HABITAT SELECTION OF THE GREAT BASIN SPADEFOOT (*SPEA INTERMONTANA*) IN THE GRASSLANDS OF BRITISH COLUMBIA

by

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ABSTRACT

Wetlands and their surrounding upland areas provide crucial habitat for the Great Basin Spadefoot (*Spea intermontana*), a species at risk in the grasslands of the southern interior of British Columbia (BC), Canada. Understanding habitat selection and how these animals respond to change is crucial in the creation and implementation of conservation plans for this species. I studied the habitat selection of the Great Basin Spadefoot in the grasslands surrounding the New Gold - New Afton Mine, located approximately 10 km from Kamloops, BC. The objectives of my study were to (1) determine what type of breeding ponds spadefoots were using, (2) determine if artificial ponds could be used as a management tool, (3) determine desirable adult daytime retreat site features and decipher movement patterns to predict habitat use, and (4) determine microhabitat preferences of newly-metamorphosed spadefoots. To analyze breeding pond selection, 18 ponds on the mine site were surveyed. There was no significant difference between breeding (n=10) and non-breeding ponds (n=8) for any of the water or pond characteristics measured. Eight artificial ponds were also constructed in November 2013, and spadefoots bred in four of the eight novel ponds the following spring. Throughout the 2013 and 2014 activity seasons, radio-telemetry was used to locate daytime retreat sites and monitor movements of 33 adult animals. The maximum and mean maximum straight-line distance (m) travelled by adult spadefoots from their breeding ponds was 506 m and 240 m ± 146 SD. The telemetered animals relocated between retreat sites, often returning to burrows used previously. There was no significant difference, in respect to soil moisture, aspect, slope or percent ground cover, between used and available habitat plots. I also conducted a microhabitat study, within artificial enclosures, that revealed that newly-metamorphosed spadefoots preferred terrestrial habitat with moist cover. Aside from this narrow window of vulnerability, my study indicates that this species has the ability to inhabit and persist in drier, altered grassland habitats in this region through a very plastic response to a wide range of conditions.

keywords: Great Basin Spadefoot, *Spea intermontana*, British Columbia, radio-telemetry, metamorph, plasticity, habitat, disturbance, artificial ponds

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A huge thanks to my little spadefoots; although involuntary participants, they were extremely valuable and super cute. I would like to thank my research assistants, Katie Bennett and Janessa Ekman, and my volunteers, Gerad Hales, Bevan Ernst and Jeff Morgan. The staff at Tk'emlúps te Secwépemc (TteS), British Columbia Ministry of Forests, Lands, Natural Resource Operations and Rural Development (MFLNRORD) and New Gold - New Afton Mine were very supportive and provided encouragement throughout the duration of the project. I extend extreme gratitude to my family and friends for their unwavering support, even when they thought I was crazy for spending so much time on "toads." To my kitties, Purrvis and Mr. Meowgi, for your companionship and keen sixth sense of knowing when I needed a break from the computer (or bout of procrastination). Last but certainly not least, I want to thank my husband, Gerad Hales, for supporting me during the highs and lows, and the laughter and tears. He provided many laughs throughout the entire roller-coaster ride, keeping me sane through insanity.

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DEDICATION

This thesis is dedicated to all the spadefoots who participated in this study to make this world a little bit better and 'hoppier'.

"Never think that you have learned
All there is to know.
That's the surest way of all
Ignorance to show."

"There are stranger things in the world to-day
Than ever you dreamed could be.
There's beauty in some of the commonest things
If only you've eyes to see."

"The Smiling Pool's a nursery
Where all the sunny day
A thousand funny babies
Are taught while at their play."

"Play a little, learn a little, grow a little too;
That's what every pollywoggy tries his best to do."

"The world is a wonderful great big place
And in it the young must roam
To learn what their elders have long since learned –
There's never a place like home."

-Thornton W. Burgess, *The Adventures of Old Mr. Toad*, 1943

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CHAPTER 1. INTRODUCTION

Understanding habitat selection and how animals respond to habitat change is crucial in the creation and implementation of conservation plans for species at risk (Dodd 1993; Fellers and Kleeman 2007). An inability to respond appropriately to changes (e.g. due to climate change or human activity) in their environment, by making the right resource selection decisions, can have detrimental effects on a species survival (Corn and Fogleman 1984; Huey 1991; Vos and Chardon 1998).

Disturbed landscapes (e.g. those resulting from mining, forestry or agricultural activity) have been used for habitat selection studies to determine how individual animals respond to short-term changes in their environment (Kaminski et al. 2007). Results of these studies have been inconsistent. The results of Warren and Büttner's (2008) study on a military training site in Germany showed that response varied greatly among species: Natterjack Toads (*Bufo calamita*) and Yellow-bellied Toads (*Bombina variegata*) thrived in breeding ponds with high levels of disturbance, European Edible Frogs (*Rana esculenta*) were prevalent in ponds with disturbance > 2 years old, and CommonTree Frogs (*Hyla arborea*), Smooth Newts (*Triturus vulgaris*) and Alpine Newts (*Triturus alpestris*) were found in ponds with all levels of disturbance. Even within a species, disturbance can have varying effects. For example, Grizzly Bears (*Ursus arctos*) in west-central Alberta, Canada responded differently to mining activity, depending on sex and whether the females were solitary or with cubs: males and solitary females avoided disturbed areas while females with cubs favoured disturbed areas (Cristescu et al. 2016).

Arid and semi-arid grasslands cover approximately 28% of the North American continent and are susceptible to change (e.g. those caused by drought, fires, cattle grazing or development) (Wikeem and Wikeem 2004) due to their typically warm temperatures, dry climates and desirable locations (i.e. residential/industrial development of valley bottoms). Average rainfall ranges from 250 to 500 mm and depending on location, temperatures can reach as high as 38°C in summer months and as low as -40°C in the winter (Wikeem and Wikeem 2004). Grassland wetlands and their surrounding upland areas provide crucial habitat for a diverse number of species in arid systems, including those at risk (Findlay and Houlahan 1997).

A variety of amphibians are able to withstand dry, hot environments. These include the Red-spotted Toad (*Anaxyrus puncatatus*), which has a relatively large clutch size (~1,500 eggs) and can metamorphose in eight days, and the Green Toad (*Anaxyrus debilis*), which can tolerate extreme heat (i.e. 40°C; Griffis-Kyle 2016). Although some amphibians have adjusted to living in arid environments, the majority of species rely on standing water for reproduction, making them vulnerable to a decrease in the number of wetlands. Amphibian populations are rapidly declining worldwide (Stuart et al. 2004) and could be partially attributed to wetland loss and/or disturbance. Myers (1997) reported a worldwide wetland loss of 50% over the last century. How various amphibians persist (or not) in response to such rapid landscape changes in certain regions is not clearly understood.

In this thesis, I examine the ecology of the Great Basin Spadefoot (*Spea intermontana*) within a disturbed landscape. In particular, I investigate the characteristics of spadefoot breeding ponds and how both adult and newly-metamorphosed spadefoot tadpoles (‘metamorphs’) use the terrestrial landscape. Little is known about the habitat preferences of adult and metamorph spadefoots within the southern interior of British Columbia (BC), on either undisturbed or disturbed landscapes. Highly disturbed areas, such as active and reclaimed mine sites, provide optimal conditions for studying the ability of this species to adjust to changes in its environment (from natural to ones evidencing anthropogenic changes). My study was located within the southern interior grasslands of BC, where a 63% decline in the number of ponds has been reported over the time period 1992-2012 (Coelho 2015). In Chapter 2, I compare ponds where spadefoots did and did not breed, test their response to artificial ponds, and compare various features of used and available daytime retreat sites. In Chapter 3, I investigate habitat preferences (at a microscale) of newly-metamorphosed spadefoots by conducting a novel microcosm experiment. Chapter 4 summarizes my study, highlights notable results and provides recommendations for management plans and further studies.

STUDY SPECIES

The Great Basin Spadefoot (Figure 1.1) is a terrestrial, burrowing anuran on the provincial Blue List (i.e. species considered vulnerable to human activities or natural events; BC CDC

2016). In 2007, COSEWIC assessed and designated the Great Basin Spadefoot "threatened" in Canada, which influenced the "threatened" status under the *Species at Risk Act* (Government of Canada 2018). The northernmost extent of its distribution is limited to the dry grasslands in south-central BC (COSEWIC 2007; BCSIRAWG 2017) (Figure 1.2). This species is an ideal subject for studying how animals can persist in harsh (i.e. arid ecosystems) and changing conditions (e.g. due to climate change or human activity). They are able to tolerate xeric conditions by efficiently absorbing the limited amount of moisture available in the soil through their permeable skin (Ruibal et al. 1969). As well, they are able to exploit a wide range of permanent and ephemeral ponds (i.e. irrigation ditches, roadsides, rain pools, water depressions made by cattle, and pond edges; Buseck 2005; COSEWIC 2007), effectively adjusting to changing environments.

Limited information is known regarding spadefoot habitat use (Dodd and Cade 1998; BCSIRAWG 2017). They rely on two specific habitats to survive—aquatic for breeding and tadpole development and terrestrial for aestivation, foraging and hibernation (Pearson 1955) (Figure 1.3). Less is known about the habitat preference of metamorphs due to their size and inability to carry transmitters within the limits of current technology (Figure 1.3).

Figure 1.1. Partially unearthed Great Basin Spadefoot at a daytime retreat site with transmitter whip visible. Photo by author.

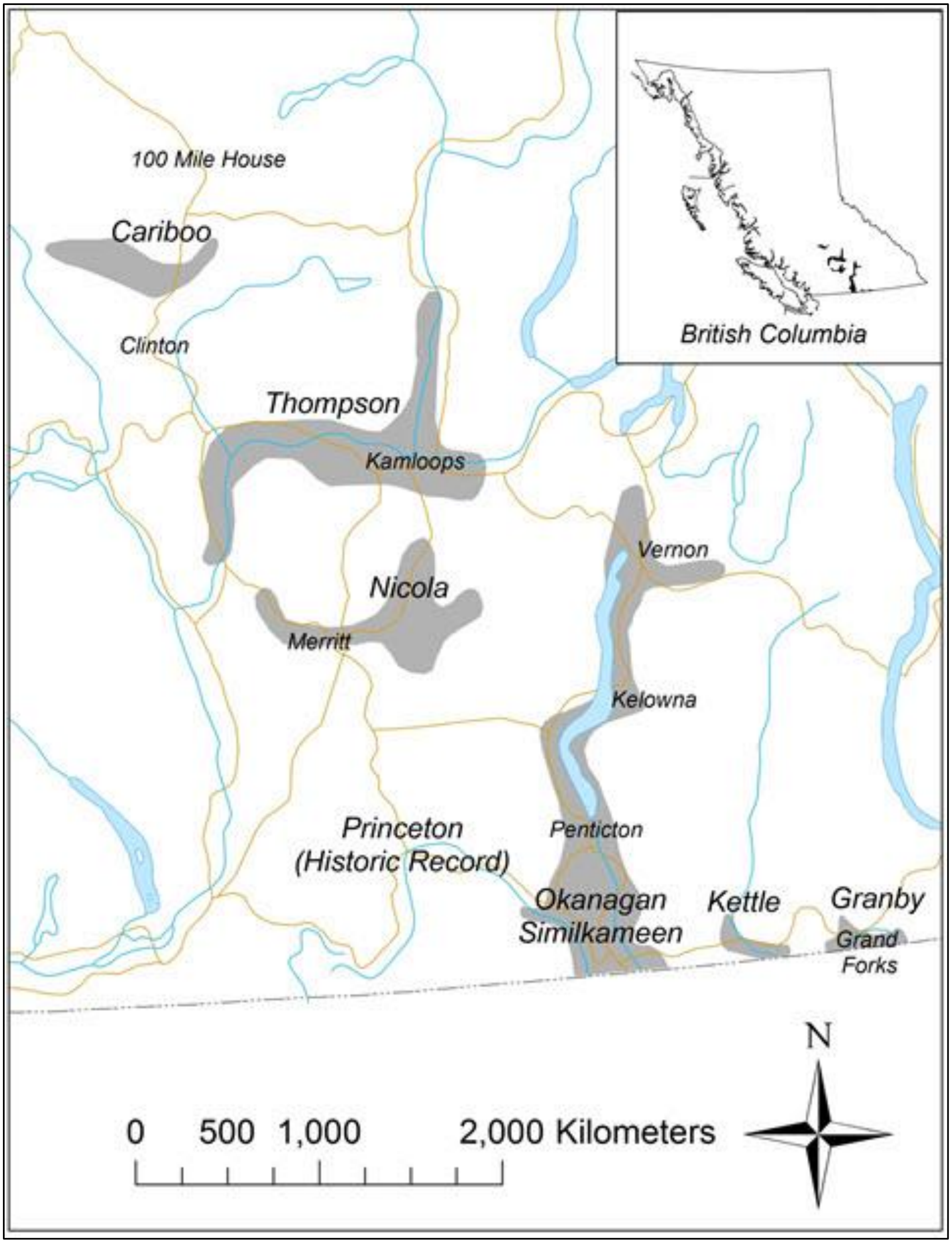

Figure 1.2. Distribution of the Great Basin Spadefoot in British Columbia (BCSIRAWG 2017).

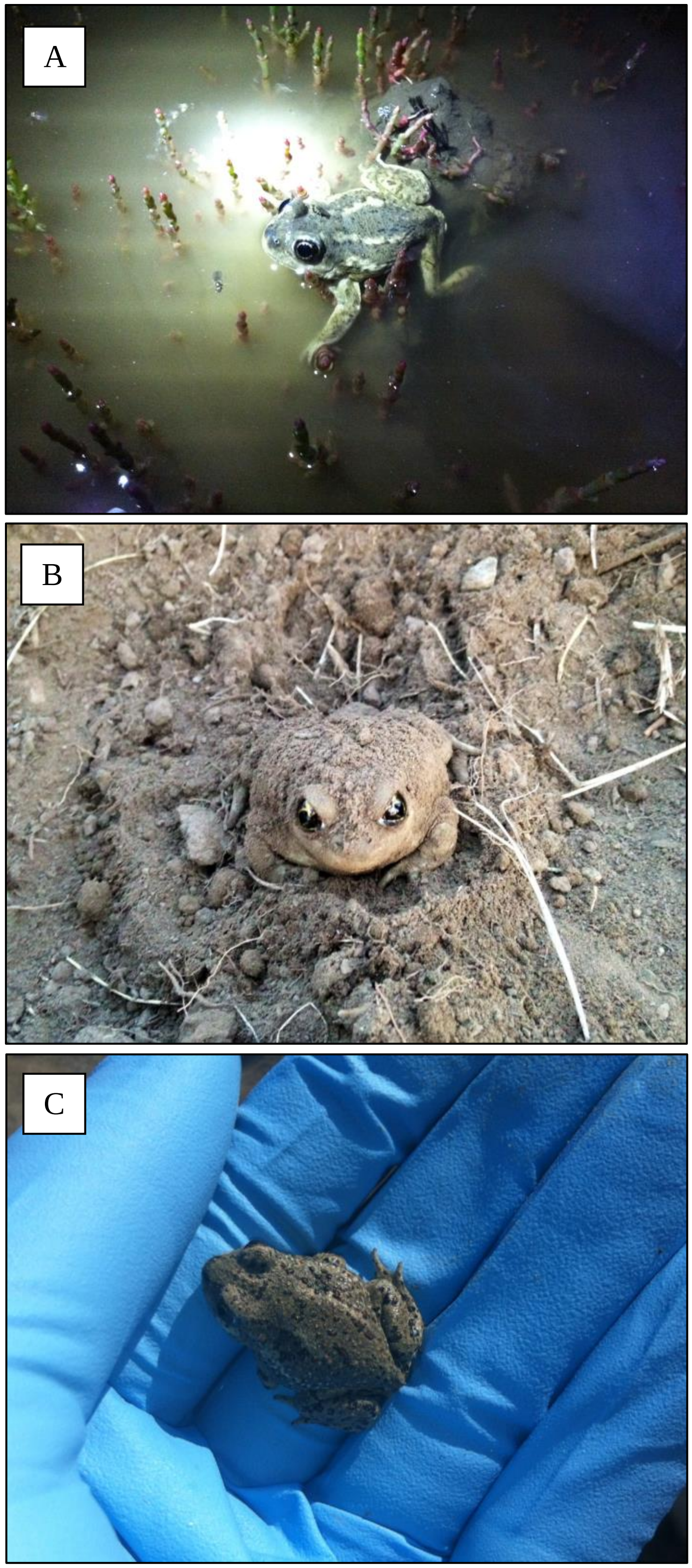

Figure 1.3. The Great Basin Spadefoot: (A) in its aquatic habitat (B) in its terrestrial habitat, and (C) newly-metamorphosed. Photos by author.

STUDY AREA

The New Gold - New Afton Mine (New Afton) is an underground copper-gold mine located approximately 10 km west of Kamloops in the southern interior of British Columbia, Canada (50°39’38” N, 120°30’50” W; elevation 650-750 m ASL), in the Ponderosa Pine and Bunchgrass biogeoclimatic zones (MFLNRORD 2016) in the Thompson-Pavilion grassland region (Wikeem 2004). The site is dominated by Ponderosa Pine (*Pinus ponderosa*), Bluebunch Wheatgrass (*Agropyron spicatum*) and Big Sagebrush (*Artemisia tridentata*) (Meidinger and Pojar 1991; MFLNRORD 2016).

This landscape provides an excellent backdrop to study habitat use and persistence of the Great Basin Spadefoot. The mine site is surrounded by agricultural activity and is situated within the traditional territory of the Tk’emlúps te Secwépemc and Skeetchestn Indian Bands, collectively referred to as the Stk’emlúpsemc of the Secwépemc Nation (SSN 2016). The study site is affected by varying levels and types of disturbance. Focal study locations on the site include the south-east portion of the mine site at Pothook Lake (telemetry) and the restored wetland on the north end of the New Afton private property (metamorph study), towards Kamloops Lake (Figure 1.4). The total area of the New Afton mining lease and all other claims is 12,450.4 hectares (New Gold 2018), which contain a variety of aquatic and terrestrial habitat types for the spadefoot (Figure 1.5 and Figure 1.6).

CLIMATE

The climate at New Afton is determined by the diverse geography of southern British Columbia. New Afton lies in a dry valley bottom, typical of similar valleys in the southern interior plateau, in the rain shadow of the westerly Coast Mountains (Chilton 1981). In this area, summers are typically warm and dry, while winters tend to be cold (but mild) with little precipitation (Chilton 1981).

Figures 1.7 and 1.8 compare the weather during my study years at New Afton to that recorded at the Kamloops Airport weather station 30-year climate normals (1981-2010). The New Afton weather station was activated in June of 2013. Throughout 2013 and 2014, New Afton temperatures were consistently slightly lower than those recorded at the Kamloops Airport, likely due to elevational differences (780 MASL versus 345 MASL, respectively).

