWM sampled along the transect, and L is the transect length (m). The forest floor plant community was sampled using established quadrats (50 × 50 cm) evenly spaced between traps along each drift fence. Within each quadrat, percent ground surface covered by vascular plants, litter, wood, moss, and lichens was estimated in 5% intervals, with a category of 1% to denote presence, and < 5% to denote limited cover. A total of 39 habitat vegetation variables were recorded and calculated (Appendix 3.2) in 2006 and 2007 by Alberta Innovates -Technology Futures.

Minimum, maximum and mean temperature, total precipitation, and mean wind speed for the study period were obtained from an automated weather station located in the Ecosystem Management Emulating Natural Disturbance (EMEND) project located within the same general geographical area as my study area. All mean values for these weather variables were calculated from daily measurements over the study months (May-August) for 2006 and 2007, and June to August for 2008 (Appendix 3.3).

3.3 ANALYSIS

Relative abundance: Because so few boreal chorus frogs and boreal toads were captured (<10% of total yearly capture in each year), they were excluded from analyses. The wood frog represented the majority of amphibians captured, so this species was the focus of statistical analysis. Wood frog capture rates were standardized as the number of individuals (only counting new, unmarked animals) captured per 100 trap nights (catch per unit effort - CPUE) for each site. Capture data were highly skewed so they were normalized before analysis using a natural logarithmic transformation of captures (CPUE+1). Small permanent stream (EBSP01) data which was an extreme outlier in 2006 because of the high number of wood frogs captured (164 animals) was excluded, and total wood frog captures, as well as the number of adult and juvenile captures, were compared among years (2006-2008), stream types (intermittent and small permanent), and fences (1-4) using repeated measures analysis of variance (ANOVA) with year, stream type, fence, and all interactions included in the model. The Tukey-Kramer post hoc method was further used to test significant relationships. Captures within a year were compared between stream type (ephemeral, intermittent, small permanent) and fence across and within trapping sessions using a two-way analysis of variance with stream type, fence, and interaction of the two factors included as fixed effects. Where the model revealed statistical significance, Tukey-Kramer adjusted pair-wise comparisons were used to determine if differences existed among fences and stream types. When CPUE was compared among stream types, ephemeral streams were not included for 2006 because pitfall trapping was not done at any ephemeral stream sites in 2006. Statistical level of significance for all analyses was set at $\alpha = 0.05$.

Movement pattern: Wood frog capture data across all sites, sessions and years combined, as well as between sessions, across years, or by stream type were analyzed using chi-square analysis to determine if there was any difference in the directionality of movement (upstream or downstream) of YOY and adult amphibians. This analysis was done to determine whether directionality differed with age class. It was assumed that animals caught on the downstream side of drift fences were moving upstream and that animals caught on the upstream side of the fences were moving downstream.

Habitat and environmental analysis: Data on vegetation structure were collected once per site over 2006 and 2007; because structure was not expected to change over the duration of the study, data were pooled across years and used as a single vegetation dataset. The proportion of vascular herbaceous plant, wood, lichen and moss cover, volume of downed woody material, density of trees, shrubs and snags were compared among stream types (ephemeral, intermittent, and small permanent) and by fence number (i.e., the location of the fence in relation to the stream) using a series of two-way ANOVAs. The relationship between wood frog captures (CPUE) summarized for all three years combined and forest structure variables was examined using Pearson correlation to identify the relationship between CPUE and each independent variable.

To check for multicollinearity in the initial dataset of vegetation structural variables, each forest structure variable was compared to the other variables using Pearson's correlation. When two variables were significantly correlated, the variable that was thought to have less relationship to amphibian ecology (based on literature and initial regression simulation) was discarded. Variables with little actual data (many empty cells in dataset) were also discarded. Only nine vegetation variables were retained and tested using forward step-wise regression to determine the relationship between the total wood frog capture rate across all sites and all fences (dependent variable) and habitat characteristics. These independent variables were stand age (in years, sourced from DMI), ground layer species richness, plant cover and lichen cover (% cover in 0.5 × 0.5 m quadrats), total DWM volume (m^3/ha), total snag density (stems/100m^2), coniferous tree density (stems/100m^2), deciduous tree density (stems/100m^2), and total shrub density (stems/100m^2). Variables that were significant in the model at a p-value of 0.05 were retained in the regression model.

The relationship between weather conditions (temperature, precipitation and wind speed) and CPUE for wood frogs was evaluated using Spearman's correlation analysis for each study year and stream type, and for all years combined to identify how weather may have influenced general wood frog movement, and thus capture rates.

3.4 RESULTS

3.4.1 Do amphibians utilize riparian zones of small streams?

The total number of amphibians captured between 2006 and 2008 was 812. Nearly all of these animals were wood frogs, with only nine boreal chorus frogs, and 24 boreal toads captured during the three study years (Table 3.2). All of the 24 boreal toads were caught at two ephemeral streams, while most of the chorus frogs (seven) were captured at one small permanent stream site. Wood frog capture rates differed among the three study years (Table 3.2), however, there was no difference in capture rates between 2006 and 2007. There were more wood frogs captured in 2008 compared to 2006 and 2007. When captures were broken down by age class, there were more adult frogs captured in 2008 than in 2006 and 2007, while there were more captures of YOY in 2006 and 2007 than in 2008. This pattern may have resulted from the fact that trapping session 3 was missed in 2008 (Table 3.1); this period (between July and August) accounted for most captures of YOY in 2007, suggesting that a substantial number of YOY was missed in 2008 (Figure 3.2). There were no differences in adult or YOY capture rate between 2006 and 2007.

3.4.2 Relationship between wood frog captures and habitat variables

(I) is there a relationship between stream types, proximity to stream and wood frog captures?

A small permanent stream (site: EBSP01) was excluded from the analysis because it was an outlier with a very high abundance of wood frogs captured. Total wood frog capture rates (both adults and YOY together) compared among years, stream types and fences (including only those site and session combinations that were sampled for all three years; Appendix 3.1) indicated that year was significant in the model ($F_{(2,23)} = 25$, $P_{value} < 0.001$) with 2008 having higher capture rates than 2006 ($P_{value} <$ 0.001) and 2007 ($P_{value} < 0.001$), respectively. Stream types ($F_{(2,23)} = 1.8$, $P_{value} > 0.4$) and fences ($F_{(3,23)} = 2.9$, $P_{value} > 0.4$) were not statistically significant in the model. For adults, only capture year was significant in the model (Table 3.3) with 2008 having a higher capture rate than 2006 ($P_{value} < 0.01$) and 2007 ($P_{value} = 0.03$), respectively. There were no significant effect of stream type on adult CPUE, and no significant interactions between stream type, year and fence (Table 3.3). For YOY analysis only, capture year was significant in the model (Table 3.3) with 2007 having a higher capture rate than 2006 ($P_{value} = 0.002$) and 2008

(P_{value} = 0.03), respectively. In addition, stream type was also significant in the model for YOY (Table 3.3), with intermittent streams having significantly higher capture rates than small permanent streams (P_{value} < 0.03).

CPUE was also compared between stream types and fences within each sampling year and session with a two-way ANOVA. For 2006, total CPUE with all sessions combined did not differ significantly between intermittent and small permanent streams, or among fences (Table 3.4). For the individual trapping sessions in 2006, there was no significant effect of fence or stream, or interaction on CPUE (Table 3.4). For CPUE in 2007 stream type was significant with CPUE significantly higher at intermittent streams than small permanent streams (P_{value}< 0.01), while fence was not significant in the model with all sessions combined (Table 3.4). For trapping session 2, fence was significant (Table 3.4) with fence 1 (the fence that straddled the stream) having significantly higher capture rates than fences 2, 3 and 4 (all $P_{value} \leq$ 0.01), respectively. For session 4, stream type was significant (Table 3.4) with higher capture rates at intermittent streams than small permanent streams (P_{value}< 0.02). Interactions of stream type by fence were not significant for any trapping session (all P_{value} > 0.16).

In 2008, analysis for all sessions combined indicated a fence effect on CPUE (Table 3.4), with more captures recorded at fence 1 than fence 2 (P_{value} = 0.0053), fence 3 (P_{value} = 0.0003) and fence 4 (P_{value} = 0.0020). Stream type was also significant (Table 3.4), with more frog captures recorded at intermittent streams than small ephemeral and permanent streams (both P_{value} < 0.01), while the interaction between stream types and fence was not significant. For session 1 (Table 3.1), stream type was significant (Table 3.4) with CPUE significantly higher at ephemeral streams than intermittent and small permanent streams (P_{value}< 0.0001 for both). Fence was also significant (Table 3.4) with fence 1 having significantly higher CPUE than fences 2 (P_{value} < 0.01), 3 (P_{value} < 0.01), and 4 (P_{value} < 0.01) respectively for all sites and years combined, but there were no significant differences between fences 2, 3 and 4 (all $P_{value} > 0.35$). The interaction between stream type and fence was not significant. For session 2, stream type was also significant (Table 3.4) with CPUE significantly higher at intermittent streams compared to small permanent and ephemeral streams ($P_{value} = 0.0003$ and $P_{value} = 0.0026$, respectively). Both fence and the interaction between stream type and fence were non-significant for session 2 ($P_{value} = 0.0688$ and $P_{value} = 0.5532$ respectively). There was no sampling in session 3, while during session 4, stream type was significant (Table 3.4) with higher capture rates at ephemeral streams than small intermittent and permanent streams (both $P_{value} < 0.033$). No pair-wise differences were statistically significant. For session 5, there was no difference between stream types and fences.

