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# Identifying Canadian Toad (*Anaxyrus hemiophrys*) Habitat in Northeastern Alberta, Canada

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*Abstract*.—**Conservation of amphibian species requires an understanding of both their aquatic and terrestrial habitats. Populations of Canadian Toads (*Anaxyrus hemiophrys*) may be declining in Alberta, Canada. Information on this species is scarce, particularly for the northeastern boreal ecoregion. Concerns exist that this species may be threatened by growth of the energy sector. We used a combination of passive acoustic monitoring and remotely measured landscape attributes to generate a predictive breeding-habitat model based on occurrence of calling males. We processed acoustic data collected over 4 y through human listening and automated recognition, resulting in 106 locations (21.3% occurrence) with Canadian Toad detections. We used Logistic Regression to relate Canadian Toad occurrence to landscape characteristics. We found Canadian Toads used a high proportion of fen and open water wetlands near upland habitat. Coarser soils were associated with breeding sites and suggest that loose soils are needed for subsurface burrowing for hibernation. We found no indication that Canadian Toads avoided human disturbances, such as roads.**

*Key Words*.—amphibians; anthropogenic disturbance; automated recognition; bioacoustics; Boreal Forest; occurrence; roads; wetlands

## Introduction

The Canadian Toad (*Anaxyrus hemiophrys*) is one of the most northerly distributed amphibians in the world. Limited data suggests they may have declined since the mid-1980s (Hamilton et al. 1998) in several areas of their range, including the province of Alberta, Canada (Eaton et al. 2005a; Fisher et al. 2007; Browne 2009). Survey data are limited (Eaton et al. 2005a; Constible et al. 2010), however, and our current knowledge is inadequate to effectively assess habitat requirements, population sizes, and the extent of distribution of the Canadian Toad (Brian Eaton et al., unpubl. report), particularly at their northern range edge.

Canadian Toads, as typical of temperate anurans, require wetlands to satisfy the aquatic half of their biphasic lifecycle (Breckenridge and Tester 1961; Roberts and Lewin 1979; Hamilton et al. 1998). In the northern part of their range, there are a variety of bogs, fens, marshes, and swamps that vary in their acidity, productivity, water flow, and vegetation structure (National Wetlands Working Group 1997). The influence of wetland type on the occurrence of Canadian Toads is unknown; however, the species is considered the most aquatic of the three bufonids in Alberta (Roberts and Lewin 1979; Hamilton et al. 1998) and some investigators speculate that they may be more likely to breed in areas with flowing water (Roberts and Lewin 1979) like fens. The importance of vegetation structure as a predictor of Canadian Toad occurrence is poorly understood but it may be crucial given that wetlands in the boreal can be dominated by graminoids, shrubs, or coniferous trees. Graminoid wetlands are the least common type of fen but often have the most flowing water (National Wetlands Working Group 1997).

Like most toads, Canadian Toads require terrestrial habitat to forage and overwinter (Breckenridge and Tester 1961; Alford and Richards 1999; Joly et al. 2003; Becker et al. 2007) but what makes good terrestrial habitat is poorly understood. Some studies have suggested that Canadian Toads require sandy soil during the winter months (Breckenridge and Tester 1961; Roberts and Lewin 1979; Kuyt 1991), presumably because this allows them to move below the frostline. Soil type, however, has not been explicitly tested as a factor influencing Canadian Toad distribution.

Previous studies have identified potential threats to Canadian Toads from human infrastructure (Roberts and Lewin 1979). Road mortality is a serious concern for anurans that move through fragmented habitats to access breeding and overwintering locations (Fahrig et al. 1995; Joly et al. 2003; Fahrig and Rytwinski 2009). Furthermore, intermittent and chronic anthropogenic noise have the potential to have negative effects on vocalizing anuran species (Penna and Zúñiga 2014; Shannon et al. 2016) if noise influences the acoustic communication used by males to attract females during the breeding season (Wells 1977; Gerhardt and Huber

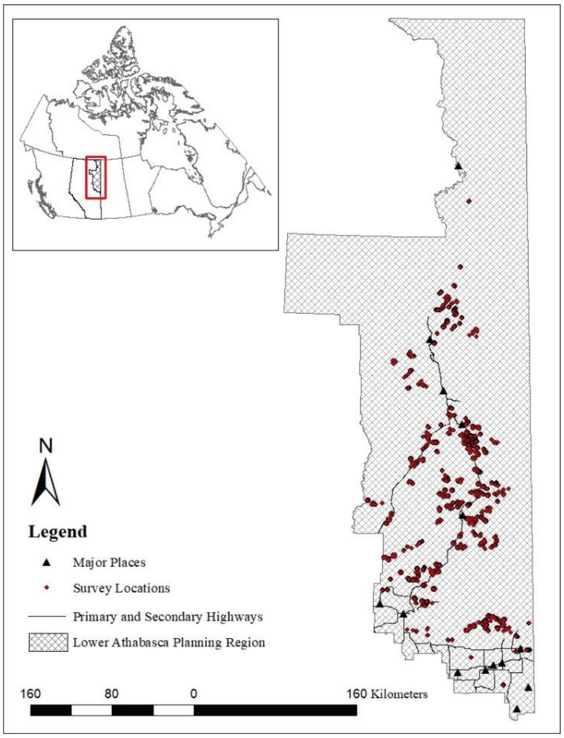


Figure 1. The study area identifying the Lower Athabasca Planning Region and Canadian Toad (*Anaxyrus hemiophrys*) survey locations (2012–2015), in northeastern Alberta, Canada.