Figure 1.4. Google image of the study area on the New Gold - New Afton Mine property.

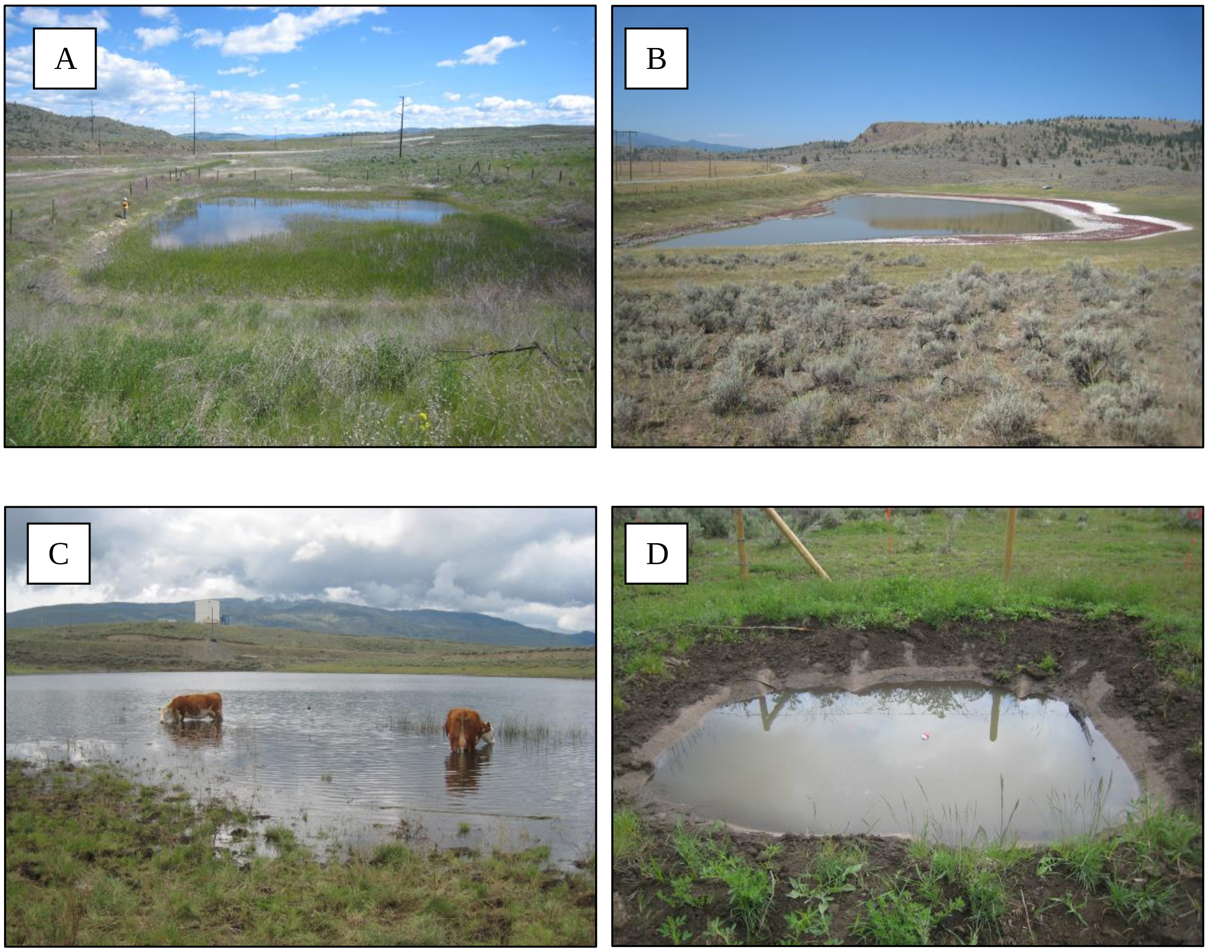

Figure 1.5. A variety of ponds located on the New Gold - New Afton Mine property: (A) ephemeral, (B) ephemeral, (C) permanent, (D) artificial. Photos by author.

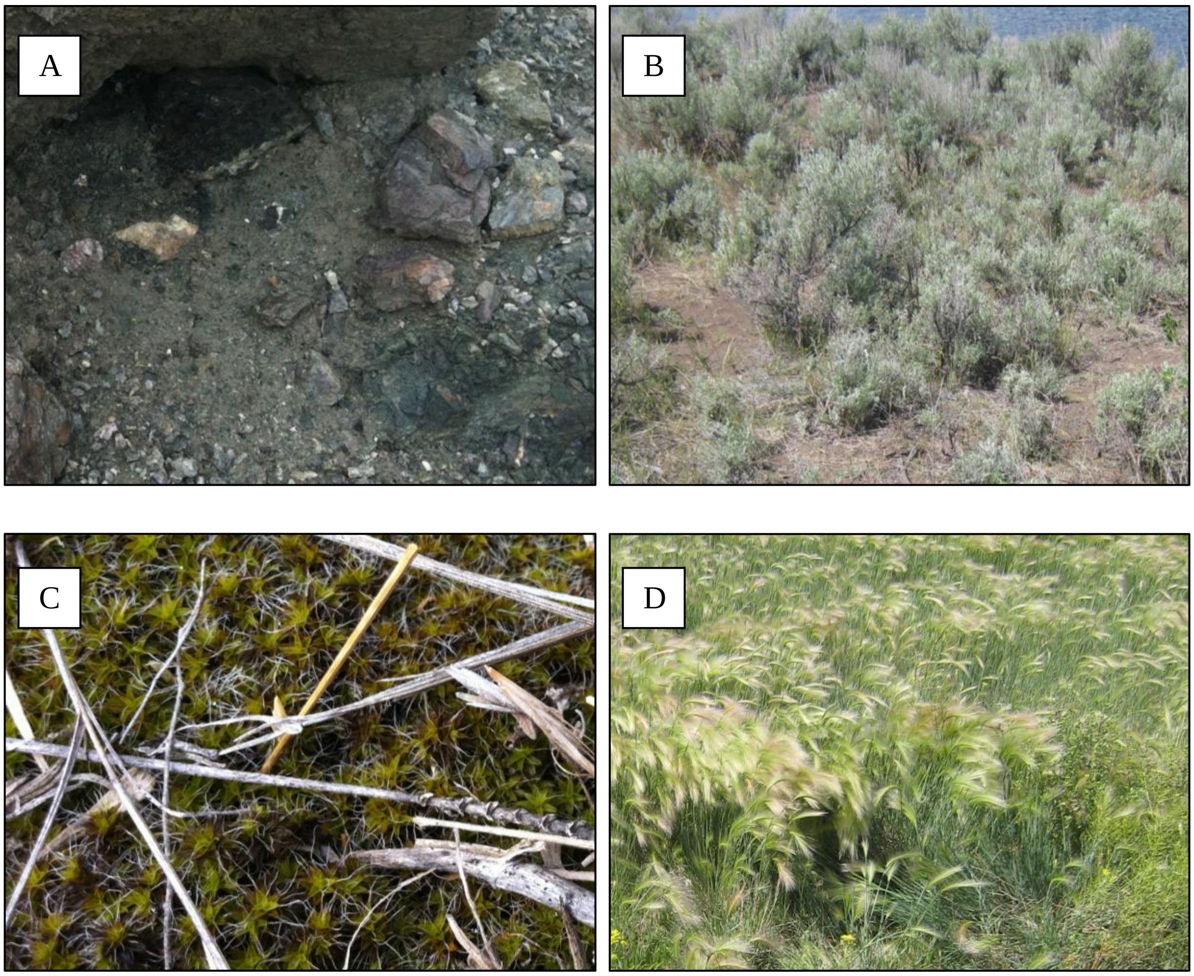

Figure 1.6. A variety of habitat types on the New Gold – New Afton Mine property: (A) rock, (B) sagebrush, (C) moss, (D) grass. Photos by author.

Overall, mean monthly temperatures for New Afton and the Kamloops Airport were reasonably consistent with the 30-year normals for both 2013 and 2014. Although the New Afton weather station did not collect precipitation data during the time of my study, monthly total precipitation at the Kamloops Airport for 2013 and 2014 was 259.5 mm and 277.6 mm, respectively, compared to the climate normals (1981-2010) of 279 mm (Figure 1.9).

OBJECTIVE

The overarching objective of my study was to understand how Great Basin Spadefoots use this modified landscape within the arid grasslands of the Kamloops region. The results of the study were used to address the following questions.

1. Do adult spadefoots use specific types of breeding ponds? If we are able to determine what type of breeding ponds they are using, we can administer the appropriate conservation plans to protect, enhance or create those water bodies.
2. Will adult spadefoots colonize artificial ponds at this site? If so, can artificial ponds be used as a management tool and what guidelines should be followed when constructing these ponds?
3. Once adult spadefoots leave the breeding ponds, are there specific features they search for in daytime retreat sites? Are there movement patterns that can help predict habitat use? If we are able to determine these features and decipher movement patterns, we can administer appropriate conservation plans to protect or enhance those features and usage areas.
4. What are the microhabitat preferences of newly-metamorphosed spadefoots, who rely on both aquatic and terrestrial habitats? Sustaining populations of the spadefoot relies on ensuring a successful transition of metamorphs from breeding ponds onto the terrestrial landscape.

Adult habitat selection, associated with questions one, two and three, are explored in Chapter 2 of this thesis. Chapter 3 is dedicated to question four, investigating microhabitat selection of newly-metamorphosed spadefoots in a microcosm study.

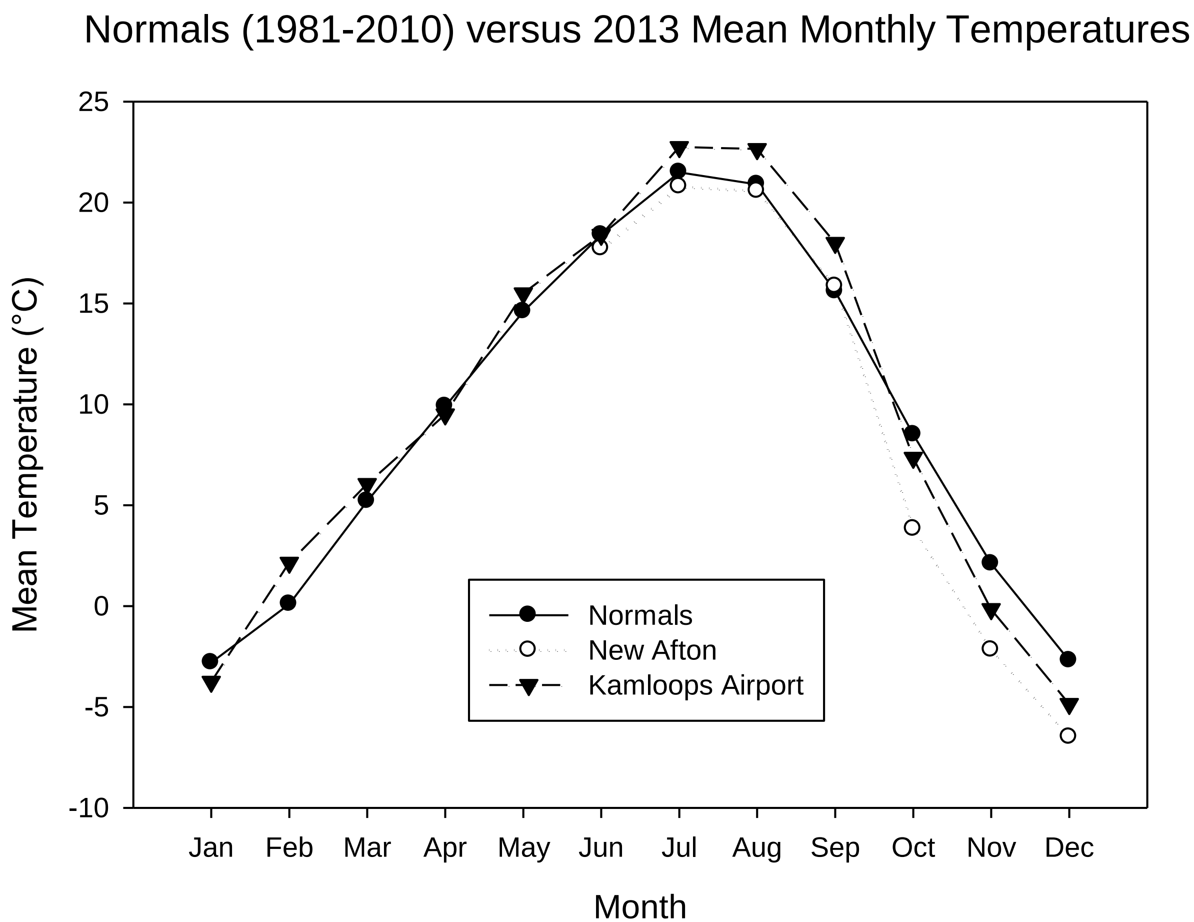

Figure 1.7. Normals (1981-2010) (Government of Canada 2016) versus the 2013 Mean Monthly Temperatures for New Afton Mine and the Kamloops Airport.

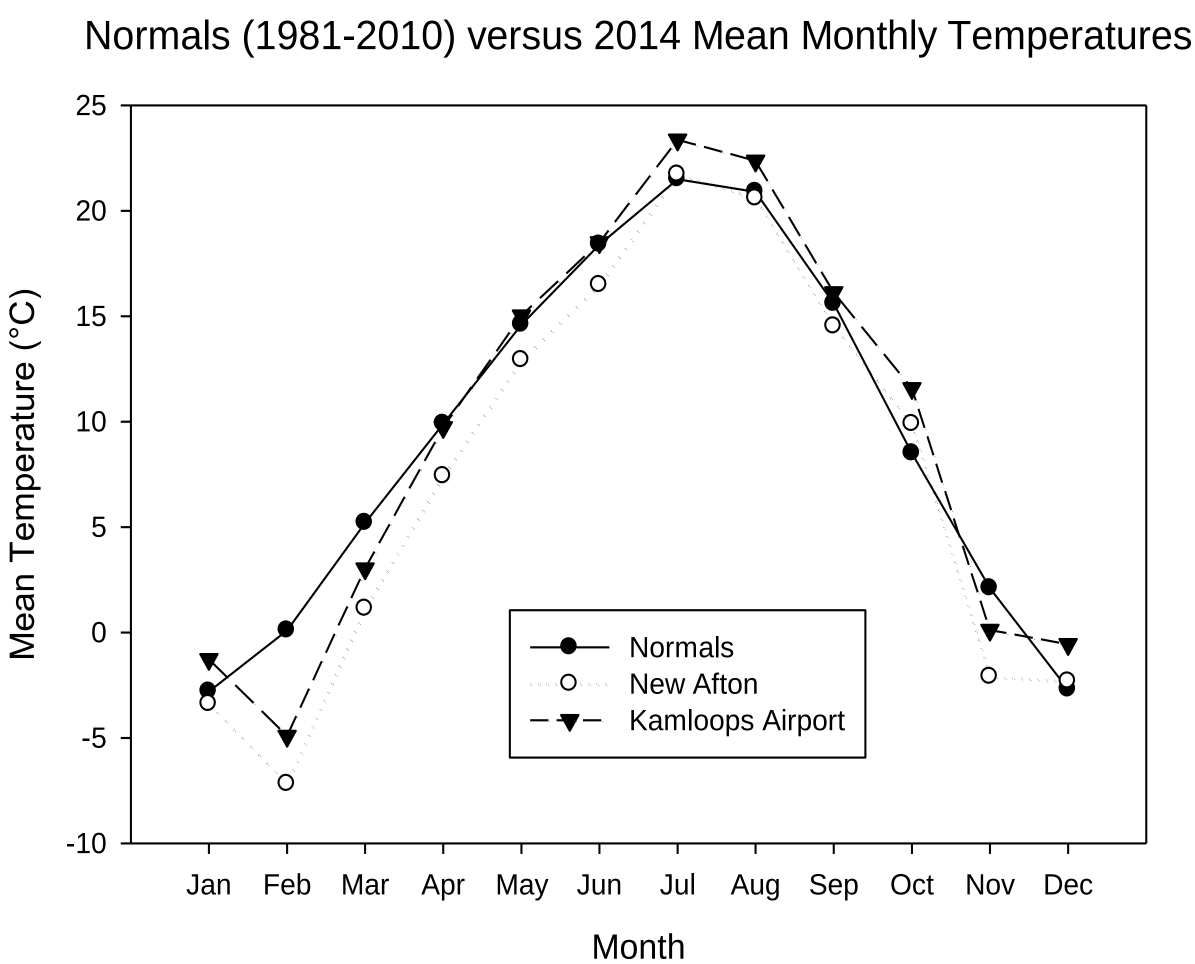

Figure 1.8. Normals (1981-2010) (Government of Canada 2016) versus the 2014 Mean Monthly Temperatures for New Afton Mine and the Kamloops Airport.

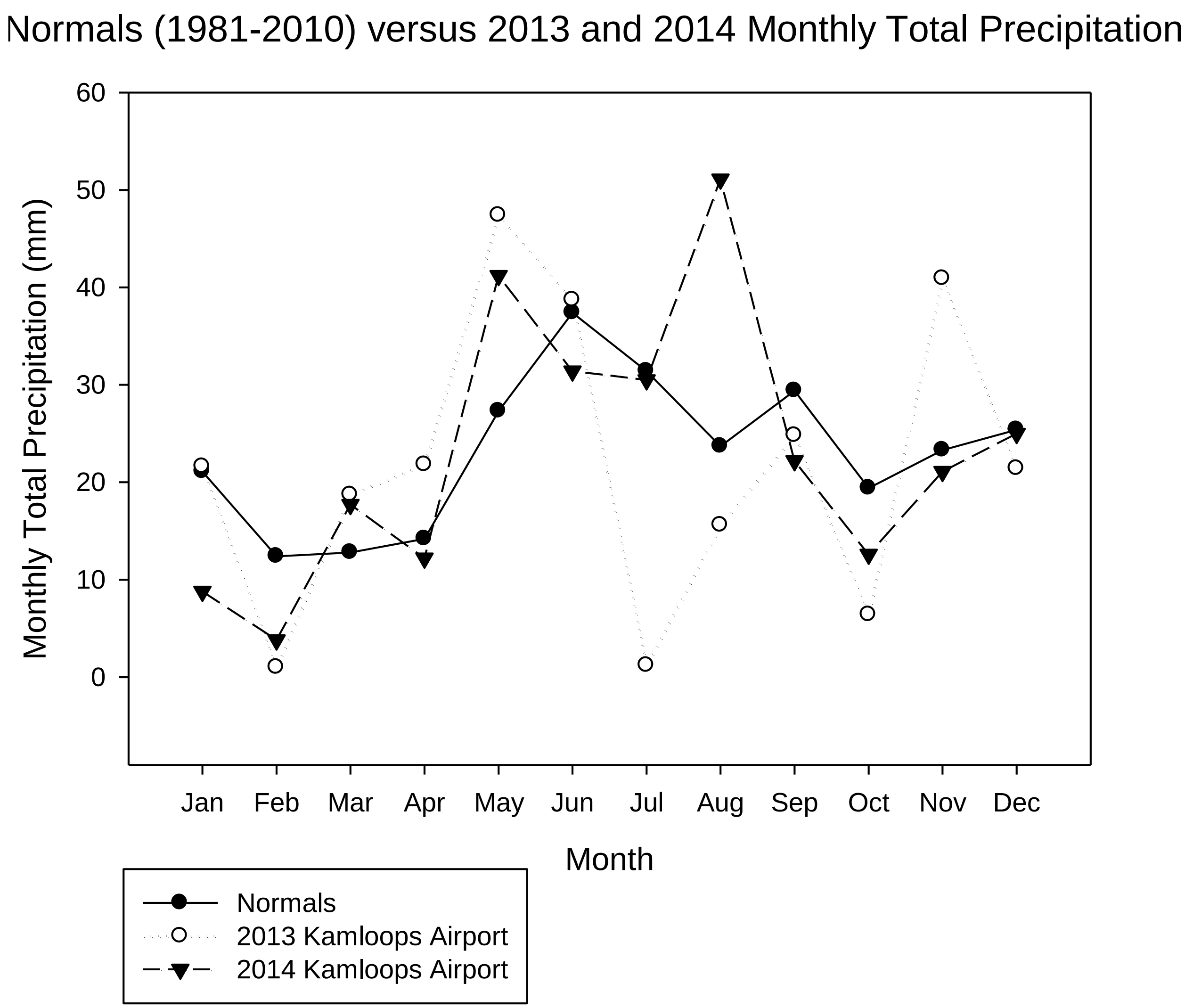

Figure 1.9. Normals (1981-2010) versus the 2013 and 2014 Monthly Total Precipitation at the Kamloops Airport.

