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Life in the Dirt: Factors Influencing the Behavior and Distribution of Spea Intermontana in Eastern Washington State

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LIFE IN THE DIRT: FACTORS INFLUENCING

THE BEHAVIOR AND DISTRIBUTION OF *SPEA INTERMONTANA*

IN EASTERN WASHINGTON STATE

A Thesis

Presented to

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In Partial Fulfillment

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by

Corey Jacob Brumbaugh

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CENTRAL WASHINGTON UNIVERSITY

Graduate Studies

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ABSTRACT

I divided my thesis into two major studies focusing on the Great Basin Spadefoot Toad, *Spea intermontana*, at the Beverley Dunes (Beverley, WA). The first study explored the effects of temperature and water level on the rate of metamorphosis. We gathered data on rates of development, survival, body mass, snout-vent length, and hind leg length of metamorphs under 4 treatments: 20C x High Water, 30C x High Water, 20C x Water Loss, and 30C x Water Loss. These data show that temperature has a stronger effect on the overall rate of metamorphosis of Great Basin Spadefoot Toads. The second study used 5 categories of field data (hydrography, elevation, soil type, land use, and land cover), to produce a predictive model for finding novel populations of Spadefoot Toads in Washington State. Data from local and government agencies were combined with recent ecological and behavioral data from a single location for the model. This model could be an integral tool when researchers are making methodical choices during initial stages of surveying for a target species. We feel our model can serve as an excellent example of an applied GIS-based approach to survey and management techniques.

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ACKNOWLEDGMENTS

First and foremost, I would like to thank all of my committee members, Dr. Steve Wagner, Dr. Wayne Quirk, and Dr. Robert Weaver. They provided me with the tools and guidance to complete this project. Thank you all for taking the time to help review and give me feedback on my research. I would also like to thank CWU GEAR UP, specifically, Kelley Quirk and Tracey Plouse, for providing me with a graduate assistantship and several exciting years working with the GEAR UP students. I also want to acknowledge Jonathan Betz and Mary Bottcher for all of their help with materials and vivarium space.

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CHAPTER 1

INTRODUCTION

The Great Basin Spadefoot Toad, *Spea intermontana*, is a small desert frog that is hard to manage due to its cryptic morphology and fossorial behaviors. These frogs are members of the family Scaphipodidae. They can be found from northern Arizona up into Southern British Columbia (Fig. 1; Matsuda et al. 2006). In the core of their range, this species is associated with arid environments, including open grassland, shrub steppe, and open forest habitats.

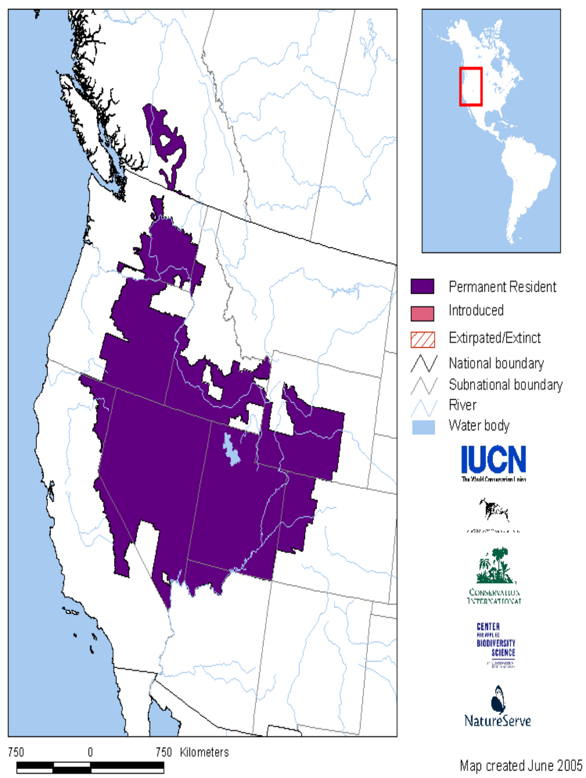

Figure 1 Range map for Spea intermontana.

While *S. intermontana* is a desert species, they utilize ephemeral water sources when breeding. During reproduction, *S. intermontana* will enter amplexus, where a male will cling to the back of the female and wait for her to lay her eggs, ensuring that he will beat out competitors for fertilizing the female's eggs (Chuang and others 2013). Females lay up to 1200 eggs in a single breeding season, with average clutch sizes ranging from 38-106 eggs per breeding event (Ashpole et al. 2014). Eggs typically hatch in 2-3 days at which time the offspring begin the stages of metamorphosis classified as the Gosner stages of metamorphosis (Gosner 1960). Metamorphosis is influenced by a variety of biotic and abiotic factors (Indermaur et al. 2010).

Spadefoots spend their time during the active season (April – November in WA) in self-made burrows (utilizing the keratinized spade on their hind feet) and on occasion, small mammal burrows (Sarell 2004). Spadefoots tend to use the burrows during the day and will emerge at night to feed on insects. However, they often can remain in burrows for extended periods of time if the environmental conditions are not suitable for emergence (Matsuda et al. 2006).

The cryptic morphology and fossorial behaviors make studying *S. intermontana* very difficult. These difficulties lead to incomplete distribution records or records only found in museums and marked on a map. As researchers, we often only have access or are provided with these outdated points or polygons that show the species range (Fig. 2). This leads into questioning where one starts their research. To determine where to start, the use of geographic information systems (GIS) can provide useful insights and help guide researchers where to begin looking.

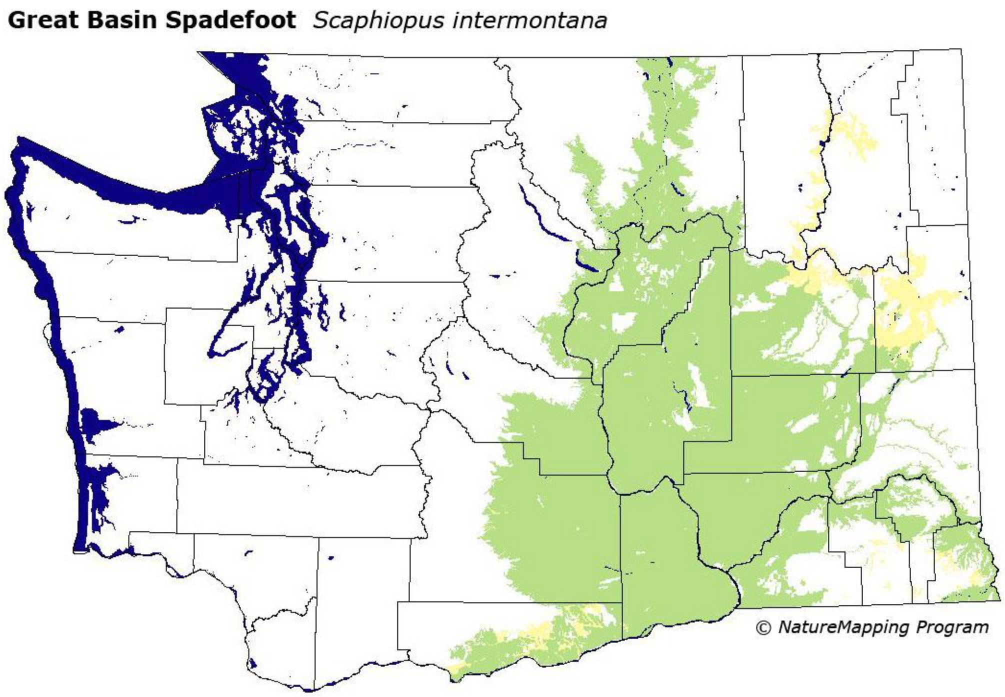

Figure 2 Distribution map for Spea intermontana in Washington State.

With climate change progressing it is crucial that we begin using less invasive management techniques. The use of GIS allows management professionals and researchers to perform less on the ground field surveys, in which habitat for other species or the focal species is disturbed. This lessens the burden of habitat destruction from researchers in environments where climate change is already pressing amphibians' distribution and available habitat. Loss of habitat and/or degradation are the most significant threats to the survival and proliferation of amphibian populations (Semlitsch 2002, Stuart et al. 2004, Blaustein et al. 2011).

This study had two major goals; first, to examine the effects of drought and climate change on the rate of metamorphosis and to test the feasibility of using a predictive suitability map model to find a cryptic desert amphibian. This study used both field and lab practices in accordance to the Central Washington University Institute Animal Care and Use Committee guidelines, along with a Washington State Department of Fish and Wildlife scientific collection permit.

CHAPTER 2

DISCUSSION

When looking at the rate of metamorphosis there are a lot of factors to think about. Metamorphosis can be influenced by environmental conditions (temperature, water availability, water quality), hormones, and predator prey interactions (Hayes and Wu 1995; Brown and Cai 2007; Alvarez and Nicieza 2002; Indermaur et al. 2010; Smith-Gill and Berven 1979; Newman 1989; Newman 1992; Wright et al. 1990). For this study, I chose to focus on the effects that we see with droughts and climate change; these being increasing temperatures and decreasing water levels. A similar study looked at Hammond's Spadefoot Toad, *Spea hammondii*, and found that the metamorphosis process could be completed in as few as 20 days in a lab setting (Denver et al. 1998). It was also found that the variations in metamorphosis timing is determined by several endocrine glands that are stimulated by these different factors (Denver 1997).

While there has been the study by Denver on *S. hammondii*, this was on a different species in a different geographical location. Washington is not the northernmost portion of *S. intermontana* distribution, we have a different climate than that of California, where *S. hammondii* is native. California tends to have more frequent droughts than Washington (Fig. 3).

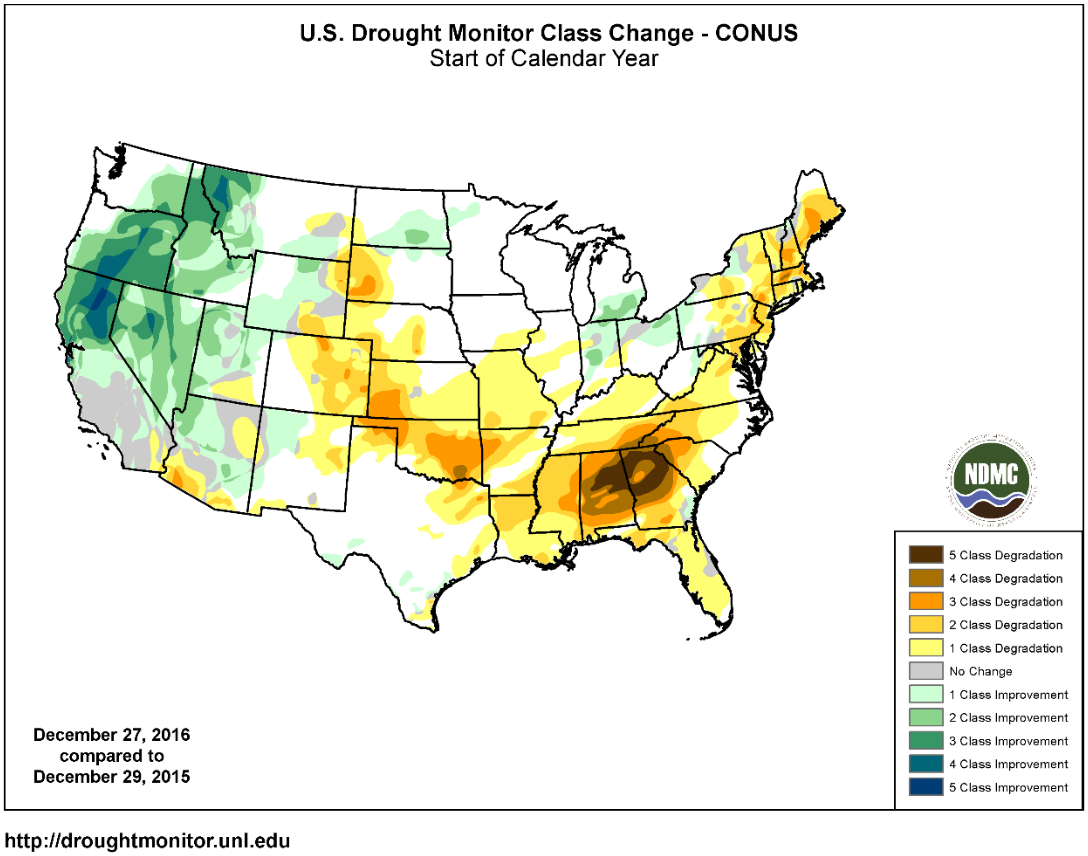

Figure 3 U.S. Drought Monitor Class Change - Showing the changes in droughts across the contiguous U.S. from December 2015 to December 2016.