In general, for all sites and years combined, more animals were captured at the ephemeral and intermittent streams, as well as at the fences closest to the streams, with a decreasing mean capture rate as distance to stream increased (Figure 3.4).

Wood frog movement patterns

For all trapping sessions combined, more adult wood frogs were captured moving downstream, and more YOY moving upstream. Session 1 had no YOY captures, but sessions 2, 3 and 4 had a larger proportion of YOY caught moving upstream than adults (Table 3.5). For session 5, 77% of captured adults were moving downstream versus 50% of YOY (Table 3.5). Downstream movement of YOY in session 5 was higher than in sessions 2, 3, and 4 (13%, 4%, and 18% of animals, respectively).

Overall, wood frog captures exhibited a significant difference between age classes (YOY or adult) in direction of movement (Table 3.5). The majority of adult frogs were found migrating downstream, whereas most YOY were observed dispersing upstream in 2006 ($\chi^2 = 24$, $P_{value} < 0.0001$) and 2007 ($\chi^2 = 84$, $P_{value} < 0.0001$). However, in 2008, 63% of adults were found moving downstream, but only 43% of YOY were found heading upstream. Thus there was no significant difference between age and direction of movement in 2008 (χ^2=1.4, P_{value} = 0.1113). This likely occurred because there may have been less production of YOY, and the missed trapping during session 3 in July 2008 normally encompassed the period of strong directional movement by YOY (Figure 3.2 and Table 3.1).

Wood frogs captured at the extra downstream fences installed in 2008 were predominantly YOY (Table 3.2), and a greater proportion of YOY (85%, n=13) were moving upstream than adults (50%, n=9). There were also a total of four recaptures (two frogs at two different sites) of YOY wood frogs upstream from these extra sites at the main fences. A majority of the YOY encountered at the extra fences were captured at the small permanent stream site (94%, n=13), but adult captures were evenly distributed between the permanent and intermittent stream sites. There were no captures at the extra fence on the ephemeral stream.

(II) Riparian vegetation structure and CPUE

There were no significant differences in shrub or tree densities, or the volume of downed woody material, across stream types or fences (Table 3.6 and Figure 3.4). Snag density differed among stream types, but not among fences (Table 3.6), with significantly lower density of snags along ephemeral streams than intermittent streams (Table 3.6). Percent plant cover was significantly different among streams, with small permanent streams having greater ground layer plant cover than intermittent streams (Table 3.6). Differences in vascular plant cover were significant among fences with fence 1 having greater plant cover compared to fence 3 (P_{value} < 0.047) (Figure 3.4). The proportion of moss cover did not differ significantly among stream types, although intermittent streams appeared to have greater moss cover than small permanent and ephemeral streams (Figure 3.4). There were no significant pair-wise interactions between stream type and fence for any of the variables measured.

Analysis of amphibian capture data across the three study years (2006 – 2008) suggested a negative correlation between the density of coniferous trees and CPUE for all streams and fences combined (Table 3.4): as the density of coniferous trees increased, the number of wood frogs captured decreased. In contrast, density of deciduous trees was positively correlated with capture rates (Table 3.7). The stepwise selection regression model indicated that density of coniferous and deciduous trees were significant predictors of relative amphibian abundance (Table 3.8 and equation 3.1). Coniferous and deciduous tree density together accounted for 14% of the variation in the capture rate of wood frogs (Table 3.8).

$$Y_{CPUE}=1.583 + 0.018(\text{Deciduous density}) – 0.01(\text{Conifer density})\ldots\ldots(3.1)$$

(III) Weather data and amphibian capture rates

Mean minimum and maximum daily temperatures recorded were 8.2°C (range: 2.1-11.6) and 19.3°C (range: 12.5-26.6), respectively across the three study years. The mean temperature recorded was 13.8°C (range: 9.0-18.3), while the mean wind speed was 5.3 km/hr (range: 4.3 – 6.9) and mean total precipitation was 1.4 mm/day (range: 0-3.2). Analysis of data combined for the three study years showed significant positive correlation between minimum temperature and CPUE ($r = 0.70$, $P_{value} = 0.0080$), whereas mean temperature had a positive but statistically non-significant correlation with CPUE ($r = 0.50$, $P_{value} = 0.082$). Thus as minimum and mean temperature increased the rate of wood frog captures also increased. Wind speed was negatively correlated with CPUE ($r = -0.53$, $P_{value} = 0.064$). At ephemeral streams, CPUE was significantly positively correlated with mean total precipitation ($r = 0.88$, $P_{value} = 0.01$, n=13), and negatively correlated with mean wind speed ($r = -0.99$, $P_{value} = 0.0001$, n=13). Thus, as precipitation increased and wind speed decreased, CPUE increased. This was also consistent with the wind speed results at intermittent streams where CPUE was significantly negatively correlated with wind speed (r = -0.76, P_{value} = 0.027). For small permanent streams, CPUE was positively correlated with minimum and maximum temperatures (r = 0.56, P_{value} = 0.04, and r = 0.84, P_{value} = 0.02, respectively). Note that the results of these analyses should be interpreted with caution, as sample sizes were small (n=13).

3.5 DISCUSSION

Amphibian utilization of riparian zones of small streams

My study provides evidence that amphibian species, particularly wood frog, utilize riparian zones associated with small streams in the boreal mixedwood forest of northwest Alberta. This is consistent with several studies that have shown that amphibians, including wood frogs, are active in terrestrial habitat along streams (Gibbs, 1998; Rittenhouse and Semlitsch, 2007; Stevens et al., 2007). Schmetterling and Young (2008) observed that boreal toads in two western Montana basins used riparian and aquatic habitats of streams more than upland habitat. Wood frogs, as well as boreal toads, use a broad range of habitats (DeMaynadier and Hunter 1999; Browne and Paszkowski, 2010), so they were probably not limited to riparian areas around ephemeral, intermittent or small permanent streams at our study sites. This probably explains why, although the effects of proximity to stream were fairly strong for trapping patterns with fence 1 being the site of most captures across all stream types, that the other three fences still captured a considerable number of wood frogs.

Other studies have observed similar results in terms of higher frog capture rates relative to proximity to streams. A study of stream riparian zones in Maine, USA by Perkins and Hunter (2006) found that captures of amphibians, including wood frogs, were higher in traps nearest to streams. In studies of red-legged frogs (Chan-McLeod, 2003) and wood frogs (Baldwin et al., 2006), post- breeding adults migrating from breeding pools to nearby upland forest and forested wetlands rely on moist refugia such as forest streams to survive dry periods. The results of my study suggest that small streams and their riparian zones can be important sites of hydration for amphibians, especially for YOY, which are highly vulnerable to desiccation during the dispersal phase following metamorphosis. Although wood frogs were captured most frequently at the traps nearest to the stream, my study did not detect a strong relationship between CPUE and distance to small streams as I captured amphibians across the entire width of the zone sampled (120 m). Wood frogs in boreal Alberta use small streams and their forested riparian zones, as has been observed in other areas (Semlitsch and Bodie, 2003: Baldwin et al., 2006 David et al., 2008).

I found that the percent of the ground covered by vascular plants was highest closest to the stream, which agrees with a study by Hagan et al. (2006) in Maine, that found more diversity of herbaceous species and greater cover within 0-5 m of streams; such cover benefits amphibians by offering foraging, shade, and protection from predators and desiccation. Young-of-the-year and adult wood frogs use forested areas because of the cover it affords them when they travel (DeMaynadier and Hunter 1999; Rittenhouse and Semlitsch, 2007). Although the present study did not identify any distinct forest structure signature that can be specifically associated with amphibian utilisation of stream habitats, my data did indicate that abundance of wood frogs was positively correlated with deciduous tree density and negatively related to conifer density, suggesting that the nature of the over-story canopy influenced habitat use. Amphibian response to tree type in my study is also consistent with other studies within the boreal forest landscape, where conifers cover has been associated with lower relative abundance of wood frogs, boreal chorus frogs and boreal toads (Browne et al., 2009). It is possible that deciduous trees provide a more amphibian-friendly habitat on the ground because of the nature of the leaves they drop, as opposed to the tough needles produced by conifers, which do not form habitats for invertebrates (frog prey) and moist refugia that leaves can offer.