2002). The Boreal Forest of northeastern Alberta has become increasingly fragmented with the expansion of the energy and forestry sectors that generate both traffic and noise. As of 2016, human footprint in the northeastern corner of Alberta totaled 15.48% of the landscape (Alberta Biodiversity Monitoring Institute [ABMI]. 2016. Status of Human Footprint in Alberta. Lower Athabasca Region. ABMI. Available from http://abmi.ca/home/reports/2018/human-footprint [Accessed 18 April 2019]). Effects of anthropogenic land disturbance on Canadian Toad have not been evaluated.

Our specific objectives were to quantify Canadian Toad occurrence: (1) in different wetland types; (2) in different soil textures; (3) as a function of vegetation structure; and (4) to evaluate the impact of roads and industrial infrastructure. We used passive acoustic monitoring to generate a predictive habitat model for the Canadian Toad in the Boreal Forest of northeastern Alberta. We hypothesized that habitat type affects the occurrence of Canadian Toads. We predict that Canadian Toads: (1) will be patchily distributed and relatively uncommon; (2) will occur in areas near water but in close proximity to upland habitat with coarser soils; (3) will be more likely to occur in areas with more open vegetation; and (4) less likely to occur in human impacted areas.

## Materials and Methods

***Study area.*****—**Our study took place within the Lower Athabasca Planning Region (LAPR) of northeastern Alberta, Canada, extending from Cold Lake, Alberta (54.4642°N, 110.1825°W) to north of Fort McMurray, Alberta (56.7264°N, 111.3803°W; Fig. 1). The LAPR covers 93,458 km$^2$ (ABMI 2015. *op. cit*.). The terrain is largely undulating, resulting in a mosaic of extensive wetlands, made up of fens and bogs dominated by Black Spruce (*Picea mariana*) and Tamarack (*Larix laricina*). It also contains swamps and marshes dominated by willow (*Salix* sp.), birch (*Betula* sp.), alder (*Alnus* sp.), sedges (*Carex* sp. and *Eriophorum* sp.) and grasses (Poaceae), and uplands dominated by Aspen (*Populus tremuloides*), Balsam Poplar (*Populus balsamifera*), White Spruce (*Picea glauca*), and Jack Pine (*Pinus banksiana*; Johnson et al. 1995; Kaheil and Creed 2009). Soils are mostly gray luvisols in upland aspen stands, eutric brunisols in sandy uplands, and organics and gleysolics in wet areas (Strong 1992). The most notable natural disturbance agent within the LAPR is wildfire (Bonan and Shugart 1989).

We used Satellite Pour l'Observation de la Terre (SPOT) satellite imagery and land-cover layers in a Geographic Information System (GIS) to select sites based on accessibility (foot, all-terrain vehicle, or helicopter) and stratified sites based on existing land-cover classifications. We did not base deployments on *a priori* knowledge about where Canadian Toads occurred but included areas suitable for wetland dependent vertebrates. Specifically, we surveyed the four dominant wetland types in the region (marshes, fens, swamps and bogs) as well as adjacent upland habitat. We did not target open water wetlands, but measured distance to open water features that could be detected from remote sensing. We collaborated with other bioacoustic projects, and therefore, we designed deployment protocols to be consistent with other data collection. The minimum distance between sampled sites was 600 m. Each site consisted of five sampling stations: four stations in a square formation, spaced 600 m apart at the corners, with a fifth station in the center.

***Acoustic survey data.*****—**We conducted acoustic surveys for Canadian Toads using Song Meter autonomous recording units (ARUs; Models SM2+ and SM3; Wildlife Acoustics, Inc., Maynard, Massachusetts, USA). We deployed a single ARU at each sampling station, so each site had five ARUs (Fig. 1). We conducted acoustic surveys over 4 y (2012–2015). We deployed and retrieved ARUs between: 9 April and 12 July 2012 (n = 477 sites); 9 May and 2 August 2013 (n = 427 sites; 41 resampled); 24 April and 6 July 2014

**Table 1.** Reclassified wetland types using the enhanced wetland classification layer from Ducks Unlimited (2011).

| New Classes | Original Classes |
|---|---|
| Marsh | Emergent marsh, meadow marsh |
| Fen | Graminoid rich fen, graminoid poor fen, shrubby rich fen, shrubby poor fen, treed rich fen, treed poor fen |
| Bog | Open bog, shrubby bog, treed bog |
| Swamp | Shrub swamp, hardwood swamp, mixed wood swamp, tamarack swamp, conifer swamp |
| Other / unclassified | Open water, aquatic bed, mudflats, upland conifer, upland deciduous, upland pine, upland other, cutblock, agriculture, anthropogenic, cloud, cloud shadow, burn |

(n = 365 sites; 16 resampled); and 3 May and 30 June 2015 (n = 489 sites; 33 resampled). We fastened ARUs approximately 1.5 m above ground to trees or wooden posts when trees were unavailable. We moved ARUs on a bi-weekly rotational system to survey all sites during the toad breeding season (Brian Eaton et al., unpubl. report). To stratify sampling of sites, three crews of two workers deployed ARUs across different areas of the LAPR at the same time. To capture detections of Canadian Toad and other species of interest to collaborators, we programmed the ARUs to turn on and record for the first 10 min of every hour daily.