These more frequent droughts are not always associated with higher temperatures and could explain why it was found that *S. hammondii* had a faster metamorphosis rate when water levels are reduced at faster rates. Washington has less droughts and drastic seasonal fluctuations in temperature. This leads to a curiosity of whether temperature is a larger factor than reduced water or if we see the same phenomenon as what is seen by *S. hammondii* in California.

With climate change and increasing droughts, cryptic or endangered species are going to be more difficult to study. This means that it is crucial that we begin to develop and practice new survey techniques for these species. Due to the nature of trying to study cryptic and endangered species, there have been a few new methods developed and implemented (eDNA, ecological niche models) during surveys (Ortega-Andrade et al. 2015; Rowley et al. 2015). Researchers have attempted to use suitability maps as predictive models with little success due to the inaccuracy in the dependencies on habitat variables, data being analyzed, and the underlying model structure (Austin 2007). However, most of these attempts have been at a fine scale looking at where in a specific environment they are most likely to occur.

If we take a step back, and look at a coarser scale in a larger geographic range there is a chance of success for finding populations rather than predicting the exact location where an individual can be found within a given area. For my predictive suitability model, I chose to use elevation, land use, land cover, hydrography, and soil type as my variables. These variables are often used for mitigation planning and management of plants and animals (Clevenger et al. 2001; Stanchi et al. 2013; Nawaz et al. 2014). Spadefoot toads tend to prefer bare ground in arid environments (Garner et al. 2006). While studies have not been conducted looking at all the habitat preferences of *S. intermontana,* there have been many studies looking at the European spadefoot, *Pelobates fuscus* and the eastern spadefoot, *Scaphiopus holbrookii*. *Pelobates fuscus* has been found to be more preferential to short vegetation with bare soil over shrub-covered areas (Eggert 2002). On the east coast, *S. holbrookii*, has been found to prefer open areas with friable soils of sandly loam, loamy sand or sand (Johnson 2003). Some of these factors and anecdotal evidence was used to determine what variables would be used to create the predictive suitability map.

The goal of the predictive model was to take information from a single population and professional judgement to try and predict the overall distribution of *S. intermontana* in eastern Washington State. This predictive map can then be used to find new populations or check to see if old populations are persisting. The success of this model could lead to new management plans being used to reduce the degradation and destruction of habitat from traditional field surveys.

Chapter 3

STUDY SITE

The major study site that was used for these studies was the Beverley Dunes near Beverley, Washington (Fig. x). This is a recreational dune site that is often used for camping, where people will often drive through the dunes on off-road vehicles. These dunes host an abundant population of *S. intermontana* and is within a close proximity to Ellensburg. Just south of the dunes is Lower Crab Creek and both near the creek and within the dunes there are ephemeral irrigation seeps that provide breeding ponds for desert amphibians.

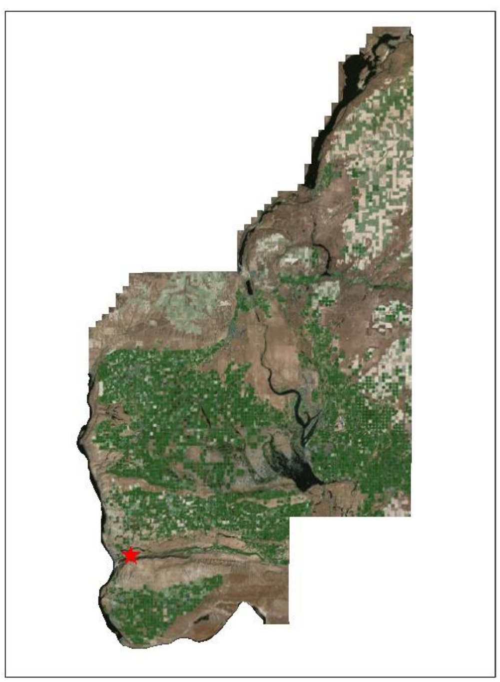

Figure 4 Map of Grant County, WA. Point on map represents the primary study site, Beverly Dunes, WA.

ANALYSIS OF ABIOTIC FACTORS INFLUENCING THE RATE OF METAMORPHOSIS IN THE GREAT BASIN SPADEFOOT TOAD, *SPEA INTERMONTANA*, IN EASTERN WASHINGTON STATE

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ABSTRACT:

Eastern Washington State has a wide variety of macro habitat types, from dense high elevation spruce-fir stands to Ponderosa Pine forests and shrub-steppe desert. However, agricultural lands, including annually irrigated crop fields, orchards, vineyards, and livestock farms are prominent features in this region. Recreational lands such as dunes are also found at scattered locations in the mid-Columbia Basin. Such areas are generally not considered suitable habitat for several species of amphibians and reptiles. However, anecdotal evidence suggests that the Great Basin Spadefoot Toad, *Spea intermontana*, is distributed among these agricultural and recreational sites. Our recent survey work has shown *S. intermontana* utilizing ephemeral ponds, narrow, water-filled tire tracks and small irrigation seeps for breeding at one such recreational site, the Beverley Dunes located near Beverley, Grant County, WA. The purpose of our study was to examine the effects of temperature and water levels on survivorship, and rate of metamorphosis of tadpoles of *S. intermontana.* To conduct our study, we collected egg masses and reared tadpoles under these varying abiotic conditions in the lab. We gathered data on rates of development, survival, body mass, snout-vent length, and hind leg length of metamorphs under 4 treatments: 20C x High Water, 30C x High Water, 20C x Water Loss, and 30C x Water Loss. Our findings show that temperature is the main factor influencing the time to survivorship and the rate of metamorphosis in *S. intermontana* in Washington State.

Key words**:** Great Basin Spadefoot Toad, Spea intermontana, metamorphosis, plasticity, Washington, Great Basin

Introduction:

The Great Basin Spadefoot Toad, *Spea intermontana*, is a small cryptic frog found throughout eastern Washington. This species is mainly associated with arid environments, including open grassland, shrub steppe, and agricultural fields. As a desert amphibian, *Spea intermontana* is an opportunistic breeder, exploiting ephemeral ponds and puddles for breeding. Breeding occurs throughout most of the spring and summer, however; the spawning window and emergence of tadpoles is a very narrow window, usually 2-3 days. As a consequence, droughts and increasing temperatures in arid environments can make relying on ephemeral spring rains difficult for amphibians such as Spadefoot Toads. Further, drying ponds, and a lack of rainwater can lead to less breeding habitat for desert amphibians.

These processes can vary in length depending on species and both abiotic and biotic factors (Indermaur and others 2010). Abiotic factors found to influence metamorphosis are 30 C x High Water (Smith-Gill and Berven 1979; Newman 1989), photoperiod (Wright and others 1990), herbicides and pesticides (Cauble and Wagner 2005), and pond duration (Newman 1992). Biotic factors that influence metamorphosis are larval density (Scott 1994; Newman 1998), predator prey 30 C x Water Losss (Werner 1986; Petranka and others 1987), and disease (Daszak and others 1999; Parris and Cornelius 2004). Anuran metamorphosis can vary in duration and methods between species and is classified into stages of metamorphosis as defined by Gosner (1960). These larval stages follow tadpoles from the initial laying of the eggs all the way to complete metamorphosis (Gosner 1960). Many species have extended larval periods, for example, *Ascaphus truei*, can spend 2+ years in a larval state (Wallace and Diller 1998) and bullfrogs, *Rana* *catesbeiana,* are well known for spending around 2 years in a larval state, as top predators in pond ecosystems (Collins 1979). In contrast, others have short periods with Hammond's Spadefoot Toad, *Spea hammondii,* completing the entire metamorphosis process in as few as 20 days in a lab setting (Denver and others 1998). Variations in timing are determined by both genetic and environmental factors which influence the activity of several endocrine glands causing a suppression or stimulate an increase in the rate of metamorphosis (Denver 1997). The rate of metamorphosis has been found to increase due to hormones, predator prey 30 C x Water Losss, 30 C x High Water, 20 C x Water Losss (drought), and water quality (Hayes and Wu 1995; Alvarez and Nicieza 2002; Brown and Cai 2007). Our study investigated the effects of 30 C x High Water and 20 C x Water Loss on the survivorship and rate of metamorphosis of *S. intermontana* in Washington State.

The majority of eastern Washington State habitat resides in the Great Basin, where there is a conservation concern for some of the desert amphibians living within this region (WDFW 2015). It is known that amphibians within temperate zones are vulnerable to the changing climate (Gerick and others 2014). In 2012, a drought was declared a natural disaster in 71% of the United States by the U.S. Department of Agriculture (Dai 2013). Within the past decade, there has been a twofold increase in the occurrence of daily record high temperatures than the daily record cold temperatures (Kunkel and others 2013). Desert environments often have unpredictable rainfall and as a result, ponds only exist for a short duration and consequently a short hatching and larval development time for amphibians is crucial for survival (Newman 1992). An increase in droughts and average temperature likely reduces overall breeding habitat for desert anurans. Thus, we investigated the effects of decreasing 20 C x Water Losss and increasing temperature on the rate of metamorphosis and survivorship of *S. intermontana* in Washington State. The goal of this study is to assess the effects of increased droughts on the metamorphosis process of *S. intermontana.* This study tries to answer the following questions: Does a decrease in water level increase the rate of metamorphosis? Does an increase in water temperature increase the rate of metamorphosis? Is there an interaction between water level and water temperature that affect the rate of metamorphosis?

METHODS:

A total of 200 eggs were collected from a tire track in the Beverley dunes near Beverley, Washington in May 2016. The puddle was about 1.5 meters long, 0.5 meters wide, and 5 centimeters deep and appeared to be created by a motor vehicle. Eggs were transported to the Central Washington University vivarium where they were placed in an aquarium to wait for tadpole emergence in a temperature controlled room set at 20˚C.

As tadpoles emerged, they were randomly assigned to one of 12 aquaria that were each prepared to house 15 individuals to avoid competition associated with high tadpole density (Semlitsch and Caldwell 1982). Tanks were divided into 4 groups of 3 aquaria resulting in 45 tadpoles for the four treatment groups: 20 C x High Water, 30 C x High Water, 20 C x Water Loss, and a 30 C x Water Loss. All tanks were filled with 10 liters of 20˚C water. The 30 C x High Water and 30 C x Water Loss aquaria were heated using submersible water heaters set at 30˚C. Reduced 20 C x Water Loss and the 30 C x Water Loss aquaria had 250ml of water removed every day without dropping below 0.5L of water remaining in the aquaria.