The lower snag density at the ephemeral and intermittent streams could be weakly associated with stand age, as older stands have more down woody materials to provide cover for amphibians and possibly support a more diverse and abundant invertebrate community (Naiman and Décamps, 1997). However, the density of snags and volume of downed woody materials showed no strong relationship with wood frog capture rate in the study. Increasing the number of small streams sampled may establish a stronger relationship between vegetation signature and frog abundance at these small streams.

Another important factor that may have influenced suitability of streams for wood frogs was stream type. In my study intermittent streams supported higher relative abundance of wood frogs than small permanent and ephemeral streams. Ephemeral streams also tended to exhibit higher relative abundance of wood frogs than small permanent streams. One reason behind this difference may be the physical hydrology of streams: ephemeral and intermittent streams have slower water flow, with sporadic channels that are not as deep and distinct as small permanent streams. More flow in the small permanent streams may have resulted in frogs travelling farther in the water (and with the expense of less energy), thus the fences/traps could not capture them leading to perceived lower relative abundance. I encountered some wood frogs at the two ephemeral streams utilising edges of the channels for movement.

The aquatic life-stages of many species of invertebrates utilise small streams habitats (Delucchi and Peckarsky, 1989; Dieterich and Anderson, 2000; Dieterich and Anderson, 2000; Wipfli and Gregovich, 2002; Johnson, 2004), thus making the stream edges a potential foraging habitat for wood frogs.

Amphibian movement patterns

Pond-breeding amphibians like the wood frog often undertake critical movements as adults migrate between breeding sites and overwintering sites in uplands, and post-metamorphic juveniles disperse from their natal ponds to terrestrial upland habitat (Semlitsch, 2008). In the present study, most YOY wood frogs were captured moving upstream, whereas most adults were caught moving downstream relative to the flow of the stream. This pattern of movement suggests that adults were migrating between downstream and upland sites to access sites for foraging and hydration in the summer or to access future overwintering sites near breeding ponds, while post-metamorphic YOY were dispersing upstream from natal sites to overwintering or foraging areas (Semlitsch, 2008; Rittenhouse et al., 2009). Anurans are known to move distances of more than 1 kilometer (mean distance 2.5 - 15.1 km/year) (Marsh and Trenham, 2001) between habitats within a year. These movements consist of a series of stop-overs to access microhabitats for cover, thermal and hydric refuge, and feeding (Semlitsch, 2008). Travelling along stream habitats provides access to moisture during movement (Rittenhouse et al., 2009). Adult and juvenile boreal toads, also encountered at the study sites, are known to travel along stream riparian areas when they move between habitats (Wind and Dupuis, 2002; Schmetterling and Young, 2008). A study of amphibian movement by Gibbs (1998) showed that pickerel frogs (*L. palustris*) preferred moving along stream beds, but the study did not specify an upstream or downstream directional pattern of movement. The recapture of marked wood frogs, that had originally been trapped at extra fences downstream, at primary fence arrays confirms that frogs were not just using riparian habitat near the original fences, but that at least some individuals were actually making directional movements along the stream courses.

Effects of climatic features on relative amphibian abundance

There was a negative relationship between wind velocity and amphibian capture rate. Usually wind drives precipitation determining drop sizes of rain, distribution and intensity of rainfall. It is possible high intensity of wind may have resulted in low rainfall. Low precipitation events can result in reduced amphibian movements (Timm et al., 2007). It is also possible that high wind intensity increased evaporative drying, therefore increasing desiccation risks and generally reducing amphibian movement. The combined effects of wind and rainfall on capture of wood frogs may reflect the moisture requirements of these anurans (Timm et al., 2007). Rainfall has been associated with movement of wood frogs in some studies. A study by Mazorelle (2001) in New Brunswick indicated that wood frog movement correlated with precipitation, increasing with higher rainfall. The effect of weather on wood frogs may help predict when they are active which can be used for planning or timing various monitoring efforts in the future.

3.6 CONCLUSIONS

Based on my study, there are indications that amphibians utilize forested riparian zones of small streams during movements between different terrestrial and aquatic habitats. Since timber harvest and oil and gas exploitation are the major anthropogenic activities in my study area and the behavioral response of amphibians to harvesting is migration to new habitats (Baldwin et al., 2006; Semlitsch et al., 2008), my results suggest that protection of small stream habitats would benefit amphibian populations. Therefore destruction or alteration of small streams and their riparian zones, and the lack of adequate buffer zones during logging and oil and gas activities, may have adverse effects on amphibian populations that depend on stream habitat for portions of their life cycles and annual activity patterns. I also conclude that the occurrence of amphibians across the full extent of the zone sampled in this study (120 m from the stream channel), suggests that a new riparian buffer width should be considered based on scientific evidence to replace the 30 m stream buffers currently specified in the Alberta guidelines.

Some limitations of my study that may have affected captures and resulting abundance estimates for wood frog and other species were timing of trapping and the nature of traps. Sampling did not start early enough in spring to document initial movements of adult wood frogs downstream from upland hibernating sites to possible breeding ponds, or movement of adults from breeding ponds to upland habitat immediately after they had reproduced. The depth of our pitfall traps and the sticks placed in the traps may have allowed boreal chorus frogs to escape as they climb well.

Adequate information is required on small stream riparian vegetation features, soil moisture levels, and water depth of small streams along a considerable length of channel to characterize these habitats. Efforts should be made to identify features of riparian habitats that are potentially important for amphibians during periods when the streams have or lack water. Some scientists are currently arguing that the one size fits all buffer width is not the best way to protect small stream habitats. Therefore, it would also be useful to identify the exact extent (width) of the riparian zone and adjacent forest that amphibians utilize, in order to propose a more concrete buffer recommendation that can adequately protect important amphibian habitat without prohibiting logging altogether.

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Table 3.1 Dates during which pitfall traps were open in the 2006-2008 study seasons.

	Trapping Session				
Year	1	2	3	4	5
2006	June 2 – 8	June 18 –25	July 4 – 13	August 4 – 12	Aug 19 – 24
2007	May 23 –29	June 5 – 11	July 5 – 10	July 31 – Aug 4	Aug 16 – 22
2008	May 30 –31	June 26 –28	Closed	July 25 – 26	Aug 20 – 22

Table 3.2 Number of amphibians captured at the stream sites for the study period 2006-2008.

	# of wood frogs captured (# per 100 trap nights)			**Other amphibian species captured (# of individuals)**		**# of trap nights**
Year	Adults	YOY	Total	Boreal chorus frogs	Boreal toads	
2006	77 (1.35)	173 (3.03)	250 (4.38)	2	1	5712
2007	117 (1.45)	244 (3.02)	361 (4.47)	3	12	8076
2008	115 (3.76)	53 (1.73)	168 (5.50)	4	11	3056
Extra fence *	9 (7.5)	13 (10.8)	22 (20.3)	0	0	120

* Capture data from the extra fence placed 100 m from the main fences of three stream sites in 2008 (one extra fence for each stream type).

Table 3.3 Results of ANOVA analyses for capture rates of wood frogs (CPUE) by age, between sampling years, stream types and fences. Significance at Pvalue < 0.05 are given in bold values.

Age	**Factors analyzed**	**F value**	**P value**
Adult	Year	$\mathbf{F_{(2,82)} = 7.5}$	**<0.01**
	Stream type	$F_{(1,45)} = 1.8$	0.18
	Fence	$F_{(3,45)} = 0.8$	0.51
	Stream type **x** Year	$F_{(2,82)} = 0.31$	0.73
	Fence **x** Year	$F_{(6,82)} = 1.2$	0.34
	Stream **x** Fence	$F_{(3,45)} = 0.33$	0.81
	Stream **x** Fence **x** year	$F_{(6,82)} = 1.01$	0.43
YOY	Year	$\mathbf{F_{(2,107)} = 9.8}$	**<0.01**
	Stream type	$\mathbf{F_{(1,76)} = 4.7}$	**0.03**
	Fence	$F_{(3,76)} = 0.20$	0.89
	Stream type **x** Year	$F_{(2,107)} = 0.27$	0.80
	Fence **x** Year	$F_{(3,107)} = 0.13$	0.99
	Stream type **x** Fence	$F_{(6,76)} = 0.37$	0.77
	Stream type **x** Fence **x** Year	$F_{(6,107)} = 0.84$	0.97

Table 3.4 Results of two-way ANOVA analyses comparing capture rates of wood frogs (CPUE) between stream types and fences by sampling sessions within each sampling year (2006-2008) excluding site EBSP01. Significance at Pvalue < 0.05 are given in bold values. Capture rates were normalized using natural log or square root transformations of the values +1.