We processed a subset of recordings using a standardized listening protocol (Lankau et al. 2015). We selected recordings from times when Canadian Toads are known to be vocally active in the study region (2200–0400) to maximize detectability (Brian Eaton et al., unpubl. report). We processed a minimum of four and maximum of 14 recordings for these hours for every ARU station per season (mean = 4.19). Trained listeners transcribed randomly selected target recordings, spanning the dates that ARUs were operating. We used the program Adobe Audition CS6 (Adobe Systems Inc., San Jose, California, USA) to visualize the recording as a spectrogram to help locate and identify species calls during listening. We found human listening to raw recordings to be time-consuming. A single season of acoustic data took approximately 355 h to process the minimum of four recordings per station per season (2012–2015). Therefore, we developed other processing methods to increase the number of locations with Canadian Toad detections.

We used a computer-automated acoustic recognizer to scan all recordings for Canadian Toad vocalizations. We used the software program Song Scope (Wildlife Acoustics, Inc., Maynard, Massachusetts, USA) to create a digital signal processing algorithm to find Canadian Toad vocalizations (Wildlife Acoustics Inc. 2011). We trained the recognizer on annotated clips of the Canadian Toad call and we chose settings based on the unique characteristics of the vocalization of the species (Appendix 1). Canadian Toads produce a long soft trill (1–7 s) in the 1.5–2.5 kHz frequency range (Appendix 2). The recognizer incorporated maximum song length, frequency minimum and frequency range (Appendix 1). Trained listeners validated Canadian Toad calls detected by the recognizer to confirm true positives and remove false positives from the dataset. A human listener could validate a season of data from the entire study region in < 20 h.

***Habitat data***.—We examined stations with Canadian Toad detections (used) and stations where we never detected Canadian Toads over the length of the study (unused). Used stations included instances when a Canadian Toad was detected only once, but typically a used location had multiple detections at different times of day and on different dates. The designation of a station as unused required a lack of any toad detections by both acoustic processing methods. It is possible that we may have observed Canadian Toads at locations we called unused if the ARUs had been out for longer or different periods of time. As well, the recognizer may also have missed some detections but those detections, if they existed, were likely quite far from the ARU (Knight and Bayne 2018). Stations classified as unused may also have been occupied by non-vocalizing individuals that could not have been detected through acoustic surveys. Thus, our estimates are minimal estimates of occurrence. Despite repeated surveys, we chose not to use occupancy style analyses (Mackenzie et al. 2002) because of the challenge of defining a unit of subsampling when using automatic recognizers relative to human listening.

We buffered used and unused stations by 150 m in GIS, and spatial attributes from the various GIS layers estimated. The approach we used to listen to the data did not allow us to determine the position of a calling toad relative to the ARU and we do not know exactly how far Canadian Toads can be heard. Modeling of bird data from ARUs in Alberta (Sólymos et al. 2014) has selected a 150 m as an appropriate buffer as most vocalizing species are not heard beyond that distance. We used the following spatial data:

*Land cover.*—We reduced 29 habitat classes from the Ducks Unlimited Enhanced Wetland Classification (DUEWC) layer (Ducks Unlimited Canada 2011) to five major classes (marsh, fen, bog, swamp, and other) in GIS (ArcGIS 10.4.1, Esri, Redlands, California, USA) to define the dominant wetland types in our study area (Table 1 and 2). We calculated proportions of broad habitat classes in a Geospatial Modeling Environment (GME; Beyer, H.L. 2015. Geospatial modelling environment version 0.7.4. Spatial Ecology. Available from http://www.spatialecology.com/gme/. [Accessed 1 October 2015]; Table 2). We determined

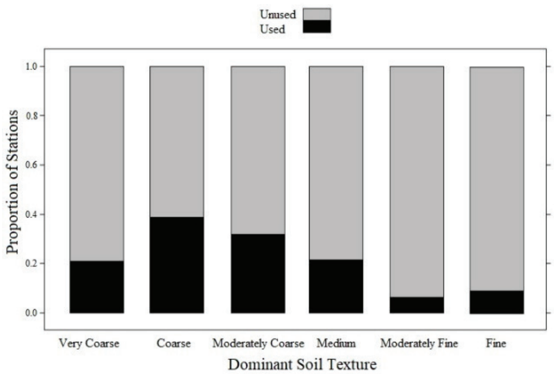


**Figure 2.** Proportion of used and unused stations binned by dominant soil texture within 150 m buffer zones around the autonomous recording unit deployed to detect Canadian Toads (*Anaxyrus hemiophrys*) in northeastern Alberta, Canada. Unused stations (n = 524) are where we did not detect Canadian Toads. Used stations (n = 142) are where we did detect Canadian Toads.

