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HIBERNATION SITES OF WESTERN TOADS (*ANAXYRUS BOREAS*): CHARACTERIZATION AND MANAGEMENT IMPLICATIONS

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***Abstract.*—Effective conservation of amphibians requires recognition of core habitat, a challenge for animals with distinct life stages that use distinct habitats. For example, toads require water to breed, but use terrestrial habitats to feed and hibernate. Suitable habitat for hibernation may be limiting for Western Toads (*Anaxyrus boreas*) in the north and at high elevations, but data on hibernation sites in Canada are lacking. We examined habitats used by Western Toads for hibernation at three areas in north-central Alberta, Canada. We radio-tracked toads to hibernacula, documented physical features for each location, and created resource selection function models to determine land-cover type selection. Western Toads hibernated in peat hummocks, Red Squirrel (*Tamiasciurus hudsonicus*) middens, cavities under spruce trees, decayed root tunnels, natural crevice systems, abandoned beaver lodges, and Common Muskrat (*Ondontra zibethicus*) tunnels. At two of three areas, the majority (53–79%) of toads hibernated in spruce-dominated tree stands. Toads moved long distances from breeding ponds to reach hibernation sites (range = 146–1936 m) and 68% of hibernacula were communal. At one study area, all hibernation sites were located within vegetated buffers designed to protect watercourses, but 90% and 84% of hibernation sites were located beyond buffers at the other two study areas. Our results suggest that a traditional approach to habitat protection, based on buffers along waterbodies, will not protect Western Toad hibernation sites, which are a critical component of core habitat. Disturbance of hibernation sites could have disproportionately large impacts on Western Toad populations especially if suitable sites are limited.**

Key Words.—*Anaxyrus boreas*; boreal forest; *Bufo boreas*; habitat; overwintering; radio-telemetry; resource selection function; Western Toad

INTRODUCTION

The Western Toad (*Anaxyrus* [= *Bufo*] *boreas*) was common historically throughout much of the western United States and Canada (Wind and Dupuis 2002; Corn et al. 2005). Recently, population declines of this species in parts of the U.S. and Canada have warranted the species' inclusion on the World Conservation Union's (IUCN) Red List of Threatened Species as near-threatened (Hammerson, G., G. Santos-Barrera, and E. Muths. 2004. *Bufo boreas*. 2007 IUCN Red List of Threatened Species. Available from http://www.iucnredlist.org. [Accessed 2 July 2009]) and as special concern by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC. 2009. Canadian Wildlife Species at Risk. Available at http://www.cosewic.gc.ca/eng/sct0/rpt/rpt_csar_e.pdf [Accessed 2 July 2009]). The major threats to this species are believed to be disease (e.g., Carey et al. 1999; Kiesecker et al. 2001), habitat and environmental degradation (e.g., Blaustein et al. 1994; Wind and Dupuis 2002; Hammerson et al. 2004. *op. cit.*), and synergistic effects between these factors where environmental degradation causes stress, immune suppression, and susceptibility to disease (Carey 1993).

Protection of amphibian habitat has focused on the creation of buffers around breeding ponds or waterways (e.g., Semlitsch and Bodie 2003; Goates et al. 2007). However, buffers are rarely larger than 100 m (Lee et al. 2004) and previous research suggests that they likely do not include portions of toad habitat that would be considered "core" (i.e., area that is used by 95% of the population, Crawford and Semlitsch 2007) if all activities of toads are considered. Western Toad movement studies indicate that toads use habitat between 600 and 2000 m from breeding ponds on average (Muths 2003; Bartelt et al. 2004; Bull 2006). Additionally, toad abundance in northwestern Alberta is related more strongly to land-cover types surrounding wetlands than the physical characteristics of the wetland itself (Browne et al. 2009). Terrestrial habitat is clearly important for Western Toads, and wetland buffers are unlikely to protect this portion of core habitat.

Winter is a critical time for amphibians in cold climates, yet current understanding of hibernation requirements for most species is at best fragmentary. Survival probability of Western Toads in Colorado is known to be influenced by minimum daily winter air temperature, snow depth, and winter environmental moisture level (Scherer et al. 2008), suggesting that the availability of suitable habitat for hibernation may be limiting at the northern edge of the species' range and at high elevations. The Western Toad is not a freeze-tolerant species (Mullally 1952; Holzwart and Hall 1984) and must find suitable sites below the frost-line for hibernation. In the Yukon, the species has only been reported from valleys that receive high snowfall, which prevents deep frost penetration (Cook 1977). Campbell (1970) found that Western Toads in Colorado hibernated communally (but not in physical contact with each other) in underground cavities near flowing ground water and insulated by snow. More recently, Jones et al. (1998) radio-tracked Western Toads in Colorado to hibernation and found that most used Golden-mantled Ground Squirrel (*Spermophilus lateralis*) burrows. The most northern records of Western Toad hibernacula are from Oregon, where Bull (2006) tracked Western Toads to hibernation sites and found they overwintered underground in rodent burrows, under large rocks, logs or root wads, and in banks adjacent to streams/lakes. Additionally, Bull (2006) determined that toad hibernacula were 180 to 6230 m away from breeding ponds. Similar information on hibernation sites for the Western Toad in Canada is lacking.

We examined habitat selection for hibernacula by Western Toads at three areas in Alberta, Canada. Our objectives were threefold: (1) to describe features of hibernation sites including temperatures and distance to breeding sites; (2) to determine whether government guidelines for watercourse buffers would encompass core terrestrial habitat for hibernation; and (3) to use resource selection function (RSF) analyses to determine what land-cover types are selected by Western Toads for hibernacula.

Based on earlier studies, we predicted that: (1) Western Toads in Alberta would select rodent burrows or cavities in terrestrial habitat for hibernation, similar to hibernacula described for this species elsewhere (Mullally 1952; Campbell 1970; Jones et al. 1998; Bull 2006); (2) the distance between breeding ponds and hibernation sites would differ among areas due to differences in habitat selection by toads and differences in landscape configuration; (3) female Western Toads would select hibernation sites farther from breeding ponds than males; and (4) current buffers designed to protect watercourses will not protect core habitat needed by Western Toads for hibernation.