Trapping session	Factors analyzed	Study year 2006		Study year 2007		Study year 2008	
All sessions combined	Fence	$F_{(3,12)}$=0.48	P=0.70	$F_{(3,32)}$=0.40	P=0.75	$F_{(3,28)}$=**4.60**	P=**0.01**
	Stream type	$F_{(1,12)}$=0.16	P=0.69	$F_{(2,32)}$=**3.63**	P=**0.04**	$F_{(2,28)}$=**18.34**	P<**0.01**
	Interaction	$F_{(3,12)}$=0.20	P=0.89	$F_{(6,32)}$=0.33	P=**0.91**	$F_{(6,28)}$=1.44	P=**0.23**
Session 1	Fence	Insufficient data		$F_{(3,19)}$= 0.64	P=0.60	$F_{(3,16)}$=**13.65**	P<**0.01**
	Stream type			$F_{(2,19)}$= 1.04	P=0.37	$F_{(2,16)}$=**51.03**	P<**0.01**
	Interaction			$F_{(6,19)}$=0.86	P=0.54	$F_{(6,16)}$=2.06	P=0.12
Session 2	Fence	$F_{(3,8)}$=0.13	P=0.94	$F_{(3,28)}$=**4.95**	P<**0.01**	$F_{(3,27)}$=2.65	P=0.07
	Stream type	$F_{(1,8)}$=2.78	P=0.13	$F_{(2,28)}$=3.15	P=**0.06**	$F_{(2,27)}$=**10.74**	P<**0.01**
	Interaction	$F_{(3,8)}$=0.32	P=0.81	$F_{(6,28)}$=1.70	P=0.16	$F_{(6,27)}$=0.84	P=0.55
Session 3	Fence	$F_{(3,12)}$=0.45	P=0.72	$F_{(3,31)}$= 1.44	P=0.25	No data	
	Stream type	$F_{(1,12)}$=0.07	P=0.80	$F_{(2,31)}$= **3.41**	**P=0.05**		
	Interaction	$F_{(3,12)}$=0.44	P=0.73	$F_{(6,31)}$= 1.01	P=0.44		
Session 4	Fence	$F_{(3,12)}$=0.98	P=0.43	$F_{(3,16)}$=0.02	P=0.99	$F_{(3,28)}$=0.29	P=0.83
	Stream type	$F_{(1,12)}$=3.01	P=0.11	$F_{(1,16)}$=**7.66**	**P=0.01**	$F_{(2,28)}$=**3.40**	P<**0.05**
	Interaction	$F_{(3,12)}$=0.30	P=0.83	$F_{(3,16)}$=0.16	P=0.92	$F_{(6,28)}$=0.29	P=0.94
Session 5	Fence	$F_{(3,12)}$=0.20	P=0.89	$F_{(3,28)}$=2.39	P=0.09	$F_{(3,28)}$=0.64	P=0.59
	Stream type	$F_{(1,12)}$=1.79	P=0.21	$F_{(2,28)}$=1.97	P=0.16	$F_{(2,28)}$=0.10	P=0.90
	Interaction	$F_{(3,12)}$=0.20	P=0.89	$F_{(6,28)}$=2.04	P=0.09	$F_{(6,28)}$=0.86	P=0.54

Table 3.5 Relationship between direction of wood frog movement and age for capture sessions combined over the three study years using Chi-square test.

Session	**Age**	**Direction of movement**		**P-value**
		Downstream % of captures (n)	**Upstream % of captures (n)**	
All	Adult YOY	62.5 (193) 17.4 (82)	37.5 (116) 82.6 (388)	**χ^2 = 124.3** **P < 0.0001**
1	Adult YOY	60.4 (61) 0	39.6 (40) 0	N/A
2	Adult YOY	61.0 (25) 13.3 (2)	39.0 (16) 86.7 (13)	**χ^2 = 9.98** **P = 0.0016**
3	Adult YOY	61.3 (73) 3.7 (5)	38.7 (46) 96.3 (130)	**χ^2 = 98.75** **P < 0.0001**
4	Adult YOY	66.7 (20) 17.6 (46)	33.3 (10) 82.4 (216)	**χ^2 = 37.1** **P < 0.0001**
5	Adult YOY	77.8 (14) 50.0 (29)	22.2 (4) 50.0 (29)	**χ^2 = 4.3145** **P = 0.0378**

Table 3.6 Results of two-way ANOVA analyses for environmental features between stream types and fences. The interaction between fences and stream were adjusted by Tukey Kramer analysis.

Environmental variables	Factors analyzed	F value	P value	Result*
Plant cover (%)	Fence	$F_{(3,32)}$=2.96	**0.047**	**F1 > F3**
	Stream type	$F_{(2,32)}$=3.68	**0.036**	**SmP > Int**
	Interaction		0.784	
Moss cover (%)	Fence	$F_{(3,32)}$=1.60	0.208	
	Stream type	$F_{(2,32)}$=2.76	0.078	
	Interaction		0.906	
DWM volume (m^3/ha)	Fence	$F_{(3,32)}$=0.10	0.961	
	Stream type	$F_{(2,32)}$=1.02	0.374	
	Interaction		0.991	
Snag density (stems/quadrat)	Fence	$F_{(3,32)}$=2.411	0.085	
	Stream type	$F_{(2,32)}$=3.652	**0.037**	**Eph < Int**
	Interaction		0.799	
Tree density (stems/quadrat)	Fence	$F_{(3,32)}$=1.255	0.305	
	Stream type	$F_{(2,32)}$=1.646	0.209	
	Interaction		0.955	
Shrub density (stems/quadrat)	Fence	$F_{(3,32)}$=1.07	0.378	
	Stream type	$F_{(2,32)}$=0.17	0.844	
	Interaction		0.939	

* Four fences are labeled F1, F2, F3 and F4; F1 straddles the stream and F4 is the farthest away from the stream. Three stream types referred to are ephemeral (Eph), intermittent (Int), and small permanent (SmP). Significant variables are in bold.

Table 3.7 Relationships between wood frog captures per 100 trap nights (2006 – 2008 capture data combined) and riparian vegetation (measured once) (N=88) . Significant correlations are in bold.

Variables	**Pearson Correlation**	**P-value**
Species richness (Vascular plants)	-0.11	0.32
% Plant cover (vascular herbaceous plants and moss)	0.02	0.85
% Lichen cover	-0.11	0.32
Volume of downed woody material (m^3/ha)	-0.11	0.31
Total snags (stems/100 m^2)	0.08	0.46
Coniferous trees (stems/100 m^2)	**-0.26**	**0.01**
Deciduous trees (stems/100 m^2)	**0.32**	**<0.01**
Total shrubs (stems/100 m^2)	-0.04	0.75

Table 3.8: Summary of the step-wise regression model showing relationship between relative abundance (catch per unit effort) and significant habitat variables of the riparian zone of the small streams.

Habitat variables	**B**	**Standard error of B**	**t-value**	**P-value**
Intercept	1.58288	0.23711	6.68	< 0.01
Deciduous Density	0.01777	0.00623	2.85	**< 0.01**
Conifer Density	-0.01904	0.00837	-2.28	**0.025**
	Regression Summary $R^2 = 0.17$ Adjusted $R^2 = 0.14$ $F(2,84) = 5.84$ P-value < 0.001 Standard error of estimate: 0.75			

*The other tested variables that were not significant in the model include stand age (in years, sourced from DMI), ground layer species richness, plant cover and lichen cover (% cover in 0.5 × 0.5 quadrat), total DWM volume (m^3/ha), total snag density (stems/100m^2) and total shrub density (stems/100m^2).