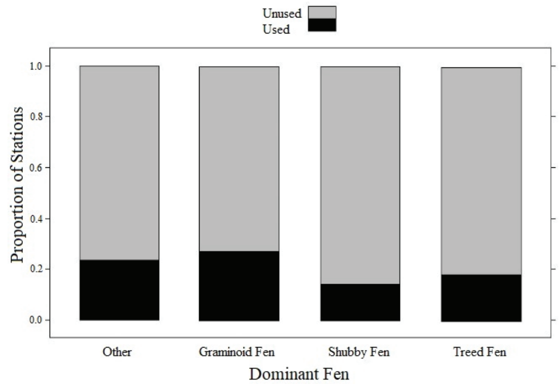


**Figure 3.** Proportion of used and unused stations binned by dominant fen type within 150 m buffer zones around the autonomous recording unit deployed to detect Canadian Toad (*Anaxyrus hemiophrys*) in northeastern Alberta, Canada. Unused stations (n = 524) are where we did not detect Canadian Toads. Used stations (n = 142) are where we did detect Canadian Toads.

distance to upland/wetland edges using classifications from the DUEWC data (Table 2). Pixels for land cover covariates were 30 × 30 m.

*LIDAR vegetation density.*—We used Light Detection and Ranging Systems (LIDAR) data from Guo et al. (2017). These data were collected from 2003 to 2014 using pulsed lasers with density ranges 1–4 returns per m2 to attain accurate distance measurements. We used return proportions for six different vegetation heights (strata): < 0.15 m, 0.15–1.37 m, 1.37–5 m, 5–10 m, 10–20 m, and 20–30 m (Table 2). These layers represent the canopy height density of vegetation calculated at each stratum (percentage of LIDAR returns) and we used them to explore vertical vegetation structure (Guo et al. 2017). Pixels for average LIDAR covariates were 30 × 30 m.

*Elevation.*—We used a Digital Elevation Model (DEM; https://www.nrcan.gc.ca/) to isolate areas of low elevation at a scale of 100 × 100 m pixels (Table 2).

*Soil.*—We extracted soil texture, drainage, and percentage sand from the Soil Landscapes of Canada (SLC; Schut et al. 2011) spatial data layer (Table 2). Soil texture ranged from very coarse to very fine, drainage ranged from very rapidly drained to very poorly drained, and sand percentages were taken at a depth of 1 m. Pixels for soil covariates were 30 × 30 m.

*Human disturbance.*—We used paved and gravel roads to generate a distance to roads layer (Table 2). We used noise-producing industrial facilities (i.e., compressor stations and industrial plants), identified from an Alberta facilities layer, to generate a distance to chronic noise layer (Table 2). Pixels for human disturbance covariates were 30 × 30 m.

***Modeling***.—We used Generalized Linear Models using a binomial error family and logit link (hereafter: Logistic Regression) to relate the used-unused status of Canadian Toads to different landscape characteristics (Boyce et al. 2002) in the statistical program Stata (StataCorp, College Station, Texas, USA). We used a forward-addition, stepwise model-building approach based on Akaike's Information Criterion (AIC; Burnham and Anderson 2002). We evaluated the variables individually and added them sequentially starting with the variables that had the lowest AIC. We continued to add new variables until the AIC did not get any smaller and we reported on the model with the lowest AIC and fewest parameters. We evaluated the accuracy and predictive power of models using the Receiver Operating Characteristic (ROC) classification approach with the associated Area Under the Curve (AUC) values (Metz 1978; Swets 1988; Manel et al. 2001).

## Results

***Acoustic survey data***.—We detected Canadian Toads at ARU stations across all study years (2012–2015). Periods of detections ranged from 14 May to 15 June 2012 (n = 4 stations), 15 May to 6 July 2013 (n = 73 stations), 20 May to 20 June 2014 (n = 50 stations), and 7 May to 12 June 2015 (n = 59 stations). We determined 142 of 666 stations as used by Canadian Toads in our study area. Of these stations, human listening identified 106 and the automated recognizer found 38 additional stations. Detections by the automated recognizer overlapped with human listening detections for 57 stations. We determined that 524 stations were unused by Canadian Toads. We did not include stations in our analyses where ARUs failed to record, had corrupt data files or were recording in unsuitable habitat (i.e., no wetland species detected).

