Predicting Areas of Suitable Habitat for Boreal Toad in Utah Using Species Distribution Modeling

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Introduction

As Boreal toad (*Anaxyrus boreas boreas*)(BT) has been listed as a species of conservation concern in Utah with a rank of vulnerable, there comes an increased need for understanding the ecological interactions of the species (State of Utah 2016). Moreover, the southern Rocky Mountain population has been listed as an endangered species in neighboring states of Colorado and New Mexico, and as a protected species in Wyoming. Many factors are known to threaten the species, however, the extent of these threats and the value of certain habitat features require further research. This will help determine population size and distribution, and aid in conservation efforts of this declining species in Utah (State of Utah 2016).

The aim of the study was to use multiple environmental variables such as temperature, precipitation and land cover to predict and describe habitat suitability and distribution of BT. The environmental variables were chosen based on a thorough study of the species habitat preferences, and is important to produce an accurate model (Elith et al. 2011). This was carried out using species distribution modeling (SDM) which determines the relationship between locational occurrences of a species and the environmental attributes of that site. This type of modeling is valuable to aid in conservation planning issues by finding suitable areas for reintroduction, predicting current distributions, estimating risk from anthropogenic landscape changes, and to predict distributions based on future climate changes (Elith et al. 2011).

Boreal Toad Environmental Niches

Estimates of boreal toad (*Anaxyrus boreas*) distribution extends along the Pacific Coast in the southwestern parts of Alaska to Northern California, Oregon and Washington, reaching eastward towards Canada in the Northwest Territory, Alberta and British Columbia, and from there, southward to western parts of Montana and Colorado, and to a large part of Idaho, Nevada, Utah and Wyoming. The distinct southern Rocky Mountain subspecies (*Anaxyrus boreas boreas*) is the most common type in Utah.

BT still remains in many historically noted sites, although the boundaries have generally reduced to smaller areas or have completely vanished. In Colorado and Wyoming, extirpation of localized populations have been observed (Carey 1993) and remain in only a few of the historical site. In New Mexico survey efforts were unable to detect any extant populations (Loeffler 2001). In Utah, populations have been historically described as prevalent and common, even being described as the "common garden toad" (Woodbury 1952) and "the common species in the canyons and mountains of central and northern Utah" (Tanner 1931), however, these definitions cannot be applied today. Historical data indicate the toad distributed amongst mountainous areas in Utah at approximately 203 localities in twenty of the twenty nine counties. From 1995 to 2005 it was only observed in thirteen counties compared to the previous twenty, showing their previous inhabited area had contracted. However, a majority of these recent sites were undocumented before and reveal that the species is more abundant in several mountain ranges than previously thought (Hogrefe et al. 2005). Moreover, new populations have been discovered as recently as 2013 (State of Utah 2014).

BT inhabits comparatively higher elevations than other western amphibians, although they have been documented at sea level. Highest elevation observations occurred at 3,640 m in Colorado, but is most commonly found at a range of 2,250 to 3,600 m (Campbell 1970; Livo and Yeakely 1997). In Wyoming, historic records reach 3,200 m, although more current records do not go beyond 2,925 m (Livo and Yeakely 1997). In Utah, historical records indicate an elevation range of 1,374 to 3,136 m, however the lower elevation has been brought into question based on absence of museum records, along with these records being located along the shore of the Great Salt Lake and Utah Lake, which is not typical habitat (Ross et al. 1995). More current estimates range from 1,570 to 3,220 m in Utah (Hogrefe et al. 2005).

BT is commonly associated with lodgepole pine and spruce fir forests (Campbell 1970), although inhabited wetlands in Utah are surrounded by an array of upland vegetation cover, including other types of coniferous forests, pinyon-juniper, mountain shrubs, sagebrush and grassland (Scott et al. 1993). They are required to re-hydrate daily which make them dependent of water sources, however, they have been found to be less reliant on water compared to other amphibians (Campbell 1970).

Larger, lentic or still bodies of water are ideal for breeding and developmental sites, as they do not dry up, and if they are deep enough, do not freeze at night during the summer. These bodies of water include beaver ponds, manmade ponds, small lakes and reservoirs (Holland 2002; Carey et al. 2005). These areas also often include emergent vegetation or submerged grasses and organic substrate (Fridell et al. 2000; Thompson and Chase 2001). Although they may have the proper temperature attributes, smaller bodies of lentic water can freeze or dry out, and desiccation has been observed as one of the primary causes of egg mortality at 63 percent (Carey et al 2005). They can also utilize slow moving, low gradient streams and springs, however they are not ideal as they can be too cold or swift (Oliver and Tuhy 2010).

The way the body of water is situated can also affect embryonic development. Eggs are generally found on the northern parts of shores that receive the highest amounts of daylight, warming the water and creating more favorable conditions (Carey et al 2005). East-West elongated bodies of water are optimal for this as the amount of shore receiving daylight is increased. Eggs are usually found in shorelines that are gently sloping and less than 10 cm deep, as these conditions and allow solar radiation to warm this water to as high as 30°C (Carey et al. 2005).