Methods

Study area.—We assessed three areas in north-central Alberta, Canada. Each area represented a different level of disturbance, ordered from least to most disturbed: Park (breeding in 2 shallow lakes [10-20 ha]), Boreal Forest (breeding in one small, shallow pond [0.07 ha] near a gravel road and under a major utility corridor), and Pasture (breeding in 4 naturalized, man-made ponds [0.09–0.4 ha] in cattle pasture). The three areas had 4.3%, 12.5%, and 73.2% of their area covered by human-modified land-cover, respectively. Park is an isolated patch of dry mixed-wood boreal forest embedded within the Aspen Parkland natural region, in Elk Island National Park (EINP) (Alberta Government. 2005. 2005 natural regions and subregions of Alberta. Available from http://tpr.alberta.ca/parks/heritageinfocentre/docs/nsr2005_final_letter.pdf. [Accessed 2 July 2009]). Park is undeveloped and comprised mostly of upland forest surrounding shallow lakes and marsh habitat, but EINP is surrounded by agricultural land. Boreal Forest is in the central mixed-wood subregion of the Boreal Forest Natural Region (Alberta Government. 2005. *op. cit.*), 150 km north of Park, and is comprised mostly of shrub swamps, peatlands, upland boreal mixed-wood forest, and forestry cut blocks. This region is influenced by the forestry and oil/gas industries (e.g., seismic lines, pipelines), but is relatively undisturbed. Pasture consists of dry mixed-wood boreal forest that has been converted to agriculture, and is located 3.5 km west of EINP and 10 km from Park. This area includes rural housing and supports a variety of crops but is interspersed with relatively undisturbed woodlots and peatland. See Browne (2010) for more details. Land-cover features (See Resource Selection Functions section below) were measured using ArcGIS 9.2 (ESRI, Redlands California, USA) within a 2-km radius of the center of each area (the main breeding pond, or the midpoint between the main breeding ponds), encompassing an area of 12.6 km^2 per study area (Fig. 1).

Table 1. The number of Western Toads (*Anaxyrus boreas*) radio-tracked to hibernation sites at each area per year and the number of toads tracked the entire season (from breeding pond to hibernation sites).

	Tracked to Hibernation		Located Breeding and Hibernation Sites	
Year/Area	**Male**	**Female**	**Male**	**Female**
2004 Park	5	5	1	0
2005 Boreal Forest	10	11	8	6
2004 Pasture	0	2	0	2
2006 Pasture	6	11	6	5

Radio-telemetry.—We captured adult toads during the active season (May to October) in 2004–2006 at breeding ponds and opportunistically. We recorded the snout-urostyle length (SUL) to nearest millimeter, mass to nearest gram, and sex of each toad at the time of capture. Toads captured between May and August received toe-clips for identification in case transmitters were lost.

To locate hibernation sites, we radio-tracked toads from 1 wk to 5 mo prior to hibernation. Transmitter

TABLE 2. Temperatures (degrees C) experienced in hibernation sites of Western Toads (*Anaxyrus boreas*) and paired reference sites during winter of 2005/2006 at Boreal Forest near Lac La Biche, Alberta. Temperatures were recorded every 3.5 h from 8 October 2005 to 28 May 2006.

Toad ID	Hibernation or Reference	Shelter type	Depth (cm)	Min. Temp. (C)	Mean Temp. +/- SE (C)	Consecutive days below 0 C	Consecutive days below –1.5 C	Consecutive days below –5.2 C
BRO	Hibernation	Red Squirrel midden tunnel	45	-2.44	0.05 +/- 0.024	176	0.7	0
BRO	Reference	Organic soil under spruce tree	45	-1.06	-0.12 +/- 0.022	154	0	0
DAR	Hibernation	Peat hummock with cavities	53	-2.40	-0.24 +/- 0.027	149	4.7	0
DAR	Reference	Peat hummock without cavities	53	-3.37	-0.50 +/- 0.036	176	22.2	0
MEA	Hibernation	Burnt peat hummock with cavities	47	-8.38	-0.72 +/- 0.033	191	10.7	0.6
MEA	Reference	Burnt peat hummock with cavities	47	-1.40	0.21 +/- 0.030	163	0	0
MU	Hibernation	Peat hummock with cavities	62	-9.46	-1.20 +/- 0.051	175	41.9	3.2
MU	Reference	Peat hummock with cavities	62	-6.31	-0.45 +/- 0.046	150	21.7	0.7

models BD-2, BD-2T, and PD-2, weighing 1.0 to 2.3 g and a minimum battery life of 28 days to 3 mo (Holohil Systems Ltd., Carp, Ontario, Canada), were attached using a waist belt made of soft surgical grade polyethylene tubing (outside diameter = 0.97 mm; CA-63018-667, VWR International, Edmonton, Alberta, Canada) and a size 9 fly-line eyelet (sensu Bartelt and Peterson 2000). All transmitters/belts were less than 10% of body weight and most were less than 5%. We located toads 2–4 times per week. During the 3 years, we radio-tracked 116 Western Toads and followed 50 to hibernation sites (Table 1).

Physical features of hibernation sites.—We measured physical features for each hibernaculum, and assigned each a category (e.g., peat hummock, natural crevices, sandy soil). We excavated each hibernation site between 14–23 October 2004, 3–6 October 2005, and 10–12 October 2006 and recorded soil texture, soil percent organic composition, soil percent moisture, soil pH, canopy cover, toad depth below surface, depth to water table (if encountered when excavating), tunnel width, and dominant plant taxa surrounding a site (See Appendices I and II for details). We also located the toad, removed its transmitter, and measured its SUL and mass. After excavation, the site was restored as closely as possible to its original condition, and the toad was returned to its hibernaculum. Each hibernaculum excavation and restoration was completed within one day.

Measurement of temperature in hibernation sites.—We placed temperature data loggers (HOBO Temperature (degrees C) 1996 Onset Computer Corp., Bourne, MA, USA) in four toad hibernation sites and four reference sites (paired with hibernation sites) on 8 October 2005 in Boreal Forest; data loggers recorded temperatures every 3.5 h until 28 May 2006. We selected reference sites that appeared visually similar to the hibernation site (e.g., peat mounds of similar size, similar soil types) and in close proximity to the corresponding hibernation site (average = 23 m between hibernation and paired reference site, range = 12–31 m). Data loggers at the reference sites were buried at the same depth as toads were found in the paired hibernation site (Table 2). The maximum number of consecutive days below 0, -1.5, and -5.2 °C were tallied. These temperatures were targeted because Swanson et al. (1996) report crystallization to occur in the tissue of other toad species (*A. cognatus* and *A. woodhousei*) within this temperature range. We used a paired *t*-test to determine if minimum winter temperatures were significantly different between the four paired hibernation and reference sites. We used a Kolmogorov-Smirnov test to determine if data were normally distributed for all parametric tests.

Communal use of hibernation sites.—We recorded the number of toads encountered in each hibernation site, confirming a communal location if more than one toad was observed. The number of communal hibernacula was likely underestimated because we did not disturb hibernation sites more than necessary to remove the radio-tracked toad. We used a Kruskal-Wallis test to determine if the number of toads per hibernaculum differed among study areas. We compared the distribution of the number of toads per hibernaculum to a Poisson distribution using a Kolmogorov-Smirnov Z test to determine if the distribution of toads was random among hibernating sites. We used alpha ≤ 0.05 to establish significance for all statistical tests.

Distances moved from breeding ponds to hibernation sites.—We compared distances moved from breeding pond to hibernation site between Boreal Forest and Pasture and between males and females using general linear models (GLMs). Park was not included in this analysis because only one toad was tracked from breeding to hibernation site. We defined distance moved from breeding pond to hibernation site as the straight-line distance between the two points.