To ensure that all aquaria received equal disturbance from the removal of water, water removal was simulated in the 20 C x High Water and the 30 C x High Water aquaria (Denver and others 1998).

Tadpoles were monitored every other day until noticeable stages of metamorphosis were reached (Saha and Gupta 2011). Tadpoles were monitored daily upon reaching Gosner stage 20 until completion of metamorphosis (Gosner 1960). Upon complete metamorphosis, frogs were measured for snout vent length (mm), hind foot length (mm), and mass (g).

All methods were followed under the guidance and in compliance with the Central Washington University Institute Animal Care and Use Committee and our scientific collection permit with the Washington Department of Fish and Wildlife.

Statistical analysis:

To assess survivorship, we examined the length of time it took for half of the population for each variable to die. Mann Whitney U tests were used to do pairwise comparisons for the average time to metamorphosis and average time to death.

RESULTS:

Survivorship:

A total of 50 frogs survived to complete metamorphosis. The survivorship was as follows: 20 C x High Water 40%, 20 C x Water Loss 2.22%, 30 C x High Water 31.11%, and 30 C x Water Loss 37.78% (Fig. 5).

Using Mann-Whitney U-tests we assessed the time-to-metamorphosis and the time-to-death for each treatment using pairwise comparisons (Fig 6-7). For the 20 C x High Water, the average time to metamorphosis was 87.82 days and the average time to death was 81.28 days. For 20 C x Water Loss, on average 64 days to metamorphosis and 57.25 days to death. For 30 C x High Water, on average 60.71 days to metamorphosis and 72.28 days to death. For the 30 C x Water Loss, on average 64.29 days to metamorphosis and 50.92 days to death. For the time to metamorphosis, there were significant differences between, 20 C x High Water and 30 C x High Water (z= 4.27, p value <0.001) and 20 C x High Water and 30 C x Water Loss (z = 3.88, p value <0.001). For the time to death here were significant differences between 20 C x High Water and 30 C x Water Losss (z = 3.88, p value <0.001), 20 C x High Water and 30 C x High Water (z = 2.28, p value <0.02), 20 C x High Water and 20 C x Water Loss (z = 4.69, p value = <0.001), 20 C x Water Loss and 30 C x Water Loss (z = -5.04, p value <0.001), and 30 C x High Water and 30 C x Water Loss (z = 3.89, p value <0.001). These results suggest that temperature is the most influential factor for the rate of metamorphosis when compared to 20 C x Water Loss for *S. intermontana* in Washington State.

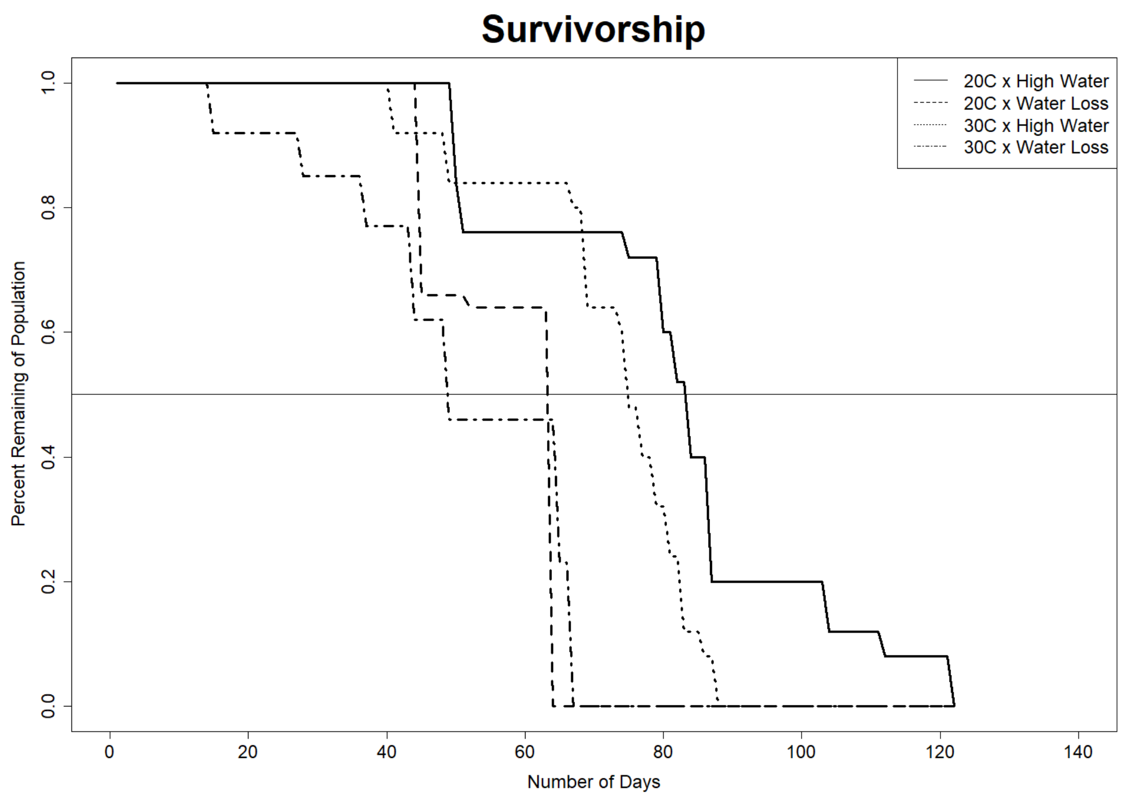

Figure 5 Plot of the duration of time before 50% of the population died off for each variable.

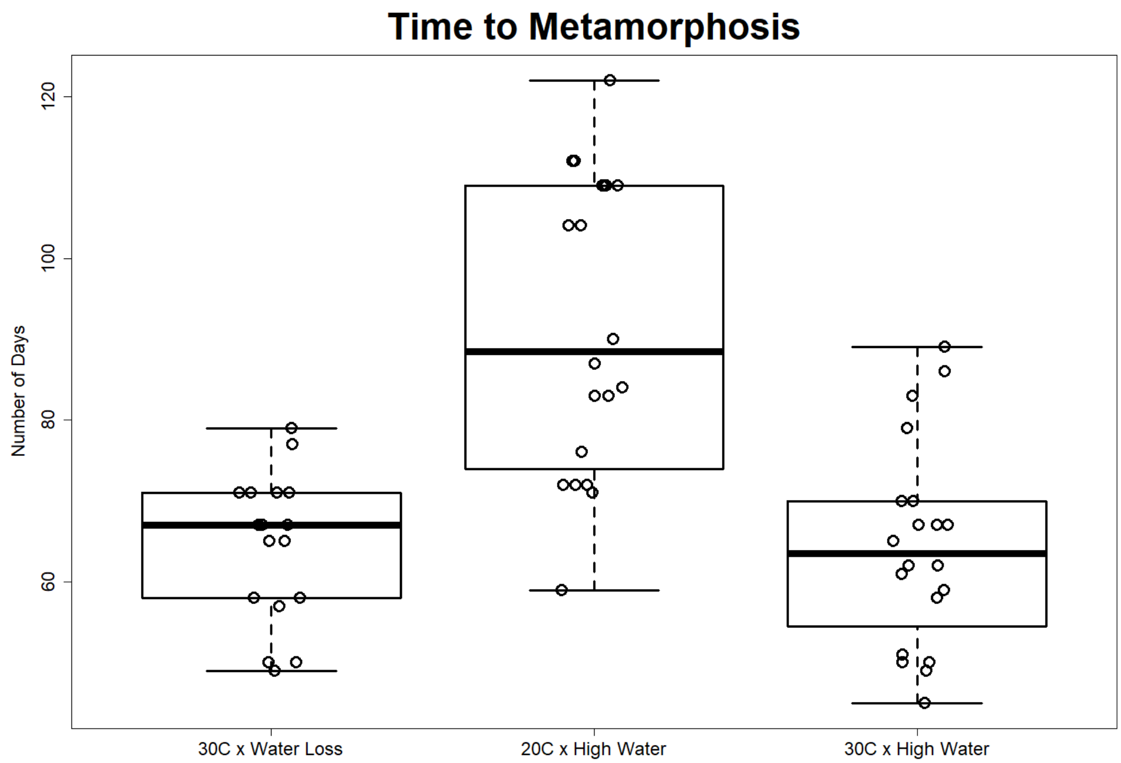

Figure 6 Boxplot of the time to metamorphosis for each variable.

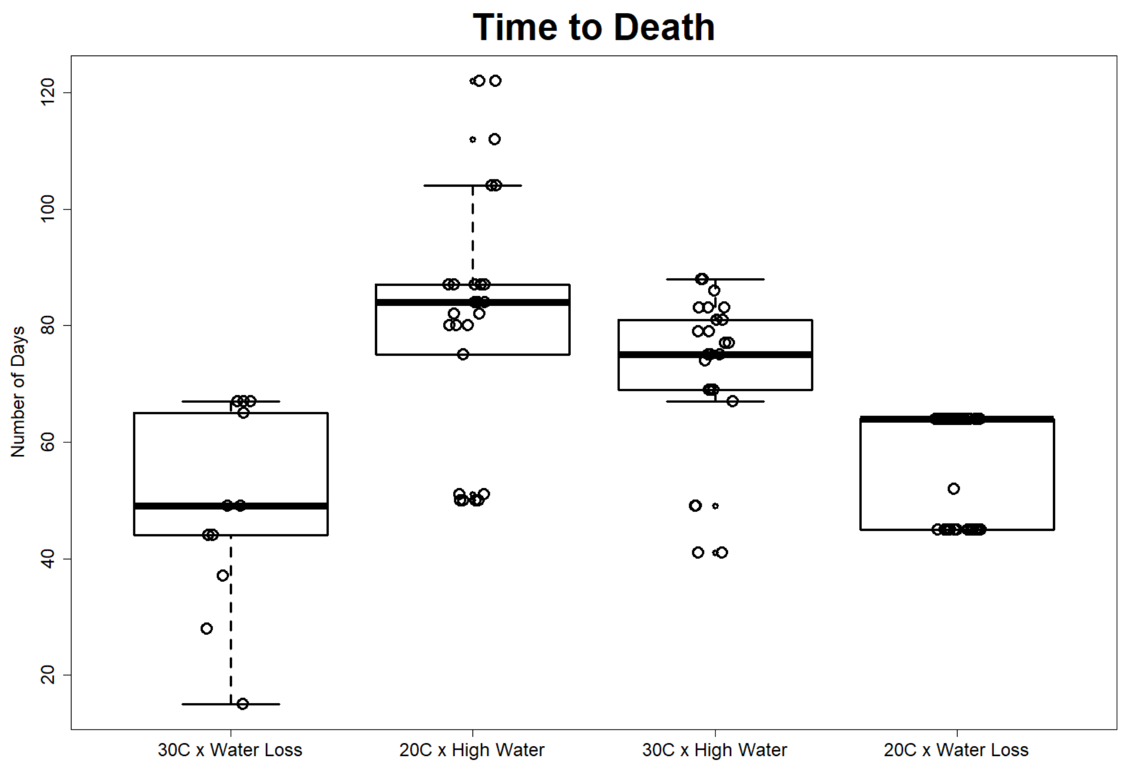

Figure 7 Boxplot of the time to death for each variable.