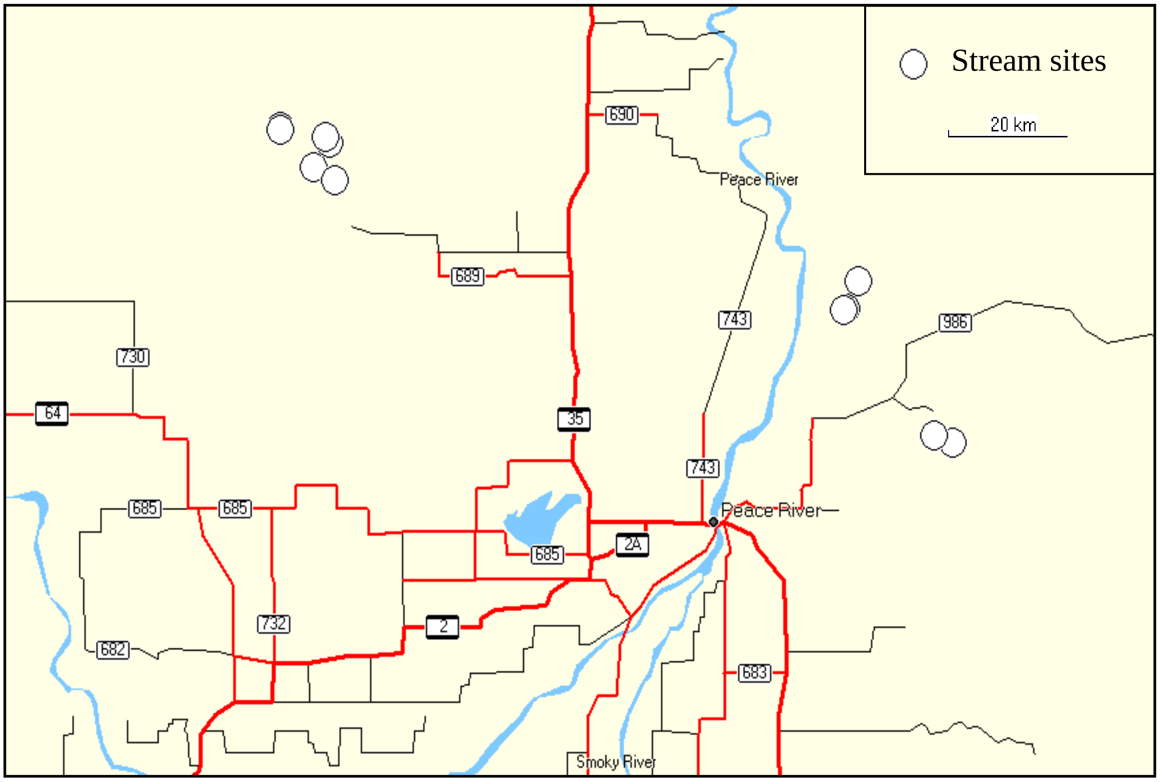

Figure 3.0 Study area showing location of stream sites at the mixedwood forest of boreal Alberta near Peace River. The stream sites are east and west of the town of Peace River; site locations are indicated by circles.

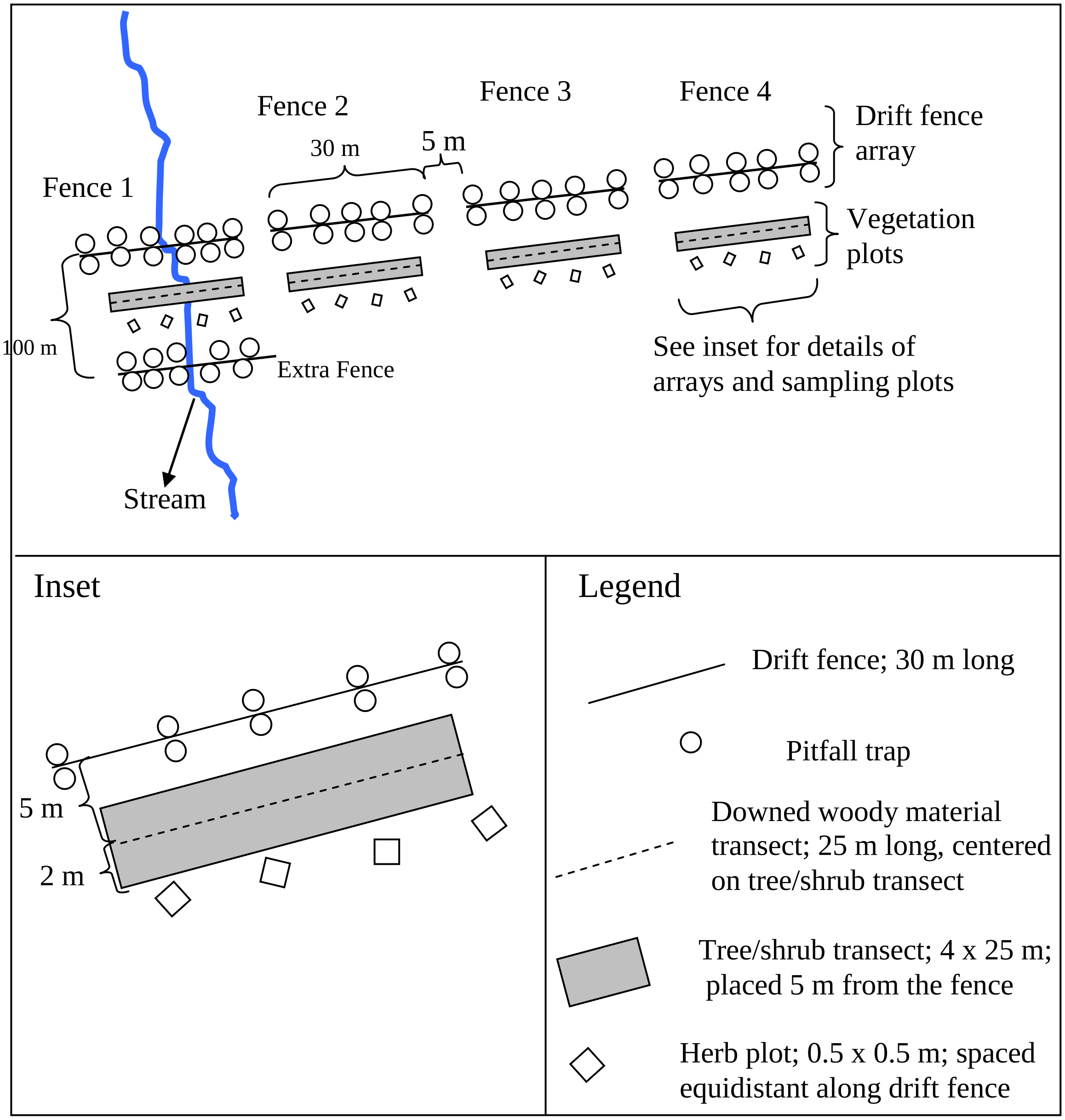

Figure 3.1 Schematic diagram of the drift fence/pitfall trapping system used for sampling at stream sites (not to scale). Each fence is 30 m long, with a 5 m gap between adjacent fences. The total length of entire array was 135 m. Extra fence was perpendicular to the stream and positioned 100 m downstream from the main fence 1. Inset: detailed schematic illustration of plant sampling methods.

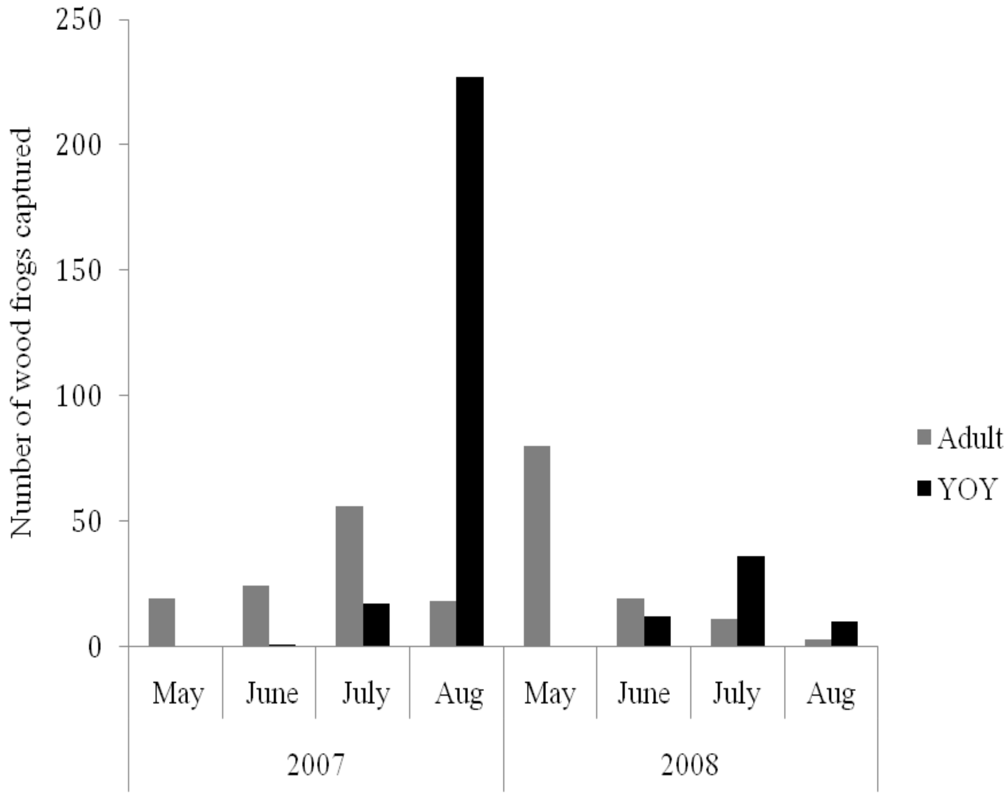

Figure 3.2 Age distribution of total number of wood frogs (adults and YOY) captured monthly for 2007 and 2008 for all stream types combined (ephemeral, intermittent and permanent streams)