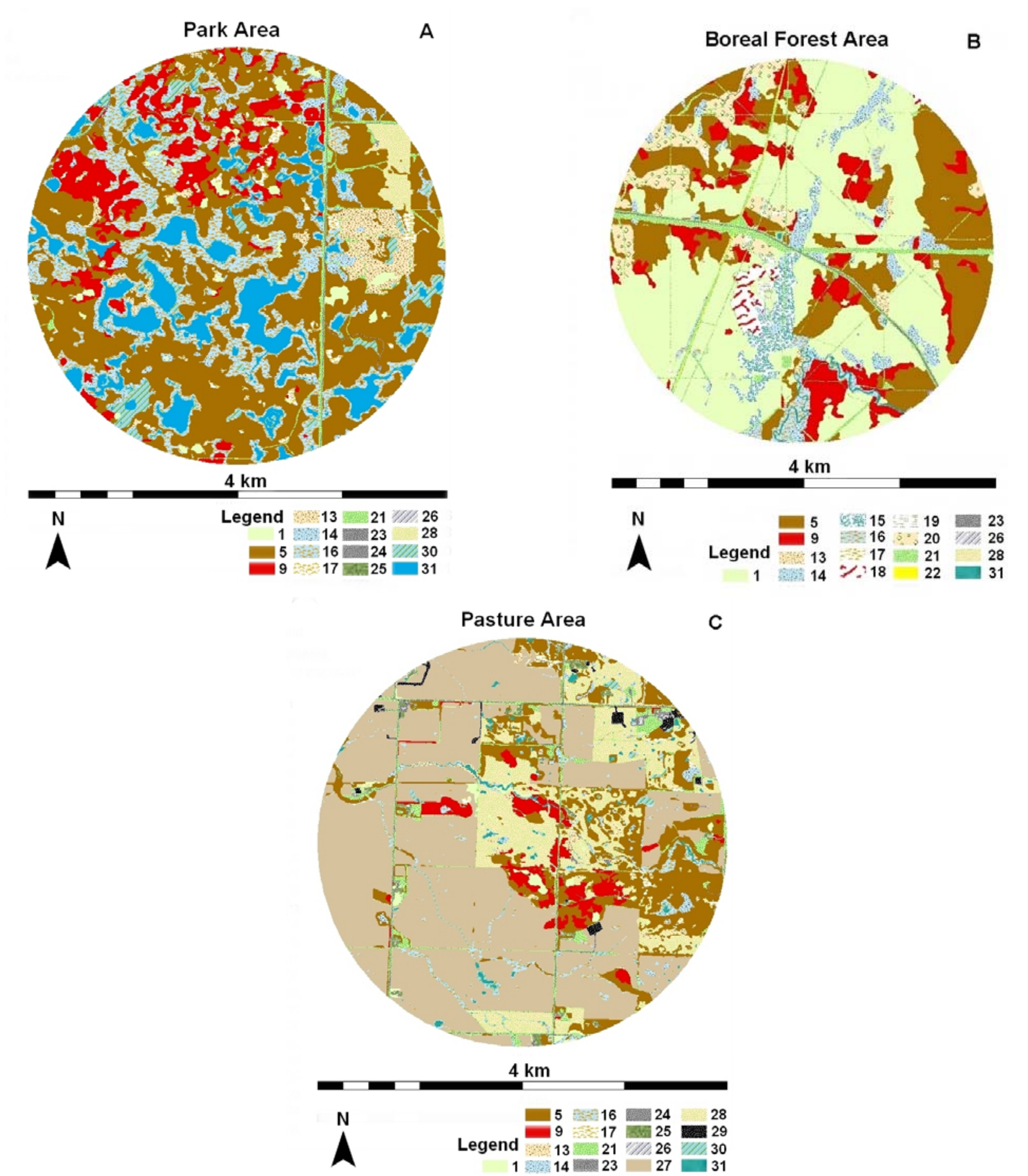

FIGURE 1. Land-cover maps created in ArcGIS for each of our study areas: (A) Park; (B) Boreal Forest; and (C) Pasture. Land-cover types are: 1 = conifer forest; 5 = deciduous forest; 9 = mixed-wood forest; 13 = dry shrubland; 14 = wet shrubland; 15 = moss; 16 = marsh; 17 = dry meadow; 18 = burn; 19 = clear-cut (grass dominated); 20 = cut-block (tree dominated); 21 = disturbed grassland; 22 = railway; 23 = gravel road; 24 = paved surface; 25 = mowed lawn; 26 = building; 27 = crop field/ hay field; 28 = pasture; 29 = exposed soil; 30 = emergent vegetation; and 31 = water.

Watercourse protective buffers.—We determined the distance between each hibernation site and the closest open water body using ArcGIS 9.1, aerial photographs, and ground-truthing. We then assessed each point to determine the percentage of hibernacula that would be protected based on the Alberta Timber Harvest Ground Rules (Alberta Government. 2008. Alberta timber harvest planning and operating ground rules framework for Renewal. Available from http://www.srd.gov.ab.ca/forests/pdf/Annex_4_draft_Jan_15_08Final.pdf [Accessed 2 July 2009]).

Resource selection functions.—We created a land-cover geographic information systems (GIS) map of 22 land-cover types from aerial photographs of each study area using ArcGIS 9.2 (See Appendix III for methods and land-cover type descriptions). We determined the number of toad hibernation sites in each land-cover type using the land-cover map and UTM coordinates for each hibernaculum, and calculated the proportion of use for each land-cover type. Available habitat for each area was calculated using ArcGIS 9.2; we considered available habitat to be any habitat within 2 km of the study-area center. Selection indices for each land-cover type were calculated by dividing the proportion of toads using the land-cover type for hibernation in a study area (number of toads in the land-cover type divided by the total number of toads) by the proportion of available habitat (area of land-cover type divided by the total area for the study area; Manly et al. 2002).

We then conducted a Resource Selection Function (RSF) analysis to determine whether the land-cover types with the highest selection indices were selected significantly more often for hibernation than other land-cover types used by Western Toads. Random locations were generated in each study area at a mean density of 1 location/1000 m^2 using Hawth's Tools (Beyer, H.L. 2004. Hawth's Analysis Tools for ArcGIS. Available from http://www.spatialecology.com/htools. [Accessed 21 August 2008]) in ArcGIS 9.2. We used Random locations that fell within land-cover types used by toads for hibernation (7765, 6266, and 2622 locations for Park, Boreal Forest, and Pasture, respectively) as available habitat points. We used logistic regression (alpha ≤ 0.05) to determine which land-cover types were most strongly selected by toads of the land-cover types used (Manly et al. 2002). We assigned a dummy variable (0 = absent, 1 = present) for each land-cover type (Hosmer and Lemeshow 2000). Three land-cover types were used for hibernation at Park, three at Boreal Forest, and four at Pasture (Table 3). We were not able to examine the same set of land-cover variables for each of our study areas because one of the land-cover types (land-cover burn, i.e., land that has recently been modified by fire) used at Boreal Forest did not occur at Park or Pasture. Therefore, we built an RSF model specific to each area using the land-cover variables that were used by toads for hibernation within that area. The reference land-cover variable (the variable omitted from the analysis to which the other variables are indirectly compared) was based on the land-cover type that occupied the greatest area within each study area. All statistical analyses were computed using SPSS version 15 (©SPSS Inc. 1989-2006. SPSS Inc., Chicago, Illinois, USA).