**Table 2.** Description, type, mean, standard deviation (SD), and range of covariates used in model building.

| Covariates | Description | Type | Mean | SD | Range |
|---|---|---|---|---|---|
| Land Cover | | | | | |
| domwetland | Dominant wetland classes (n = 5) | Categorical | NA | NA | NA |
| upland | Proportion of upland | Continuous | 0.168 | 0.260 | 0–1 |
| dstwat | Minimum distance to open water bodies (km) | Continuous | 0.994 | 1.040 | 0–4.550 |
| dstup | Minimum distance to upland (km) | Continuous | 0.165 | 0.296 | 0–1.990 |
| LIDAR Vegetation Density | | | | | |
| below0pnt15 | Return density proportions below 0.15 m | Continuous | 0.521 | 0.249 | 0–0.999 |
| 0pnt15to1pnt37 | Return density proportions between 0.15–1.37 m | Continuous | 0.156 | 0.105 | 0–0.597 |
| 1pnt37to5 | Return density proportions between 1.37–5 m | Continuous | 0.128 | 0.010 | 0–0.532 |
| 5to10 | Return density proportions between 5–10 m | Continuous | 0.079 | 0.087 | 0–0.707 |
| 10to20 | Return density proportions between 10–20 m | Continuous | 0.056 | 0.099 | 0–0.688 |
| 20to30 | Return density proportions between 20–30 m | Continuous | 0.010 | 0.043 | 0–0.536 |
| Elevation | | | | | |
| elev | Elevation from digital elevation model (km) | Continuous | 0.480 | 0.143 | 0.200–0.719 |
| Soil | | | | | |
| tsand | Total sand at a 1m depth (%) | Continuous | 58.8 | 23.0 | 14.8–90.1 |
| soiltext | Soil texture classes (n = 7) | Categorical | NA | NA | NA |
| drain | Soil drainage classes (n = 5) | Categorical | NA | NA | NA |
| Human Disturbance | | | | | |
| dst2road | Minimum distance to linear features used by motor vehicles (km) | Continuous | 1.97 | 1.84 | 0–9.08 |
| dst2chnoise | Minimum distance to industrial chronic noise source (km) | Continuous | 9.59 | 11.3 | 0–97.6 |

We examined the number of days that toads were detected, at stations with Canadian Toad detections, using recognizer results (n = 516 cases). We found that for the days that ARUs were deployed, analysis of recordings from 4 d using our human listening protocol was sufficient to detect the presence of toads 65.3% of the time. By additionally using the recognizer on these same data, we are confident in our detections of Canadian Toads with the combination of these processing methods.

***Habitat data and modeling***.—We detected Canadian Toads on soils with coarser grain-size more than on soils with finer grain-size (Fig. 2). Given the importance of fen habitat, we refined the model and evaluated how vegetation structure influenced Canadian Toad occurrence. While most toad detections came from treed fens, the proportion of detections relative to locations surveyed, indicated highest occurrence in graminoid fen (Fig. 3). Habitats dominated by open water, such as lakes or smaller water bodies, had the highest occurrence of Canadian Toads (Fig. 4).

The most parsimonious model influencing Canadian Toad occurrence used LIDAR-derived data to explain vegetation structure and supported that both wetland and upland habitats drive occurrence of toads (pseudo $r^2$ = 0.284, AUC = 0.846; Table 3 and 4). The proportion upland expressed as a quadratic term provided the best fit, and highlighted toad occurrence in edge habitat between uplands and wetlands (marsh, fen, bog, swamp). Areas with coarser soil textures were identified as having high Canadian Toad occurrence (Table 4). LIDAR strata data showed occurrence in areas with vegetation < 1.37 m in height (Table 4). As vegetation height (as measured

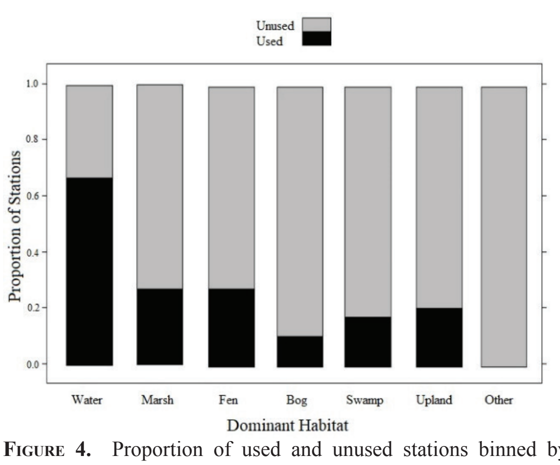


**Figure 4.** Proportion of used and unused stations binned by dominant habitat type within 150 m buffer zones around the autonomous recording unit deployed to detect Canadian Toad (*Anaxyrus hemiophrys*) in northeastern Alberta, Canada. Unused stations (n = 524) are where we did not detect Canadian Toads. Used stations (n = 142) are where we did detect Canadian Toads.