Temperatures found to be optimal for embryonic development ranged from 28° – 34°C, where the minimum is above 10°C and maximum above 37°C (Carey et al. 2005; Beiswenger 1978). Carey et al. 2005 found 9 percent of eggs did not reach embryonic stage due to freezing and an added ~5 percent due to temperature in general. When they are not breeding, habitat preference appear to differ between the sexes and depend on habitat surrounding breeding areas (Campbell 1970; Campbell 1976). Females tend to venture further away from the original breeding site, even to drier areas, compared to males that tend to stay more near to the original breeding site. (Jones et al. 1998; Muths et al. 2003)

Climatic variables have also been shown to greatly impact population sizes and distribution of metamorphosed sub adults. Carey et al. 2005 found that summer air temperatures determine weight and growth rates, where individuals held at 7°C would not grow and lost weight. In contrast those held at 25°C gained around 40 percent of their initial weight, and on average grew 7 percent in length. They then simulated cycling temperatures between 7°C minimum for nighttime and 25°C maximum for daytime. They gained on average 29 percent of initial weight and grew 4 percent in length, so they did not grow as much as those held at 25°C, but not as little as those held at 7°C. High summer temperatures are unlikely to negatively impact adult amphibians (Rome et al. 1992), but combined with xeric or dry conditions may increase the chance of dehydration or impair gas exchange (Berger et al. 2004). However, shrub cover greater than 21 percent may decrease the chance of dehydration, with optimum cover being greater than 35 percent (Bartelt 2000). Although, this study was done in a national forest, and whether this applies to other habitats in Utah, such as in shrub steppe or piñon-juniper woodland is unknown, and higher cover may be required (Oliver and Thuy 2010).

For adults, colder wintertime temperatures have shown to reduce the probability of persistence for populations of temperate amphibians (Anholt et al. 2003; Scherer et al. 2005), and Scherer et al. 2008 found unusually low minimum daily winter air temperatures the primary climatic factor affecting BT survival of populations in Colorado. During hibernation, availability of certain features such as burrows created by other animals, beaver dams, overhangs of stream banks, small rocky cavities, and certain soil characteristics can determine their likelihood to survive colder winters.

Population decline of the southern Rocky Mountain population is largely attributed to a result of widespread chytrid fungus (Batrachochytrium dendrobatidis [Bd]) infection (Muths et al. 2003; Greenwald 2001; United States Fish and Wildlife Service 2012). Climatic conditions such as maximum ambient temperature—or daily high—have been related to the occurrence of the fungus in the Rocky Mountains. Ambient temperature greater than 17°C were correlated to Bd presence, whereas it was not detected when it did not reach 17°C, with 17°C – 25°C being the suitable growth zone, and 30°C and above being lethal (Piotrowski et al., 2004; Muths and Livo 2008). This has been further shown, especially in Central and South America and Australia, where mid- to high-elevations provide fitting temperatures for Bd, making them more susceptible to the fungus (Daszak et al. 2003; Woodhams and Alford 2005; Drew et al. 2006). Furthermore, warming temperatures and moisture at high elevations in these tropical areas have also been attributed to an increased spread (Bosch et al., 2006; Pounds et al., 2006; Seimon et al., 2006).

However, some populations appear to be more resilient to Bd induced mortality, especially in north-eastern Utah where the fungus has been detected frequently, yet still remains as one of the healthiest populations in the northern region (State of Utah 2014). Moreover, in central Utah, a population infected with Bd has not seen an increase in infection rates between 2008 and 2013 (State of Utah 2014).

Species Distribution Models

Species distribution models (SDMs) are used to estimate the relationship between environmental variables such as temperature, precipitation, and elevation, and the known location of a species. SDMs are generally able to determine to what extent these variables are affecting the species distribution, and produce a geographical representation of the suitable habitat. MaxEnt was selected based on its predictive performance; where Elith et al. 2006 found it scored highest compared to other SDMs when modeling 226 species from six different regions around the world. Moreover, MaxEnt been used extensively by governmental and nongovernmental organizations for finding correlates of species occurrences, mapping distributions and predicting distributions in future climates (Elith et al. 2011).