RESULTS

Physical features of hibernation sites.—As predicted, all toads selected pre-existing tunnels or cavities for hibernation. Seven types of hibernation sites were used (Table 4) and all were terrestrial although at some hibernation sites the water table was as little as 33 cm below surface (3 cm below recorded toad locations; Appendix I). Therefore, some toads may have entered the ground water later in the winter.

All peat hummocks were found in treed peatlands and one site was in a burnt treed peatland. Peat hummocks consisted of mounds of peat and moss. Cavities in these hummocks appeared to originate as rotted tree stumps. Toads hibernated in abandoned and active Red Squirrel (*Tamiasciurus hudsonicus*) middens and tunnels that occurred in coniferous or mixed-wood forest stands. Underground crevices occurred at two locations, one at Park and the other at Pasture. Crevices were more than 2 m deep, 2-5 cm wide, and extended many meters horizontally. Crevices appeared to be formed on pond bottoms that had dried and cracked; the surface layer was hard, dark brown, organic soil with an underlying layer of grey Gleysol. Park crevices were located in an upland grassy meadow and Pasture crevices were located within an open deciduous forest stand with an extensive shrub layer. Six toads at Pasture hibernated in cavities under White Spruce (*Picea glauca*; n = 3) or Black Spruce (*P. mariana*; n = 3) trees situated in either a treed peatland, coniferous forest, or mixed-forest. Root channels were cavities left by rotted tree roots. We found three hibernacula in such root cavities in wet shrub habitat at Boreal Forest and two hibernacula in deciduous or mixed-forest at Pasture. Abandoned American Beaver (*Castor canadensis*) lodges that were used by toads for hibernation were adjacent to lakes (Park) or streams (Pasture). The lodge adjacent to the lake was a log pile surrounded by marsh. The two lodges along streams were located in the bank and bore abundant shrub cover (e.g., Trembling Aspen [*Populus tremuloides*]; Red-osier Dogwood [*Cornus stolonifera*]; Rose [*Rosa acicularis*]). Common Muskrat (*Ondatra zibethicus*) tunnels used for hibernation were at the edges of shallow lakes at Park. These tunnels ran from deciduous forest, through marsh, and into lakes. One hibernation site was in aspen forest 20 m from the lake; the other two were in the marsh 10-15 m from the lake.

TABLE 3. Proportional use of each land-cover type occupied by 43 hibernating Western Toads (*Anaxyrus boreas*), available land-cover (proportion within 2 km of the breeding site), and selection indices for each study area, (A) Park (n = 5), (B) Boreal Forest (n = 19), and (C) Pasture (n = 19). Larger values for the selection index indicate land-cover types that were selected most strongly relative to availability. Selection index values between 0 and 1 indicate land-cover types that were used but less than proportionately available.

(A) Park (n = 5)	**Land-cover type**	**Available**	**Used**	**Selection Index**	**Standardized Selection Index**
	Dry meadow	0.015	0.2	13.00	0.76
	Marsh/wet meadow	0.165	0.6	3.63	0.21
	Deciduous forest †	0.440	0.2	0.45	0.03
	Mowed lawn	<0.001	0	0	0
	Building	<0.001	0	0	0
	Paved surface	0.001	0	0	0
	Gravel road	0.004	0	0	0
	Conifer forest ‡	0.013	0	0	0
	Pasture/sparsely vegetated	0.018	0	0	0
	Disturbed grassland	0.020	0	0	0
	Wet shrubland	0.039	0	0	0
	Dry shrubland	0.040	0	0	0
	Emergent vegetation	0.052	0	0	0
	Mixed-wood forest ℓ	0.092	0	0	0
	Water	0.100	0	0	0
(B) Boreal Forest (n = 19)	**Land-cover type**	**Available**	**Used**	**Selection Index**	**Standardized Selection Index**
	Burn	0.015	0.05	3.62	0.42
	Wet shrubland	0.048	0.16	3.27	0.38
	Conifer forest ‡	0.435	0.79	1.82	0.21
	Dry meadow	0.001	0	0	0
	Mixed-wood forest	0.002	0	0	0
	Railway	0.002	0	0	0
	Gravel road	0.005	0	0	0
	Clear-cut (grass dominated)	0.006	0	0	0
	Water	0.006	0	0	0
	Dry shrubland	0.007	0	0	0
	Marsh/wet meadow	0.015	0	0	0
	Moss/peat wetland	0.033	0	0	0
	Cut-block (tree/shrub)	0.051	0	0	0
	Disturbed grassland	0.061	0	0	0
	Mixed-wood forest ℓ	0.098	0	0	0
	Deciduous forest †	0.216	0	0	0
(C) Pasture (n = 19)	**Land-cover type**	**Available**	**Used**	**Selection Index**	**Standardized Selection Index**
	Conifer forest ‡	0.009	0.53	58.89	0.76
	Dry shrubland	0.008	0.11	13.41	0.17
	Mixed-wood forest ℓ	0.037	0.16	4.32	0.06
	Deciduous forest †	0.154	0.21	1.36	0.02
	Building	0.002	0	0	0
	Paved surface	0.004	0	0	0
	Dry meadow	0.006	0	0	0
	Exposed soil	0.006	0	0	0
	Mowed lawn	0.008	0	0	0
	Gravel road	0.009	0	0	0
	Water	0.009	0	0	0
	Emergent vegetation	0.010	0	0	0
	Wet shrubland	0.011	0	0	0
	Marsh/wet meadow	0.024	0	0	0
	Disturbed grassland	0.035	0	0	0
	Pasture/sparsely vegetated	0.140	0	0	0
	Crop field/hay field	0.528	0	0	0

† Deciduous forests were defined as having >80% deciduous trees.
‡ Coniferous forests have >80% conifer trees.
ℓ Mixed-wood forest have >20% of both deciduous and coniferous trees.