**Table 3.** Forward-addition stepwise model building, where covariates were added only if model AIC improved. Null model includes no predictive covariates. The top model, with lowest Akaike's Information Criterion (AIC) showing Canadian Toad (*Anaxyrus hemiophrys*) habitat use in the Boreal Forest of northeastern Alberta (last model above null). ΔAIC shows the difference in AIC between each generated model and the top model. For each model, we also include the degrees of freedom (df) and log-likelihood (logLik).

| Model | df | logLik | AIC | ΔAIC |
|---|---|---|---|---|
| domwetland+elev | 6 | -319.71 | 651.42 | 125.19 |
| domwetland+elev+soiltext | 11 | -275.54 | 573.07 | 46.84 |
| domwetland+elev+soiltext+upland+upland2 | 13 | -262.57 | 551.15 | 24.92 |
| domwetland+elev+soiltext+upland+upland2+dst2road | 14 | -256.07 | 540.13 | 13.9 |
| domwetland+elev+soiltext+upland+upland2+dst2road+1pnt37to5 | 15 | -250.96 | 531.92 | 5.69 |
| domwetland+elev+soiltext+upland+upland2+dst2road+1pnt37to5+0pnt15to1pnt37 | 16 | -247.11 | 526.23 | 0 |
| null | 5 | -337.61 | 685.23 | 159 |

by LIDAR data) increased, models showed a lower likelihood of occurrence, indicating that Canadian Toads were calling in habitat with short trees and shrubs, or in open grassy areas. Predicted occurrence was higher at stations located nearer linear features used by motor vehicles, and of stations nearer open water bodies (Table 4). Areas at lower elevations were also more likely to support Canadian Toad occurrence (Table 4).

## Discussion

We found that edge habitat between upland and wetland landscapes is important for breeding Canadian Toads based on the quadratic relationship between toad occurrence and the proportion upland covariate. Models consistently showed toad occurrence in wetlands directly adjacent to uplands. Toads are known to typically leave wet areas to forage in uplands following breeding, so proximity of breeding sites to upland habitat seems to be important (Roberts and Lewin 1979; Hamilton et al. 1998; Hannon et al. 2002; Bull 2006; Long and Prepas 2012). Our results agree with findings of Browne and Paszkowski (2010) regarding Western Toads (*Anaxyrus boreas*) in Alberta, which indicated that an approach based solely on understanding wetland conditions is not sufficient to identify suitable habitat. We did

**Table 4.** Logistic Regression output for the top model describing Canadian Toad (*Anaxyrus hemiophrys*) breeding habitat use, based on presence/absence, in northeastern Alberta, Canada. For significance, three asterisks (***) $P = 0$, two asterisks (**) $P \leq 0.001$, one asterisk (*) $P \leq 0.010$, and a period (.) $P \leq 0.050$. For all others, $P > 0.050$.

| Variable | β coefficient | Standard Error | z | $P > \|z\|$ | 95% confidence interval | |
|---|---|---|---|---|---|---|
| Land Cover | | | | | | |
| domwetland: marsh | 1.328 | 1.111 | 1.19 | 0.232 | -0.852, 3.507 | |
| domwetland: fen | 0.557 | 0.950 | 0.59 | 0.558 | -1.305, 2.418 | |
| domwetland: bog | 0.139 | 1.045 | 0.13 | 0.894 | -1.910, 2.188 | |
| domwetland: swamp | -0.039 | 0.922 | -0.04 | 0.966 | -1.846, 1.768 | |
| upland | 1.364 | 0.401 | 3.40 | 0.001 | 0.577, 2.150 | ** |
| upland^2 | -0.834 | 0.417 | -2.00 | 0.046 | -1.652, -0.016 | . |
| LIDAR Vegetation Density | | | | | | |
| 0pnt15to1pnt37 | 0.374 | 0.134 | 2.79 | 0.005 | 0.111, 0.636 | * |
| 1pnt37to5 | -0.532 | 0.149 | -3.57 | 0.000 | -0.824, -0.240 | *** |
| Elevation | | | | | | |
| elev | -2.216 | 0.292 | -7.59 | 0.000 | -2.788, -1.644 | *** |
| Soil | | | | | | |
| soiltext: coarse | 2.845 | 0.607 | 4.69 | 0.000 | 1.656, 4.034 | *** |
| soiltext: moderately coarse | 3.550 | 0.598 | 5.93 | 0.000 | 2.378, 4.723 | *** |
| soiltext: medium | 2.453 | 0.636 | 3.86 | 0.000 | 1.207, 3.698 | *** |
| soiltext: moderately fine | 1.454 | 0.746 | 1.95 | 0.051 | -0.008, 2.916 | |
| soiltext: fine | -0.058 | 0.566 | -0.10 | 0.918 | -1.169, 1.052 | |
| Human Disturbance | | | | | | |
| dst2road | -0.673 | 0.178 | -3.77 | 0.000 | -1.022, -0.323 | *** |

not, however, evaluate breeding success and can only comment on our higher detections of breeding behavior (i.e., male vocalizations) in these areas.

Browne and Paszkowski (2010) found that Western Toads traveled nearly 2 km to reach hibernation sites in the Boreal Forest. Canadian Toads have been recorded to move up to 1.5 km from the breeding wetland and use upland habitats for overwintering (Constible et al. 2010; Patrick Garcia et al., unpubl. report). While not physically observed, it can be inferred that neighboring upland habitats are used by Canadian Toads in our study area for post-breeding foraging and for access to overwintering habitat. Historically, many viewed the Canadian Toad as the least terrestrial of the bufonids found in western North America (Breckenridge and Tester 1961; Roberts and Lewin 1979). Early reports on this species did not associate this toad with forest habitats (Breckenridge and Tester 1961; Roberts and Lewin 1979); however, our results suggest this toad is quite terrestrial and other studies have documented the use of upland forests following breeding by males, females and young of the year (Hamilton et al. 1998; Eaton et al. 2005a; Constible et al. 2010).