Post metamorphosis:

Upon completion of metamorphosis, frogs were measured by SVL and hind foot length before being weighed. For mass, significant differences were observed between 20 C x High Water and 30 C x Water Loss (z = -4.06, p value = <0.001), 20 C x High Water and 30 C x High Water (z = 4.28, p value = <0.001), and 30 C x High Water and the 30 C x Water Loss (z = -2.79, p value = <0.003) (Fig. 6). For SVL, significant differences were observed between 20 C x High Water and 30 C x Water Loss (z = -4.88, p value = <0.001) and 20 C x High Water and 30 C x High Water (z = 4.62, p value = <0.001) (Fig. 7). For hind foot length, significant differences were observed between 20 C x High Water and 30 C x Water Loss (z = -2.79, p value = <0.003) and 20 C x High Water and 30 C x High Water (z = 3.39, p value = <0.001) (Fig. 8). When these results are compared with days to first and last metamorphosis, it is seen that individuals whom metamorph over a longer period of time have higher mass, SVL, and hind foot length.

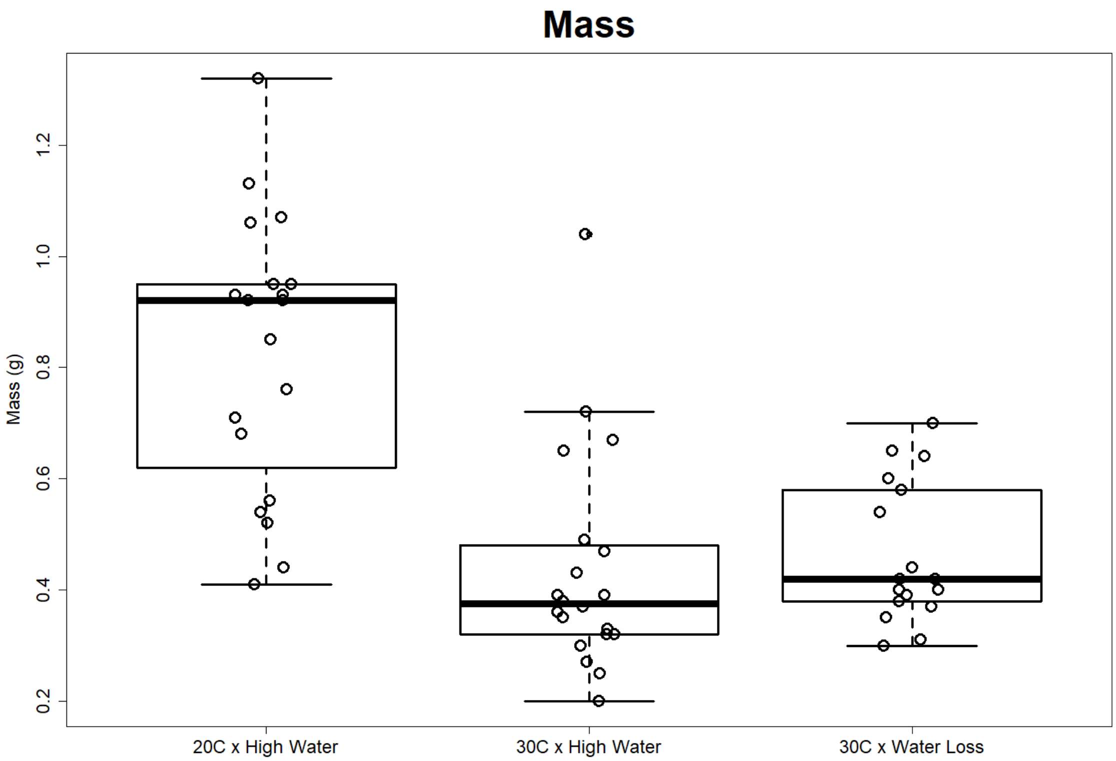

Figure 8 Mass of individuals post-metamorphosis per treatment. 20 C x Water Loss treatment was removed due to low survivorship. Solid bars represent means of treatments. Upper and low bars represent the maximum and minimum treatment measurements. Data points represent outliers.

DISCUSSION:

Our results suggest that 30 C x High Water was the main factor influencing the rate of metamorphosis of *S. intermontana,* when compared to reduced 20 C x Water Loss (Fig. 5). Interestingly, in a similar study on *S. hammondii* in California; it was found that 20 C x Water Loss seemed to have a stronger influence on the rate of metamorphosis (Denver 1998). Reasons to explain this difference could be due to simple genetic variations between the two species or a geographical difference resulting in a different climatic fluctuation throughout a single year. The geographical difference between Washington and California are quite drastic. Washington has more climatic fluctuations in a single year ranging from -10 C to 45 C, where California has a more stable warm environment year-round. Geographical differences can lead to large differences in the geological characteristics of ponds, altering the rate of pond drying (Bragg 1965; Newman 1992). In the natural environment, as a puddle or pond dries, the temperature of the water increases significantly (Newman 1989). When considering survivorship, desiccation of habitats is a main threat to larval individuals. However, when there is a 30 C x Water Loss of increased 30 C x High Water and a decrease in the 20 C x Water Loss it results in a higher survivorship. This suggests that perhaps there is not enough influence from a reduction of 20 C x Water Loss alone to stimulate neuroendocrine centers that 20 C x High Water metamorphosis (Denver 1997).

There are obvious trade-offs between mortality in a larval habitat and size upon metamorphosis. We found that individuals who completed metamorphosis at a faster rate, were smaller (Fig. 8-10). It is known that plasticity during the development period results in size variation at metamorphosis (Wilbur and Collins 1973; Werner 1986; Newman 1992). Smaller individuals could result in a lower fitness in a terrestrial habitat. These individuals may escape a desiccating larval habitat early but as a result risk reduced juvenile survivorship, physiological performance, and size at reproductive maturity (Martof 1956; Turner 1962; Berven 1982; Pough and Kamel 1984; Taigen and Pough 1985; Werner 1986; Smith 1987; Semlitsch and others 1988; John-Alder and Morin 1990; Goater and others 1993; Newman and Dunham 1994).

We could see that 30 C x High Water alone has a large influence in the rate of metamorphosis. We also observed that a faster rate of metamorphosis lead to a smaller SVL, mass, and hind foot length, potentially reducing overall fitness levels post-metamorphosis.

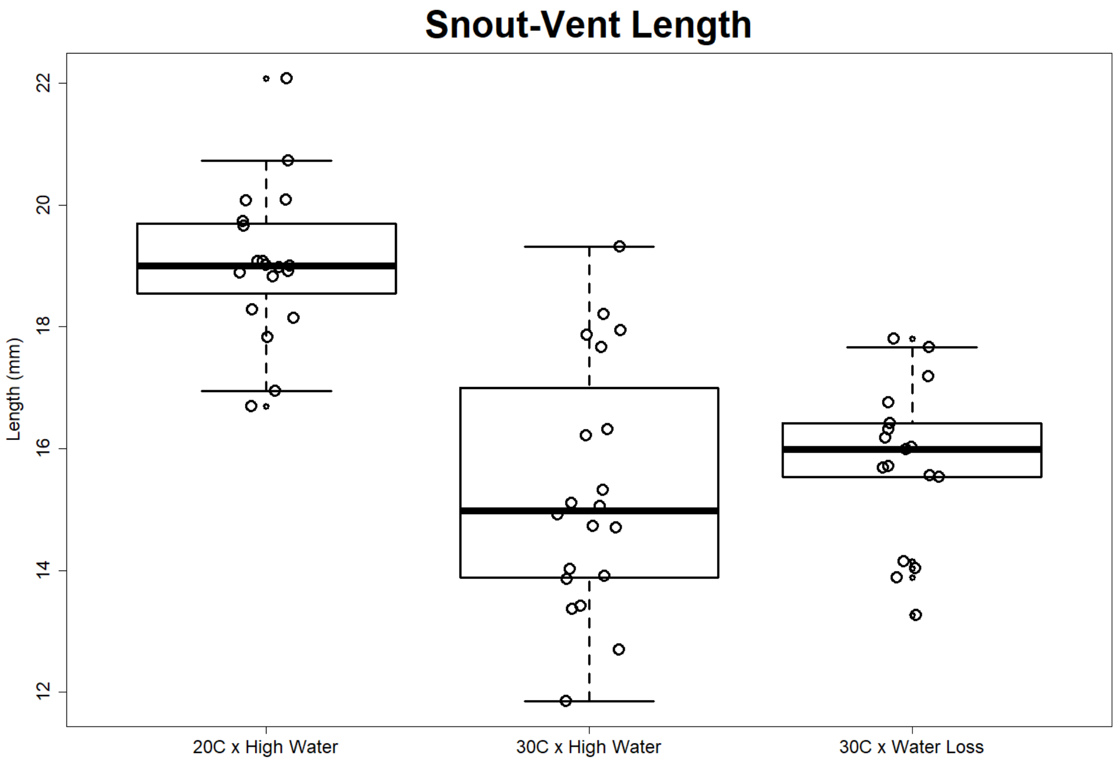

Figure 9 Snout-vent-length of individuals post-metamorphosis per treatment. 20 C x Water Loss treatment was removed due to low survivorship. Solid bars represent means of treatments. Upper and low bars represent the maximum and minimum treatment measurements. Data points represent outliers.

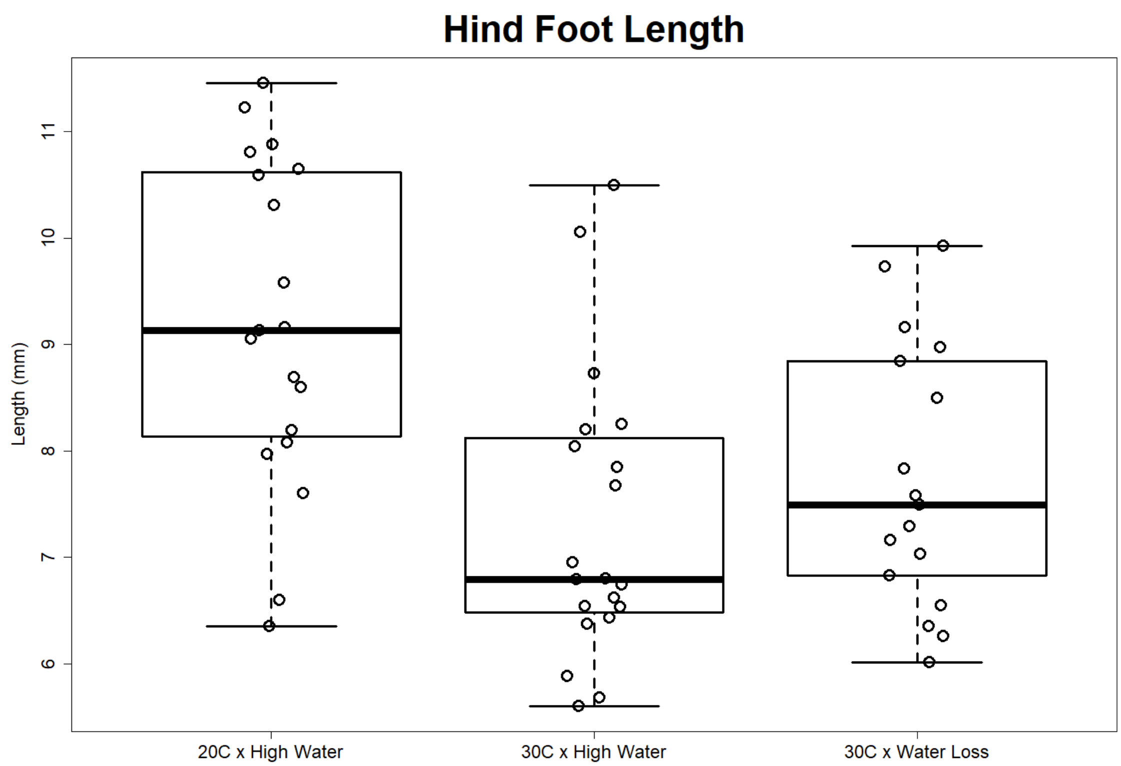

Figure 10 Hind foot length of individuals post-metamorphosis per treatment. 20 C x Water Loss treatment was removed due to low survivorship. Solid bars represent means of treatments. Upper and low bars represent the maximum and minimum treatment measurements. Data points represent outliers.