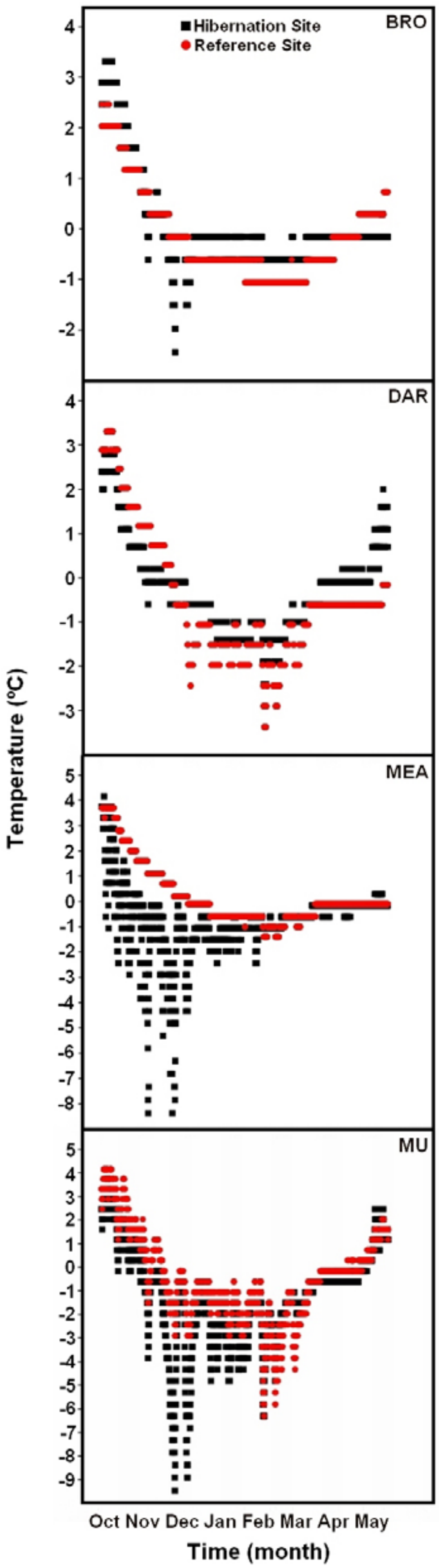

FIGURE 2. Temperatures recorded by data loggers every 3.5 h at four hibernation sites and reference sites at Boreal Forest from 8 October 2005 until 28 May 2006.

Measurement of temperature in hibernation sites.—Temperature varied little throughout the day at some sites but other sites experienced fluctuations (Fig. 2). The minimum temperature at all hibernation sites fell below –1.5 °C at some point during winter (Table 2; Fig. 2) but only two hibernation sites and one reference site experienced temperatures below –5.2 °C (Table 2; Fig. 2). The distribution of minimum temperatures from all monitored sites was not different from a normal distribution (Z = 0.689, n = 8, P = 0.729) and minimum temperatures were not different between hibernation and reference sites (t = 1.572, df = 3, P = 0.214).

Communal use of hibernation sites.—We observed communal hibernation for 68% of radio-tracked toads. Communal hibernacula contained up to 29 toads (Fig. 3); however, sites with two to five toads were most common (Fig. 4). The number of toads per hibernaculum did not differ significantly among study areas (Kruskal-Wallis χ^2 = 2.396, df = 2, P = 0.302). The distribution of the number of additional toads per hibernaculum was significantly different from a Poisson distribution (Z = 2.529, n = 50, P < 0.001; Fig. 4), indicating that toads were not distributed randomly amongst hibernation sites.

We found 125 toads in hibernacula (among 39 hibernation sites), of which 50 were our radio-tracked individuals, two were recaptures that were marked 5 mo earlier, and 73 had not previously been captured. In three cases, toads that we captured at the same breeding pond in the spring entered the same hibernation site. Of the toads captured at the breeding pond at Boreal Forest, two pairs of males shared a communal hibernaculum; these hibernacula were located 1020 m and 661 m from the breeding pond. A male and two females from Pasture moved 368 m from their breeding pond to a common hibernation site.

Males and females, and adults and juveniles (including young-of-the-year), were found together. We found toads clustered in physical contact with each other at some sites, but at other sites individuals were not touching. Inactive toads aroused quickly when disturbed.

Distances moved from breeding ponds to hibernation sites.—We tracked 28 individuals (15 males and 13 females) for the entire active season, from their breeding ponds to hibernation sites (Table 1). Toads moved farther between breeding and hibernation sites at Boreal Forest (mean = 1086 m ± 128 SE, 95% CI = 835–1337 m, range = 220–1936 m, n = 14) compared to Pasture (mean = 373 m ± 39 SE, 95% CI = 297–449 m, range = 146–682 m, n = 13). Parametric statistics were used because the distribution of distances moved was not significantly different from a normal distribution (Z = 0.922, n = 27, P = 0.363). There was a significant

TABLE 4. Hibernation sites used by Western Toads (*Anaxyrus boreas*) in north-central Alberta.

Hibernation structure type	2004 Park	2005 Boreal Forest	2004 Pasture	2006 Pasture
Cavities in peat hummocks	0	14	0	1
Red Squirrel middens	0	4	2	3
Natural crevices	6	0	0	2
Cavities under spruce trees	0	0	0	6
Decayed root channels	0	3	0	2
Abandoned beaver lodges	1	0	0	3
Muskrat tunnels	3	0	0	0

TABLE 5. Results of a general linear model examining the influence of study area and sex on the straight-line distances moved by Western Toads (*Anaxyrus boreas*) between breeding ponds and hibernation sites.

Source	df	*F*	*P*-value
Model	3	8.625	0.001
Intercept	1	102.715	<0.001
Study area	1	23.974	<0.001
Sex	1	0.460	0.504
Study area * Sex	1	0.209	0.652
Total	27		

difference in distances moved between Pasture and Boreal Forest but not between sexes (Table 5).

Watercourse protective buffers.—All toad hibernation sites at Park were located within 100 m of a lake. At Boreal Forest, one hibernation site was located within 30 m of a small permanent stream (channel width 0.7–5 m) and another was located within 60 m of a large permanent stream (channel width > 5 m), while all other hibernation sites (n = 15 sites and 19 tracked toads, 90% of toads tracked) were located beyond the watercourse protective buffer. At Pasture, three toads hibernated within 30 m of a small permanent stream, but all other hibernation sites (n = 15 sites and 16 tracked toads, 84% of toads tracked) were located over 100 m from water.

Resource Selection Functions.—We excluded toads first captured in September or October within 25 m of another radio-tracked toad with which they eventually hibernated (five from Park in 2004 and two from Boreal Forest in 2005) from analyses because these observations were not independent; i.e., these late-season toads were encountered only because they congregated near hibernacula that we had already located via radio-tracked toads. All land-cover types used for hibernation had selection index values greater than one, except for deciduous forest at Park (Table 3). Therefore, all land-cover types used were selected at rates higher than their relative availability, except for deciduous forest at Park, which was used at lower rates than its occurrence on the landscape.

Of the land-cover types used for hibernation, dry meadow at Park, and conifer forest and dry shrubland at Pasture, were selected significantly more frequently than the reference land-cover, deciduous forest (Table 6). In contrast, of the land-cover types used for hibernation at Boreal Forest, none showed significant selection or avoidance compared to conifer forest (Table 6).

DISCUSSION

Physical features of hibernation sites.—Our study is the first known to locate and describe, in detail, hibernation sites for the Western Toad in Canada, or any amphibian at these latitudes in North America. Western Toads hibernated terrestrially and selected pre-existing tunnels or cavities in north-central Alberta. This is consistent with observations from other parts of the species' range (Mullally 1952; Campbell 1970; Jones et al. 1998; Bull 2006). Sandy patches were common at our study areas, but none of our toads dug into the sand or loose soil as described for Canadian Toads (*A. hemiophrys*; Breckenridge and Tester 1961; Kuyt 1991) and Natterjack Toads (*Epidalea calamita*; Denton and Beebee 1993; Bosman et al. 1996). The tubercles on the hind-feet (used for digging) of the Western Toad are much smaller and softer than those of the Canadian Toad (Wayne Roberts, pers. comm.), possibly hindering their ability to burrow.