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CHAPTER 2. ADULT HABITAT SELECTION OF THE GREAT BASIN SPADEFOOT (*SPEA INTERMONTANA*) WITHIN DISTURBED ARID GRASSLANDS

INTRODUCTION

Amphibian populations have been rapidly declining worldwide (Stuart et al. 2004), a phenomenon largely attributed to landscape alteration, disturbance and contamination (Knutson et al. 1999; Collins et al. 2003). The level of habitat disturbance on individual amphibian species and their perseverance on the landscape is inconsistent: while disturbance has been shown to negatively affect many amphibians, other studies have shown a positive response (Warren and Büttner 2008) or little effect (Alford and Richards 1999). Blaustein and Kiesecker (2002) even suggest that populations of the same species may respond differently to similar disturbances. This irregularity requires further analysis to improve our understanding of amphibian habitat selection and the persistence of species on disturbed landscapes (i.e. arid grasslands).

Studies on many amphibian species have largely focused on breeding sites as opposed to upland habitat use. This is not surprising since Myers (1997) reported a worldwide wetland loss of 50% over the last century and Semlitsch and Bodie (1998) highlighted the significance of small, ephemeral wetlands to amphibian species and biodiversity. Semlitsch et al. (2015) studied 200 amphibian breeding ponds within the Midwestern US (with anthropogenic and/or natural disturbance) and suggested that conservation and management of amphibians should concentrate on intermediate-sized ponds (200 – 4000 m^2) to increase abundance, richness and diversity. Various breeding pond studies have occurred on disturbed sites, yielding contrasting results: peat mining in Eastern Canada dramatically modified bog habitat complexity which decreased Green Frog (*Rana clamitans*) and Wood Frog (*Rana sylvatica*) populations, but increased the abundance of American Toads (*Bufo americanus*; Mazerolle 2003). The effect of cattle disturbance on amphibian breeding habitat also seems to vary with the species. American Toads were more numerous than Green Frogs in cattle-grazed wetlands in Tennessee (Burton et al. 2009), while Roche et al. (2012) reported no impacts from cattle grazing on the Yosemite Toad (*Bufo canorus* Camp). For terrestrial species, upland habitat choice is as equally important as breeding pond selection (Forester et al. 2006) yet has been insufficiently researched and poorly defined (Semlitsch and Bodie 2003). Determining differences in all habitat types and species preference is imperative in understanding species requirements and their persistence on a disturbed landscape.

North American spadefoots (genera *Scaphiopus* and *Spea*) are generally associated with drier, warmer habitats. They tolerate relatively dry conditions by having the ability to absorb soil moisture through their permeable skin (Ruibal et al. 1969) and develop rapidly in ephemeral ponds (COSEWIC 2007). Even though spadefoots have the quickest metamorphic rates (time from egg-laying to metamorphosis) among anurans (16-28 days; Bucholz and Hayes 2002) they can increase their rate of metamorphosis even more when exposed to water and food restriction (Boorse and Denver 2004). Bucholz and Hayes (2002) also determined that the optimal growth and development temperature for North American spadefoots was 32°C, as compared to the European spadefoots (genus *Pelobates*; 28°C) and the Parsley Frog (genus *Pelodytes*; 24°C). The spadefoot's ability to adjust to unpredictable environments has allowed it to persist in harsh conditions. This is an interesting phenomenon, which is central to the conservation of the taxon. Despite this, there are limited studies on spadefoot upland habitat use (Timm et al. 2014), particularly on disturbed landscapes.

The Great Basin Spadefoot (*Spea intermontana*) ranges north into the grasslands of south-central British Columbia (BC), an ecosystem historically subjected to a multitude of disturbances including ranching, forestry and development (Wikeem and Wikeem 2004; Klenner et al. 2008). This species is known to take advantage of a variety of habitats that are in most cases undesirable or inhospitable to other species (Hovingh 1985; COSEWIC 2007; BCSIRAWG 2017). This situation provides a suitable backdrop for examining habitat use and persistence of the spadefoot in the face of environmental change. In BC, spadefoot tadpoles have shown higher phenotypic plasticity than the Northern Red-legged Frog (*Rana aurora*) and the Pacific Tree Frog (*Pseudocris regilla*) when subjected to warmer, temporary pools (O'Regan et al. 2014). Adult spadefoots have been observed to utilize a variety of permanent and ephemeral ponds (e.g. irrigation ditches, roadsides, rain pools, water depressions made by cattle, and pond edges; Wright and Wright 1949; COSEWIC 2007). Leupin et al. (1994) found spadefoots breeding in ponds in the BC Thompson Nicola region with a wide range of pH, turbidity, temperature and vegetation levels. Auditory surveys conducted by Kline and Packham (2009) in the BC Cariboo region recorded the presence of calling spadefoots at ponds to delineate spadefoot occurrence. In addition, Garner (2012) tracked the upland movements of the spadefoot near the northernmost limits of its range, revealing core upland daytime retreat sites contained a high proportion of bare ground or rock located across the landscape. Although spadefoots can be considered specialists in this northern region due to their distribution within arid to semi-arid grasslands, they also appear plastic in their larval development period, use of breeding sites and use of daytime retreat sites within the ecosystem. Less than 1% of the land base in BC is a grassland ecosystem (Wikeem and Wikeem 2004); this ecosystem is quickly deteriorating due to anthropogenic and natural disturbance. Naturally, spadefoots in this region should be relatively resilient to these alterations, but further research is needed to determine the perseverance of these animals in this disturbed, arid ecosystem.

To add to our knowledge of how spadefoots thrive in a changing environment, I conducted an ecological study on habitat use by this species across an altered and disturbed landscape. My objectives were: (1) to compare ponds where the spadefoot did and did not breed, (2) to create artificial ponds to see if and how rapidly spadefoots would colonize them and (3) to compare used and available daytime retreat sites. Identifying features used by spadefoots for selecting breeding ponds and daytime retreat sites will allow the crafting of appropriate conservation plans to protect and enhance those features.

METHODS

Study Area

This study took place during the spadefoot active season (May—August 2013 and 2014) within the arid grasslands of the Thompson River valley, approximately 10 km west of Kamloops, BC, Canada (50°39’38” N, 120°30’50” W; elevation 650-750 m ASL). The maximum daily temperature normal (1981-2010; May—August) in this area ranges between 21.5°C and 28.3°C, with minimums ranging from 7.7°C and 13.4°C, respectively. Total average monthly rainfall at the valley bottom (elevation 345 m ASL) was 29.95 mm during the same time period (Figures 1.7, 1.8, 1.9; Government of Canada 2017). The dominant natural habitat types in this region are characterized by Ponderosa Pine (*Pinus ponderosa*), Bluebunch Wheatgrass (*Agropyron spicatum*) and Big Sagebrush (*Artemisia tridentata*) (Meidinger and Pojar 1991; MFLNRORD 2016).

The dominant causes of land disturbance (past and present) on the site are mining and cattle grazing. Both natural and anthropogenic ephemeral and permanent ponds occur sporadically across the landscape, providing a variety of water bodies (e.g. ephemeral ponds, ditches, groundwater seepage ponds) that could potentially support spadefoot breeding. More details on the site are provided in Chapter 1 of this thesis.

Breeding Pond Selection

Observations of ponds in 2013 determined which breeding and non-breeding ponds were selected for the study in 2014. Since the focus of this study was on adult preferences, a pond was categorized as being used for breeding if eggs, tadpoles and/or metamorphs were detected during multiple diurnal surveys. Breeding period was determined by adult calling (multiple nocturnal surveys), the presence of new eggs and/or recently hatched tadpoles in the ponds. Spadefoot breeding was prolific on this site (e.g. occurred in roadside ditches, flooded fields, in groundwater seepage ponds). Non-breeding ponds were less commonly found, which limited the number of ponds that could be included in the study. Water sampling and pond surveys were conducted at ten breeding and eight non-breeding ponds, within an area ≈ 9 km^2, to determine aquatic habitat preferences of the spadefoot. Eleven of the 18 ponds were anthropogenic, six of which were breeding ponds. Both natural and artificial ponds were monitored at least once a week to observe tadpole development. Stages of larval development were recorded as per Gosner (1960).

Water Characteristics

In 2014, 36 water samples were taken using a YSI Professional Plus Handheld Multiparameter Instrument and an Extech DO600 ExStik II handheld dissolved-oxygen meter (18 samples in May; 18 samples in July). Date, time, location, pH, temperature (°C), conductivity (uS/cm) and dissolved oxygen (mg/L) were recorded at all ponds following previous studies that were focused on amphibian breeding pond habitat selection (Hazell et al. 2004; Rannap et al. 2012; Drayer and Richter 2016). In addition to the temperature recorded with a handheld device, four Maxim Integrated iButton Thermochron® temperature data loggers (model DS1921G) recorded temperature in each pond every two hours over the duration of the field season (May through August 2014). A total of 797 iButton temperature readings were collected. All data loggers were individually encapsulated in waterproof cases. Two of the four data loggers at each pond were anchored just below the surface and two at the bottom of each pond to obtain an overall average of pond temperature.

Pond Characteristics

In addition to temperature, monitoring of other pond characteristics was conducted at the 18 ponds across the site at the same time as the water sampling. Pond persistence (ephemeral or permanent), hydroperiod (number of weeks containing water), origin (natural or anthropogenic), depth (m), area (hectares) and percent cover of available plant habitat (marginal, emergent, submergent, bare) were recorded.

An ephemeral pond was defined as a pond that typically dried out by mid-summer and a permanent pond was one that contained water year-round during the study period. Hydroperiod was defined as the period in which the soil area was waterlogged (Merriam-Webster 2017). The majority of rainfall in the spring of 2014 (April through June) occurred in May (41.2 mm; Government of Canada 2017). Therefore, for the purposes of this study, I considered hydroperiod to have begun on May 1, 2014 for ponds that dried up before the end of the summer.

Artificial Pond Construction

On November 9-10, 2013, four sites for pond creation were identified within a 2 km^2 area of the study site. These sites were chosen based on accessibility to roads, sufficient area to accommodate the ponds and the ability of the machinery to avoid having substantial impact on the environment. Pond excavation was conducted using a John Deere 225C LC hydraulic excavator and a Caterpillar 304CR compact excavator. One pair of ponds was established at each site (see location details in Appendix A). One pond was dug to a depth of 0.46 m and the other to a depth of 0.8 m, to approximate a shallow ephemeral pond and a deeper permanent pond, respectively. These depths were chosen based on observations of existing natural ponds, and considerations of logistics and cost. The two ponds at each site were 10 m apart and ≈ 2.5 m x 2.5 m in size.

Excavated ponds were lined with linear low-density polyethylene geomembrane liner (LLDPE). The edges of the liner were buried to provide a seamless transition from the surrounding area to the pond. Barbed-wire fences were constructed around the perimeter of each pair of ponds to protect them from cattle. The ponds were left exposed over the following winter (2013-2014) to collect precipitation.

On April 1, 2014 exposed liners along the edges of each pond were covered with burlap and overlaid with approximately 1 cm of soil to simulate the natural edges of a pond. On April 30, 2014 the water level in each pond was augmented with nearby lake water to establish water depths matching the 0.46 m and 0.8 m criteria (see above). A Ponderosa Pine tree branch was submerged within each pond to provide a substrate for egg laying and cover for tadpoles (Appendix B).

Movement and Daytime Retreat Site Selection

Radio-telemetry

Radio-telemetry was conducted to monitor terrestrial movements of adult spadefoots, and to locate daytime retreat sites (Garner 2012) on land. Adult female spadefoots were caught by hand at night between June 14—August 27 in 2013 and between June 16—24 in 2014. Males were captured between June 13—August 27 in 2013 and May 14—June 17 in 2014. Females were not captured or otherwise disturbed during the breeding period (defined by the time which males were calling) to prevent undue stress. At capture, individuals were weighed (g) on a portable electronic scale (Salter 1250BKEF) and measured (snout to vent length (SVL)). Animals at least 13.5 g were outfitted with a Holohil 0.73 g BD-2X transmitter (18-day battery life); individuals ≥ 20-22 g were equipped with 0.73 g or 0.83 g Holohil BD-2 transmitter (18- or 26-day battery life, respectively). In all cases, the total weight of transmitter and belt did not exceed 5% of the animal's body weight (Resources Inventory Committee 1998). Telemetered animals were located every 2—3 days. Locations were flagged to permit future habitat measurements and GPS coordinates were taken with a Garmin GPSMAP 62st handheld device. Date, time, location, animal ID, weather (sunny, cloudy, dry, rainy), elevation (m) and daytime retreat type (self-made burrow or small mammal burrow) were also recorded.

I categorized each daytime retreat site as a 'self-made burrow' if it was shallow (i.e. just below surface), self-dug and did not connect to a small mammal tunnel. The 'small mammal burrow' designation was applied to burrows within or connected to an active or inactive small mammal tunnel or mound. Following Pearson (1955) and Garner (2012), core daytime retreat sites were considered as those sites used multiple times in one season.

When transmitter batteries were nearing expiration dates, each telemetered animal was re-captured (nighttime period preferred to prevent disturbance to daytime retreat site), re-weighed (g) and re-measured (SVL).

Percent Ground Cover and Soil Moisture

Habitat features were assessed at each daytime retreat site using a 1 m × 1 m quadrat. Three reference plots representing 'available' habitat were also established 5 m from each retreat site at bearings of 0°, 120° and 240°. This scale would encompass and expand on the microhabitat scale used in the Garner 2012 study. Within each plot, the percent cover for six different ground types (bare, rock, litter, moss-lichen-fungi, grass-herb-shrub, coarse woody debris) were recorded along with aspect and slope. In 2014, soil moisture (%) was recorded in all plots (three readings per plot) using a soil meter (Campbell Scientific HS2 Hydrosense II Display and Sensor). Care was taken to prevent injury to the buried animal when pushing the instrument's detection rods (12 cm length) into the soil. If the position of the animal could not be confidently estimated (i.e. transmitter whip not visible or weak signal) soil moisture was not recorded.

Statistical Analysis

Statistical analysis was performed using R 3.2.5 (R Core Team, 2015) using α=0.05 as a guide to significance. Prior to conducting analysis, the categorical variables were appropriately designated using the *ordered* (for ordered categorical (ordinal) variables) and *factor* (for categorical (nominal) variables) functions (Bolker et al. 2011; Kabacoff 2011).

I tested for correlation between my predictor variables by calculating variance inflation factors (VIF) as outlined by Zuur et al. (2012). As recommended by Zuur et al. (2010), I used a VIF value of 3 as my pre-selected threshold (indicating no collinearity) versus the higher (and more flexible) value of 10 used by Montgomery and Peck (1992).

I used the *DAAG* package (Maindonald and Braun 2010) to perform a multiple logistic regression (MLR) to compare individual sampling periods (i.e. May, July) between breeding and non-breeding ponds. To determine if there was a difference in use between (1) breeding and non-breeding ponds and (2) used and available upland habitats, I conducted logistic regression using a generalized linear mixed model (GLMM; Bolker et al. 2013) in the *glmmADMB* package (Fournier et al. 2012; Skaug et al. 2015). My 'grouping variables' (pond ID and spadefoot ID) were treated as random effects and all explanatory variables (habitat measurements) were considered fixed effects.

RESULTS

Breeding Pond Selection

Spadefoot breeding was detected in ten of the 18 water bodies I monitored at the study site (seven breeding ponds throughout May, two ponds in mid-June and one pond at the end of July). Metamorph emergence was observed at seven of ten breeding ponds, with the earliest emergence detected on June 19 and the latest on August 22. At the other three breeding ponds, the last observations of tadpoles (i.e. observations were discontinued) indicated anuran development between Gosner stages 25 and 41 (Gosner 1960). An instance of developmental plasticity was observed when tadpoles in an artificial ephemeral pond developed more quickly and left their natal pond (after ~ 6 weeks of development) much earlier than tadpoles hatched a week prior in the paired permanent pond (where some remained until the end of August).

Water Characteristics

When I analyzed pH, temperature (°C), conductivity (uS/cm) and dissolved oxygen (mg/L) for May and July 2014 individually, all VIF values were < 3, indicating no collinearity; this allowed all four covariates to be used in the analysis. The above-mentioned variables were not significantly different between breeding and non-breeding ponds (all Ps ≥ 0.10). When the data for both May and July were combined, dissolved oxygen was collinear to pH, temperature (°C) and conductivity (uS/cm), so it was removed from the analysis. Once dissolved oxygen was removed, there was no significance for the combined data (all Ps $\geq$ 0.84; Table 2.1). Over the duration of the field season, iButton temperature readings revealed that daily average pond temperatures in breeding ponds were higher than non-breeding ponds (Figure 2.1).

Pond Characteristics

Within pond characteristics measurements, VIF values resulted in only pond persistence and area being removed due to collinearity, allowing elevation, hydroperiod, pond origin and pond depth to be used in the analysis. None of the pond characteristics that I measured differed significantly between breeding and non-breeding ponds (all Ps ≥ 0.97; Table 2.2).