MaxEnt combines occurrences of the species, along with environmental variables such as temperature and precipitation to find the largest spread (maximum entropy), or predicted distribution over a geographic space. Randomly generated background points are used in conjunction with presence-only data to determine the probability density of environmental variables at an occurrence site (Elith et al. 2011). This differs from other common SDMs that use presence/absence or presence-only samples for modeling, and makes MaxEnt most suitable for presence only data

(Guillera-Arroita et al. 2014). The use of background points makes up for drawbacks of presence/absence and presence-only data modeling methods. When presence-only points are used, prevalence, or the proportion of occupied sites compared to the total landscape cannot be identified, even with a large sample size (Ward et al. 2009). Moreover, selection bias, where occupied areas are sampled more densely than others (e.g. easily accessible areas near roads) or environmental boundaries that limit the area surveyed (e.g. visiting marshes) have a strong effect on the model compared to presence-absence (Philips et al. 2009). Absence data faces problems of detection probability, where even if a species is not detected from an initial visit, one cannot conclude that the species will not occur there indefinitely (Wintle et al., 2004; MacKenzie, 2005), suggesting presence-absence data is not unrivaled in estimating prevalence.

The following explanation of MaxEnt was derived from "A statistical explanation of MaxEnt for ecologists" (Elith et al., 2011): Maxent presumes that presence-only is available, or a set of locations within L (the study area) where the species is sampled. Designating $y = 1$ as presence and $y = 0$ as absence, z as a vector of environmental covariates (environmental conditions available landscape wide), and background points as defined by every location within L (a random sample thereof). Denoting $f(z)$ as a probability density of covariates across L, and $f1(z)$, the probability density of covariates across spaces in L where the species is present, and also, $f0(z)$ where the species is found to be absent. These probability densities determine the relative likelihood of random variables across the range, and may be univariate or multivariate. The outcome is to find the probability of presence of a species joined with environmental variables: $Pr(y = 1|z)$. The presence and background data employed allows for modeling both $f1(z)$ and $f(z)$, where we will be within a constant of $Pr(y = 1|z)$ as Bayes' rule gives:

$$Pr(y = 1 \mid z) = f1(z) Pr(y = 1) / f(z)$$

The covariate data from the occurrence data and the background sample are used to estimate the ratio of f1(z)/f(z). This is accomplished by making an approximation of f1(z) that is congruent with the occurrence data. There are a variety of distributions that are available, but the one closest to f(z) is selected. The distance from f(z) is the relative entropy of f1(z) with respect to f(z) (also called the Kullback-Leibler divergence). Background points feed the model information about f(z), and gives the foundation for comparison with f1(z). In other words, background data helps determine the density of environmental covariates across the study area and is used to compare the density of environmental covariates occupied by the species. It must also be noted that MaxEnt does not give probabilities of occurrence, but rather relative suitability (Guillera-Arroita et al. 2014).

Data

Occurrence records of BT were obtained from the State of Utah Natural Heritage Program, where 2,367 occurrence points were available, which later was lowered to 830 (Figure 1). Overlapping coordinates, points outside of the study area, less reliable, older data (pre 1990), points with greater than 50 m locational uncertainty were removed. Multiple environmental variables were chosen based on their likelihood to describe the species habitat preferences, and moreover, to find their overall influence on the distribution of species (Table 1). These chosen variables were also loosely based on a model of Western Toad conducted by the Montana Natural Heritage Program that showed the significance of certain environmental factors for the species (Burkholder 2016). These layers were then altered to have the same spatial extent, cell size of 30 m and projection, then converted to ASCII format to allow for MaxEnt run the analysis. A cell size of 30 m produce more accurate results as it is the finest spatial scale available to most closely represent the landscape.