Unlike Western Toads from Colorado (Jones et al. 1998) and California (Mullally 1952), toads in Alberta did not use ground-squirrel tunnels for hibernation, even though Richardson ground squirrel (*Spermophilus richardsonii*) tunnels were abundant at Pasture and were commonly used by toads during the spring and summer (~15% of all locations during radio-tracking). One toad occupied a ground squirrel tunnel 25 m from his breeding pond for the entire foraging season, but moved 446 m to a coniferous forest in early September to hibernate. Most of the ground squirrel tunnels were located in open habitat with sandy soil, so perhaps these locations were too cold, dry, or poorly insulated for toad hibernation.

Some of the toads in our study were found hibernating in locations where the water table was close to the surface. Because some species of toads are known to continue to burrow throughout the winter to stay below the frost line (Tester and Breckenridge 1964a), toads in the present study may have entered ground water later in

TABLE 6. Resource Selection Function models examining whether land-cover types were significantly selected by Western Toads (*Anaxyrus boreas*) compared to reference land-cover types: deciduous forest at Park (n = 5) and Pasture (n = 19), and conifer forest at Boreal Forest (n = 19). *P*-values less than 0.05 indicate significant selection (positive coefficient) or avoidance (negative coefficient) in relation to the reference land-cover variable.

Study Area	Variable	Coefficient	S.E.	Odds ratio	*P*-value
Park	(Constant)	-8.616	1.000		<0.001
	Dry meadow	3.541	1.416	34.5	0.012
	Marsh	2.071	1.155	7.9	0.073
Boreal Forest	(Constant)	-5.904	0.259		<0.001
	Wet shrubland	0.622	0.634	1.9	0.326
	Burn	0.705	1.036	2.0	0.496
Pasture	(Constant)	-6.185	0.501		<0.001
	Conifer forest	3.708	0.599	40.8	<0.001
	Dry shrubland	2.233	0.872	9.3	0.010
	Mixed-wood forest	1.156	0.766	3.2	0.131

the season. We did not measure how deep the frost-line penetrated the substrate at these sites, but peatlands in northern Alberta can freeze up to 80 cm deep (Kevin Devito, pers. comm.). Western toads have never been observed hibernating in water, but some locations where we found toads at Boreal Forest appeared likely to freeze down to the water table. Cavities filled with water were present in the ground at some of these sites, which would have allowed toads to move deeper, if they were able to hibernate in water. In Sweden, Hagstrom (1982) discovered that Common Toads (*Bufo bufo*; typically a terrestrial hibernator) hibernate on land or in water, with the preferred location dependent on local conditions. Therefore, toads from northern climates may have different adaptations for hibernation than populations farther south.

Measurement of temperature in hibernation sites.—Hibernation sites at Boreal Forest were not significantly warmer in winter than paired references sites selected based on visual similarity to hibernacula, suggesting that other variables (e.g., soil moisture, water-table level, presence of tunnels, cavity size) play a role in the selection of hibernacula. Toads are not freeze-tolerant and have been reported to die at temperatures between –1.5 to –5.2 °C (Swanson et al. 1996). Tissue crystallization temperature depends on substrate moisture; toads freeze at higher sub-zero temperatures on wet substrate because inoculative freezing occurs (Swanson et al. 1996). Temperatures at two of our hibernation sites fell well below this range (–8.38 and –9.46 °C) and were below –5.2 °C for over 0.5 d (Table 2); therefore, any toads that remained at this location likely did not survive. We suspect that the toads at these sites remained, but dug deeper into the soft organic soil to keep below the frost line; however, we did not attempt to relocate toads in the spring. Alternatively, *A. b. boreas* may have greater tolerance to freezing temperatures. We are not aware of any studies that have examined temperature tolerance for Western Toads in the northern part of their range.

Communal use of hibernation sites.—We provided evidence for communal hibernation in Western Toads, corroborating earlier studies (Campbell 1970; Jones et al. 1998; but see Bull 2006, who did not find communal hibernation in Western Toads in Oregon). Toads may hibernate communally because suitable hibernation sites are limited or there are benefits to aggregation (e.g., predator defense; a predator may sample only one individual in a group, as this genus is known to be toxic; Licht and Low 1968). We propose that suitable sites for hibernation are uncommon across the study landscapes, as toads traveled long distances from their breeding ponds to reach hibernacula (range = 146–1936 m). The fact that two to three toads, that were radio-tracked the entire season, shared hibernation sites on three occasions indicates that communal hibernation is not simply a by-product of large population size. Tester and Breckenridge (1964b) suspected that communally hibernating Canadian Toads were selecting sites based on physical characteristics, independent of the presence of other toads.

Distances moved from breeding ponds to hibernation sites.—Movement distance ranged from 13–1936 m (mean = 717 m, n = 28) and toads from Boreal Forest moved farther from breeding ponds to reach hibernation sites than toads from Pasture. A difference in movement distances between areas suggests that toad movements are not fixed, but are labile in response to the configuration of the landscape. The majority (16 of 19) of toads at Pasture hibernated in a woodlot located 50–900 m from breeding ponds. The Pasture landscape was dominated by agriculture (67%), which was never used by toads for hibernation and presumably was unsuitable.

FIGURE 3. Twenty-nine Western Toads (*Anaxyrus boreas*) captured from a peat hummock hibernacula at Boreal Forest. (Photographed by Constance Browne).

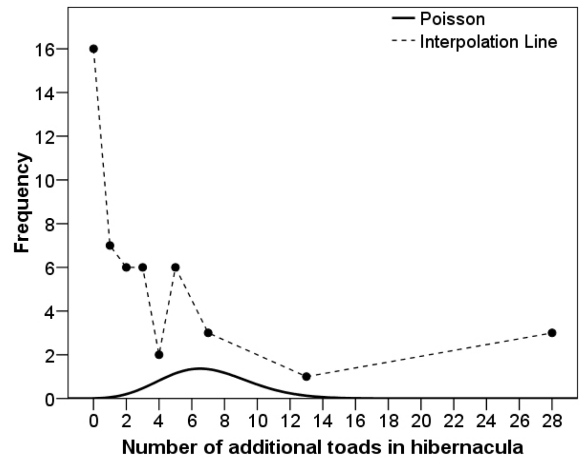

FIGURE 4. The distribution of the number of Western Toads (*Anaxyrus boreas*) per hibernaculum (in addition to the radio-tracked individual) differs from a Poisson distribution, indicating that toads were not distributed randomly amongst appropriate hibernation sites.