The VIF values for vegetation were <3, indicating no collinearity, allowing all variables to be used in the analysis. There was no significant difference in percent cover of plant habitat measurements (marginal, emergent, submergent, bare) between breeding and non-breeding ponds when May and July data were combined (all Ps ≥ 0.88; Table 2.3). When I analyzed individual sampling periods, marginal and bare vegetation requirements were removed from analysis in May, and emergent was removed from analysis in July, due to collinearity. Subsequent analysis showed no significant difference between breeding and non-breeding ponds (all Ps ≥ 0.16).

Artificial Pond Construction

Of the eight artificial ponds constructed, three permanent ponds and one ephemeral pond experienced spadefoot breeding activity in the 2014 active season. My first observation of spadefoot eggs was made on May 21 in a permanent pond, located furthest from known breeding ponds (~ 1 km). This was followed by the detection of eggs in the paired ephemeral pond on June 3. Spadefoot eggs were found in a permanent pond on June 10, approximately 2 km south of the May 21 observation and 375 m south of a known breeding pond. Newly hatched eggs were last observed in a permanent pond on July 29, approximately 540 km north west of a known breeding pond. I detected tadpoles reaching the metamorphic stage at

Table 2.1. Comparison of pH, temperature (°C), conductivity (µS/cm) and dissolved oxygen (mg/L) measured in May and July 2014 between ten breeding and eight non-breeding ponds. Mean values ± standard deviation are shown, with minimum and maximum values appearing in parentheses.

Sampling Period	Pond Type	pH	Temperature (°C)	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)
May	Breeding	8.3 ± 0.6 (7.1 – 9.1)	17.4 ± 2.5 (13.5 – 22.3)	2506.5 ± 3140.0 (109.0 - 8349.0)	5.8 ± 1.0 (4.0 – 7.1)
	Non-Breeding	8.2 ± 0.7 (7.4 – 9.6)	16.7 ± 3.5 (11.6 – 22.7)	4059.0 ± 6327.1 (199.5 – 18832.0)	4.9 ± 1.2 (2.8 – 6.3)
	P-value	*0.88*	*0.63*	*0.28*	*0.11*
July	Breeding	8.6 ± 0.7 (7.2 – 9.6)	27.8 ± 3.1 (21.7 – 31.4)	5882.7 ± 7239.3 (212.2 – 20525.0)	3.5 ± 1.3 (1.3 – 5.8)
	Non-Breeding	8.7 ± 0.7 (7.8 – 9.8)	27.0 ± 4.3 (19.1 – 32.1)	7779.9 ± 12845.3 (493.9 – 38757.0)	2.2 ± 1.2 (0.5 – 3.5)
	P-value	*0.35*	*0.27*	*0.29*	*0.10*
Combined	Breeding	8.5 ± 0.7 (7.1 – 9.6)	22.6 ± 6.0 (13.5 – 31.4)	4194.6 ± 5700.4 (109.0 – 20525.0)	4.7 ± 1.6 (1.3 – 7.1)
	Non-Breeding	8.4 ± 0.7 (7.4 – 9.8)	21.9 ± 6.6 (11.6 – 32.1)	5919.4 ± 9968.7 (199.5 – 38757.0)	3.5 ± 1.8 (0.5 – 6.3)
	P-value	*0.91*	*0.96*	*0.84*	*no value (collinear)*

Table 2.2. Comparison of pond elevation (m), hydroperiod (days), depth (m) and pond area (ha) between ten breeding and eight non-breeding ponds. Mean values ± standard deviation are shown, with minimum and maximum values appearing in parentheses.

Pond Type	Elevation (m)	Hydroperiod (days)	Pond Depth (m)	Pond Area (ha)
Breeding	684.0 ± 44.9 (586 – 750)	35.9 ± 20.2 (11 – 52)	0.7 ± 1.0 (0.1 – 3.5)	1.3 ± 2.4 (0.002 – 7.9)
Non-Breeding	682.5 ± 56.1 (589 – 761)	37.4 ± 19.6 (11 – 52)	0.7 ± 0.5 (0.1 – 1.6)	2.5 ± 3.7 (0.002 – 9.2)
P-value	*> 0.99*	*0.97*	*0.99*	*no value (collinear)*

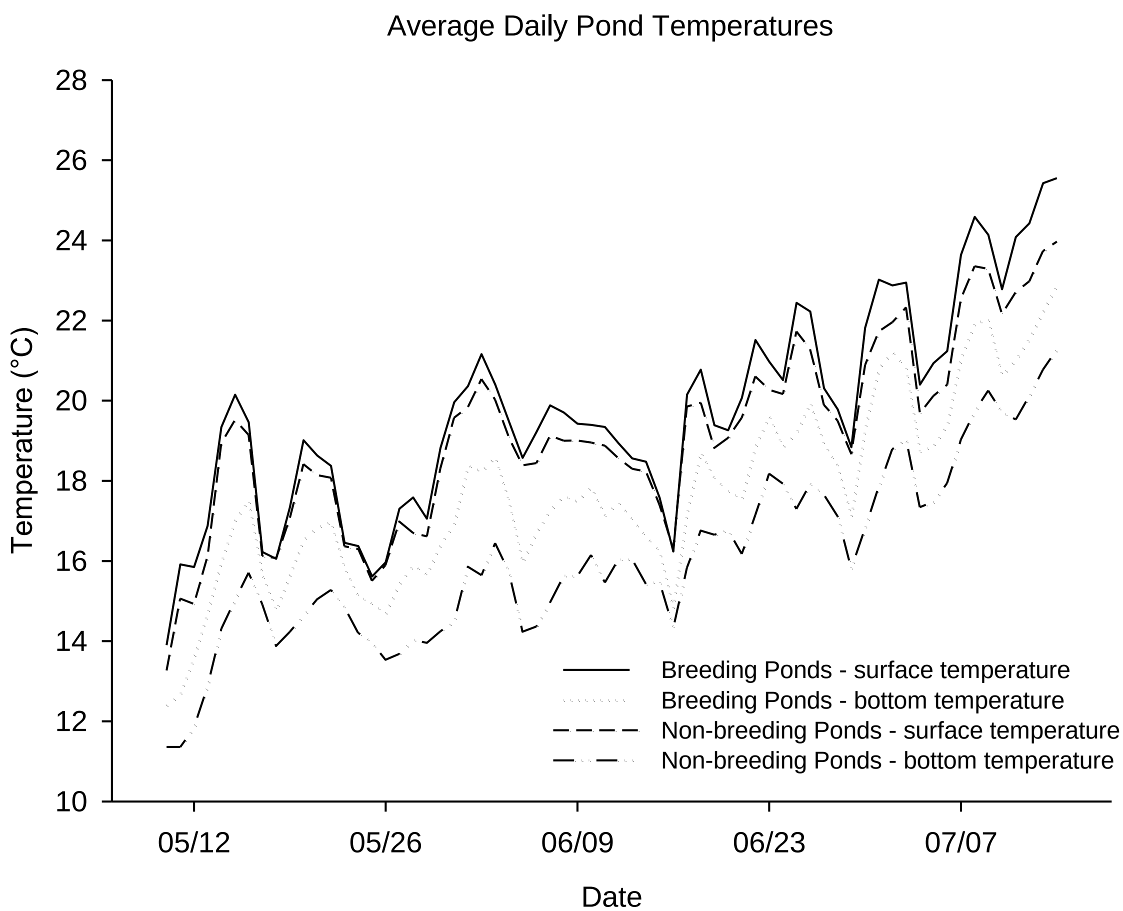

Figure 2.1. Average daily surface and bottom temperatures (°C) measured using iButton Thermochron® temperature data loggers between May and July 2014 comparing ten breeding and eight non-breeding ponds.

Table 2.3. Comparison of percent cover of each of the four plant habitats (marginal, emergent, submergent, bare) measured in May and July 2014 between ten breeding and eight non-breeding ponds. Mean values ± standard deviation are shown, with minimum and maximum values appearing in parentheses.

Sampling Period	Pond Type	Marginal (%)	Emergent (%)	Submergent (%)	Bare (%)
May	Breeding	5.0 ± 4.5 (0 - 10)	19.0 ± 26.5 (0 - 70)	7.8 ± 13.4 (0 - 40)	65.1 ± 39.6 (10 - 99)
	Non-Breeding	5.0 ± 5.3 (0 - 10)	19.4 ± 24.3 (0 - 60)	8.1 ± 9.2 (0 - 20)	62.6 ± 40.9 (5 - 99)
	P-value	*no value (collinear)*	*> 0.99*	*0.96*	*no value (collinear)*
July	Breeding	5.7 ± 3.5 (1 - 10)	17.8 ± 24.3 (0 - 60)	12.1 ± 17.0 (0 - 45)	22.3 ± 22.3 (0 - 55)
	Non-Breeding	4.5 ± 4.8 (0 - 10)	18.9 ± 27.4 (0 - 60)	10.6 ± 17.0 (0 - 50)	13.1 ± 16.2 (0 - 50)
	P-value	*0.30*	*no value (collinear)*	*0.68*	*0.16*
Combined	Breeding	5.4 ± 4.0 (0 - 10)	18.4 ± 24.8 (0 - 70)	10.0 ± 15.0 (0 - 45)	43.7 ± 38.2 (0 - 99)
	Non-Breeding	4.75 ± 4.9 (0 - 10)	19.1 ± 25.0 (0 - 60)	9.4 ± 13.3 (0 - 50)	37.9 ± 39.5 (0 - 99)
	P-value	*0.88*	*0.92*	*0.99*	*0.92*

all four ponds. All-natural ponds in the vicinity of the artificial ponds were utilized by cattle and prone to desiccation.

Movement and Daytime Retreat Site Selection

Radio-telemetry, Percent Ground Cover, Soil Moisture

Twenty-three males (weight $\bar{x}$ = 17.2 $\pm$ 1.5 SD, SVL $\bar{x}$ =51.8 mm $\pm$ 0.2 SD) and 10 females (weight $\bar{x}$ = 22.4 g $\pm$ 1.5 SD, SVL $\bar{x}$ = 55.4 mm $\pm$ 2.2 SD) were monitored with telemetry throughout 2013 and 2014. The average weight of all adult spadefoots at capture (i.e. when the transmitter was affixed) and at release (i.e. transmitter was removed) was 18.5 g ± 3.4 SD (n=33). The telemetered animals were each tracked on average 23.7 $\pm$ 18.1 SD days per individual (min = 2, max = 63), which provided 111 daytime retreat sites for analysis. In total, the telemetered spadefoots were relocated 442 times during this study and provided 781 tracking days. Average relocations per individual was 13.4 $\pm$ 7.7 SD (min = 2, max = 28).

Overall, the maximum and minimum straight-line distance (m) travelled from a breeding pond over the tracking seasons was 506 m and 0.8 m respectively. The mean of the maximum straight-line distance travelled from the breeding pond of all telemetered spadefoots (n=33) was 240 m ± 146 SD.

In 2014, five out of 20 telemetered spadefoots (4 males; 1 female) utilized core retreat sites, exhibiting similar behaviour to that reported by Pearson (1955) and Garner (2012). This pattern was particularly clear for an individual (spadefoot #2014M08) that relocated 28 times over 63 days (Figure 2.2; details in Appendix C). Of the 28 locations recorded, one location was used as a retreat site ten times, designating this site as a core retreat site, which was a self-dug burrow ~ 6 cm in diameter at the edge of a well-used cattle trail. Another male (spadefoot #2014M15), over a 17-day period, travelled ~ 740 m round-trip (Figure 2.3; details in Appendix C). This individual was lost due to transmitter failure on July 7 but found on July 9 in a previously used daytime retreat site. Both #2014M08 and #2014M15 repeated use daytime retreat sites were within 20 m of a breeding pond. An adult female (spadefoot #2014F01) utilized core retreat sites between June 16 and July 30 (Figure 2.4; Appendix C). Twenty locations were recorded during this time. An abandoned coyote den

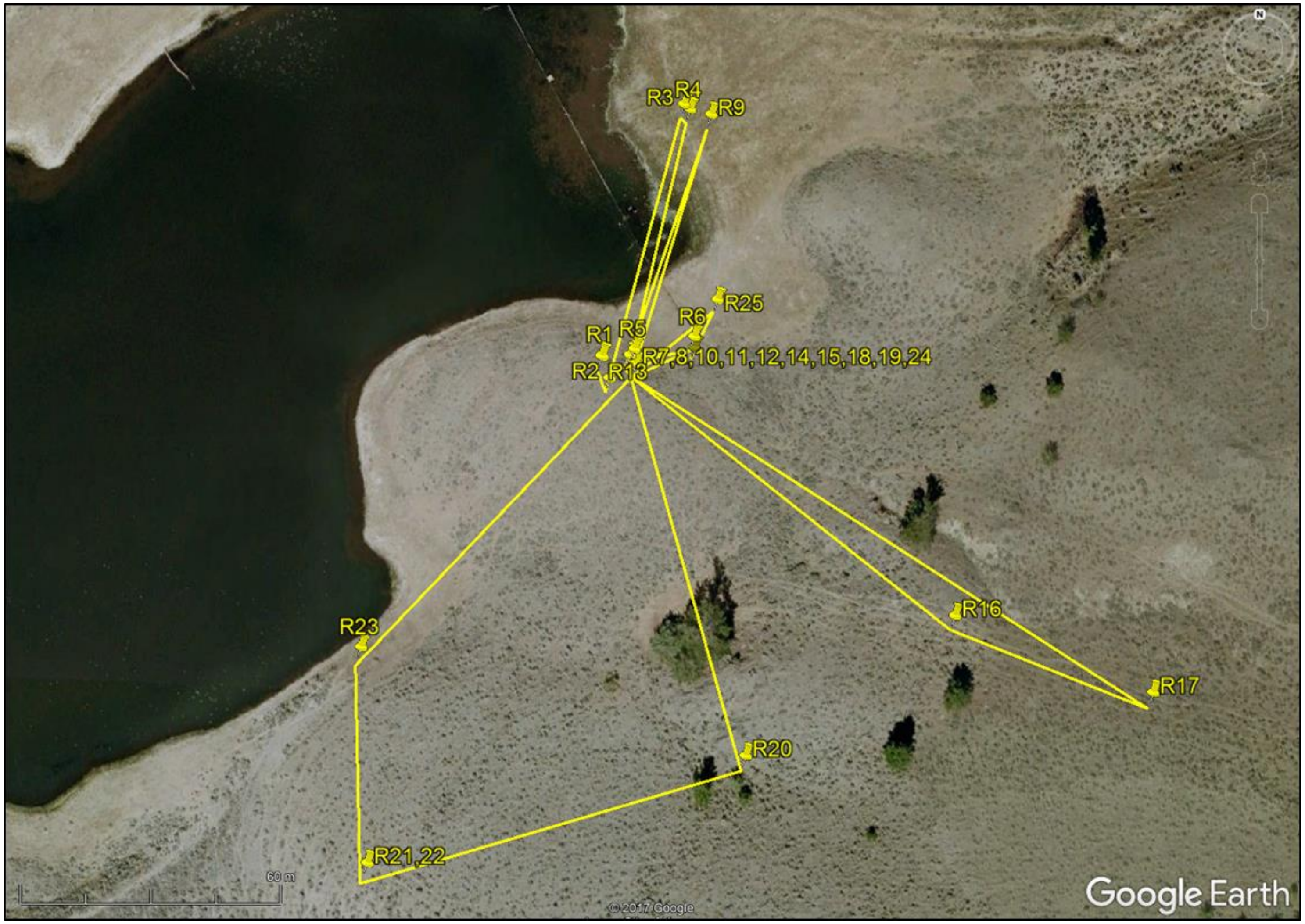

Figure 2.2. Google Earth image of the movement of spadefoot #2014M08 during the 2014 tracking season. Each marker represents each of the 28 relocations (in sequence) of the individual, beginning with R1 and ending with R28.

Figure 2.3. Google Earth image of the movement of spadefoot #2014M15 during the 2014 tracking season. Each marker represents each of the 12 relocations (in sequence) of the individual, beginning with R1 and ending with R13.

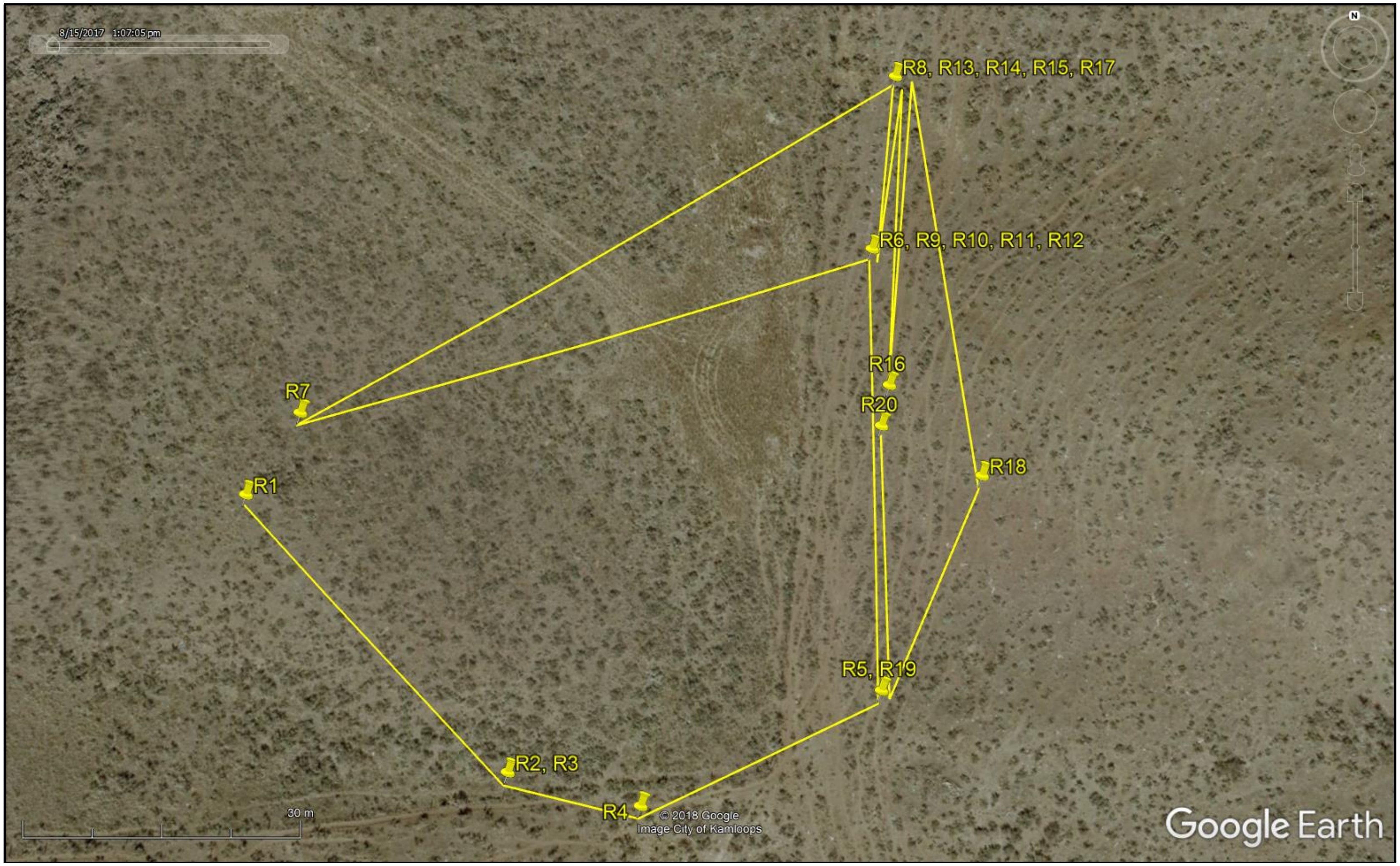

Figure 2.4. Google Earth image of the movement of spadefoot #2014F01 during the 2014 tracking season. Each marker represents each of the 20 relocations (in sequence) of the individual, beginning with R1 and ending with R20.

was utilized as a core retreat site five times between July 2 and July 23, with the spadefoot travelling a maximum distance of ~ 40 m to and from this site. This individual was initially captured ~ 300 m from the breeding pond. Garner (2012) found a positive correlation between movement in relation to weather. In this study, an observation of movement potentially related to weather occurred between June 23 and June 26. Nine out of ten telemetered spadefoots being monitored (7 males; 2 females) exhibited extensive movements between daytime retreat sites (max = 338.3 m; min = 36.8 m; $\bar{x}$ = 154.0 m ± 117.0 SD). At this time, two additional females were captured and affixed with transmitters. Historical climate data (Government of Canada 2017) indicates June 24 experienced 12.3 mm of precipitation, ending a 10-day dry spell, and preceded an additional 28 days without precipitation. This was the only occurrence of this synchronized dramatic movement over a short time period across the site.