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UTILIZATION OF A PREDICTIVE MODEL OF *SPEA INTERMONTANA*: IMPLICATIONS FOR SURVEY AND MANAGEMENT OF CRYPTIC SPECIES

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ABSTRACT:

Throughout the years, researchers have conducted field studies to locate, monitor and effectively manage new wildlife populations. Often, researchers may struggle with identifying starting points in the search for populations of cryptic or endangered species. Geographic Information Systems (GIS) is one tool that may be used to find such starting points. This in turn, may lead to further areas of ecological study. We created a predictive distribution model to locate and map novel populations of the Great Basin Spadefoot Toad, *Spea intermontana* in eastern Washington State. Our predictive model is created using 5 criteria: hydrography, elevation, soil type, land use, and land cover. Data files on these 5 criteria were available from local and government agencies. Combining these data files with recent ecological and behavioral data sets on *S. intermontana* from a single survey site, we were able to produce a predictive model suitable for Washington State. This model can be adapted to use a variety of other variables, such as: cost distance analyses, road networks, direct human disturbance and many others. Such a model will allow researchers to make methodical choices during initial stages of surveying for a target species. We feel our model can serve as an excellent example of an applied GIS based approach to survey and management techniques. This is an important first step toward facilitating the ease and efficacy of field based research. It could also be an integral tool when addressing questions about the status of endangered or cryptic species.

Key words**:** Great Basin Spadefoot Toad, Spea intermontana, GIS, distribution, Washington, Great Basin, predictive model

INTRODUCTION:

As biologists, we commonly conduct field surveys to monitor and locate new and old wildlife populations. Often, these surveys are near known locations that fall adjacent to one another. This is due to having a higher chance of success at finding individuals and a lack of knowledge as to where else to look. These surveys are very practical when looking for animals that are abundant or easy to locate. Researchers become habituated in field methods and both researchers and managers for projects do not always have access to or knowledge of other methods (Zielinski and others, 2010; Loos and others 2014). However, when a researcher is trying to monitor or study a cryptic or endangered species, where do they begin to look? Cryptic and endangered species can be very difficult to study and a variety of methods (eDNA and ecological niche models) are used during surveys in hopes of finding these animals (Ortega-Andrade and others 2015; Rowley and others 2015).

S. intermontana is a small cryptic desert anuran that spends the majority of its life under the surface substrate making it very difficult to find. Spadefoot toads are small to medium-sized light-colored frogs with a plump body, broad waist, short legs, and relatively smooth skin. Spadefoot toads get their name from the sharp-edged black “spade” present on the inside of the hind foot. This spade is used to burrow below the substrate, where individuals will remain for long periods of time. Like many species, *S. intermontana* has a cryptic morphology and behavior and can be difficult to locate for study (Carolina and others 2016; James and others 1976; Scriven and others 2015). This study investigated if a predictive model could be created using a suitability map based on a limited amount of information for the Great Basin Spadefoot Toad, *S. intermontana.* Suitability maps have long been used for a variety of reasons ranging from management strategies and conservation to the movement and distribution of animals (Belongie 2008; Deitmars and Bart 1999; Andres et al., 2016; Barrows et al., 2008; Keenan et al., 2011; Barbosa 2003; Rondini et al., 2005; Cianfrani et al., 2010). Model-based habitat predictions are not always the most accurate but are often the most informative method for approximating habitat relationships underlying a species' distribution when data is not immediately available (Heikkinen et al., 2012; Latif et al., 2013; Pearson and Dawson 2003)

The predictive accuracy at which a habitat suitability model can be successful, greatly depends on the habitat variables, data being analyzed, and the underlying model structure (Austin 2007). The most effective habitat suitability models use presence and absence data in which the areas that are most suitable are deemed by presence and those with absence are least suitable (Guisan and Zimmermann 2000; Scott et al., 2002; Hirzel and Le Lay 2008). It is also important to remember that absences can be misconstrued as unsuitable habitat when in fact it is caused due to human perturbations or ecological barriers, as demonstrated with a virtual species dataset (Pulliam 2000; Gibson et al., 2007; Hirzel and Le Lay 2008; Lobo et al., 2008; Hirzel et al., 2001).

For *S. intermontana*, we chose to use elevation, land use, land cover, hydrography, and soil type. Many of these variables are often used for mitigation planning and management of both plants and animals, including agricultural crops (Clevenger and others 2001; Stanchi and others 2013; Nawaz and others 2014).

METHODS:

Study area:

The scope of this predictive model is the entire state of Washington. However, we chose to create the model using a single population. This population is near Lower Crab Creek in the Beverley dunes near Beverley, Washington.

Data collection:

We chose to use 5 variables to create our predictive maps; elevation, land use, land cover, hydrography, and soil order. Data was collected from both local and government sources. All of the data collected was statewide data files. For elevation, a 30m digital elevation model (DEM) was collected from the Central Washington University data collection. Both the land use and hydrography datasets were obtained from the Washington State Department of Ecology GIS department. The land cover dataset was provided by the Washington Department of Fish and Wildlife GAP analysis program. Soil data was collected using Web Soil Survey from the National Resource Conservation Service (NRCS).

Reclassification:

Using ArcGIS, all the data sets were rasterized into a reclassified 1-10 scheme, with 1 being the least suitable and 10 being the most suitable (Table 1). All the reclassifications were chosen via professional judgement. To complete reclassification, some datasets needed to be manipulated.

Table 1 Predictive Model Classifications

Reclassification	Land Use	Land Cover	Hydrography	Soil Order	Elevation
1	Water	Current and Historic Mining Activity	4000-4500	Vertisol	2500+
2	Public Assembly	Temperate & Boreal Alpine Vegetation	3500-4000	Ultisol	2250-2500
3	No Zoning	Semi-Desert Nonvascular & Sparse Vascular Vegetation	2500-3000	Alfisol	0-250
4	Transportation (Roads)	Developed & Urban	2000-2500	Spodosol	2000-2250
5	Nature Exhibits, recreation, camp sites	Freshwater Aquatic Vegetation/Barren/Recently Disturbed or Modified	3000-3500	Inceptisol	1750-2000
6	Business	Introduced & Semi Natural Vegetation	1500-2000	Null/Histosol	1250-1500
7	Residential	Temperate & Boreal Shrubland & Grassland/Polar & High Montane Nonvascular & Sparse Vegetation	1000-1500	Andisol	1000-1250
8	Mining and Forest	Temperate Forest/Saltwater Aquatic Vegetation/Open Water	0-500	Entisol	750-1000
9	Undeveloped Land	Mediterranean, Temperate & Boreal Nonvascular & Sparse Vegetation/Herbaceous Agricultural Vegetation	500-1000	Aridisol	250-500
10	Agriculture	Cool Semi-Desert Scrub and Grassland	4500+	Mollisol	500-750

Hydrography was rasterized using Euclidean distance from each body of water. The raster was then reclassified into 500m increments with being closer to water being more favorable (Fig 11). The soil dataset had map units at the soil series level and had to be recreated using soil orders. The soil orders were then reclassified based on soil order present within the original study site (Fig 12). Land use and land cover were reclassified based on zoning and land division (Fig. 13-14). Elevation was reclassified with lower elevations being more favorable (Fig. 15).

This allows for the use of the *Raster Calculator* tool for creating the final output raster. The raster calculator uses Boolean logic to create a final raster based on the rasters used in the equation. The different rasters can be weighted using Boolean logic based on which one is considered to hold more value toward the project. In this case, my Boolean equation was as follows: (Land Use*0.1)+(Land Cover*0.1)+(Water*0.2)+(DEM*0.2)+(Soil*0.4). These weights were chosen based on professional judgement after limited field surveys. The raster calculator then multiplies each of the respective factors by their weights. Once this has happened, the calculator will then stack all of them on top of each other and add up the values for the same cells in each raster. This gives a final raster output, in this case showing the best suited sites for spadefoot toads (Fig. 16).