Occurences from the Natural Heirtage Database

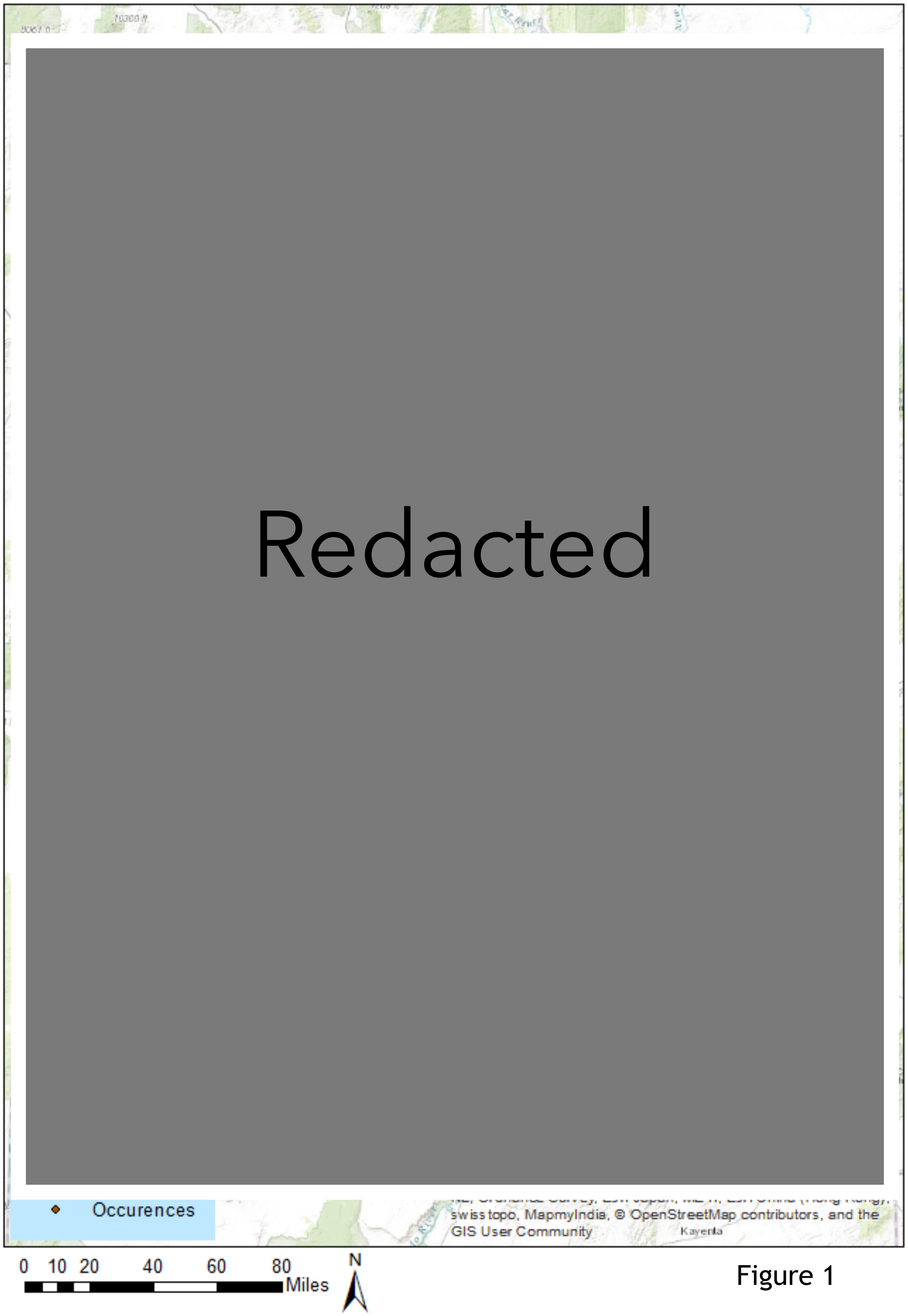

Figure 1

Layer	Identifier	Original Scale	Description/Source
Annual Precipitation	anlavgprecip	800m	Average annual precipitation (mm) for 1981—2010. Oregon State Prism Climate Group
January Precipitation	janprecip	800m	Average precipitation (mm) in January for 1981 – 2010. Oregon State Prism Climate Group
July Precipitation	julyprecip	800m	Average precipitation (mm) in July for 1981 – 2010. Oregon State, Prism Climate Group
Max Summer Temp	tmax	800m	Average Maximum Temperature (°C) in July for 1981-2010. Oregon State, Prism Climate Group
Min Winter Temp	tmin	800m	Average Minimum Temperature (°C) in January for 1981-2010. Oregon State, Prism Climate Group
Elevation	elevation	30m	Elevation in meters above mean sea level. USGS GAP Data
Fresh Standing Water	freshstand		Fresh, standing water with brackish flowing water and wet vegetation masked out. USGS GAP Data
Fresh Flowing Water	freshflow	30m	All types of flowing water with fresh standing water masked out. USGS GAP Data
Fresh Water Vegetation	freshveg	30m	Fresh wet vegetation such as swamps and marshes, with brackish water masked out. USGS GAP Data
Slope	slope	30m	Percent of change of elevation, based on DEM data. USGS GAP Data
Solar Radiation	solarrad	Vector	Physical Solar Model (PSM) Direct Normal Irradiance in kWh/sq.m/day for 1998-2014. NSRDB Data
Land Cover Type	landcover	30m	Ecological systems GAP National Land Cover Data
Forest Edge	forestedge	30m	Transitional areas between forests and non-forested areas. USGS GAP Data

Table 1. Environmental layers used in the study

Methods

Multiple default settings in MaxEnt were changed to customize and improve the output. Replicates, or the number of runs, was changed to 3, where an average was created that allows for the model to measure the amount of variability. Random test percentage was changed to 25 to set aside a part of the data for testing to obtain the models performance. This test data is important, as it would otherwise use training data to assess the models, which would create a bias and give an overestimate of the model performance. Replicated run type was left on cross validate to define a dataset that will test the model while it is being trained to limit over fitting. Convergence, or the number of iterations, was increased to 3500 to give the model enough time for convergence so that the model will not over-predict or under-predict relationships. The rest of the settings were left on default for the run. Three different mapping areas were used to determine the changes of the predicted suitable habitat. The first map covered the entire area of Utah. The second map reduced the area to exclude a sub-population of the species in the upper north-west corner, as this population has been recently been determined to be a subspecies and not a part of the southern Rocky Mountain population. The area was also reduced to to areas where the species is unlikely to occur, or where habitat suitability information is not needed. Limiting the area used for the model has shown to improve model performance in MaxEnt and limit sampling bias (Elith et al. 2001). The third map included the north-west population, along with the other unnecessary areas removed.