We found that habitats dominated by open water, such as lakes or smaller water bodies, had the highest occurrence. Previous studies have found these habitats to be suitable breeding sites for the Canadian Toad (Hannon et al. 2002; Eaton et al. 2005b) and this result is consistent with the aforementioned characterization of the species as highly aquatic (Breckenridge and Tester 1961; Roberts and Lewin 1979). We rarely sampled open water wetlands ($n = 6$), however, and they accounted for 0.9% of the locations. Under-sampling of this habitat is partially caused by the challenges associated with observers being able to safely deploy an ARU near open water. How open water is used by Canadian Toads requires further investigation. Fens and bogs within the Boreal Forest have a considerable amount of standing water (National Wetlands Working Group 1997) that is not accurately measured in remote sensing layers, therefore, the distance to open water bodies may not be important when considering the high number of wet areas in the Boreal Forest.

Models with a high proportion of graminoid fen showed the highest occurrence. Fens are minerotrophic, meaning they are rich in nutrients derived from groundwater feeding into peatlands (Karns 1992). These wetlands have slow moving water, low acidity (pH > 5.0) and are highly productive (Karns 1992). Graminoid fens are characterized by low vegetation and are the wettest of the fen types (National Wetlands Working Group 1997). The water table is typically above the surface in graminoid fens while it is below the surface in shrubby and treed fens (National Wetlands Working Group 1997). Like graminoid fens, marshes are areas of wet and open vegetation. Marshes are relatively uncommon in our study area, but we expect they would support high Canadian Toad occurrence as well.

In comparison to fens, bogs have very low productivity. Bogs are ombrotrophic peatlands, meaning they collect water through nutrient-poor precipitation, which contributes to their acidity (pH < 4.5; Bonan and Shugart 1989; Karns 1992). Karns (1992) looked at larval development and survival of six amphibian species in acidic bog water (pH = 4.2) and neutral water (pH = 7.5). Wood Frog (*Lithobates sylvaticus*) was the only species that had eggs hatch successfully and larvae survive in acidic water (Karns 1992). Other species, including the American Toad (*A. americanus*), did not hatch or survive as larvae in bog water, but did in neutral water (Karns 1992). Our results indicate low occurrence of Canadian Toads in bogs.

We found soil texture to be important in understanding Canadian Toad occurrence. Locations with coarser soils had higher occurrence than locations with fine soils. Coarse, rocky soils have poor water-holding capacity and drain much quicker than fine-grained soils (Dayton and Fitzgerald 2006). This reduces the number of ephemeral breeding pools on a landscape; however, coarser soils may allow toads to dig into the earth to overwinter. Migration distances of Canadian Toad to access overwintering habitat are variable, ranging between 0.6–1.5 km (Constible et al. 2010; Patrick Garcia et al., unpubl. report), and we included information on soil texture at this scale (Schut et al. 2011).

Canadian Toads are not freeze-tolerant and need to get below the frost line to survive the winter (Storey and Storey 1986; Hamilton et al. 1998; Russell et al. 2000). The co-occurring Western Toad will use pre-existing cavities, made by mammals or plant root systems, to hibernate, rather than digging their own burrows (Bull 2006; Browne and Paszkowski 2010). Canadian Toads, however, have not been documented using existing burrows and records of overwintering habitat for this species agree that it uses areas with sand or other loose soil types (Breckenridge and Tester 1961; Roberts and Lewin 1979; Kuyt 1991; Constible et al. 2010).

We found no effect of noisy human infrastructure (i.e., compressor stations and industrial plant facilities) on Canadian Toad occurrence; however, the distance to roads used by motor vehicles (i.e., primary and secondary roads) was a significant predictor, with toads occurring in areas closer to roads. Most roads in this region are built in uplands but do regularly cross into fens. The Boreal Forest of northeastern Alberta has a high density of roads (Foote and Krogman 2006) that continues to be developed. Higher Canadian Toad occurrence near roads may be a sampling artifact. The difficulty of moving in the Boreal Forest required that all ARUs were no greater than 10 km from a road; however, there was a reasonable spread (range = 0–9.08 km, mean = 1.97 km ± 1.84) of distances. Alternatively, while the road surface themselves may not be suitable toad habitat, environmental features near roads may be, particularly if roads are wide and cause water to pool on one side.

The vegetation alongside roads is short (< 1.37 m, as indicated by LIDAR data), providing warm, open areas for toads to forage. Soils near roads are often loose and coarse in texture, which may provide easy access to overwintering locations. Kuyt (1991) noted two occasions of Canadian Toads migrating to breeding locations at the sides of roads in the Boreal Forest of Wood Buffalo National Park, Northwest Territories, Canada, that resulted in multiple road-killed toads. Though suitable hibernation sites may exist in a ditch or roadbed, mortality is a large concern if these animals must travel across busy roads (Kuyt 1991; Fahrig et al. 1995).