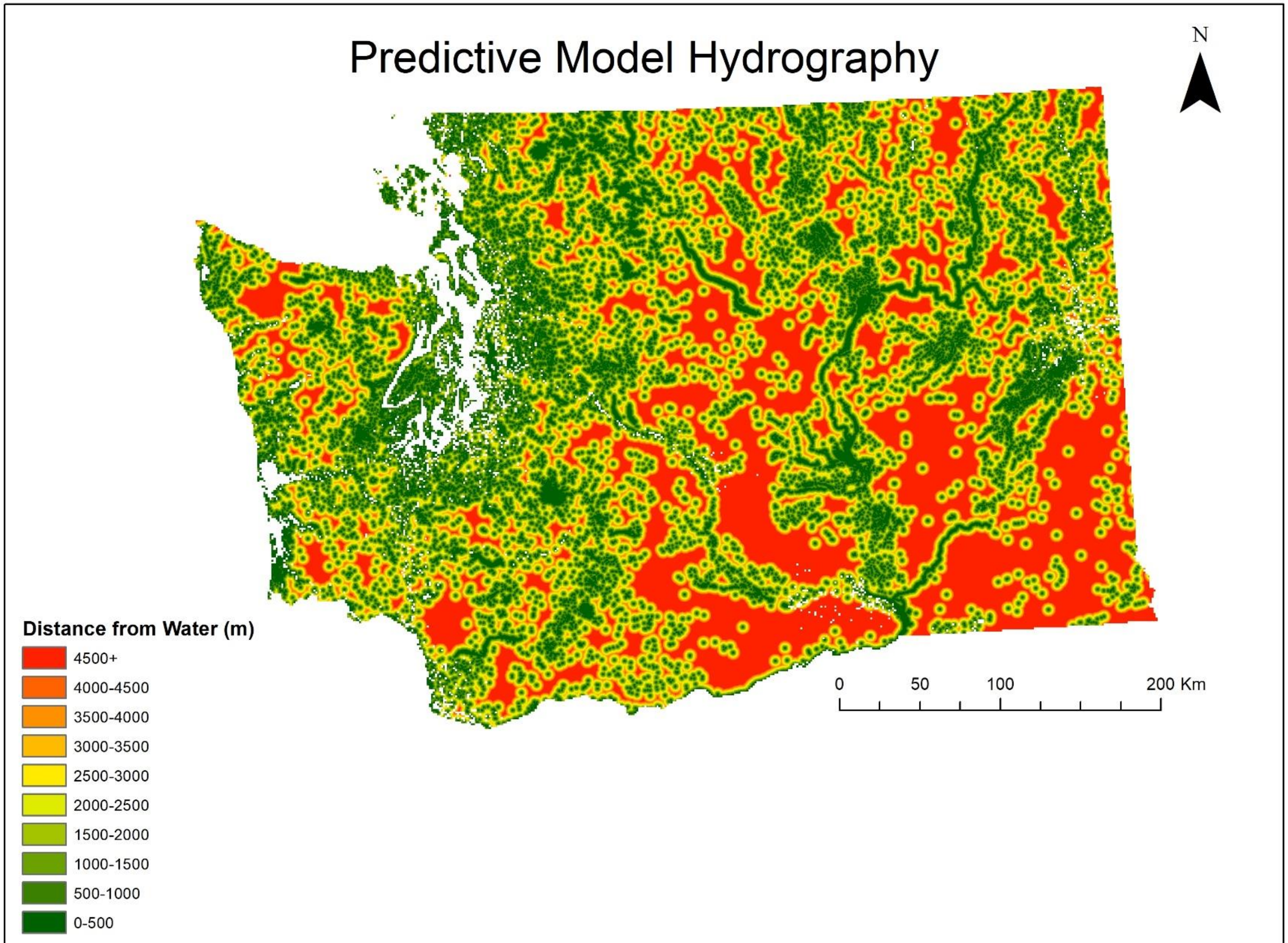

Figure 11: Distance from Water Classification

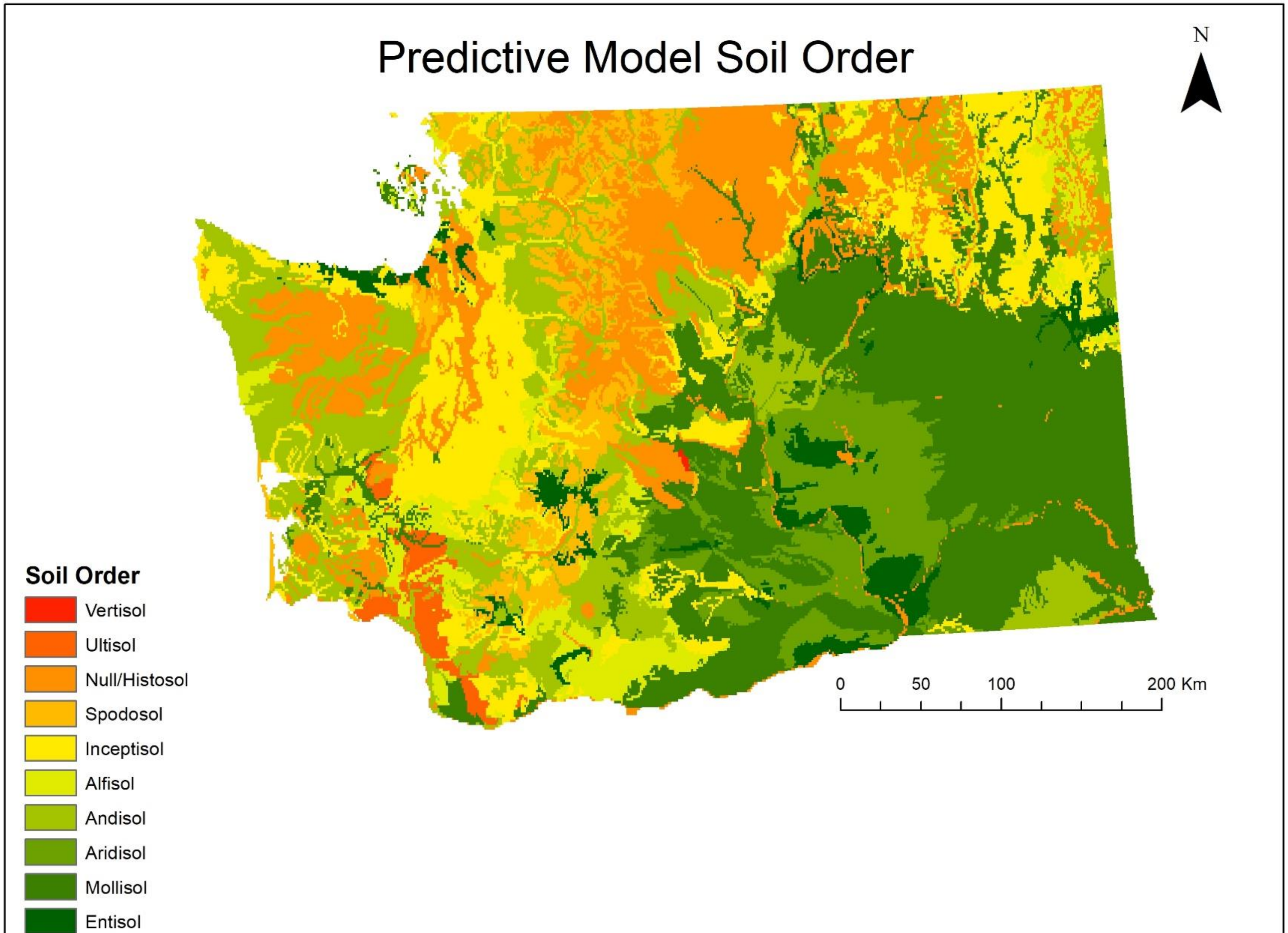

Figure 12: Soil Order Classification

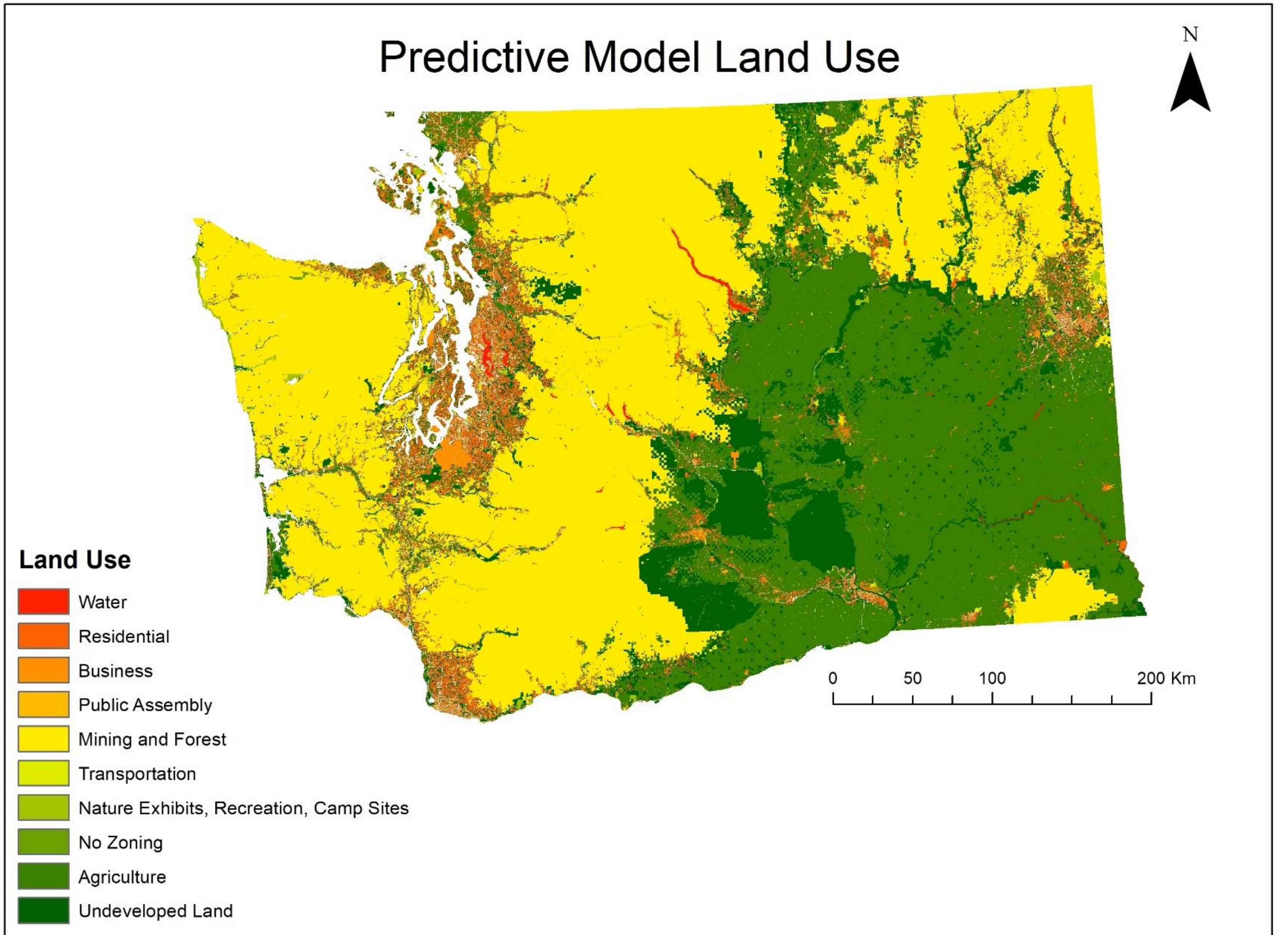

Figure 13: Land Use Classification

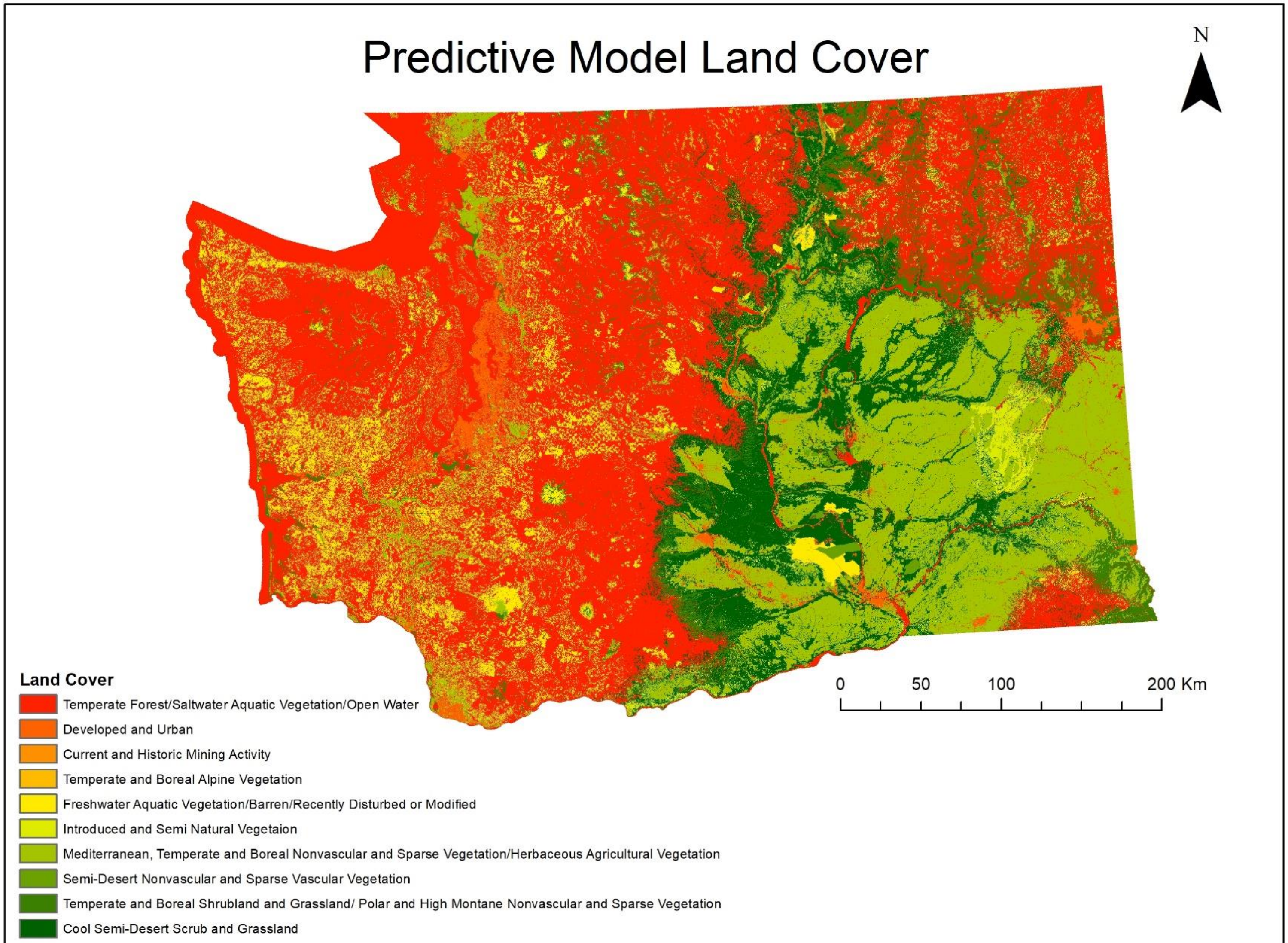

Figure 14: Land Cover Classification

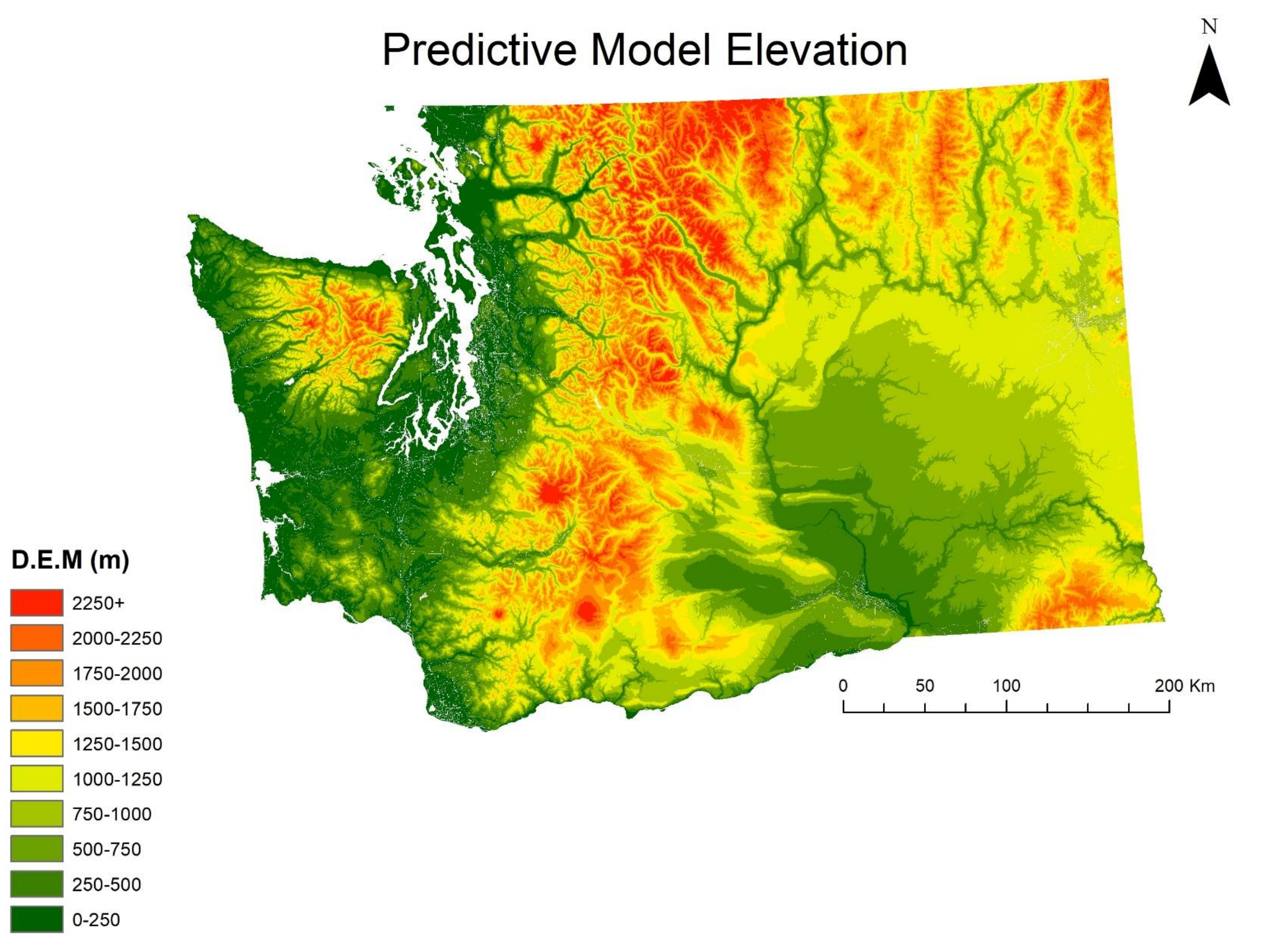

Figure 15: Elevation Classification

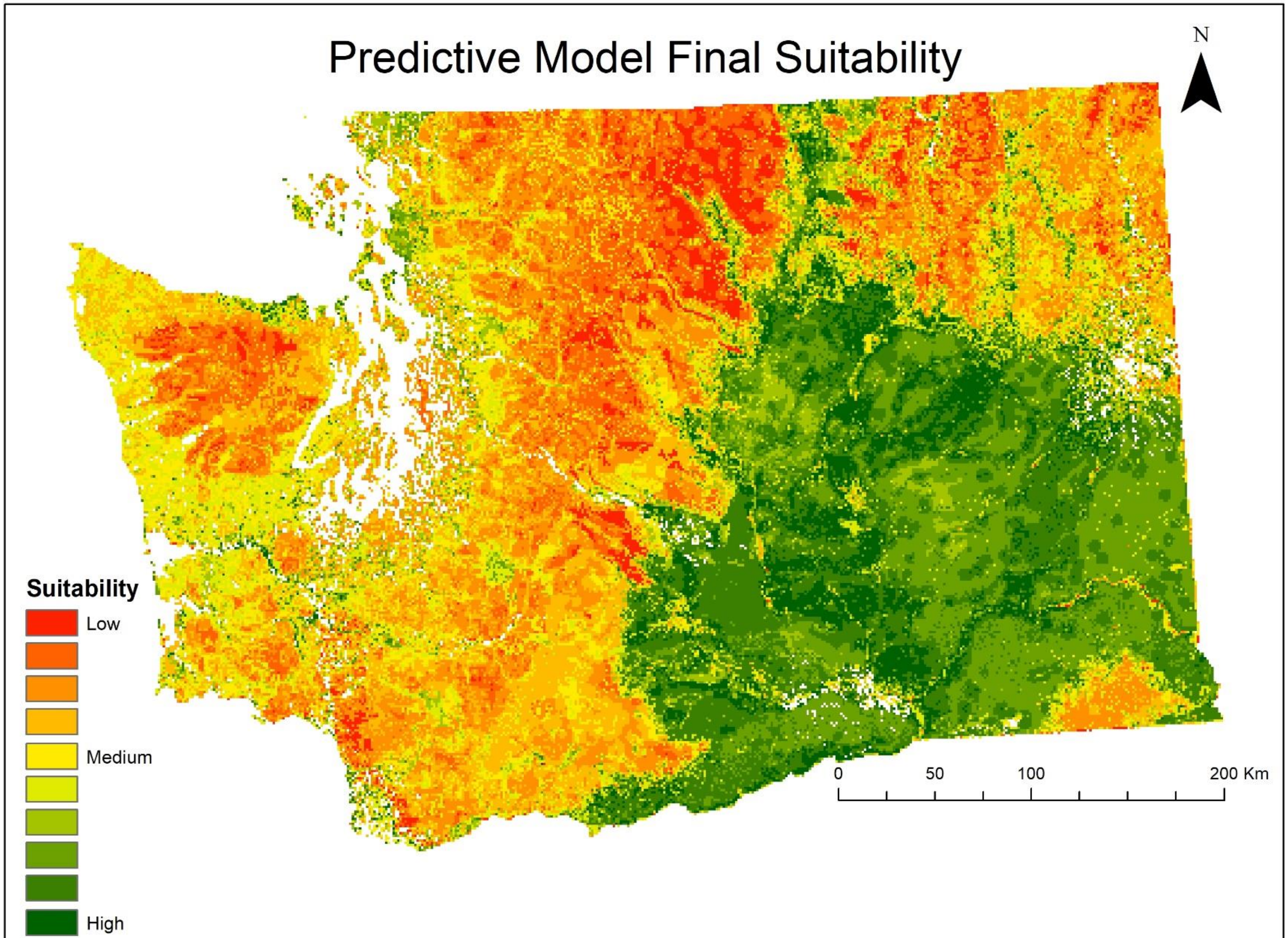

Figure 16: Final Suitability

Field testing:

In order to field test this predictive model, we used both field checks and known locations provided by Washington State Department of Fish and Wildlife. GPS locations were overlaid onto the predictive map (Fig 17). These new known locations were then used to complete model testing.

Model Testing:

To verify the strength of the initial model, we compared the ideal classifications based on all known locations to the predicted locations. The ideal classifications were determined using the same methods as the predicted with all known locations, except for our findings at Lower Crab Creek, for each variable. Each variable was then reordered 1-10 to determine the ideal classification (Table 2; Fig. 18-22). A final ideal suitability map was created and compared to the predicted model by comparing the percentage of known locations in each 1-10 category (Fig 23-24; Table 3-4).

Table 2 Ideal Model Classification.