Results

The output gives many different interpretations of the input including a current and predicted distribution map, jackknife scores, and receiver operating characteristic (ROC) amongst others. We will start with the ROC curves for Sensitivity vs. 1 - Specificity for Boreal Toad that also gives us the area under curve (AUC) scores. Figure 2 gives a representative sample of the graphs that is similar to the others. An AUC score is a performance measurement of a logistic regression, where random positive and negative observations give the proportion that is guessed correctly. A perfect score is 1, whereas random guessing is around .5, or 50 percent chance. All of the models gave predictions well above the random prediction of AUC = 0.5, showing the prediction is better than random. The red line shows the training data, or 75 percent of the total data, where the remainder was set aside for the random test percentage. This tells us how well the model fit to the data that was used to calibrate, with the models AUC score ranging from 0.960 to 0.969, which are satisfactory scores. The blue line is the most important curve, as it shows us how well the model fits to the test data. The range of the AUC scores for the test data were from 0.962 to 0.964, which is slightly lower than the training data, but is to be expected. The closeness of these two curves also informs us that the model is not over fitting.

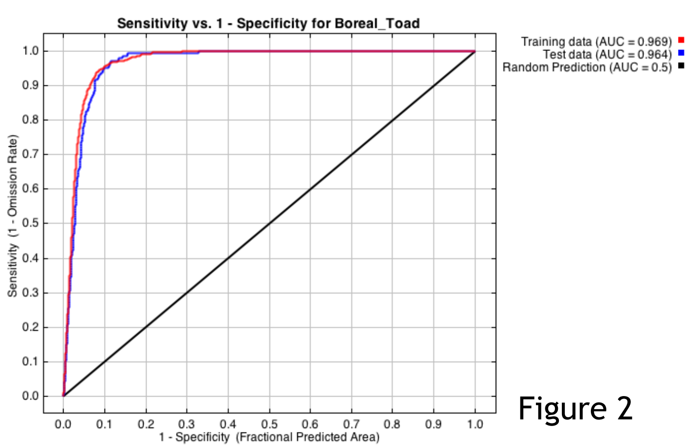

Figure 2

To find which environmental variables contribute to the model the most we run a jackknife test to measure variable importance. The outputs are created giving each variable in isolation, and one using all variables. The first is an example of one of the jackknife results (fig. 3) of regularized training gain. We see that if only slope is used there is little gain on the training, showing it is not useful for estimating the distribution. On the other hand, average maximum temperature for July allows a fairly good fit to the training data. The lighter blue bars, where each variable is excluded, shows that no variable holds a large amount of useful information that is not contained in any of the other variables. To calibrate the model, multiple layers were removed after the initial run as they showed little contribution to the overall model. These variables were aspect, percent canopy cover, forest edge and human avoidance. However, this does not indicate that these features are not important to the species, rather that they were not highly valuable to the model for explaining the distribution and habitat preferences compared to the other environmental layers.

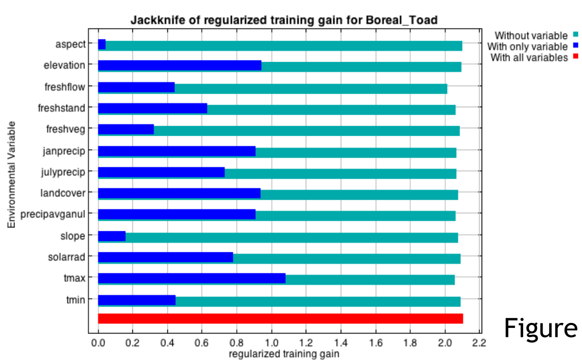

Figure 3

MaxEnt give two more plots, one jackknife for test gain (fig. 4) and one of AUC (fig. 5), both showing a typical output across the tests. The jackknife of AUC shows average maximum temperature for July, average annual precipitation, elevation, and average precipitation for January are the most effective variables for creating the model of the data when performance is based on AUC, and was true for all three runs. The same variables also