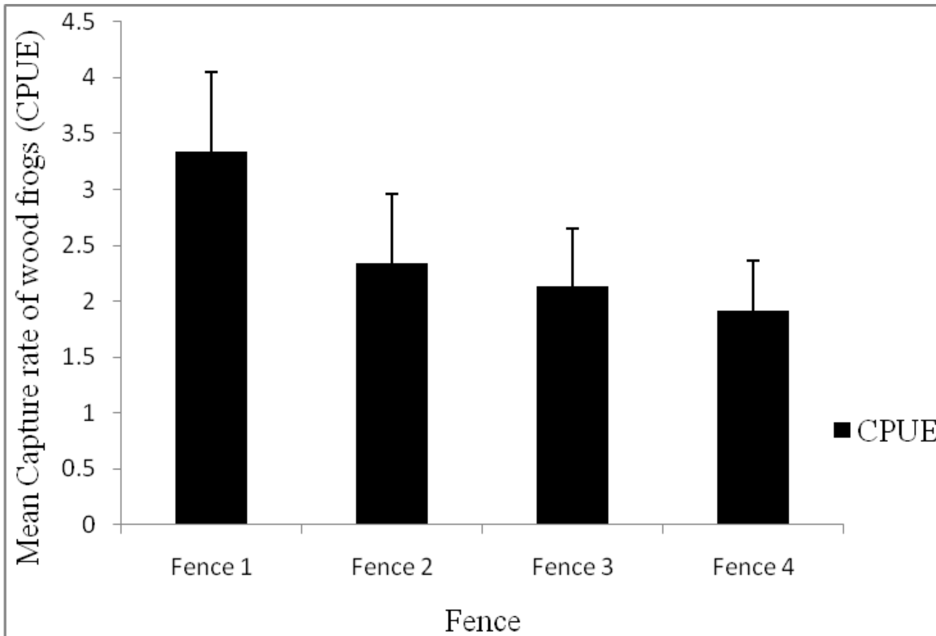

Figure 3.3 Capture of wood frogs relative to the proximity of stream over the three study years (2006-2008): fence 1 runs across the stream, while 2,3,4 respectively are further away from the stream (N=432)

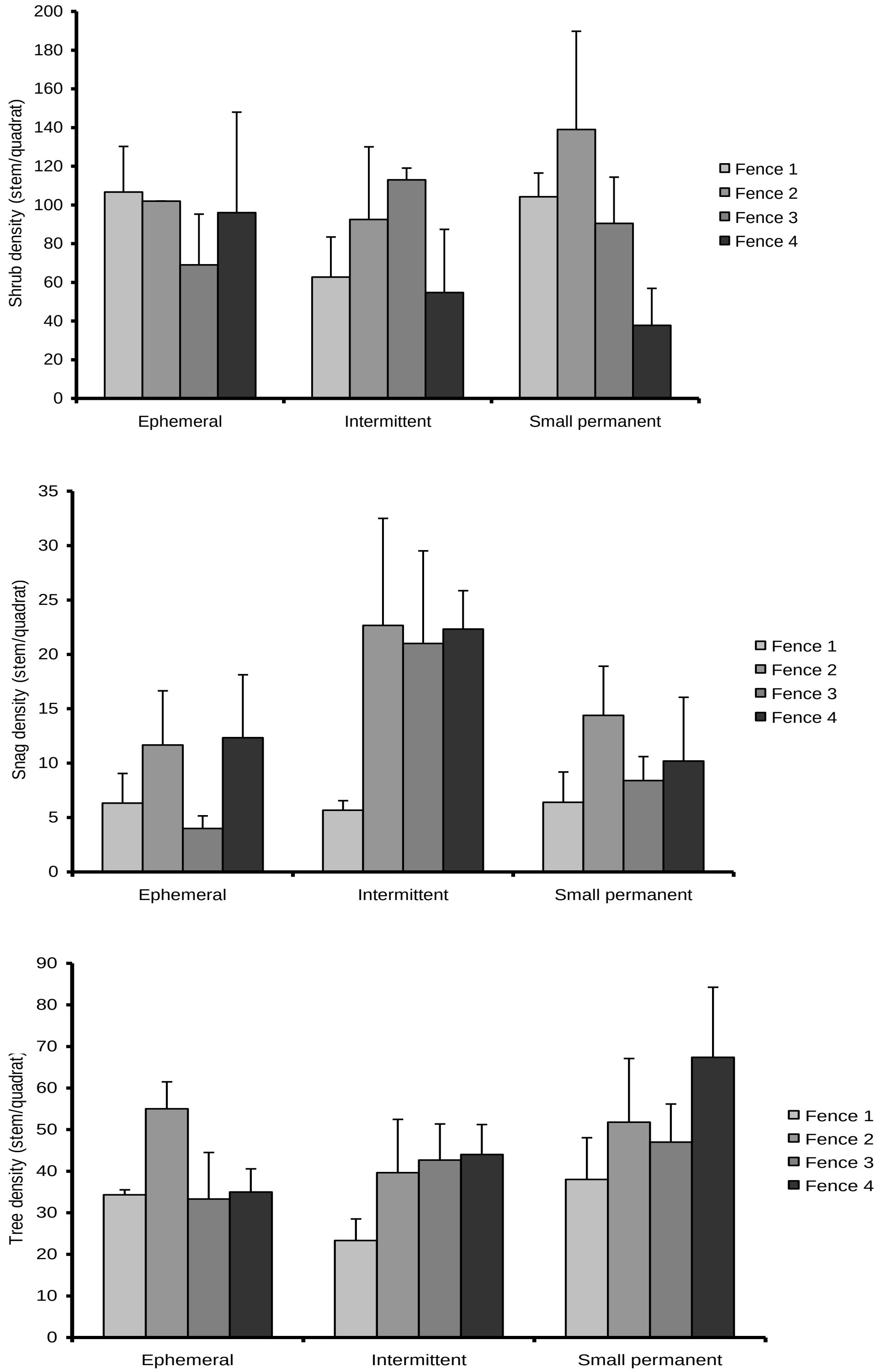

Figure 3.4 Mean (± SE) of the vegetation characteristics for each fence and stream type Vegetation features included density of shrubs, snags and trees (N=88)

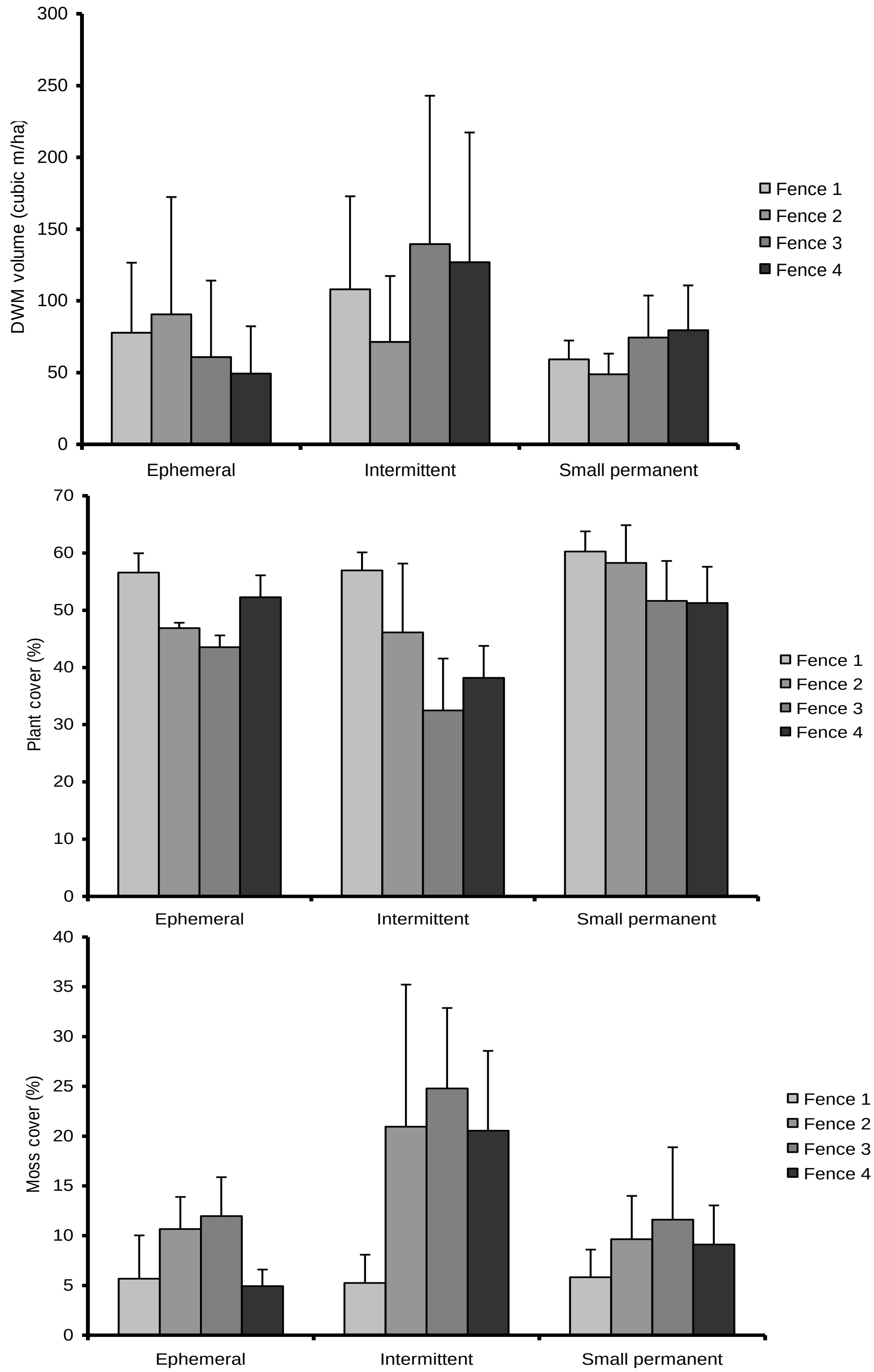

Figure 3.4 *Continued*: Mean (± SE) of the vegetation characteristics for each fence and stream type. Vegetation features included volume of downed woody material, % plant cover and % moss composition (N=88).