We found our model to have good predictive power and model accuracy (AUC = 0.846), indicating its usefulness in identifying Canadian Toad occurrence during the breeding season in northeastern Alberta. There are currently very few monitoring programs in place designed to survey anuran amphibians in the LAPR, and most detections are a by-product of research and monitoring on other species. Use of passive acoustic monitoring for this study resulted in an enormous amount of data. Detections of Canadian Toads across study years, revealed that they are patchily distributed and would have been difficult to detect without an intensive survey effort. Furthermore, by employing multiple methods of acoustic processing (human listening and automated signal recognition), we generated the largest dataset on Canadian Toad occurrence in the province.

While our model can serve as a tool for locating potential Canadian Toad breeding locations, we advise against extrapolating these results to other ecoregions. Canadian Toad occurrence and habitat use is known to change across its range (Eaton et al. 2005a), thus, suitable habitat determined by this model may not be suitable elsewhere. Likewise, we did not survey all habitat types known to support breeding Canadian Toads in Alberta, specifically, shallow (< 3 m deep), productive lakes (Hannon et al. 2002; Eaton et al. 2005b).

Our study contributes to a growing dataset (Browne 2009; Constible et al. 2010) indicating that this species is not as aquatic as once described (Breckenridge and Tester 1961; Roberts and Lewin 1979). Furthermore, our study identifies the importance of coarse soils for Canadian Toads, information possibly linked to its overwintering requirements. Our model identifies breeding habitat used by an uncommon toad in the Boreal Forest of northeastern Alberta. To develop the full picture of the habitat required by this species, future studies should broaden the scope of surveys to incorporate post-breeding occurrence of Canadian Toad. We were only able to speculate why upland habitats are important, and future research should build on our model to include these unmeasured variables and activity periods.

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**Natasha C. Annich** first dove into the world of bioacoustics in her Bachelor of Science degree at MacEwan University, Edmonton, Alberta, Canada. Her thesis project evaluated calling behavior and relative abundance of Boreal Chorus Frogs (*Pseudacris maculata*), Wood Frogs (*Lithobates sylvaticus*), and Western Toads (*Anaxyrus boreas*) at borrow pit locations in northern Alberta. She recently graduated from her Master of Science degree at the University of Alberta, Edmonton, Canada, where her thesis was also focused on using bioacoustic technology to assess anurans breeding in and around the energy sector in northeastern Alberta. She evaluated habitat use by Canadian Toads and looked at the impacts of energy sector roads on Boreal Chorus Frog calling behavior and relative abundance. (Photographed by Cassandra Hardie).

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**Appendix 1**. Details of the settings used for the automated computer recognizer built in Song Scope to detect the breeding call of the Canadian Toad (*Anaxyrus hemiophrys*).

| Recognizer settings | Canadian Toad |
|---|---|
| Min. quality[a] | 20 |
| Min. score[b] | 50 |
| Sample rate (Hz) | 16,000 |
| Max. complexity[c] | 32 |
| Max. resolution[d] | 6 |
| FFT size[e] | 128 |
| FFT overlap[f] | 0.5 |
| Frequency minimum (Hz) | 1,000 |
| Frequency range (Hz) | 2,875 |
| Amplitude gain (dB) | 0 |
| Background filter (s) | 1 |
| Max. syllable length (ms) | 1,000 |
| Max. syllable gap (ms) | 1,000 |
| Max. song length (ms) | 7,000 |
| Dynamic range (dB) | 10 |
| Algorithm | 2.0 |
| Recognizer performance statistics | |
| Cross training (% ± SE) | 84.51 ± 6.79 |
| Total training (% ± SE) | 83.68 ± 8.30 |
| Model states | 25 |
| State usage | 8 ± 3 |
| Feature vector | 6 |
| Mean symbols (n) | 178 ± 97 |
| Syllable types | 7 |
| Mean duration of syllable (s) | 2.77 ± 1.3 |
| No. of annotations used | 75 |
| Sources for annotations | Gavin Berg, ESRD |

[a]Quality values range from 0 to 100 and indicate signal quality confidence
[b]Score values range from 0 to 100 and indicate percent match with recognizer
[c]Number of states used to generate the model for the recognizer
[d]Size of feature vectors in the recognizer
[e]Number of samples used by the Fast Fourier Transform algorithm to generate a recognizer
[f]Amount of overlap between each Fast Fourier Transform window

**Appendix 2**. Canadian Toad (*Anaxyrus hemiophrys*) vocalization is a long soft trill (1–7 s). (A) Spectrogram of the Canadian Toad call (1.5–2.5 kHz) visualized in the program Audacity (Audacity Team, freeware version 2.1.2); x-axis = time (s), y-axis = frequency (kHz). (B) A Canadian Toad from a station near McClelland Lake, Alberta, Canada. (Photographed by Natasha C. Annich).