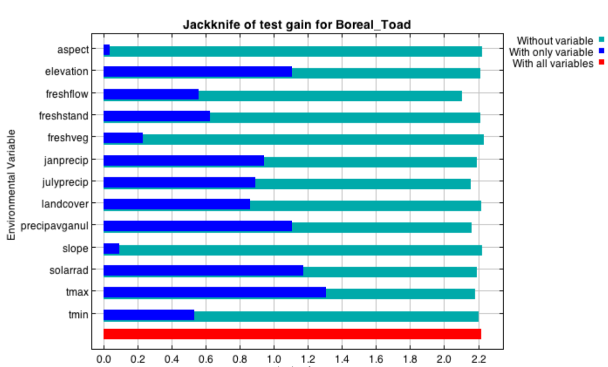

Figure 4

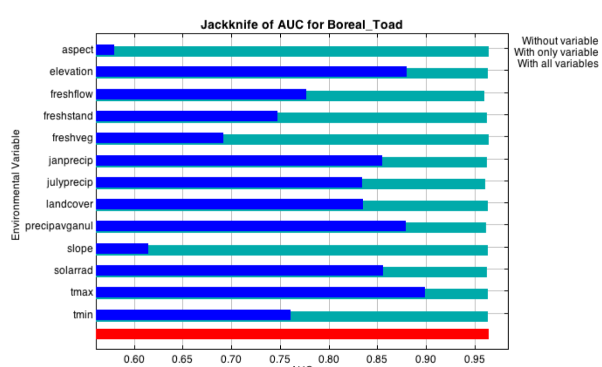

Figure 5

score high on the test gain plot. From this, we can assess that distribution and suitable habitat is highly dependent on temperature and precipitation.

The final three maps showed the habitat suitability closely relate to the known distribution and habitat preferences of the species. All three runs of the model for the different mapped areas (the entire state, only the eastern and central areas, and the eastern and central areas with the northwest area added) showed very small differences and were not significant enough to determine changing the boundaries affected to model. Figure 6 is the map with the entire state boundaries used, and figure 7 is the map with the north west region and uninhabited areas cut out. The only difference being the suitable habitat areas contracted slightly for the map with the northwest region cut out. The final map that was chosen was the map with the northwest region included, as it had final suitable habitat boundaries in between the other two—making it somewhat of an average of the two—and also gave higher AUC scores (figure 8). Moreover, this map give us a good understanding of the species distribution and suitable habitat combined. The final map was reclassified based on the 10 percentile training presence logistic threshold given by MaxEnt which was at 22 percent (fig. 9). This was used because the data collected likely contained some errors, therefore 90 percent of the data used to determine habitat suitability is used to limit these errors.