Human-altered land-cover types were not used for hibernation at Park or Boreal Forest either, but these study areas contained less human-altered land-cover (4.3% and 12.5%, respectively) than Pasture (73.2%). Movement distances for Western Toads in Alberta are shorter than distances moved between breeding ponds and hibernation sites in Oregon (mean = 1968 m, range = 180–6230 m, n = 26, Bull 2006) perhaps due to the landscape, which, in that study, was described as mountainous coniferous forest. Interestingly, in another mountainous landscape, Martin (2008) radio-tracked the Yosemite Toad (*A. canorus*) and reported distances moved between breeding ponds and hibernation to be shorter (mean = 194 m, range = 142–235 m, n = 3) than distances we measured.

We found no difference in distances moved from breeding ponds to hibernation sites between males and females, similar to Huste et al.'s (2006) results for the Natterjack Toad. We suspect that the reason we found no difference between the sexes is that males and females require similar, specific conditions for overwintering and appropriate sites are uncommon. We suggest that the distance traveled to reach hibernacula is unrelated to distances traveled to forage. Consistent with our suggestion, Johnson et al. (2007) found that overwintering sites of male and female Gray Treefrog (*Hyla versicolor*) were located similar distances from the breeding pond, but during the foraging season females moved significantly farther from the breeding pond than males. Data from our study area and earlier studies from Colorado, Idaho, Oregon, and Utah corroborate this information on foraging and report female Western Toads traveling farther than males to reach their summer foraging grounds (Muths 2003; Bartelt et al. 2004; Bull 2006; Goates et al. 2007; Browne 2010).

Watercourse protective buffers.—Hibernation sites of Western Toads are difficult to locate in the field, so hibernacula protection depends on protecting suitable habitat near water-bodies or known breeding ponds. Small permanent streams (channel width 0.7–5 m), large permanent streams (channel width > 5 m), and lakes are present in our study areas; these watercourses are assigned protective forested buffers of 30, 60, and 100 m, respectively (Alberta Government 2008. *op. cit.*). All toad hibernation sites at Park received *de facto* protection because they are located in a National Park; however, they were also located within 100 m watercourse buffers. In contrast, 90% and 84% of toads tracked hibernated outside of buffers at Boreal Forest and Pasture, respectively. Thus, current regulations prescribing watercourse buffers in Alberta do not protect the core terrestrial habitat required for hibernation at these areas. We suspect that core terrestrial habitat would not be protected by watercourse buffers for many populations, since Western Toads in Oregon were also found to hibernate over 100 m from their breeding pond (range = 180–6230 m, Bull 2006).

A wetland-based approach of protecting a buffer of terrestrial habitat surrounding all breeding ponds at Pasture and Boreal Forest is unrealistic because very wide buffers (449–1337 m; using 95% upper confidence limits for the distance between breeding pond and hibernation site) would be needed to protect core terrestrial habitat for these areas. These distances are larger than the mean maximum distance of 368 m recommended by Semlitsch and Bodie (2003) for core terrestrial habitat of anurans. A different approach to managing habitat is needed for the Western Toad, perhaps identification of critical habitat patches aimed at protecting an entire population.

Resource selection functions.**—**Toads were found to hibernate in a variety of natural land-cover types, but did not hibernate in any human-altered land-cover types (e.g., agricultural fields, forestry cut-blocks, residential yards, roadsides). Human-altered land-cover occurred in all of our areas and dominated Pasture. Natural sites often have less bare ground and more vegetative structure (higher densities of vegetative stems in the understory, trees in the canopy, and woody debris), which provides insulation from wind and low temperatures (Dolby and Grubb 1999), and traps blowing snow to provide further insulation (Ross et al. 1968).

All land-cover types used for hibernation were clearly selected (selection index values > 1) beyond simple availability except for deciduous forest (weakly selected at Pasture, used below proportional availability at Park, and not used at all at Boreal Forest). Deciduous forest (dominated by aspen) appears to be poor habitat for hibernation in these areas and structures selected as hibernation sites by toads (Table 4) were uncommon in these stands. Furthermore, aspen forest tends to be less insulated from cold winter temperatures than spruce stands (Balland et al. 2006). However, toads may select deciduous forest for hibernation in landscapes dominated by land-cover types that are completely unsuitable for hibernation, such as found in Pasture.

Conifer forest was the most strongly selected of the land-cover types used for hibernation at Pasture. Fifty-three percent of tracked toads in this area hibernated in coniferous forest, despite its scarcity on the landscape (0.9%). We suspect that toads selected conifer forests for hibernation because of differences in frost depth and availability of suitable microhabitats (e.g., tunnels). Balland et al. (2006) compared winter frost depth among Jack Pine (*Pinus banksiana*), Black Spruce, and aspen stands in central Saskatchewan and showed that frost penetrated the least in Black Spruce stands. Peat hummocks, Red Squirrel tunnels, and cavities under spruce trees (the structures used by 71% of toads at Pasture) were associated with conifer forests.

Dry shrubland was the other land-cover type that was selected more frequently than deciduous forest at Pasture. The selection value for dry shrubland was large, even though only two hibernation sites occurred in it, because this land-cover type was rare (0.8% cover). Similar to the dry shrubland habitat at Pasture, dry meadow habitat at Park showed disproportionate selection because it was rare and one hibernaculum occurred in a meadow (Table 3).

Conifer forest, wet shrubland, and a patch of burnt forest (originally Black Spruce/Tamarack [*Larix laricina*] stands) were the land-cover types used at Boreal Forest. The wet shrubland and burn land-covers had higher selection values than conifer forest because they were rare on the landscape, but selection of these land-cover types was not significantly greater than conifer forest because the vast majority of toads (79%) hibernated in Black Spruce/Tamarack stands.

Conclusions.**—**Our results suggest that hibernation sites for Western Toads are limited in several landscapes in north-central Alberta. We found that toads moved long distances to reach hibernation sites; that communal hibernation was common; and that there was significant selection of certain land-cover types. Our research also highlights the importance of conducting species-specific, region-specific studies to manage habitat for species at risk, since general guidelines (e.g., Semlitsch and Bodie 2003) will not adequately protect all species at all localities. Our results illustrate that even if breeding wetlands remained intact, the destruction or degradation of small patches of key terrestrial habitat can potentially translate into large negative impacts on populations. As it is unrealistic to institute prescriptive procedures to create protective buffers surrounding ponds that are large enough to encompass hibernation sites for the Western Toad, we hope that land managers will use our results to identify habitat that is potentially suitable for hibernation. We suggest that patches of spruce-dominated conifer forest with complex habitat structure that creates subterranean spaces and insulation on the ground be protected for Western Toads in north-central Alberta. Other habitat types should also be recognized as providing suitable conditions for hibernation if appropriate microhabitats are present (e.g., crevice and root systems, beaver and muskrat structures).