There was no significant difference between daytime retreat sites (‘used’) and randomly chosen sites with respect to comparison of soil moisture, aspect and slope or percent ground cover (all Ps ≥ 0.32). These analyses suggest that, at least at the scale I measured, the adult spadefoots were not basing selection of the daytime retreat sites on any of the parameters I measured. Thirty out of 110 (≈ 27%) daytime retreat sites utilized by spadefoots were created by small mammals. Detailed information on each individual telemetered is summarized in Appendix C.

DISCUSSION

I found that spadefoots in this particular study are able to use a variety of habitats to complete both the breeding and summer foraging components of their life history. This species has been deemed a ‘specialist’ due to its distribution within arid to semi-arid ecosystems and is ‘specialized’ to utilize ephemeral ponds (e.g. rapid larval development) and dry upland habitat (e.g. moisture absorption through skin) unlike most amphibian species (but see Garner 2012). However, within this ecosystem, they are capable of breeding and completing metamorphosis within a range of water bodies. Further, I did not detect any habitat characteristics particular to their upland daytime retreat sites at the microhabitat scale examined. These observations support the notion that the species has the ability to inhabit drier grassland habitats as a result of a very plastic tolerance of a fairly wide range of conditions. These observations suggest opportunities may exist to successfully manage for this species under specific disturbance scenarios.

Throughout the study, I observed that breeding pond type, breeding times and metamorphosis were not synchronized across the study site. This behaviour is similar to that reported for the Great Basin Spadefoot in California (Morey and Reznick 2004). This variability is not uncommon in other anurans, such as the Foothill Yellow-legged Frog (*Rana boylii*; Wheeler et al. 2015) and the Northern Leopard Frog (*Lithobates pipiens*; Randall et al. 2014). Accelerated growth of tadpoles to reach metamorphosis prior to pond drying is common, as previously recorded in European Spadefoot Toads (genus *Pelobates*) in Romania (Cogălniceanu et al. 2013). To account for the unpredictability of spadefoot utilization of breeding ponds in this area, species-specific and site-specific monitoring programs must be incorporated into management plans.

Although for the aquatic parameters I studied, there was no significant difference between breeding and non-breeding ponds, a detailed chemical analysis of breeding water bodies might show some features that are used by spadefoots for pond selection. The permeable skin of anurans, which permits soil moisture absorption also makes the animals susceptible to various chemicals. For example, chloride concentration was found to influence breeding sites of the Caucasian Salamander (*Mertensiella caucasica*) in the western region of Turkey and Georgia (Sayım et al. 2009). High concentrations of copper sulfate ($CuSO_4 \cdot 5H_2O$) was lethal for newly-hatched tadpoles of the Northern Leopard Frog, but had no effect on the eggs of this species (Landé and Guttman 1973). A literature review of 39 papers conducted by Albecker and McCoy (2017) revealed that increasing saltwater concentrations decreased anuran survivorship across all life stages. Previous studies on two species of the European spadefoot revealed variation of salinity tolerance between life stages and species (Stănescu et al. 2017). In my study, conductivity was used as a measure of salinity in breeding ponds; it ranged from 109 to 20525 μS/cm compared to the range of 10 to 1300 μS/cm in breeding ponds for four other amphibian species (Boreal/Western Toad, *Anaxyrus boreas*; Boreal Chorus Frogs, *Pseudacris maculate*; Columbia Spotted Frogs, *Lithobates luteiventris*; and Barred Tiger Salamanders, *Ambystoma mavortium*) in the Greater Yellowstone Ecosystem

(Klaver et al. 2013). Because the response to chemicals in breeding ponds varies so much between amphibian species and life stages worldwide, more research is required to determine tolerance levels of the spadefoot in southern BC and if this impacts breeding pond selection.

The successful attraction of adult spadefoots to artificial breeding ponds within the first spring following construction suggests there is value in creating breeding ponds in drier environments. Creating and monitoring artificial breeding sites is considered an important element for recovery of this species in British Columbia (BCSIRAWG 2017). There is concern that artificial ponds may become ecological traps (COSEWIC 2007), but considering this species is known to utilize shallow ditches and puddles for breeding, and can develop rapidly from tadpole to metamorph in such situations, artificial ponds should prove beneficial in areas lacking or at risk of losing breeding ponds (Pechmann et al. 2001). Artificial ponds can be constructed quickly and with very limited equipment and funds, especially since spadefoots don't seem particularly demanding with respect to their design; my results suggest that they do not have highly specific habitat requirements for breeding. Artificial ponds should be monitored for effectiveness, built with specific species in mind and managed appropriately.

There is little comparative information about the upland movements of adult Great Basin Spadefoots from other parts of their range. The mean minimum and mean maximum movements from the breeding pond (after the breeding period) to upland habitat detected in this study are less than those found for 19 other anuran species similarly studied (see review by Semlitsch and Bodie 2003). Garner (2012) used similar methods on spadefoots near their extreme northern limit (approximately 110 km NW from my study site) and reported a smaller mean maximum straight-line distance of 135.9 m ± 98.2 SD. Timm et al. (2014) reported that Eastern Spadefoots (*Scaphiopus holbrookii*) showed a maximum mean distance of 130 m ± 28.0 SD from breeding habitats. The Garner (2012) study was conducted in a moister environment that had been impacted by decades of cattle grazing, which likely compacted the ground. Studies on the effects of cattle grazing on amphibians have produced inconsistent results, with no clear indication of overall effects (Pyke and Marty 2005; McIlroy et al. 2013). In BC, cattle grazing has been reported to cause changes in vegetation, prey species and soil compaction (Cragg 2007), that could either help or hinder amphibian species, depending on management regimes. The main drivers of, or impediments to upland movement (e.g. cattle disturbance) have yet to be determined.

Radio-telemetry revealed that during the summer, adult spadefoots in my study area travelled through the grasslands using a ‘network’ of daytime retreat sites, with individual animals often returning to specific sites. Vegetation percent cover comparisons show little variation between used and available sites. These analyses suggest that adult spadefoots are not basing their selection of these daytime retreat sites on the parameters measured in this study. A comparison of soil moisture at the daytime retreat sites to that at neighbouring available sites also revealed no significant difference. Small mammal burrows (e.g. gophers and mice) have been identified as providing refuge for spadefoots (Stebbins 2003), a feature possibly more critical when soils are compact (Sarell 2004). On my study site, small mammal burrows were used as daytime retreat sites 27% of the time.

The use of daytime retreat sites in this study was similar to observations made by Pearson (1955) and parallel to the Garner (2012) study. Spadefoots have the ability to return to the precise location of a previously-used retreat. Studies on the Spotted Salamander (*Ambystoma maculatum* - McGregor and Teska 1989) found olfaction to be used for orientation, while Reshetnikov (1998) reported that the Common Tree Frog (*Hyla arborea)* and the Green Toad (*Bufo viridis*) used a combination of olfaction and air humidity to locate breeding ponds. Russell et al. (2005) and Sinsch (2006) suggest a combination of acoustic, magnetic, mechanical, olfactory and visual cues are used by amphibians for orientation and navigation. They also recommend the need for additional studies to understand these behaviours. These studies examined orientation to breeding ponds, but not to specific daytime retreat sites which are about 6 cm in diameter. Results of my study could not explain the strong fidelity of some individuals to specific daytime retreat sites, and possibly hibernation sites. Further study is required to determine the homing capability and the attraction to frequently-utilized daytime retreat sites.

Overall, the results of this study suggest these animals may be flexible (e.g. have the ability to adjust to spatial shifts in the arrangement of breeding ponds) to changes in their environment and well-crafted management plans should be effective in maintaining animals on modified landscapes. Species-specific and site-specific aquatic and terrestrial habitat analyses are required to provide insight into species permanence in environments undergoing both long-term and short-term change (Greenberg and Waldrop 2008; Smallbone et al. 2011). In my study area, successful breeding by the animals was accomplished in a range of water bodies over two years of study. Combined, these observations suggest that the creation of artificial water bodies to replace those lost to anthropogenic or natural disturbance should be effective in helping spadefoots persist on altered landscapes. In Chapter 3, I also address the importance of appropriate microhabitat along the edges of breeding ponds. Mitigation process should be carefully structured to ensure replacement of landscape features at a pace matching that of disturbance loss. Such plans are impossible under processes that remove habitat permanently (e.g. urban sprawl), but partial mitigation can at least be attempted through the creation or re-construction of important habitat features such as water bodies and upland habitat.

Although the above findings don’t address all current knowledge gaps, they are vital to the conservation of this species. Additional information is needed about the importance of hibernation sites, and the benefits of re-using specific daytime retreat sites during the course of summer upland movements. The overall effects of landscape fragmentation and how travelling spadefoots counter resistance are also largely unexplored. Further research is required to fill these knowledge gaps and improve our management of these and other similar terrestrial species.

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Chapter 3. Microhabitat Selection By Newly-metamorphosed Great Basin Spadefoots (*Spea intermontana*): A Microcosm Study

INTRODUCTION

Habitat selection by juvenile animals is poorly understood, particularly for those species without any level of parental care or association. In these cases, habitat associations and preferences demonstrated by the young animals may be critical to immediate survival and, ultimately, successful recruitment into the population (Patrick et al. 2008). Amphibians provide striking examples of this situation: individuals transforming from aquatic larvae to terrestrial animals will abruptly face a different suite of environmental conditions, and the ability to find appropriate habitat may be imperative to survival (Rittenhouse et al. 2008). Understanding habitat selection during this stage of development is important to designing conservation strategies that do not focus solely on adult habitat needs (Biek et al. 2002; Vonesh and De la Cruz 2002).

North American spadefoots (genera *Scaphiopus* and *Spea*) are terrestrial, burrowing amphibians associated with arid or semi-arid habitats. They rely on two distinct habitats to survive: (1) water bodies for breeding and tadpole development and (2) terrestrial habitat for feeding, aestivation and hibernation (Pearson 1955). Habitat studies on these species have focused largely on adult breeding sites (e.g. Nystrom et al. 2002; Morey and Reznick 2004). As a result, very little is known about the habitat preference of newly-metamorphosed spadefoots ('metamorphs'), owing in part to their small size and cryptic nature. As post-metamorphic juveniles do not remain in the water, they are likely vulnerable to desiccation and predation upon emergence, so habitat available near the water's edge will likely play a key role in enabling some proportion of the animals to survive the critical early stages of terrestrial life (Rothermel and Semlitsch 2006; Roznick and Johnson 2009). Heinen (1993) and Baughman and Todd (2007) conducted lab experiments on recently metamorphosed anurans and concluded that vegetative cover was chosen over bare ground, and that cover was significant in providing protection from predators; however, neither of these studies included soil moisture as a factor. Jansen et al. (2001) concluded that Eastern Spadefoot metamorphs (*Scaphiopus holbrookii holbrookii*) preferred moist substrate over dry. Grover (1998) analyzed cover and soil moisture and found both to be significant in predicting abundance of both juvenile and adult terrestrial salamanders (*Plethodon cinereus* and *Plethodon glutinosus*) in a Virginia forest. Further studies are clearly required to explore the relationship between cover and moisture in determining habitat selection during the critical emergence stage of amphibians. Such work can guide the artificial creation of breeding ponds or the retention of key microhabitats during reclamation or other habitat management.

The Great Basin Spadefoot (*Spea intermontana*) ranges further north than any other spadefoot in North America, occupying the semi-arid grasslands of British Columbia (BC) (COSEWIC 2007; BCSIRAWG 2017). This ecosystem makes up less than 1% of the province (Wikeem and Wikeem 2004). Summer temperatures in these grasslands are reasonably warm during June and July, when metamorphic spadefoots tend to emerge from water bodies. The ecosystem has been affected over many decades by various forms of both anthropogenic and natural disturbance, substantially altering the habitat. This includes a dramatic decrease in grassland ephemeral ponds (Coelho 2015) that are used by the spadefoot. Extensive grazing and water use by cattle has also degraded the habitat around many of the remaining ponds (Jones et al. 2011; Teuber et al. 2013).

Given the small size of metamorphic spadefoots (see Methods), I hypothesized that newly-metamorphosed animals would be highly susceptible to the effects of desiccation, particularly in the relatively warm, dry climate in this region. In this study, I report on a microcosm experiment used to investigate microhabitat preferences of newly-metamorphosed Great Basin Spadefoots. The ultimate purpose of this work was to provide information that would help shape emerging guidelines for the rehabilitation, protection and creation of spadefoot habitat on the BC interior landscape. My work on a suite of water bodies (see Chapter 2) suggests that these animals are able to successfully breed under a wide range of physical conditions. This suggests that appropriate shoreline habitat that facilitates the transition of offspring to terrestrial habitat may play a more important role in maintaining the species on the landscape.

METHODS

Study Area

This study took place throughout August 2014 in the semi-arid grasslands in the Thompson River valley, approximately 10 km west of Kamloops, BC, Canada (50°41’38” N, 120°32’7” W). Typically, summers here are warm and dry (Chilton 1981) with normal average temperatures during June and July ranging from 11.6°C to 25.1°C and14.2°C and 28.9°C respectively (Government of Canada 2017). Ephemeral alkaline ponds and wetlands are sporadic on the landscape, a feature typical of this zone (Meidinger and Pojar 1991). Due to current and historical cattle grazing, Big Sagebrush (*Artemisia tridentata*), Cheatgrass (*Bromus tectorum*) and Knapweed (*Centaurea sp.)* dominate upland sites. The elevation of the study area is ≈ 643 meters above sea level (MSL).

To minimize artificial effects, I conducted this work outdoors in the field, in close proximity to a known spadefoot breeding site (Figure 3.1), where tadpole development was occurring naturally (see Chapter 1). This location provided a protected ‘semi-natural’ environment, open to fluctuating ambient temperature and humidity, and the diurnal cycle.

Microcosm Construction

I established a total of four enclosures (i.e. microcosms) using plastic arenas (children's wading pools) approximately 1.2 m diameter with a wall height of approximate 20 cm. Each microcosm was divided into four quadrants with one central starting platform (Figure 3.2). Across these quadrants I established four different microhabitat types: dry-bare, dry-cover, moist-bare and moist-cover. Each arena was filled to a depth of 5 cm (volume = 0.06 m^3) with a 1:1 mixture of sand and silt. Two litres of deionized water was applied to the half of the microcosm containing moist habitat. Plastic dividers were used to separate the moist soil in these quadrants from the dry treatments, but care was taken to ensure that there were no physical surface barriers for the metamorphs between the moist and dry halves. A fresh soil mixture was used in each trial to remove any chemical traces from the soil, similar to the precautions taken by Baughman and Todd (2007). The soil mixture was sifted prior to being placed into the arena to ensure all large particles were removed. Light raking ensured an even surface prior to commencement of the trial. Pine cover boards (~ 15 cm x 30 cm) were

Figure 3.1. Location of metamorph microhabitat selection study in the semi-arid grasslands in the Thompson River valley, approximately 10 km west of Kamloops, BC, Canada. Photo by author.

placed in two of the four quadrants to create ‘covered’ habitats. The boards were raised ~ 2.5 cm above the soil with wooden sticks. Stones were positioned on top of the cover boards to ensure stability. During the trials, each arena was covered with a screen, fine enough to prevent predators from entering the pools and to prevent metamorphs from escaping, but coarse enough to prevent shading.

Although the four arenas were laid out in an identical fashion, each one was sequentially rotated 0, 90, 180 and 270 degrees at the start of each trial to avoid bias in directional orientation. Following Heinen (1993) and Baughman and Todd (2007), the rotation of the arenas also controlled for other possible stimuli in the surrounding environment (e.g. presence of a wetland, direction of the sun). To collect comparative temperatures, two Maxim Integrated iButton Thermochron ® temperature data loggers (model DS1921G) were buried 2.5 cm along the outside edge of each quadrant. These loggers recorded temperatures every hour over the 36-hour trial period. Data from the loggers allowed me to verify that temperatures across the four treatment quadrants did not vary significantly and therefore exert an effect on the metamorphs.

Metamorph Introduction

During this study, metamorphosis of larvae occurred between 7 to 13 weeks of age; size at emergence from the water was 18.7 mm SVL ± 2.8 SD (n= 130) and 0.66 g ± 0.33 SD (n=130). I fenced natal ponds when tadpoles neared the later stages of metamorphosis in order to capture the animals immediately upon emergence from the water. Metamorphs were hand captured inside these fences shortly before each series of trials was about to begin (45 minutes or less). I only selected individuals that had completely absorbed their tail into their body (i.e. Gosner stage 46; Gosner 1960) and were physically able to move onto land. The animals were transported to the arenas in small plastic containers. Once there, individuals were weighed (g) on a portable electronic scale (Salter 1250BKEF) and permanently marked on the right, hind foot with fluorescent yellow Visible Implant Elastomer (VIE) (Northwest Marine Technology, Inc.). The VIE marker was utilized to ensure individuals participated in only one trial and were not later recaptured and retested.