Redacted

Figure 6. First model run with entire area of Utah

Figure 7. Second model run with the northwest region cut out

Raw Suitable Habitat for Boreal Toad

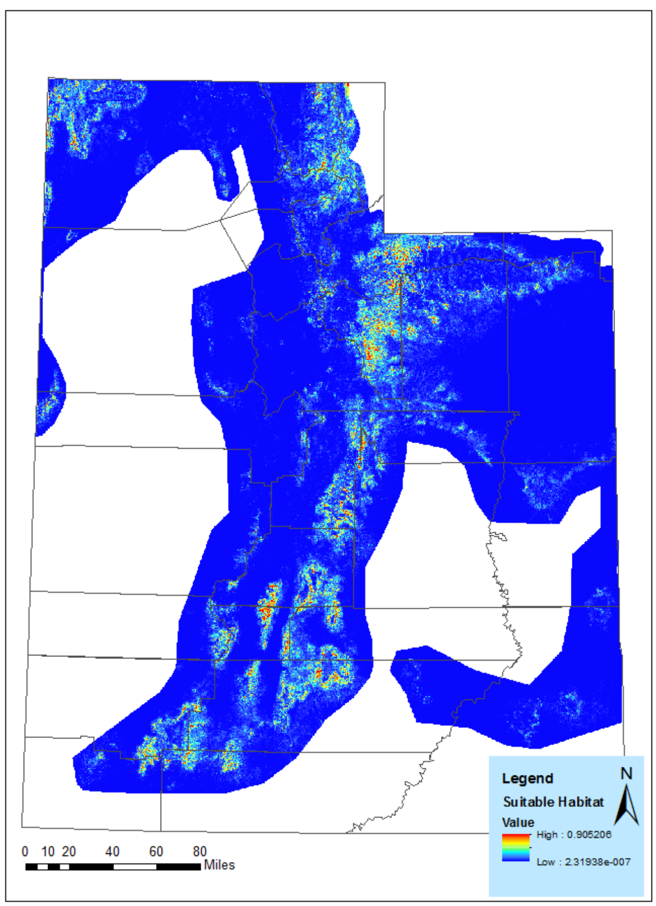

Figure 8. Final raw map with northwest region included

Suitable Habitat for Boreal Toad - Threshold Applied

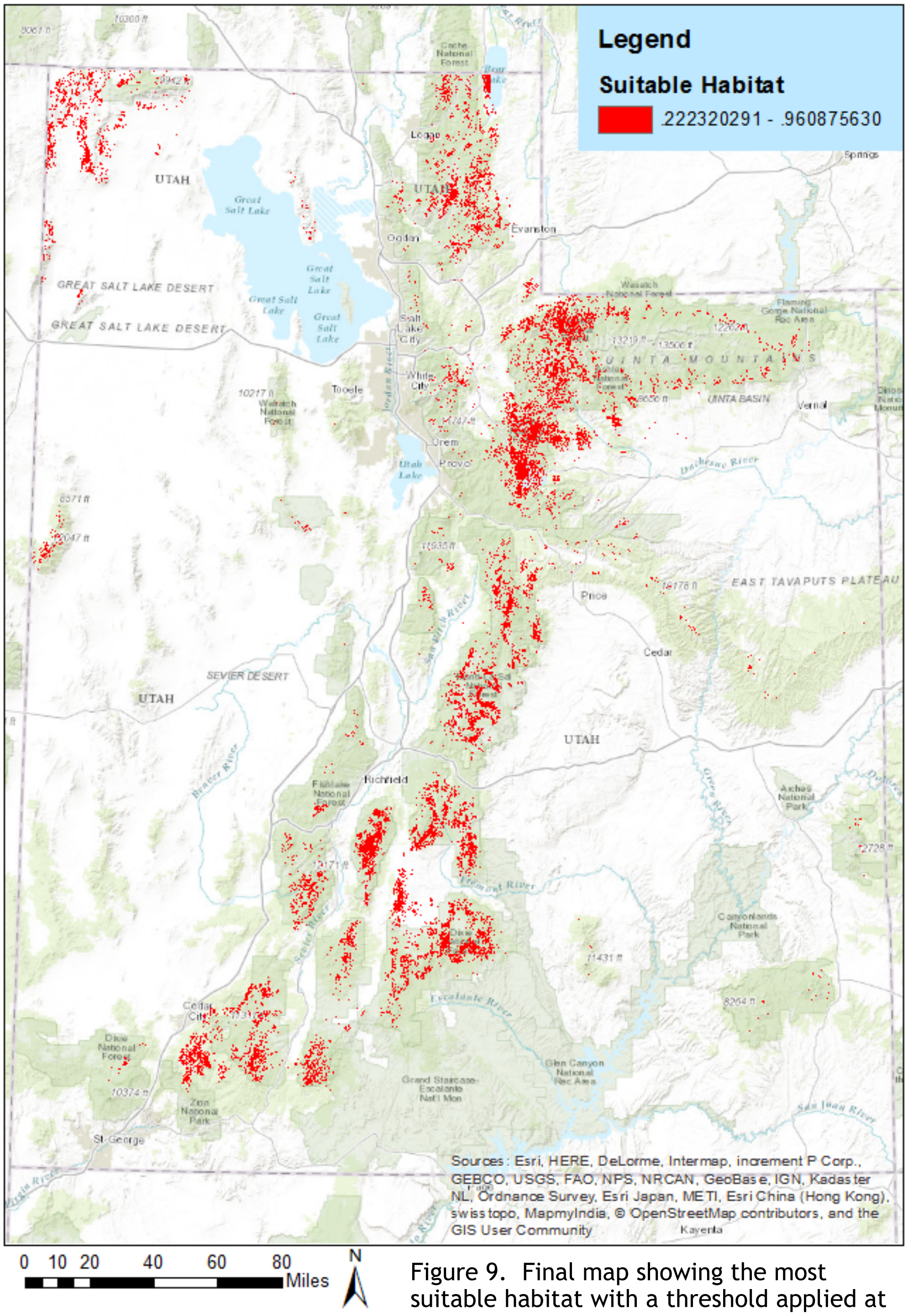

Figure 9. Final map showing the most suitable habitat with a threshold applied at 22 percent.

Deductive Environmental Niches

Outside of MaxEnt, the environmental variables were extracted based on the occurrence records to find the average, minimum, maximum, mode and standard deviation summarized in Table 2 for the most important variables. We can see that the elevation deviates slightly from current estimates in Utah which range from 1,570 to 3,220 meters, whereas the minimum here is 1,343 meters with a maximum of 3,300 meters.

For maximum July temperature, they seem to prefer areas that average about 23°C, and where it does not fall below 18°C or rise above 35°C. These are fairly low maximum average temperatures for July in Utah, which indicate they do not prefer high summer temperatures and may make them more susceptible to Bd. This is based on the optimal temperatures for Bd to proliferate being between 17 - 25°C (42). Moreover, Bd presence in the Rocky Mountains have found to be in areas where daily highs are greater than 17°C, compared to areas where it was not detected generally did not reach 17°C and rarely did it reach 30°C which is lethal to Bd (Piotrowski et al., 2004; Muths et al. 2008). However, the average minimum temperature of -11°C for January likely limits the effects of Bd, as temperatures below 10°C have shown to limit its growth (Piotrowski 2004). Even though they may occur in areas where temperature is optimal for Bd, some populations in Utah that are unlikely affected by its presence (State of Utah 2014).

They also seem to prefer areas of high annual precipitation, reaching 676 mm as the average, whereas the average for the state is around 400 mm (NOAA 2017). They also were found in areas that received more precipitation than the average for the state, where the average for the state in January is around 31 mm, and for July is around 17 mm (NOAA 2017), whereas for areas where BT occurs, the average is 66 mm for January and 36 mm for July—more than double the amount for both months.