CHAPTER 4 MANAGEMENT IMPLICATIONS AND RECOMMENDATIONS

4.1 INTRODUCTION

The long-term survival of a healthy population of any species is largely dependent upon the integrity of its habitat. The morphological and physiological characteristics and breeding patterns of amphibians make them especially dependent on access to surface water for survival and reproduction. Because of this, it is important to conserve aquatic features that contribute to the persistence of this group of animals in an area. However, not all aquatic features may serve as suitable habitat, so research efforts should be directed at identifying those hydrological features that create appropriate habitats to protect amphibian populations. Amphibians in the boreal forest have complex habitat requirements including standing water for breeding, upland habitat for foraging and overwintering, and suitable movement corridors between the two (Baldwin et al., 2006). Both aquatic and terrestrial habitats are important to supplying the life-long requirements of the common species of amphibians like the wood frog, boreal chorus frog and boreal toad in the boreal mixedwood forest of Alberta, thus both require conservation through habitat protection.

Disruption of habitats that are important to amphibian population persistence occurs in part because there is a current lack of knowledge about the habitat needs of these species in the boreal forest. This makes it difficult for land managers to promote appropriate conservation strategies. Given the intensity and magnitude of forestry and energy extraction activities in the boreal mixedwood forest, and the poor information on amphibian use of small water bodies and water courses, there is a risk of continual inadvertent destruction and degradation of amphibian habitats. Wetland and water course protection in Canada has historically favoured large-sized wetlands and streams with longer hydroperiod, partly because these systems are detectable using map products or when planning activities on the ground (e.g. setting out cut blocks), and are likely to contain fish which are viewed as a valuable resource.

I examined the distribution and abundance of amphibians in and around small wetlands and streams in northwest Alberta to evaluate these features as amphibian habitat. The results of my study have broad relevance to protection of amphibian breeding sites and habitats used for foraging and as corridors for movement. The following discussion proposes habitat management guidelines to help minimise future amphibian habitat loss within the context of the boreal mixedwood forest. It will also stimulate further research on these small water bodies by stakeholders, and encourage further documentation of these water bodies as habitat for wildlife.

4.2 SMALL EPHEMERAL WETLANDS

Based on my study, small ephemeral wetlands serve as amphibian habitat in the mixedwood forest of boreal Alberta. Therefore, regulations that exclude these wetlands from protection during forestry and oil and gas development, based on their small size and ephemeral nature, may be detrimental to amphibian populations that use these habitats for hydration, foraging, and breeding. Some critical features of these wetlands uncovered by my study can be used by forestry managers and other stakeholders to identify which small wetlands (< 0.1 ha) are potentially used by amphibians. These features include wetlands with (i) hydroperiods that persist from spring melt until late July/early August, (ii) water pH 5.0 to 8.0, (iii) open forest canopy (< 40% cover), and (iv) a riparian zone dominated by deciduous trees rather than conifers. Canopy cover is the simplest indicator that can be used by forestry managers to recognize wetlands that will accommodate breeding by the amphibian species sampled, so it is a very useful indicator.

Because there are many small wetlands in the mixedwood forest of boreal Alberta (Eaton, 2004; Natural Regions Committee, 2006), it follows that they are important to amphibian conservation in this region. It is, however, difficult and costly to protect all of these wetlands, so carefully planned and sustainable logging may be an effective means that allows use of forest resources while preserving wetlands, thus protecting the amphibian that use them. Based on the study results, I suggest the following specific recommendations:

(1) Wetlands should be included in the Alberta regulations for habitat protection irrespective of size.

(2) Methods of tree harvest that utilize selective removal of trees such as variable retention is better than clear cutting and some small ephemeral wetlands and associated riparian buffers should be included within the retained forest patches. It will also be useful for companies operating in the area to do a pre-harvest assessment of ephemeral wetlands to detect amphibians during the spring and summer when the ponds will contain water. I am aware that DMI has recently been practicing a form of variable retention during forest harvest and ongoing studies at the Ecosystem Management Emulating Natural Disturbance EMEND study area are showing that variable retention is contributing to conservation of invertebrates such as bark dwelling spiders *Araneae* (Pinzon and Spence, 2010). Since all the small wetlands in an area cannot be realistically protected, I recommend identification (based on canopy cover) and protection of between over 50% and 75% of small ephemeral wetlands with respect to amphibians within each cut block. The ratio of small ephemeral wetlands to larger wetlands across the entire landscape can be determined through a larger scale study over a longer period of study time, and I propose that more than 50 % of these wetlands across the entire landscape being logged (based on breeding at >50 % of my study wetlands) can be protected. However, this should be carefully done with consideration of other wildlife and flora that utilize resources within the preserved cut blocks. Further studies are required to determine precise proportion of wetland to receive protection based on the distribution of small ephemeral wetlands in the boreal mixedwood forest.

(3) Further research and long term monitoring of amphibian use of small ephemeral wetlands is required to strengthen the results of this study, and to

determine how to identify small ephemeral wetlands during the winter when most logging is done, as well as through the hydrological variations (wet and dry seasons) that occur across years. Inter-annual variability in amphibian presence at the wetlands can also be monitored to examine how amphibians use the wetlands in relation to hydroperiod. Monitoring of closed canopy wetlands before and after selective logging of the riparian zone can also be done to determine if they can be transformed into wetlands used by amphibians for breeding, therefore playing a role in habitat restoration/creation methods. More surveys on amphibians and wetlands before and after logging can be integrated into assessments in order to estimate the frequency of occurrence of amphibians in these wetlands at a landscape level and the impacts that forestry and energy industries have on them.

4.3 SMALL STREAMS

The cost of movement of young-of-the-year and adult wood frogs between breeding ponds and terrestrial habitats includes reduced chance of survival due to desiccation and to predation by birds and mammals (Rittenhouse et al., 2009). My study on small streams suggests that amphibians are found along the riparian zones of small stream, and that use them as corridors for movement between wetlands and terrestrial uplands. The riparian zones of small streams may play a vital role, providing connectivity between habitats to help maintain amphibian populations (Semlitsch, 2002). With current resource exploitation in this region, it is advisable for government and companies operating in the boreal forest to protect small stream riparian habitats from degradation and destruction. Buffers have been recommended around streams and wetlands to maintain various habitat parameters, including water temperature (Macdonald et al. 2003), and amphibian populations (Semlitsch and Brodie, 2003) during timber harvest. Several studies have recommended buffer zones with widths between 20 m and 300 m around streams (Semlitsch and Bodie, 2003; Olson et al., 2007). However, not many recommendations have considered small ephemeral and intermittent streams of the size range that I studied. In Alberta, the government guideline recommends buffers of 30 m around small permanent streams that contain fish, while harvesting is allowed around intermittent and ephemeral streams (ASRD, 2005).

However, to make buffer zones more effective, directional components should be included in the protection plans. For example, if the downstream part of a small stream leads to an amphibian breeding pond, the riparian zone of the small stream should be treated as a conservation priority and protected along its full length as a complex with associated wetlands. Based on the results of my study, I put forward the following specific recommendations:

(1) Amphibians utilize small streams for movement, thus ephemeral, intermittent and permanent streams should be protected irrespective of size, and be identified in guidelines for protection on the basis of habitat function for amphibians.

(2) Operation of heavy equipment and utilization of road crossings should be reduced at the riparian zone of small streams. Since I captured amphibians up to 125 m from the streams, I suggest a new buffer distance with respect to amphibian habitat use, should be researched and considered based on scientific evidence to replace the 30 m buffer recommended by the Alberta government guidelines.

(3) Plans for watershed restoration projects such as clearing the high volumes of woody debris, and channel reconstruction and monitoring should be adopted after logging operations. This will ensure that sites are flagged as candidates for restoration before the winter period when logging is done. As small streams may be numerous on the landscape, variable retention of forest patches and associated streams will be useful during logging, and protecting small streams encountered within cut blocks with over 30 m buffers during logging will aid continued connectivity for amphibians.