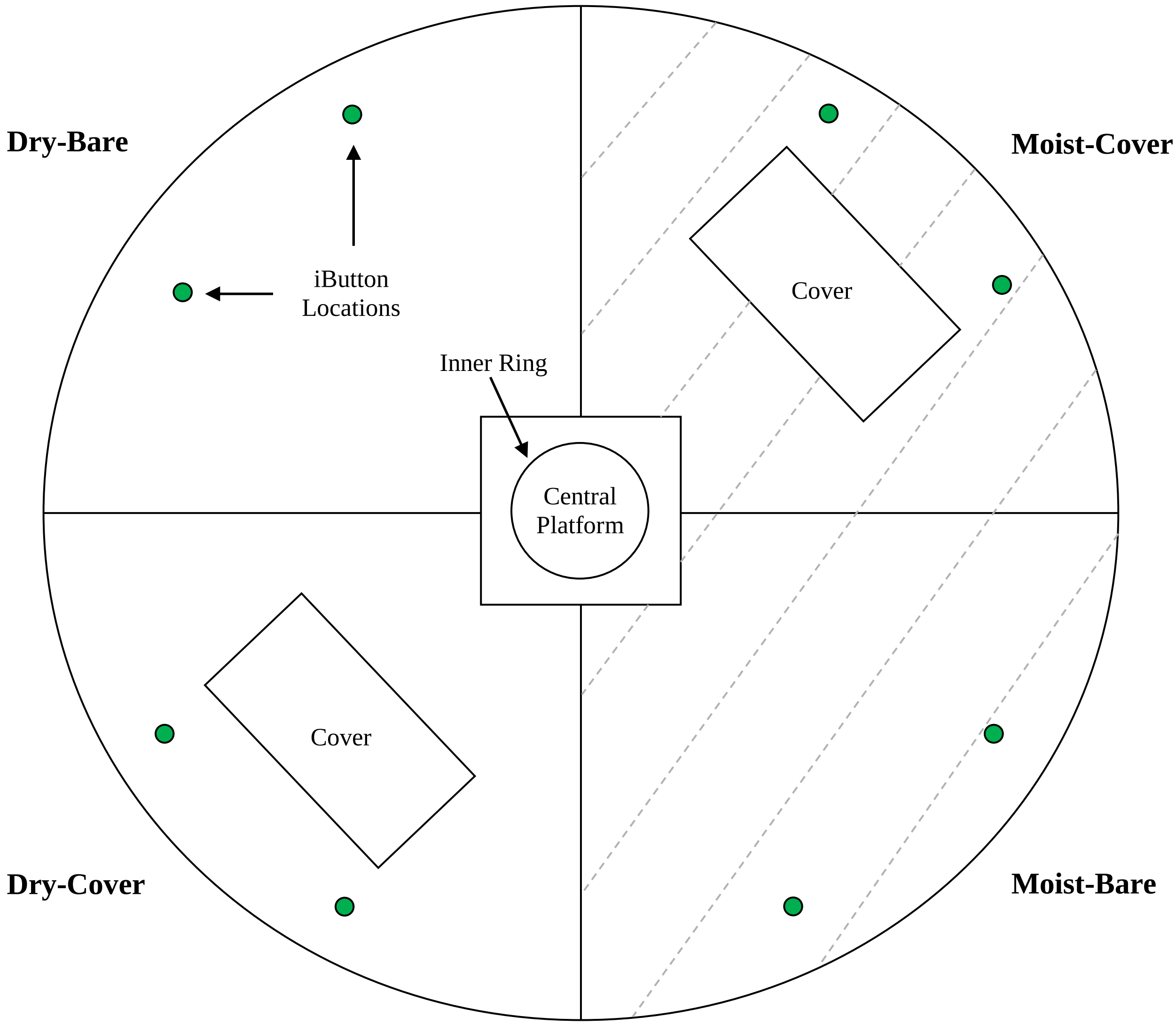

Figure 3.2. Schematic of artificial enclosure (i.e. microcosm) divided into four habitat types (e.g. dry-bare, dry-cover, moist-bare, moist-cover) to investigate microhabitat selection by newly-metamorphosed Great Basin Spadefoots.

Each trial consisted of ten newly-metamorphosed spadefoots being introduced into the centre of each of the four microcosm arenas. Once each trial was complete, the individuals were removed from the arenas and immediately released back into their original natal pond.

Microhabitat Analysis

I conducted a total of 13 trials (i.e. one set of ten spadefoots in an enclosure = one trial), run in four batches. Of 16 possible trials, one trial was omitted due to metamorphs escaping the enclosure and two were omitted due to lack of metamorphs available. Each batch took place over two nights, spanning 36 hours from start to finish. Prior to initial release, as per Baughman and Todd (2007), the animals were placed on the central platform and covered within the inner ring for ten minutes, allowing time for the individuals to partially adjust to their surroundings. The inner ring and cover was then removed and the animals were visually monitored until each had left the central platform and entered one of the four habitat quadrants. The location of each metamorph, according to quadrant association, was recorded at three time periods: At release, 12 hours and 36 hours. ‘At release’ was defined as the exact moment each individual left the inner ring and entered a quadrant. My rationale for the latter time periods was to provide ample time (including two night periods) for the animals to explore, adjust and choose a position within their new surroundings.

To determine locations of the metamorphs in the arenas at the 12 hour and 36 hour points, the screen was removed gently to prevent disturbance and a visual inspection was completed. When necessary, cover boards were briefly removed and animals were counted. Once all ten animals were accounted for in each arena, cover boards and screens were gently repositioned. Extreme care was taken to acquire individual locations as quickly as possible with no disturbance to either the animal or the arena. Metamorphs were gently unearthed if no sighting could be made, but evidence of a burrow existed; they were then promptly covered with soil.

Statistical Analysis

Statistical analysis was performed using R 3.2.5 (R Core Team , 2015). Prior to conducting analysis, the categorical variables (e.g. direction, cover type) were appropriately designated using the *ordered* (for ordered categorical (ordinal) variables) and *factor* (for categorical (nominal) variables) functions (Bolker et al. 2011; Kabacoff 2011).

I tested for correlation among my predictor variables (i.e. direction, cover type, soil temperature) by calculating a generalized variance inflation factor (GVIF) following the procedure outlined by Zuur et al. (2012) and Fox and Monette (1992). The GVIF measures how much the variance of a predictor is increased because of linear dependence with other predictors. As recommended by Zuur et al. (2010), I used a GVIF value of three as the pre-selected threshold (indicating no collinearity), versus the higher (and more flexible) value of ten as used by Montgomery and Peck (1992).

I tested whether the metamorphs exhibited equal preference for the four habitat types and directionality in each arena by conducting Fisher's exact tests using the *lattice* package in R (Sarkar 2008). The results indicated whether data within each batch of trials could be pooled for a robust analysis of metamorph microhabitat preference.

To effectively predict metamorph microhabitat selection, I analyzed the zero-inflated, grouped, non-normal count data with mixed effects using a zero-inflated Poisson (ZIP) generalized linear mixed model (GLMM; Bolker et al. 2013). The ZIP model accounted for the high number of true zeros in the count data (38.5%) (Lambert 1992; Zuur et al. 2009). The *glmmADMB* package (Fournier et al. 2012; Skaug et al. 2015) was used with a loglink function, to determine whether there was a relationship between the number of observations (i.e. number of metamorphs) within each quadrant for each trial and time period, and the three explanatory variables 'direction', 'cover' and 'soil temperature'. The random effects were attributed to our grouping (i.e. nesting) variables, 'time' and 'trial'. I completed the analysis by checking the data set for overdispersion (Crawley 2002) following the process of Zuur et al (2012).

RESULTS

In total, I collected data from thirteen arena trials (in four batches) and 130 animals. The mean air temperature (°C) during trials one through four ranged from 25.4 ± 0.9 SD and 20.9 ± 2.8 SD. Total precipitation (mm) for trial 1, 2, 3, and 4 was 0.0, 4.4, 0.7, and 0.0

respectively. At release (immediately after the ten minute acclimation period in the center of the arenas), the metamorphs dispersed into all four habitat types (e.g. dry-bare, dry-cover, moist-bare, moist-cover) showing no preference for a particular habitat type. After 12 hours, the metamorphs were beginning to show a preference for moist-cover. After the 36 hour time period, there was a clear indication that metamorphs were selecting for moist-cover habitat (Figure 3.3).

Data on microhabitat choice from the 13 trials could be pooled, as per Fisher's exact tests, for both cover type (P = 0.07) and direction (P = 0.07). The GVIF values for direction, cover and soil temperature were 1.02, 1.11 and 1.09 respectively. Metamorphs (n=130) were frequently found aggregated in the different quadrants, which in turn resulted in the majority of quadrant counts containing zero animals.

The resulting analysis of the pooled data indicated that metamorph habitat choice was dependent on cover type (P = 0.04) but independent of the direction of the arena (P = 0.62). After 36 hours, 74% of metamorphs were located in moist-cover habitat rather than dry-bare, dry-cover or moist-bare habitats. Metamorphs chose quadrants based on the type of cover represented regardless of the direction the arena was rotated.

The ZIP GLMM indicated that the metamorphs strongly preferred moist-cover habitat type (z = 6.24, P < 0.001, n=130). All other habitat types, direction and soil temperature were not significant (all other Ps > 0.19).

DISCUSSION

Previous laboratory experiments have shown that recently-metamorphosed anurans prefer some type of vegetative cover over bare ground (not including moisture as a factor) (Heinen 1993; Baughman and Todd 2007), but this study demonstrates that newly-metamorphosed Great Basin Spadefoots prefer moist microhabitats with cover. Although this response is intuitive for a small metamorphic amphibian entering a terrestrial environment, this is the first clear demonstration for such a preference within this life-history stage of this species. While this work was performed in an arena, it seems likely that metamorphs emerging from water bodies would exhibit the same behaviour in a natural setting. Observations in the field

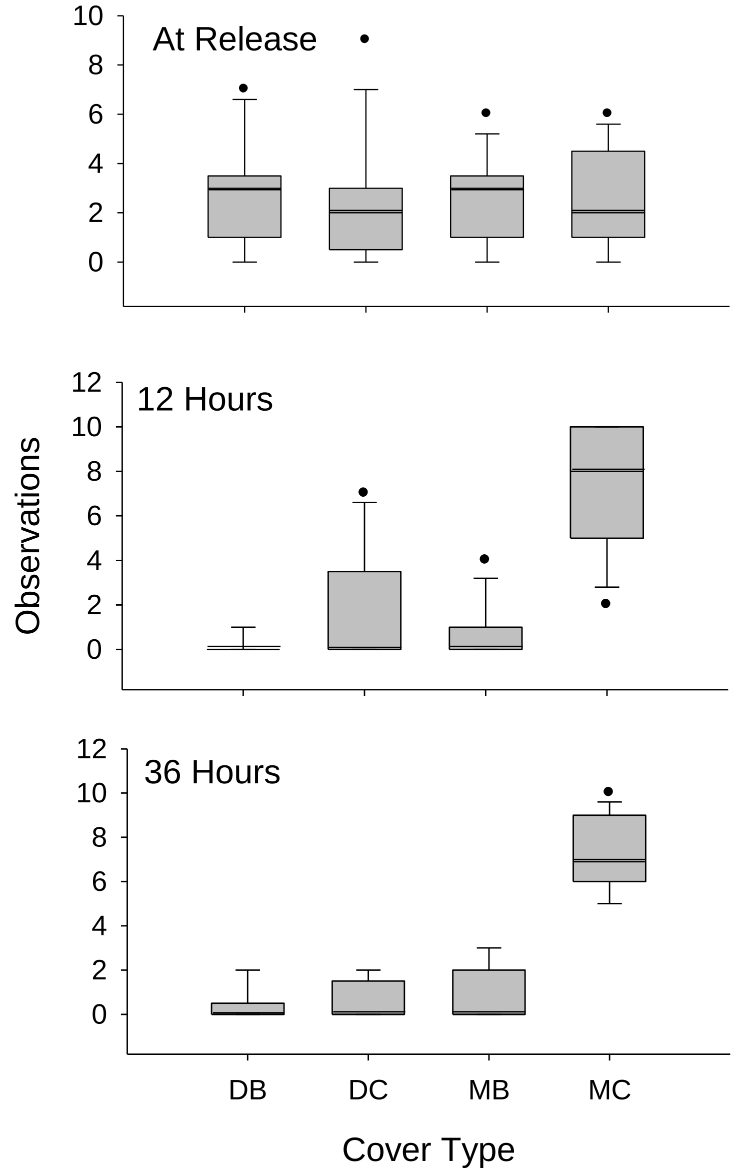

Figure 3.3. Microhabitat selection of metamorphic Great Basin Spadefoots within microcosm arenas (n=130). The four available habitat types in each arena: dry-bare (DB), dry-cover (DC), moist-bare (MB) and moist-cover (MC), are displayed on the ordinate. The locations of the metamorphs were determined over three time periods: At Release, 12 hours and 36 hours. After 36 hours, there is a clear indication that moist-cover habitat is preferred over other habitat types.

support this theory: I detected metamorphs taking refuge in moist soil under plywood adjacent to an evaporating pond, and within moist fissures at the edges of other ponds. My results parallel a field study conducted by Weintaub (1980), who found recently-metamorphosed New Mexico Spadefoot (*Scaphiopus multiplicatus*) individuals under boards, in shallow retreats, cow dung or fissures caused by drying of pond edges during the daytime. Baughman and Todd (2007) also found similar results for newly-metamorphosed Eastern Spadefoot (*Scaphiopus holbrookii*) in laboratory experiments in South Carolina. Walston and Mullin (2008) found that juvenile amphibians in Illinois, including the Small-mouthed Salamander (*Ambystoma texanum*), American Toad (*Bufo americanus*), and Wood Frog (*Rana sylvatica*), exhibited non-random orientation moving in the direction of forested habitat versus disturbed open areas with little canopy cover. Combined, these findings suggest that many, if not most, species of amphibians transitioning from an aquatic juvenile stage to one that uses drier upland habitat would preferentially seek out moist habitat with cover.

Garner (2012) studied upland habitat selection of Great Basin Spadefoots near their northern limit (about 110 km NW of the present study). Using telemetered adult animals, she found selection for daytime retreat sites that contained a relatively high proportion of bare ground (see Chapter 2). Superficially, this seems to suggest a very different pattern of habitat selection between life-history stages in this species (i.e. habitat preferences might change or shift as the animal's age). However, her study site was situated within a cooler, moister ecosystem, suggesting the animals may have been more limited by heat and thus selected for bare (warmer) ground to bury into. Further, the smaller surface area: volume ratio of the adult animals may enable them to remain buried underground for longer periods of time, retaining and/or absorbing soil moisture through their permeable skin (Ruibal et al. 1969). Metamorphs, being much smaller in size, likely have a lower tolerance for dry conditions, and therefore have different habitat requirements. This study did not examine all factors that could influence the terrestrial habitat choice of newly-metamorphosed spadefoots, but it did determine that, given the conditions provided, moist habitat with cover is preferred directly following metamorphosis.

This work has important implications for the management of this species, particularly in drier environments. Given the results of this and similar studies, I recommend retaining or establishing breeding water bodies with natural or artificial cover material (e.g. plants, coarse woody debris, cover boards) situated along the immediate perimeter (within 0.3 m) of the pond edge to provide shelter and moisture. Such conditions should increase the quality of suitable terrestrial microhabitats for vulnerable, newly-metamorphosed spadefoots. The presence of these features may be extended over larger areas surrounding water bodies to provide additional resources for the animals as they disperse further from the breeding pond. Breeding ponds also should be protected from sources of disturbance (e.g. cattle, development). Livestock use of water bodies and riparian areas can leave shorelines and neighbouring habitat devoid of vegetation and other cover.

Our knowledge of upland habitat requirements for metamorphs is significantly constrained by technology, including telemetry. Knowledge of the dispersal phase for these animals is particularly limited: the distance travelled from the breeding pond upon metamorphosis, day retreat site locations and types, and hibernation locations are virtually unknown for juvenile animals. Inventive methods will need to be employed to collect these sorts of data; for example, Popescu and Hunter (2011) tracked movement and recorded habitat preferences of newly-metamorphosed Wood Frogs using ‘runway’ enclosures with pitfall traps and tracking stations. Similar methods may be needed to further our understanding of habitat requirements for spadefoots across all life-history stages.

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CHAPTER 4. CONCLUSION

SUMMARY

The purpose of this study was to improve our understanding of the habitat associations of the Great Basin Spadefoot (*Spea intermontana*) within disturbed arid grasslands. The goal was thus to provide recommendations for action that will maintain spadefoot populations in such environments, and to assist in the development of spadefoot conservation management plans and policies such as that created by the author for the New Gold - New Afton Mine (Appendix D). Like most amphibians, the biphasic life cycle of the spadefoot requires a parallel analysis of two very distinct habitats that are each necessary for the species' survival (Pearson 1955; Melcher 2015). I investigated a variety of attributes of the aquatic and terrestrial habitats available to the species at the New Gold - New Afton Mine, and also conducted a novel microcosm study investigating metamorph habitat preferences. Prior to my study, little was known regarding adult habitat preferences within the dry, southern interior of British Columbia (BC), and even less was known about these preferences for animals in the metamorphic stage. This study provides a critical link between adult and metamorph habitat requirements. My main questions were:

1. Do spadefoots use specific types of breeding ponds?
2. Will adult spadefoots colonize artificial ponds at this site?
3. Once adult spadefoots leave breeding ponds, are there specific features they search for in daytime retreat sites? Are there movement patterns that can help predict habitat use?
4. What are the habitat preferences (at the micro-scale) of newly-metamorphosed spadefoots who rely on both aquatic and terrestrial habitats?

Notable results from my research are:

- Adult spadefoots in this area exhibited flexibility to a variety of aquatic and terrestrial conditions.
- Adult spadefoots were variable in their upland movement patterns.

- Artificial ponds were quickly colonized with successful emergence of metamorphs.
- Appropriate microhabitat (i.e. cover) along edges of breeding ponds is significant for newly-metamorphic spadefoots as they disperse into upland habitat.

My results indicated that spadefoots in this area did not select specific aquatic or terrestrial habitat features, at least within the timeframe and range occurring on my study site. This suggests the animals can utilize a variety of habitats on this arid landscape. Adult spadefoots were quick to locate and breed in artificial ponds, resulting in successful metamorphosis of spadefoots within the first season of construction. Upon exiting the ponds, newly-metamorphosed spadefoots selected daytime retreat sites that provided moisture and cover. Adult spadefoot movement patterns (e.g. distance travelled from breeding ponds, use of core daytime retreat sites) were similar to the Garner (2012) study conducted in their northernmost part of their range in the BC Cariboo region.