This shows a decrease in precipitation in the future will likely affect breeding and spawning locations. This will likely increase severity of forest fires which has shown to cause direct mortality and increase forest fragmentation (Hogrefe et al 2005). Moreover, amphibians are highly susceptible to drought and limits their breeding areas (Livo and Loeffler 2003; Scherer et al. 2005).

Average solar radiation amount was 5.95 kWh/sq.m/day, being a medium-high level, indicating they prefer higher solar radiation. This is likely due to the fact that higher radiation warms water which is essential for embryonic development (Carey et al. 2005) .

	Tmax	**Janprecip**	**Anlavgprecip**	**Julyprecip**	**Elevation**	**Solarrad (kWh/sq.m/ day)**
Mean	23.88˚C (74.98 ˚F)	66.81 mm (2.63 in.)	676.09 mm (26.61 in.)	36.37 mm (1.43 in.)	2,689 m (8,822 ft.)	5.95
Mode	26 ˚C (78.8˚F)	79.2 mm (3.11 in.)	677.23 mm (26.66 in.)	29.82 mm (1.17 in.)	2,317 m (7,601.70 ft.)	6.17
Min	18.61˚C (65.49˚F)	14.35 mm (0.56 in.)	207.88 mm (8.18 in.)	16.1 mm (0.63 in.)	1,343 m (4,406.16 ft.)	0
Max	35.68˚C (96.24˚F)	179.47 mm (7.06 in.)	1,445 mm (56.88 in.)	61 mm (2.40 in.)	3,300 m (10,826 ft.)	7
STDEV	2.4	22.56	171.29	7.88	385	0.43

Table 2. Data extracted from environmental variables based on occurrence records

Extracting the values from the land cover type layer, we find the most common habitat was inter mountain basins with montane sagebrush steppe (Table 3). Elevations here range from 1000 to 3000 m, and characteristics generally including gently sloping topography, areas with higher than normal precipitation, finer soils, mesic conditions, and sweeping sagebrush cover. Next was rocky mountain aspen forest and woodland, that ranges from 1525 to 3050 m in elevation, and is defined by high soil moisture that counteracts regular evapotranspiration, low temperatures, high cover of *Populus tremuloides* with an understory of shrubs and low cover of conifers. Third most common is rocky mountain subalpine dry-mesic spruce-fir, ranging from 1275 to 3355 m in elevation, and are usually the highest reaching forests in an area.

They maintain colder temperatures year-round, where snow is the primary form of precipitation, and usually does not melt until later summer. Frost is also common all summer in certain areas, and covered mostly by *Picea engelmannii* and *Abies lasiocarpa*. These definitions closely agree with findings extracted from the occurrence records (table 2) which indicate habitat with elevations around 3000 m, large amounts of precipitation and low wintertime temperatures.

Most Common Habitat Types Based on Occurrence Records (Definitions from USGS GAP Data)
1. Inter Mountain Basins Montane Sagebrush Steppe
2. Rocky Mountain Aspen Forest and Woodland
3. Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland
4. Rocky Mountain Alpine-Montane Wet Meadow
5. Open Water (Fresh)

Table 3

It should be noted that these averages are not site specific, indicating sub populations may experience different averages and the standard deviation should be used to determine to what extent this varies.

Conclusion

The model shows that BT habitat preference and distribution to be best described by climatic variables, as temperature and precipitation were the highest contributors to the final model. Embryonic developmental success is dependent on specific water temperature and levels, and is amongst the most important factors determining the survival of BT (Oliver and Thuy 2010). Moreover, desiccation has been observed as one of the primary causes of egg mortality at (63.3%) (Carey et al 2005).

Adults are unlikely influenced by higher temperatures (Rome et al. 1992), however, increased temperatures combined with xeric conditions may further reduce the total amount of water available for the species and impair gas exchange (Berger et al. 2004). Moreover, this may make them more dependent on areas with higher shrub cover (Oliver and Thuy 2010). This shows areas of low precipitation or drought in the future may cause a drop in population and/or change in distribution.

Lower than normal wintertime temperatures have shown to greatly limit persistence of BT (Scherer et al. 2008) which will be less frequent in future climate changes. The benefits from this may be negated by higher summertime temperatures—although this would require further study to validate. A SDM based on future predictions of temperature and precipitation could be supplemental to understanding this interaction. BT is located in areas where temperatures are ideal for Bd, some populations appear to be more resilient and other factors may be influencing the effect of Bd on these populations.

It must be noted that these results are limited to the inputs of the model, meaning other factors that can influence the species distribution and habitat such as livestock farming and ranching, habitat degradation and loss, prescribed burns, and other species including the tiger salamander (State of Utah 2016; Oliver and Tuhy 2010) were not included in this assessment. These factors should be considered for conservation planning, and should not rely completely on the model.

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