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APPENDIX I. Physical characteristics of different types of hibernacula. Soil texture was determined using the soil texture triangle (NASA's Goddard Space Flight Center. 2002. Soil texture – to determine soil texture. Available from http://soil.gsfc.nasa.gov/pvg/texture2.htm. [Accessed 2 July 2009].). Soil textures are organic (O), organic/needles (O/N), clay loam (CL), sandy loam (SL), loamy sand (LS), loam (L), sandy clay loam (SCL), silt loam (SiL). Percent organic composition of the soil was determined using the 'direct estimation of organic matter by loss-on-ignition' method (Ravindranath, N.H., and M. Ostwald. 2007. Carbon Inventory Methods Handbook for Greenhouse Gas Inventory, Carbon Mitigation and Roundwood Production Projects. Springer, Netherlands.). Percent moisture and pH of the soil were determined using a pH/soil moisture reader (Kelway®, Frostproof, Florida, USA). Canopy cover was measured using a spherical densiometer; measurements were taken at waist height and the average of four readings (facing each of the four cardinal directions) was used. Soil moisture, pH, and canopy cover were not recorded in 2004. NA = not applicable.

	Peat hummocks	**Squirrel middens**	**Natural crevices**	**Spruce cavities**	**Root channels**	**Beaver lodges**	**Muskrat tunnels**
N	15	9	8	6	5	4	3
Soil textures	O	O, O/N	O	O, O/N	O	O, CL, SL, LS	L, SCL, SiL
Mean (range) % organic of soil	86 (74–96)	81 (66–97)	86 (71–89)	75 (64–84)	76 (57–84)	9 (2–18)	7 (3–12)
Mean (range) % moisture of soil	58 (40–71)	66 (45–100)	73 (65–80)	62 (30–75)	54 (30–70)	60	NA
Mean (range) soil pH	6.7 (6.4–7.0)	6.6 (6–7)	7 (6.9–7.1)	6.9 (6.6–7)	6.9 (6.7–7)	7 (6.9–7)	NA
Mean (range) % canopy cover	42 (8–77)	80 (53–95)	13 (4–22)	76 (47–95)	28 (3–56)	33 (15–42)	NA
Mean (range) depth of toad below surface (cm)	44 (30–70)	38 (30–50)	~80 (~20–100)	47 (30–70)	39 (25–53)	79 (35–130)	31 (30–34)
Depth to water table (cm)	≥ 33	≥ 40	NA	NA	≥ 38	NA	NA
Tunnel/cavity width (cm)	6.5 to 100	4 to 15	2 to 5	≥ 10	≥ 15	10 to 40	9

APPENDIX II. Dominant plant taxa recorded in the immediate vicinity of hibernation sites (listed in approximate order of abundance).

Type	Area	Under-story vegetation
Peat hummocks	Boreal Forest	Labrador Tea (*Rhododendron groenlandicum*), Lingonberry (*Vaccinium vitis-idaea*), grass (family Poaceae), Horsetail (*Equisetum spp.*), False Soloman's Seal (*Maianthemum spp.*), Currant (*Ribes spp.*), Kidney Leaf Violet (*Viola renifolia*), Raspberry (*Rubus idaeus*), and Red-osier Dogwood (*Cornus stolonifera*).
	Pasture	Labrador Tea.
Squirrel middens	Boreal Forest	No vegetation at three sites. Labrador Tea, Lingonberry, and Horsetail at one site.
	Pasture	Sparse vegetation. Bunchberry (*C. canadensis*), Raspberry, and grass on some locations.
Natural crevices	Park	Grass, Stinging Nettle (*Urtica dioica*), and Raspberry.
	Pasture	Grass, Stinging Nettle, and Raspberry.
Spruce cavities	Pasture	Grass, Kidney Leaf Violet and Labrador Tea.
Root channels	Boreal Forest	Grass, Raspberry, Current, Sweet-scented Bedstraw (*Galium triflorum*), and Horsetail.
	Pasture	Grass and Bunchberry.
Beaver lodges	Park	Stinging Nettle, Hemp-nettle (*Galeopsis tetrahit*), and grass.
	Pasture	Aspen (*Populus tremuloides*), Red-osier Dogwood, Rose (*Rosa acicularis*), Bracted Honeysuckle (*Lonicera involucrata*), Snowberry (*Symphoricarpos*), and Horsetail.
Muskrat tunnels	Park	Hazelnut (*Corylus cornuta*), grass, and Willow (*Salix spp.*) at some or all of the sites.

Appendix III. Methods used to create the land-cover geographic information systems (GIS) map used for the resource selection function analyses (A), and descriptions of land-cover types (B).

(A) Methods used to create land-cover map:

A land-cover geographic information systems (GIS) map of 22 habitat types was created from aerial photographs of each of the study areas using ArcGIS 9.2 (digitized at a resolution of 1:1890). Photographs of the Boreal Forest area were taken in 2006 and had a raster resolution of 1:1890 except for a small (~ 0.3 km^2) section that was photographed in 2004 at a 1:3780 resolution. Pasture photographs (from 2005) had a resolution of 1:944. The photograph of Elk Island National Park (from 2001) had a resolution 1:945. Two square kilometres of Park extended beyond the photograph into Lamont County. All aerial photographs were black and white except for the photo of Lamont County (from 2002), which was colored and had a resolution of 1:3780. Alberta Vegetation Inventory (AVI) data were available for the Boreal Forest area (from 2006) and the Park (1995) and were used to help designate land-cover type. AVI data included information on moisture conditions, canopy density, dominant tree species present and percent cover, and human land-use. However, AVI data was only used as an aid in determining land-cover type because it was at a coarser scale than required

(B) Description of each land-cover type used to create maps

Land-cover type	Description
Conifer forest	Tree cover of 6-100% crown closure with over 80% of trees being conifer.
Deciduous forest	Tree cover of 6-100% crown closure with over 80% of trees being deciduous.
Mixed-wood forest	Tree cover of 6-100% crown closure with over 20% of both conifer and deciduous trees.
Dry shrubland	Shrub cover of 6-100% with a dry to moderately well drained substratum.
Wet shrubland	Shrub cover of 6-100% with a poorly drained to flooded substratum.
Moss/peat wetland	Less than 6% tree/shrub cover. Ground is predominately covered by mosses/bryophytes.
Marsh/wet meadow	Less than 6% tree/shrub cover. Ground is predominately covered by graminoids. Substratum is poorly drained.
Dry meadow	Less than 6% tree/shrub cover. Ground is predominately covered by graminoids. Substratum is dry to moderately well drained.
Burn	Burn/partial burn.
Clear-cut (grass dominated)	Clearcut/partial cut. Ground is predominately covered by graminoids.
Cut-block (tree/shrub)	Clearcut/partial cut. Ground is predominately covered by shrubs or young trees.
Disturbed grassland	Roadsides, cutlines, pipelines, utility corridors, or any other human modified landscape with the ground predominately covered by graminoids.
Railway	Railway.
Gravel road	Gravel surface.
Paved surface	Paved surface.
Mowed lawn	Graminoid surface cover that is mowed several times/year.
Building	Building.
Crop field/hay field	Cultivated farmland growing hay or crops.
Pasture/sparsely vegetated	Cattle pasture.
Exposed soil	Non-vegetated soil (e.g., roads through farm-fields)
Emergent vegetation	Aquatic habitat with emergent vegetation.
Water	Water with submersed or no vegetation.