MANAGEMENT IMPLICATIONS

These results on the life-stage requirements of the spadefoot, provide a valuable resource for generating plans for this species in this region. This study addresses knowledge gaps in BC regarding movement and habitat use of spadefoots, and can thus help provide guidelines for the creation of artificial spadefoot habitat (BCSIRAWG 2017). For the most part, BC recovery objectives align with my results, but lack acknowledgement of newly-metamorphic spadefoot requirements.

It is imperative that we acknowledge and understand the significance of each life stage and the desirable landscape features of a species when creating effective management plans. Developing a management plan for an elusive, small nocturnal species at risk is challenging. However, collecting basic information on the natural history of these animals often enables managers to create and/or refine conservation strategies. The results of my research emphasize that management plans must be site and species specific to account for aquatic and terrestrial environments, and variations in life stage requirements. My research builds upon that of the Garner (2012) study (conducted at the extreme northern limit of the species, approximately 110 km NW of my site). As mentioned earlier, the Garner study was conducted in a considerably wetter and cooler habitat, so combined the two studies, provide valuable insight into the habitat requirements of the spadefoot in BC.

Aquatic Habitat Management

Artificial ponds, like the ones I constructed, can be used as management tools, especially in disturbed areas where there is little or no difference between the breeding and non-breeding ponds I examined. It is a staggering reality that natural breeding ponds are quickly declining, and the supplementation of breeding ponds is now a necessity. Coelho (2015) reported a 63% decline in the number of ponds in BC's southern interior grasslands from 1992-2012. Concerns that artificial ponds can be ecological sinks are valid (i.e. unsuitable breeding habitat (Sarell 2004; COSEWIC 2007)), but studies have shown that artificial ponds can be beneficial (Pechmann et al. 2001). I believe these ponds can be built in areas thought to be void of spadefoots (where they were previously observed) or provide 'stepping stones' from a pond at risk of natural or man-caused destruction to a healthy pond. Breeding times and tadpole development were not synchronized across my site, leading to my recommendations that both artificial and natural breeding ponds be maintained and protected from disturbance from the onset of the breeding season (typically April) through to complete emergence of metamorphs (exact timing is pond-dependent).

Terrestrial Habitat Management

In my study, spadefoots travelled approximately 500 m maximum distance from breeding ponds which support previous provincial habitat management zones of at least 500 m around breeding ponds to maintain connectivity (BCMFLNRORD 2014). A recent review of 162 publications (Correa Ayram et al. 2016) revealed that management plans, for a variety of species, stress the importance of habitat connectivity. Connectivity is crucial for species with biphasic life cycles, as demonstrated by the Natterjack Toad (*Bufo calamita*) in mainly-artificial habitats in Southern Belgium (Stevens and Baguette 2008) and the endangered Houston Toad (*Bufo houstonensis*) on a Boy Scouts of America Ranch in Texas (Vandewege et al. 2013). Breeding ponds are necessary for recruitment, but the majority of a spadefoot's life is spent on the terrestrial landscape.

Healthy small mammal communities (especially burrowing species) should be maintained within spadefoot habitat management zones. At the site of my study, small mammal burrows were utilized as daytime retreat sites by spadefoots ≈ 27% of the time, suggesting that these features may provide critical refuge in areas of disturbance with highly compacted soil. It has been suggested that terrestrial, burrowing anurans make use of other species burrows for refuge, potentially saving energy and alleviating desiccation (Denton and Beebee 1993; Parris 1998).

Variations in Life Stage

My work suggests that favourable habitat attributes for metamorphic spadefoots may be more specific than that of adults, requiring a more complex, holistic approach to habitat management for this species. Future populations of the spadefoot rely on successful emergence of the metamorphs from breeding ponds onto the terrestrial landscape. Metamorphs, compared to adults, are likely at a greater risk of mortality due to desiccation and predation (Beebee 2013; Cabrera-Guzmán et al. 2013). Metamorphs also experience high mortality when they emerge from the breeding ponds and seek refuge on an unknown terrestrial landscape (Rothermel and Semlitsch 2006; Roznick and Johnson 2009). This supports my microcosm results. There was a clear indication that metamorphs selected moist terrestrial habitat with cover immediately after exiting the breeding pond. This is in contrast to adult behaviour in which there was little to no significant difference in vegetation cover and soil moisture between used and available daytime retreat sites. Natural and/or artificial cover material (e.g. vegetation, coarse woody debris, cover boards), placed within the pond, staggered along the perimeter of the pond (within 0.3 m) and at various distances from the pond edge would provide shelter and moisture for metamorphs as they transition to the terrestrial landscape and would offer protection for adults during the breeding season.

LIMITATIONS AND FUTURE RESEARCH PRIORITIES

The spadefoot metamorph microcosm study attempted to replicate their natural environment in an effort to gain insight into their post-metamorphic behaviour (e.g. microhabitat preference immediately upon emergence), which is relatively unknown. Replicating natural environments can be challenging, due to uncontrollable factors (e.g. weather). The timeframe to conduct the study was limited to the rate of metamorphosis of the individuals, which varied considerably between ponds. Metamorph movement pattern studies are difficult due to their size (excludes telemetry), and their reliance on the aquatic habitat (excludes fluorescent powdering), but would further our understanding of habitat requirements during the critical transition period between land and water.

Further studies to investigate water and soil chemistry are recommended. One such study could explore spadefoot tolerance levels to metal concentrations in soil and water. Metal concentrations may be significant on disturbed landscapes, and are not always readily apparent through human observation. Levels of chloride concentration were found to negatively influence breeding sites of the Caucasian Salamander (*Mertensiella caucasica*) at lower thresholds than other amphibians in the Western Lesser Caucasus (Turkey and Georgia; Sayım et al. 2009). This suggests amphibian tolerance levels to chemical exposure should be explored in further detail.

My research has proven that not all breeding ponds are utilized at the same time, and adult spadefoots can be up to 1 km away from a breeding pond during the time period that breeding would be expected. A common 'false-negative' error in amphibian inventory is making the conclusion that a species is absent in an area simply because they are not detected. Environmental DNA (eDNA) may be useful in determining the presence of spadefoots on the landscape where breeding ponds are lacking, do not persist long enough to facilitate breeding, or where breeding simply did not occur. Although eDNA rapidly degenerates in water, it can persist in soil for decades (Thomsen and Willerslev 2015); therefore, detecting presence of a species, even though breeding did not occur or individuals were not observed. Further exploration of eDNA monitoring methods is listed as an essential (i.e. urgent) recovery action within the BC Recovery Plan for the Great Basin Spadefoot (BCSIRAWG 2017).

CONCLUDING REMARKS

My study provides room for optimism in the conservation of this iconic grassland species, suggesting that spadefoots can persist in altered habitats in this region. Due to either anthropogenic or natural disturbance, the grasslands of southern BC are rarely static. Warren and Büttner (2008) and Rose et al. (2015) proposed that some levels of disturbance were favourable to amphibian species at risk. Keeping this in mind, it is imperative that we understand spadefoot habitat requirements at all life stages to create specific strategies for recovery.

In conducting this research, I built upon past research, brought forth more questions, and most importantly, in my opinion, taught myself the significance of persistence, endurance and the ability to work with one's surroundings in order to cope with a changing world. On a narrow scale, my research focussed on the habitat requirements of the Great Basin Spadefoot in the disturbed arid grasslands. Yet, on the broad scale, that resource managers make decisions that can either help or hamper our environment and both the large and small species that reside within it. We must work together to promote biodiversity and holistic management. Spadefoots have been able to survive in these harsh environments through time, working with their environment rather than against it. We must search beyond the norm and commit to learn as much as we can about these enigmatic creatures in a concerted effort to cohabitate in an ever-changing world.

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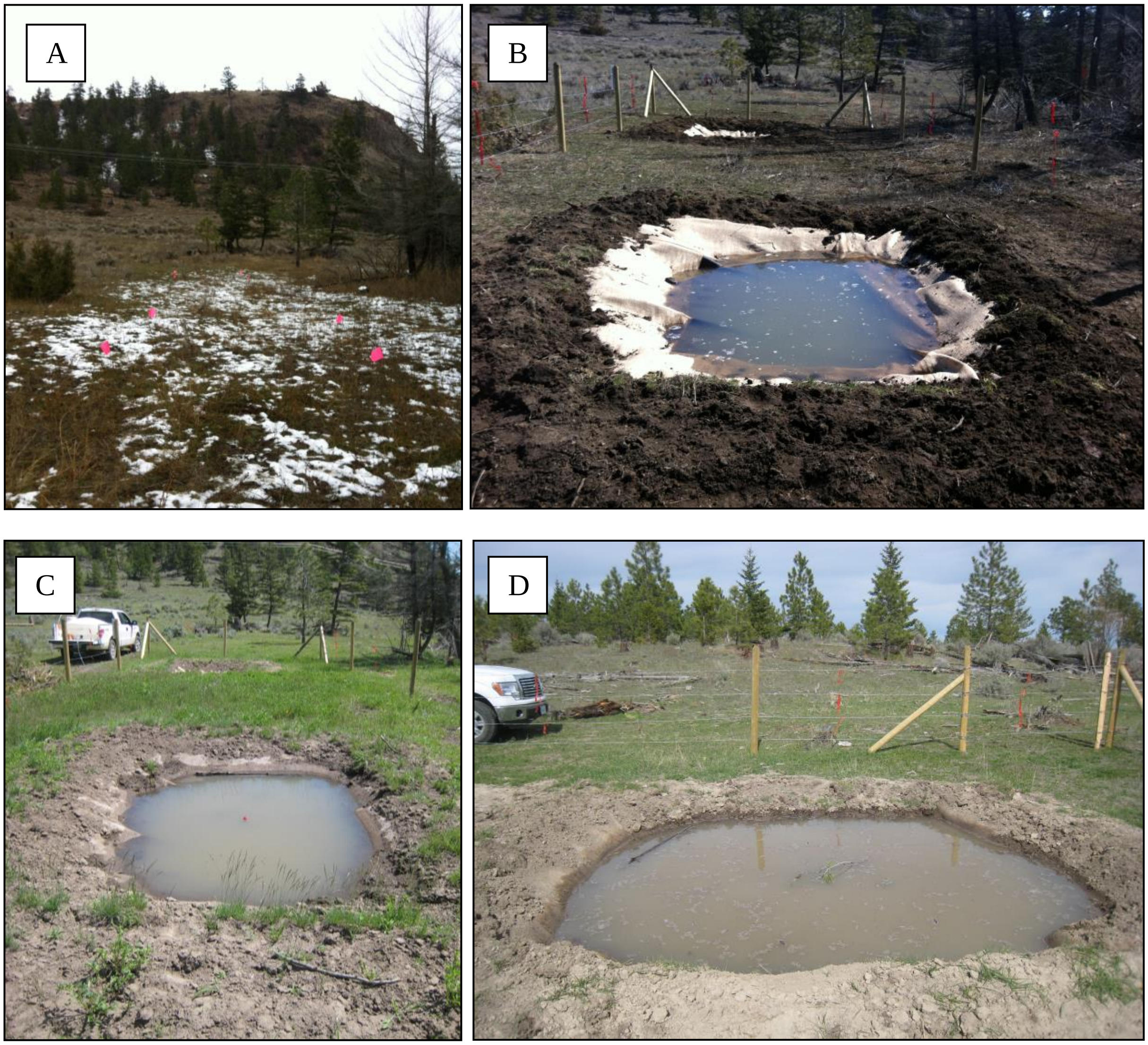
APPENDIX A. MAP OF ARTIFICIAL POND LOCATIONS

APPENDIX B. ARTIFICIAL POND CONSTRUCTION



(A) Layout of artificial pond site #2 in November 10, 2013. (B) Site #2 after exposed polyethylene geomembrane liner was covered with burlap. Note completion of barbed-wire fence surrounding the perimeter. (C) Site #2 on May 1, 2014. (D) The addition of Ponderosa Pine branch (*Pinus ponderosa*) visible in the center of the ephemeral pond at Site #3. Photos by author.

APPENDIX C. SPADEFOOT RELOCATION SUMMARY TABLE

Marker # (relocations)	Spadefoot #2014M08		Spadefoot #2014M15		Spadefoot #2014F01	
	Date of Relocation	Distance from Previous Location (m)	Date of Relocation	Distance from Previous Location (m)	Date of Relocation	Distance from Previous Location (m)
R1	15-May-14	n/a	10-Jun-14	n/a	17-Jun-14	n/a
R2	16-May-14	5.2	11-Jun-14	8	18-Jun-14	45.2
R3	19-May-14	67.3	13-Jun-14	0	20-Jun-14	0
R4	20-May-14	1.9	16-Jun-14	18.5	23-Jun-14	17.1
R5	22-May-14	58.0	18-Jun-14	141.7	25-Jun-14	31.2
R6	24-May-14	14.2	20-Jun-14	15.2	26-Jun-14	54.25
R7	26-May-14	15.1	23-Jun-14	0	30-Jun-14	71.7
R8	27-May-14	0	25-Jun-14	62	02-Jul-14	84.1
R9	30-May-14	61.5	26-Jun-14	309.3	04-Jul-14	22.7
R10	02-Jun-14	61.5	30-Jun-14	0	07-Jul-14	0
R11	04-Jun-14	0	02-Jul-14	0	09-Jul-14	0
R12	06-Jun-14	0	04-Jul-14	0	11-Jul-14	0
R13	09-Jun-14	1.0	09-Jul-14	367.5	14-Jul-14	22.9
R14	11-Jun-14	1.0			16-Jul-14	0
R15	13-Jun-14	0			17-Jul-14	0
R16	16-Jun-14	94.1			21-Jul-14	39.4
R17	18-Jun-14	47.5			23-Jul-14	39.4
R18	20-Jun-14	141.4			25-Jul-14	50.6
R19	23-Jun-14	0			28-Jul-14	28.5
R20	26-Jun-14	93.9			30-Jul-14	31.5
R21	30-Jun-14	90.2				
R22	02-Jul-14	0				
R23	04-Jul-14	49.3				
R24	07-Jul-14	91.2				
R25	09-Jul-14	24.4				
R26	11-Jul-14	12.2				
R27	14-Jul-14	0				
R28	16-Jul-14	0				

APPENDIX D. RADIO-TELEMETRY DATA SUMMARY TABLE

Spadefoot ID*	Number of Relocations	Distance from Breeding Pond (m)			Burrow Type		Days Transmitted	Weight Change (g)		
		Max	Min	Avg	Self-made	Small Mammal		At Capture	At Release	Difference
2013M01	9	65.5	14	33.9	3	0	11	13.28	13.28	0
2013M02	16	59	2	33.0	2	0	17	17.42	15.36	- 2.06
2013M03	15	115.7	0.8	29.0	2	0	16	19.96	19.44	- 0.52
2013M04	27	322.7	2.3	113.3	13	6	28	17.63	20.51	2.88
2013M05	13	125.8	28.4	67.8	2	2	14	17.22	15.73	- 1.49
2013M06	13	188.1	30	116.0	1	4	14	23.44	27.41	3.97
2013M07	5	400	396.6	398.3	1	0	5	19.18	19.18	0
2013F01	21	435	294	384.3	2	1	22	19.43	18.76	- 0.67
2013F02	15	399.6	6.1	155.0	7	2	16	23.71	19.80	- 3.91
2013F03	7	300	9.8	167.2	5	1	7	18.36	20.17	1.81
2013F04	16	205.2	179.4	194.5	1	1	22	20.65	20.65	0
2013F05	14	143.1	135	139.8	1	1	17	21.19	21.19	0
2013F06	4	440.2	414.8	427.5	-	-	7	25.00	25.00	0
2014M01	25	273	10	141.1	3	0	63	17.36	17.60	0.24
2014M02	3	19.7	12.2	15.1	-	-	5	14.99	14.99	0
2014M03	28	362.7	5	120.6	5	0	63	14.19	13.96	- 0.23
2014M04	10	505.7	7.4	377.5	-	-	19	17.80	16.83	- 0.97

Spadefoot ID*	Number of Relocations	Distance from Breeding Pond (m)			Burrow Type		Days Transmitted	Weight Change (g)		
		Max	Min	Avg	Self-made	Small Mammal		At Capture	At Release	Difference
2014M05	20	255.3	3.1	27.2	4	1	43	15.86	17.75	1.89
2014M06	9	111.4	4	19.0	1	0	16	17.62	17.62	0
2014M07	9	60.7	4.5	31.0	1	0	16	17.35	17.35	0
2014M08	28	144.5	3.9	25.4	4	1	63	14.82	18.59	3.77
2014M09	2	-	-	-	-	-	2	14.95	14.95	0
2014M10	25	288.7	5.5	126.8	2	0	63	18.16	15.40	- 2.76
2014M11	20	381	3.1	208.4	2	3	43	16.92	18.40	1.48
2014M12	9	37	6.7	14.3	1	0	16	17.39	17.39	0
2014M13	6	58.3	57.3	38.4	1	0	13	14.38	10.93	- 3.45
2014M14	5	22	4.8	11.7	1	0	10	15.00	14.05	- 0.95
2014M15	13	369.2	7.6	126.1	1	0	30	16.01	18.51	2.5
2014M16	5	210.9	150.5	198.8	1	1	10	16.28	16.28	0
2014F01	20	325.7	243.7	292.6	7	2	44	21.25	20.20	- 1.05
2014F02	8	249.1	140.3	189.0	4	1	18	23.67	23.67	0
2014F03	15	338.2	317.7	336.8	1	1	32	23.40	23.20	- 0.2
2014F04	7	460.7	335.8	367.9	1	2	16	25.60	25.60	0
Average	13.4	239.8	88.6	154	2.8	1.0	23.7	18.47	18.48	0.01
Sum	442				80	30	781	609.47	609.75	0.28
Max	28	505.7	414.8		13	6	63	25.6	27.4	3.97
Min	2	19.7	0.8		1	0	2	13.28	10.93	-3.91

* Gender is indicated by either 'M' or 'F' in the numbered sequence in the Spadefoot ID.

APPENDIX E. NEW GOLD - NEW AFTON MINE GREAT BASIN SPADEFOOT AND WESTERN TOAD MANAGEMENT PLAN – CREATED BY AUTHOR

newgold New Afton Mine		ENV-PLAN-G312 Great Basin Spadefoot and Western Toad Management Plan	
Owner: Senior Environment Coordinator	**Approver:** Manager – ESR&T	**Status:** Approved	**Date Created:** 5/1/2015
		Review Frequency: 3 Years	**Effective Date:** 12/20/2017

Objective

New Afton Mine is committed to biodiversity conservation management, as per the Biodiversity Conservation Management Plan. With this commitment comes the responsibility to improve biodiversity, protect species at risk and "do what's right." This document outlines the proactive approach that is applied by New Afton in order to ensure that it can successfully manage the Great Basin Spadefoot and the Western Toad, both listed species at risk, as part of ongoing operations and at mine closure.