(4) Future work on detecting vegetation signatures that influence amphibian abundance and identify riparian zones of small streams is necessary so that foresters can easily identify these features when they set out cut blocks even in the fall and winter. Drift fences can be installed parallel to the flow of the

stream to study the frequency of frog movements to small streams from the adjacent terrestrial habitat, to identify the direct utilization of small streams by the local amphibians. Radio-tracking adult amphibians also offers an effective way to follow movements of amphibians and their association with small streams.

In summary small ephemeral wetlands and small streams, as well as their riparian zones, require protection. They should be integrated into the guidelines for protection of water-bodies in Alberta based on their utilization as habitat for amphibian species, and not just physical features. Furthermore, since the boreal forest stretches across much of Canada, the results and recommendations from my study can be logically applied to other parts of Alberta and Canada where similar amphibian species, mixedwood forest type and small water-bodies exist. Further studies are required to fully establish all the habitat roles of these small water-bodies for local amphibian species and other animals, and their response to multiple, complex land-use activities that occur within different parts of the boreal forest. This will guide the generation of more effective riparian buffers during forestry for better protection of amphibian populations, small streams, and small ephemeral wetlands.

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Appendix 2.1 List of wetland study sites by field identification labels and wetland type. Table also shows presence (P) or absence (AB) of life stages of amphibians encountered. (WF=wood frogs, BCF= boreal chorus frogs, BT=boreal toads)

Wetland ID	Type	Geographic co-ordinates	Wood frogs			Boreal chorus frogs			Boreal toads		
			Eggs / Larvae	YOY	Adult	Eggs / Larvae	YOY	Adult	Eggs / Larvae	YOY	Adult
WW01	B	0416378 6292633	AB	AB	P	AB	AB	AB	AB	AB	AB
WW02	A	0414130 6290318	P	P	P	P	P	P	AB	AB	AB
WW03	B	0416007 6292660	P	P	P	AB	P	P	AB	AB	AB
WW04	B	0419009 6289737	P	P	P	P	P	P	AB	AB	AB
WCW01	A	0422392 6285366	AB	AB	AB	AB	AB	AB	AB	AB	AB
WCW02	B	0422384 6283094	AB	AB	AB	AB	AB	AB	AB	AB	AB
WCW03	B	0421724 6282804	AB	AB	P	AB	AB	P	AB	AB	AB
WCW04	A	0417490 6289449	P	P	P	P	P	P	AB	AB	AB
WCW05	A	0422919 6281176	P	P	P	P	P	P	AB	AB	AB
WEAW01	B	0416815 6290886	P	P	P	P	P	P	AB	AB	AB
WEAW02	A	0419028 6289783	P	P	P	P	P	P	AB	AB	AB
WEBW01	B	0416802 6290895	AB	AB	AB	AB	AB	AB	AB	AB	AB
WEBW02	A	0416852 6291108	AB	AB	P	AB	AB	P	AB	AB	AB
W875W01	B	0414397 6290266	AB	AB	AB	AB	AB	AB	AB	AB	AB
W875W02	B	0414402 6290273	AB	AB	AB	AB	AB	AB	AB	AB	AB

Appendix 2.1 continued; List of wetland study sites by field identification labels and wetland type. Table shows presence (P) or absence (AB) of life stages of amphibians encountered.

Wetland ID	Typ	Geographic co-ordinate	Wood frogs			Boreal chorus frogs			Boreal toads		
			Eggs / Larvae	YOY	Adult	Eggs / Larvae	YOY	Adult	Eggs / Larvae	YOY	Adult
W892W03	A	0414179 6290273	P	P	P	P	P	P	AB	AB	AB
WFA01	A	0413274 6289913	P	P	P	AB	P	P	AB	AB	AB
WBIG01	B	0413271 6289889	P	P	P	AB	P	P	AB	AB	AB
WSRW01	A	0438538 6272789	P	P	P	P	P	P	AB	AB	AB
WDMI01	C	0429991 6283698	P	P	P	AB	AB	AB	AB	AB	AB
WDW01	A	0413272 6289902	AB	AB	P	AB	AB	P	AB	AB	AB
ECW01	A	6257806	P	P	P	P	P	P	AB	P	P
ECW02	B	0510889 6257820	AB	AB	P	AB	AB	P	AB	AB	AB
EDW01	A	0515887 6244754	P	P	P	P	P	P	P	P	P
EDW02	B	0525377 6244754	AB	AB	AB	AB	AB	AB	AB	AB	AB
EHRW01	B	0504232 6262961	AB	AB	AB	AB	AB	AB	AB	AB	AB
EHRW02	B	0504427 6263034	AB	AB	AB	AB	AB	AB	AB	AB	AB

The geographical coordinates are northings and eastings; a Universal Transverse Mercator (UTM) coordinate system based a grid method of specifying locations on the surface of the earth measured in meters. Easting is the projected distance of the position eastward from the central meridian, while northing is the projected distance of the point north from the equator.

Appendix 3.1. Summary of sampling sessions by treatment, site, and year. See Table 3.1 for dates for each trapping session. Note that shaded cells indicate cases where data were collected for all three years during the same sessions at a site.

Treatment	**Site**	**Year**	**Sessions Sampled**				
			1	**2**	**3**	**4**	**5**
Ephemeral	EBEPH01	2006					
		2007	✓	✓	✓		✓
		2008	✓	✓		✓	✓
	EBEPH02	2006					
		2007			✓		
		2008	✓	✓		✓	✓
	EDEPH02	2006					
		2007	✓	✓	✓		✓
		2008		✓		✓	✓
Intermittent	EDINT01	2006		✓	✓	✓	✓
		2007	✓	✓	✓		✓
		2008					
	WBINT01	2006	✓	✓	✓	✓	✓
		2007	✓	✓	✓	✓	✓
		2008	✓	✓		✓	✓
	WCINT02	2006		✓	✓	✓	✓
		2007	✓	✓	✓	✓	✓
		2008	✓	✓		✓	✓
Small perm.	EBSP01	2006			✓	✓	✓
		2007	✓	✓	✓		✓
		2008		✓		✓	✓
	WBSP01	2006	✓	✓	✓	✓	✓
		2007	✓	✓	✓	✓	✓
		2008	✓	✓		✓	✓
	WCSP01	2006			✓	✓	✓
		2007	✓	✓	✓	✓	✓
		2008		✓		✓	✓
	WDSP01	2006					
		2007		✓	✓	✓	✓
		2008	✓	✓		✓	✓
	WDSP02	2006					
		2007		✓	✓	✓	✓
		2008	✓	✓		✓	✓

Appendix 3.2 Structural vegetation variables collected in riparian zones around the study streams sites (39 variables).

Ground layer species richness	Snag density decay class 5 (softest)
Proportional plant cover	Snag density size class 1 (<10cm)
Proportional litter cover	Snag density size class 2 (10-15cm)
Proportional wood cover	Snag density size class 1 (>15cm)
Proportional moss cover	Total tree density
Proportional lichen cover	Tree density size class 1 (<10cm)
Mean herb cover	Tree density size class 2 (10-15cm)
Mean woody stem plant cover	Tree density size class 3 (>15cm)
Total DWM volume	Coniferous tree density
Coniferous DWM volume	Deciduous tree density
Deciduous DWM volume	Total shrub density
Unidentified wood DWM volume	Shrub density height class 0 (0.5-1.5m)
Decay class 1 (hardest) DWM volume	Shrub density height class 1 (1.5-3m)
Decay class 2 DWM volume	Shrub density height class 2 (3-5m)
Decay class 3 DWM volume	Shrub density height class 3 (5-10m)
Total snag density	Shrub density height class 4 (10-20m)
Snag density decay class 1 (hardest)	Shrub density size class 1 (<7cm)
Snag density decay class 2	Shrub density size class 2 (7-15cm)
Snag density decay class 3	Shrub density size class 3 (>15cm)
Snag density decay class 4	

Appendix 3.3 Summary of weather data by year and session for the study area during the study period. Data were collected at the EMEND project site.

Year	**Session**	**Temperature (^oC)**			**Total precipitation (mm)**	**Mean wind speed (km/hr)**
		Minimum	**Maximum**	**Mean**		
2006	1	6.57	17.96	11.89	2.83	5.70
2006	2	9.05	20.19	14.98	0.19	5.73
2006	3	10.71	19.31	14.83	3.00	4.76
2006	4	7.77	19.70	13.88	0.34	5.25
2006	5	10.03	22.27	15.82	0.00	4.99
2007	1	2.10	17.64	10.28	1.00	5.51
2007	2	6.99	18.03	12.59	0.87	5.88
2007	3	9.52	20.27	14.82	1.38	4.74
2007	4	10.30	19.60	15.11	1.60	4.82
2007	5	7.54	16.16	11.79	1.19	4.76
2008	2	7.80	21.00	15.11	0.17	6.92
2008	4	11.65	26.60	18.83	3.18	4.29
2008	5	6.37	12.50	9.04	2.10	5.17