Scope

The Great Basin Spadefoot and Western Toad Management Plan addresses the following key areas:

- Mapping and Distribution
- Monitoring Processes and Programs
- Enhancement and Conservation
- Education and Communication
- Annual Reporting

Introduction

New Afton mine is situated in the Bunchgrass and Ponderosa Pine biogeoclimatic zones in the southern interior of British Columbia. Wetlands are scattered throughout the property, including the private land owned by New Gold Inc. north of the Trans-Canada Highway #1. A variety of species rely on these habitats for survival, including the Great Basin Spadefoot and the Western Toad.

Great Basin Spadefoots and Western Toads require two specific habitats to survive - aquatic for breeding and terrestrial for aestivation, foraging and hibernation. They are a significant component of the ecosystem, feeding on a variety of insects (e.g. mosquito larvae, beetles) and being fed upon by other species (e.g. owls, coyotes, snakes).

The conservation status of Great Basin Spadefoots and Western Toads can be found in the table below:

	British Columbia Status	Canadian SARA Status
Great Basin Spadefoot	Blue	Threatened
Western Toad	Yellow	Special Concern

THE GREAT BASIN SPADEFOOT

The Great Basin Spadefoot is a terrestrial, burrowing anuran on the provincial blue-list (species considered vulnerable to human actions) (BCCDC 2015). In 2007, COSEWIC designated the Great Basin Spadefoot "threatened" in BC (COSEWIC 2007). The northernmost extent of its distribution is limited to the grasslands in south-central BC.

Identification

- adults average between 40-65 mm in length and 10-26 g in weight (see Figure 8)
- small, round bodies (see Figure 8)
- coloring ranges from olive green to light brown with darker spots and two lighter streaks down the back (see Figure 8)
- raised, reddish orange spots are more prominent in newly metamorphosed Great Basin Spadefoots (see Figure 5), spots darken in adults
- cat-like pupils, golden eyes (see Figure 7)
- black, keratinized spades on hind feet, used for digging (see Figure 6)

Aquatic Habitat

- typical breeding ponds are isolated, ephemeral, shallow ponds
- breeding typically occurs throughout May to early June
- males have loud, distinctive breeding calls http://amphibiaweb.org/sounds/Spea_intermontana2.mp3
- egg masses are laid on vegetation or the bottom of ponds (see Figure 1 and 2); hatching within two to four days
- tadpole development is generally 6-8 weeks (see Figure 3)
- metamorphs emerge from breeding ponds, utilizing both aquatic and terrestrial habitats (see Figure 4)

Terrestrial Habitat

- adults and juveniles (i.e. post-metamorphosis) spend most of their time on land, feeding on insects, aestivating in burrows and traversing the landscape
- on average, adults can be found within 10 m of their breeding pond DURING breeding season and 200 m of their breeding pond AFTER breeding season
- Great Basin Spadefoots hibernate in burrows (either self-dug or small mammal) below the frost line during the winter months and emerge in the spring

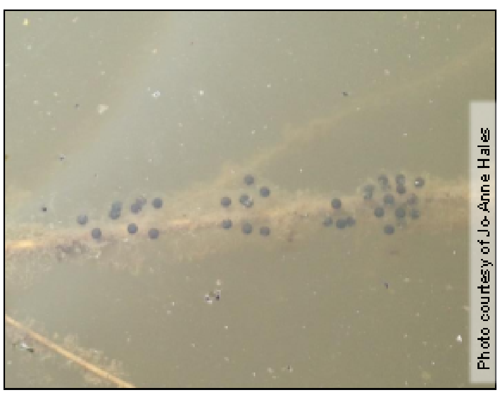


Figure 1 Great Basin Spadefoot eggs attached to vegetation in clusters.

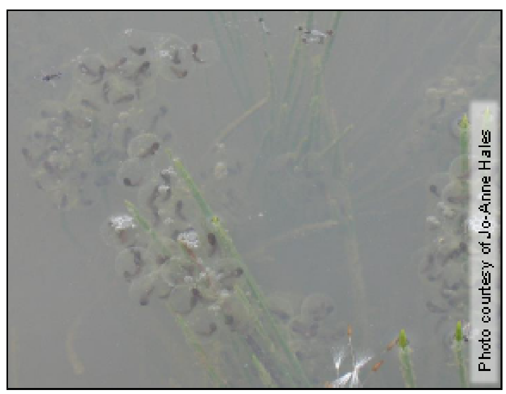


Figure 2 Great Basin Spadefoot eggs attached to vegetation, approximately 2-3 days old.

Figure 3 Great Basin Spadefoot tadpole. It has a transparent body and tail with a metallic sheen.

Figure 4 Great Basin Spadefoot. Metamorphosis is nearly complete. A remnant of the tail is visible.

Figure 5 Dorsal (back) view of newly metamorphosed Great Basin Spadefoot. Orange spots are visible.

Figure 6 Ventral (underside) of newly metamorphosed Great Basin Spadefoot with black, keratinized spades on hind feet, used for digging burrows.

Figure 7 Adult Great Basin Spadefoot with characteristic vertical, cat-like pupils.

Figure 8 Small, round adult Great Basin Spadefoot showing light stripes and darker spots on its back.

THE WESTERN TOAD

The Western Toad is a terrestrial, burrowing anuran on the provincial yellow-list (species apparently secure, with some cause for concern) (BCCDC 2016). In 2002, COSEWIC designated the Western Toad "special concern" in BC (COSEWIC 2002). The Western Toad can be found throughout most of BC.

Identification

- adults average between 60-125 mm in length (see Figure 6) (BCCDC 2015)
- horizontal pupils, gold-flecked eyes (see Figure 4)
- bumpy, dry skin (see Figure 5)
- coloring ranges from pale green to dark brown with a single yellow stripe down the back (see Figure 6)
- stocky bodies, short legs (see Figure 6)
- prominent parotoid glands behind the eyes (see Figure 6)

Aquatic Habitat

- breeding typically occurs in ponds, stream edges and shallow margins of lakes (COSEWIC 2002)
- breeding typically occurs throughout May to early June
- males have a quiet, chirping breeding call, due to their lack of a vocal sac (BCCDC 2015) http://amphibiaweb.org/sounds/Anaxyrus_boreas_boreas2.mp3
- eggs are laid in long strands amidst vegetation or on the bottom of the pond (see Figure 1 and 2)
- tadpole development is generally 4-12 weeks (see Figure 3) (BCCDC 2015)

Terrestrial Habitat

- adults and juveniles (i.e. post-metamorphosis) spend most of their time on land, feeding on insects, aestivating in burrows and traversing the landscape
- Western Toads hibernate in moist burrows (either self-dug or small mammal, below the frost line) during the winter months and emerge in the spring (COSEWIC 2002)

Figure 1 Western Toad eggs in a long individual strand.

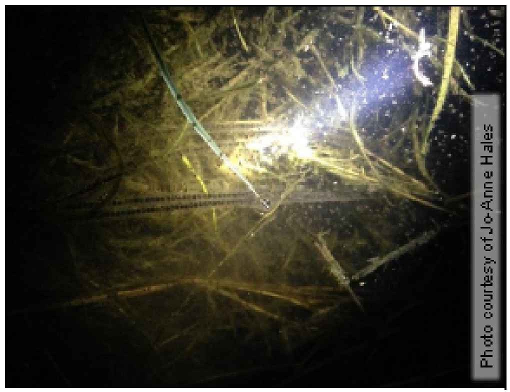


Figure 2 Multiple strands of Western Toad eggs.

Figure 3 A group of Western Toad tadpoles, black in colour.

Figure 4 A young Western Toad, lighter green in color, with bulging eyes and horizontal pupils.

Figure 5 Adult Western Toad with characteristic bumpy skin.

Figure 6 Adult Western Toad. Parotoid glands are visible behind the eyes. A single, yellow (off-white) dorsal stripe is clearly visible.

Legal and Other Regulatory Requirements

- *Mines Act* Permit M-229
- Corporate Health, Safety, Environment (HSE) and Corporate Social Responsibility (CSR) Policy
- MAC – TSM Initiative
- Wildlife Act, British Columbia
- Species at Risk Act, Canada

Responsibilities

General Manager

- Support implementation of the Great Basin Spadefoot and Western Toad Management Plan.

Department Managers

- Support the Great Basin Spadefoot and Western Toad Management Plan and ensure respective areas support the plan and all of its components.

Environment Department

- Ensure compliance with all legal and other requirements.
- Complete regulatory reports in accordance with permits and licenses.
- Communicate awareness and support workforce on the requirements under this plan.

Employees and Contractors

- Perform tasks in accordance with this plan and legal obligations as applicable.

Definitions

Aestivation

- A state of dormancy (i.e. lowered metabolic rate, inactivity) in response to high temperatures and arid conditions.

Biodiversity

- 'The variability among living organisms from all sources including, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems,' as defined by The Convention on Biodiversity at the Earth Summit in Rio de Janeiro in 1992.

Blue-listed

- In BC, a ranking for any indigenous species or subspecies that have characteristics that make them particularly sensitive or vulnerable to human activities or natural events.

Community of Interest (COI)

- Includes all individuals and groups who have an interest in, or believe they may be affected by, decisions respecting the management of operations. They include, but are not restricted to:
  - Employees
  - First Nations
  - Mining Community Members
  - Suppliers
  - Neighbours
  - Customers
  - Contractors
  - Environmental organizations and other non-governmental organizations
  - Government agencies
  - Shareholders

Conservation

- The maintenance of environmental quality and resources among the species present in a given area.

COSEWIC

- The Committee on the Status of Endangered Wildlife in Canada (COSEWIC). COSEWIC was established by the Species at Risk Act (SARA) as the authority for assessing the conservation status of wildlife species that may be at risk of extinction in Canada.

Enhancement

- The action of improving the quality of wildlife and habitats.

Ephemeral

- Temporary pools of water that provide habitat for distinctive plants and animals. They are typically non-fish bearing.

Extirpation

- Local extinction. The species no longer exists in the wild in an area. It may still occur in other areas.

Metamorphosis

- The process of transformation from an immature form to an adult form in two or more distinct stages. A 'metamorph' refers to the life stage at which an amphibian tadpole has absorbed its tail, has four limbs and can successfully emerge from the water and travel on the land.

Parotoid Gland

- An external skin gland on the back, neck or shoulder of toads, and some frogs and salamanders, which has the ability to secrete a substance to deter predators.

Species at Risk

- A species that has been defined as 'at risk' (of extirpation) by either the federal or provincial government.

Stk'emlúpsemc of the Secwépemc Nation (SSN)

- Joint partnership comprised of the Skeetchestn Indian Band and Tk'emlúps te Secwépemc.

Yellow Listed

- In BC, a ranking for any indigenous species or subspecies that are apparently secure and not at risk of extinction, but with some cause for concern.

Management Practices

1. Mapping and Distribution

Scope: To identify areas on the mine site where Great Basin Spadefoot and Western Toad breeding ponds are located and where the species have been sighted on the terrestrial landscape. This map is to be updated regularly as new information/locations are reported. This information will provide managers and key personnel with the knowledge to make informed decisions and/or plans regarding Great Basin Spadefoot and Western Toad management. This map will be updated and maintained by the Environment Department and utilized for assessment of ground disturbance approvals.

A Google Earth KMZ file is saved on the network drive at N:\ENVIRONMENTAL\0200-0299 Environment\0250 Monitoring & Measurement\065 Wildlife\Spadefoot and Western Toad Master Map.KMZ. The naming convention is spadefoot and western toad breeding pond = SPWT BP (pink wording), SP S or WT S being species specific sightings (green lettering).

Observations and mortality shall be verbally reported or recorded and submitted to the Environment Department using the *ENV-FORM-0004 Wildlife Observation Form*.

Example:

a) Sample **unofficial** google earth map showing breeding pond and sighting locations. Current map maintained by Environment Department.

2. Monitoring Processes and Programs

I. Monitoring Processes

Scope: To abide by, review and update processes at New Afton that directly relate to Great Basin Spadefoot and Western Toad habitat and if necessary, develop action plans to specifically address these species concerns.

Current Processes at New Afton Mine:

a) New Afton ESR Policy
b) Biodiversity Conservation Management Plan
c) Wildlife Management Plan
d) Integrated Pest Management Plan
e) Surface Dust Mitigation Plan
f) Communications Management Plan
g) Soils and Vegetation Management Plan

II. Monitoring Programs

Scope: To invest in monitoring, research and development that enhances New Afton's understanding of the Great Basin Spadefoot and Western Toad. Current knowledge gained through monitoring programs is crucial in the implementation and success of the Great Basin Spadefoot and Western Toad Management Plan.

Examples:

a) Masters of Science in Environmental Science Project

- A partnership between Tk'emlúps te Secwépemc, Thompson Rivers University and New Gold Inc. to research habitat selection of the Great Basin Spadefoot.

b) Field Monitoring
- Breeding Pond Locations
  - o The landscape is prone to change due to anthropogenic activities (i.e. mining) and naturally occurring events (i.e. dry/hot vs. wet/cold summers). On-site ponds/wetlands shall be monitored yearly for breeding, tadpole and metamorph activity. Environmental Technician may complete this if time allows, or work will be externally contracted.
- Adult Terrestrial Movement
  - o Great Basin Spadefoots and Western Toads are nocturnal species, emerging from their daytime retreat sites shortly after sunset to feed and explore. Due to their nocturnal lifestyle, they are difficult to locate during the day without disturbance. Night time monitoring is recommended to acquire and record visual locations. Outside of the breeding period, amphibian activity appears to be greater during cooler nights between 10:00 pm and 1:00 am.

3. Enhancement and Conservation

Scope: To create and implement programs that will maintain and improve Great Basin Spadefoot and Western Toad habitat on and/or off New Afton property. Recommendations to support this objective are as follows:

I. Enhancement Programs

- A 2013 project on New Afton private land, north of highway #1 rehabilitated a wetland prone to desiccation and cattle disturbance. The wetland provides aquatic habitat for a variety of species, including species at risk. It also provides habitat for terrestrial wildlife such as deer, bear and chipmunks.
- Artificial ponds were created in conjunction with the MSc project to determine if Great Basin Spadefoots would colonize new, artificial ponds on the landscape. Great Basin Spadefoots and Western Toads colonized the ponds within the first year.
- ***General Guidelines for Pond Creation/Enhancement***
  - o Depending on the area and water available, ponds can be as small as 8' x 8' in size and at least 2' deep to withstand summer dry-out. The water in the pond needs to last until the tadpoles have metamorphed and exited the pond.
  - o Ensure the amphibians have an easy access point in and out of the pond (i.e. gradual slopes, corners or edges).
  - o If pond water levels are dependent on spring run-off and rain events, ensure the pond edges are level with the surrounding ground.
  - o For low maintenance ponds, look for areas that provide natural water catchment.
  - o Ensure the pond has substrate to attach eggs to (e.g. vegetation, branches, burlap). Vegetation also provides shade and protection from predators.
  - o If the area surrounding the pond has been highly disturbed, seed the area with a native seed mix approved by the Environment Department, to limit the amount of invasive weed growth.
  - o Provide areas of cover (e.g. cover board placement, segments of tree bark, logs) around the outside of the pond for adult amphibians and metamorphs to hide and burrow under during the day.
  - o In areas with cattle, enclose the pond with a well-constructed fence (i.e. post and rail, barbed wire) to prevent cattle access. If necessary, create a limited cattle access point that allows cattle to drink from a small area of the pond, but not enter it.
  - o Do not put fish in the pond. They will eat amphibian eggs.

II. Conservation

All conservation efforts listed below shall be monitored, controlled and/or approved by the Environment Department.

- **Prevent Access to Undesirable Ponds**
  As per *Wildlife Act* Permit, drift fences should be constructed if Great Basin Spadefoots and Western Toads are accessing undesirable ponds (i.e. fire water storage reservoir).
- **Capture and Release**
  As per *Wildlife Act* Permit, live capture and release is permitted on-site only, by authorized personnel and terms of a Wildlife permit. A permit allows the capture and release of Great Basin Spadefoots and Western Toads if they are located in an undesirable area.
- **Habitat Corridors**
  Connectivity corridors should be maintained between breeding ponds and terrestrial habitat to avoid habitat fragmentation. These species require unobstructed access to and from breeding ponds through-out the year.
- **No Go Zone/High Activity Periods**
  The breeding season is a highly active and sensitive time period for amphibians. Precautions should be made to ensure that breeding ponds are left undisturbed during this time. Great Basin Spadefoots and Western Toads are nocturnal species and can be frequently located along roadsides during the night. Precautions should be taken (i.e. drive slowly) when driving on roads at night, to prevent their mortality by road traffic. Install road signs to alert employees, contractors and visitors of Great Basin Spadefoot and Western Toad activity on the roads at night.
- **Pollution Control**
  Amphibians are highly sensitive to pollution (i.e. toxic chemicals). All precautions should be made to prevent pollution of breeding ponds and surrounding areas (within 200 m). Care should be taken when applying dust control and pesticides in areas that are known Great Basin Spadefoot and Western Toad habitat.

4. Education and Communication

Scope: To participate in programs that will inform, educate, consult with and/or engage key COI regarding the Great Basin Spadefoot and the Western Toad.

Examples:

a) Education, Communication and Awareness

- Sustainability Newsletters – Quarterly external publication, raising awareness of production statistics, activities and projects including environmental topics.
- Environmental Bulletins released as required to notify all New Afton employees when Great Basin Spadefoots and Western Toads are active. Employees are to report any amphibian sightings to the Environment Department.
- Information and updates discussed at quarterly Environmental Monitoring Committee (comprised of employees from various departments) and Environmental Monitoring Board meetings (comprised of SSN, Ministry and New Afton representatives).
- Species at Risk awareness training included in employee and visitor orientations.

5. Annual Reporting

Scope: The Great Basin Spadefoot and Western Toad Management Plan is to be reviewed at a maximum frequency of every 3 years by the Environment and Social Responsibility Manager to ensure the plan is meeting and/or exceeding the needs of the COI and New Gold Inc. New Afton reports wildlife onsite annually in the Annual Reclamation Report as part of the M-229 Permit. If a *Wildlife Act* Permit is obtained, it is suggested to be for a 5 year time frame, which would require annual reporting to the Ministry of Forests, Lands and Natural Resource Operations. New Afton is assessed annually against the Mining Association of Canada (MAC) Towards Sustainable Mining (TSM) initiative, which includes a biodiversity component.

Preparation

- N/A

Job Step

- N/A

Document and Records

- N/A

Revisions

(Insert Date MM/DD/YYYY) Version (Editor's name):

(11/01/2016 Version) Korah DeWalt-Gagnon:

- *Updated table and footer.*

(11/07/2016 Version) Chris Higgins:

- *Minor alterations to text, no changes to intent of the plan.*

(10/15/2017 Version) Chris Higgins:

- *Added state and federal acts*
- *Removed gazette and added newsletters*
- *Added status summary table*
- *Altered Western Toad BC status to yellow*

(12/20/2017 Version) Luke Holdstock:

- *Adjusted wording based on previous comments, Wildlife Act permit is optional, review frequency is 3 yearly.*
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