Reclassification	Land Use	Land Cover	Hydrography	Soil Order	Elevation
1	Water	Current and Historic Mining Activity	4000-4500	Vertisol	2500+
2	Public Assembly	Temperate & Boreal Alpine Vegetation	3500-4000	Ultisol	2250-2500
3	No Zoning	Semi-Desert Nonvascular & Sparse Vascular Vegetation	2500-3000	Alfisol	0-250
4	Transportation (Roads)	Developed & Urban	2000-2500	Spodosol	2000-2250
5	Nature Exhibits, recreation, camp sites	Freshwater Aquatic Vegetation/Barren/Recently Disturbed or Modified	3000-3500	Inceptisol	1750-2000
6	Business	Introduced & Semi Natural Vegetation	1500-2000	Null/Histosol	1250-1500
7	Residential	Temperate & Boreal Shrubland & Grassland/Polar & High Montane Nonvascular & Sparse Vegetation	1000-1500	Andisol	1000-1250
8	Mining and Forest	Temperate Forest/Saltwater Aquatic Vegetation/Open Water	0-500	Entisol	750-1000
9	Undeveloped Land	Mediterranean, Temperate & Boreal Nonvascular & Sparse Vegetation/Herbaceous Agricultural Vegetation	500-1000	Aridisol	250-500
10	Agriculture	Cool Semi-Desert Scrub and Grassland	4500+	Mollisol	500-750

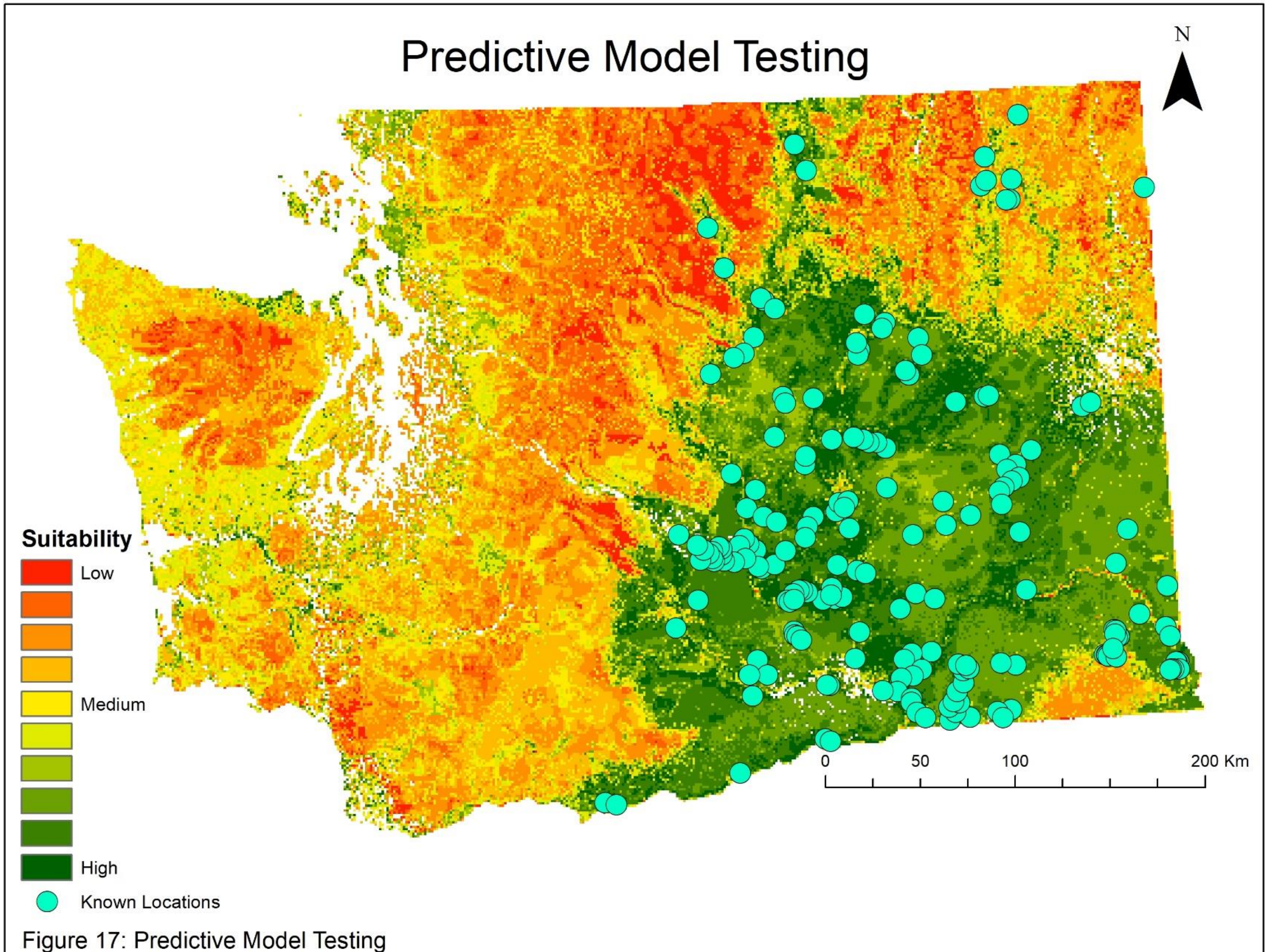

Figure 17: Predictive Model Testing

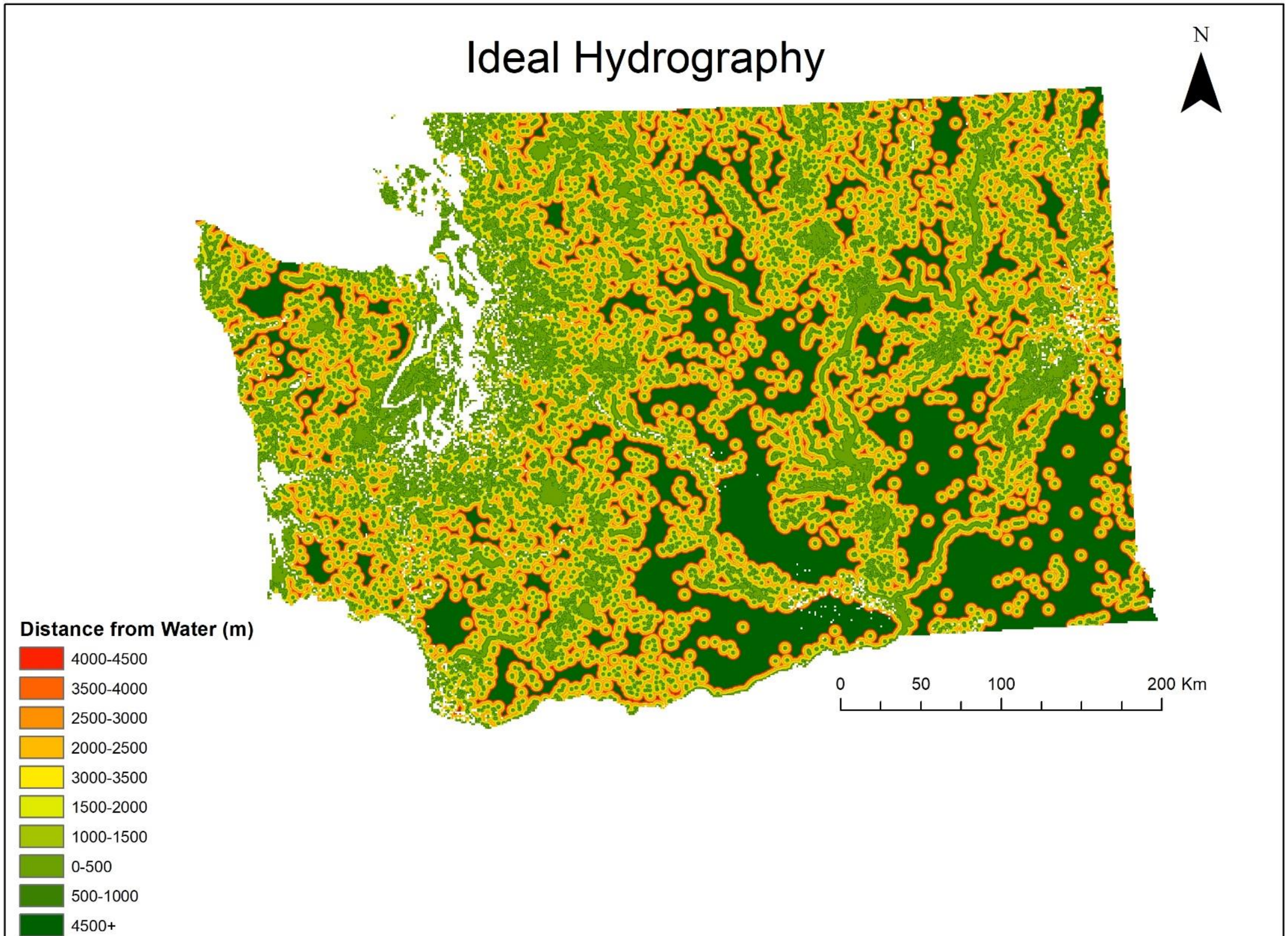

Figure 18: DIstance from Water Classification

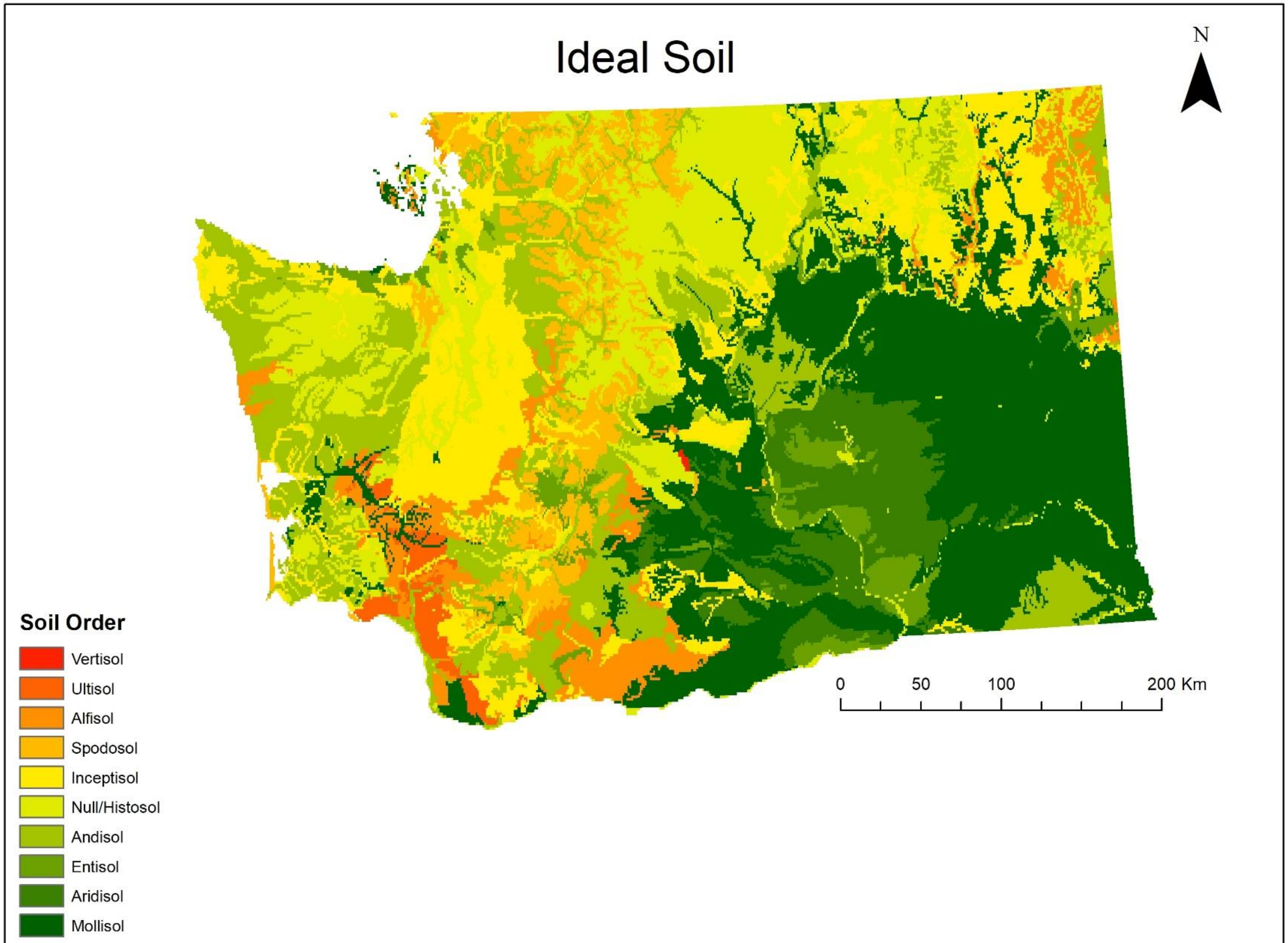

Figure 19: Soil Order Classification

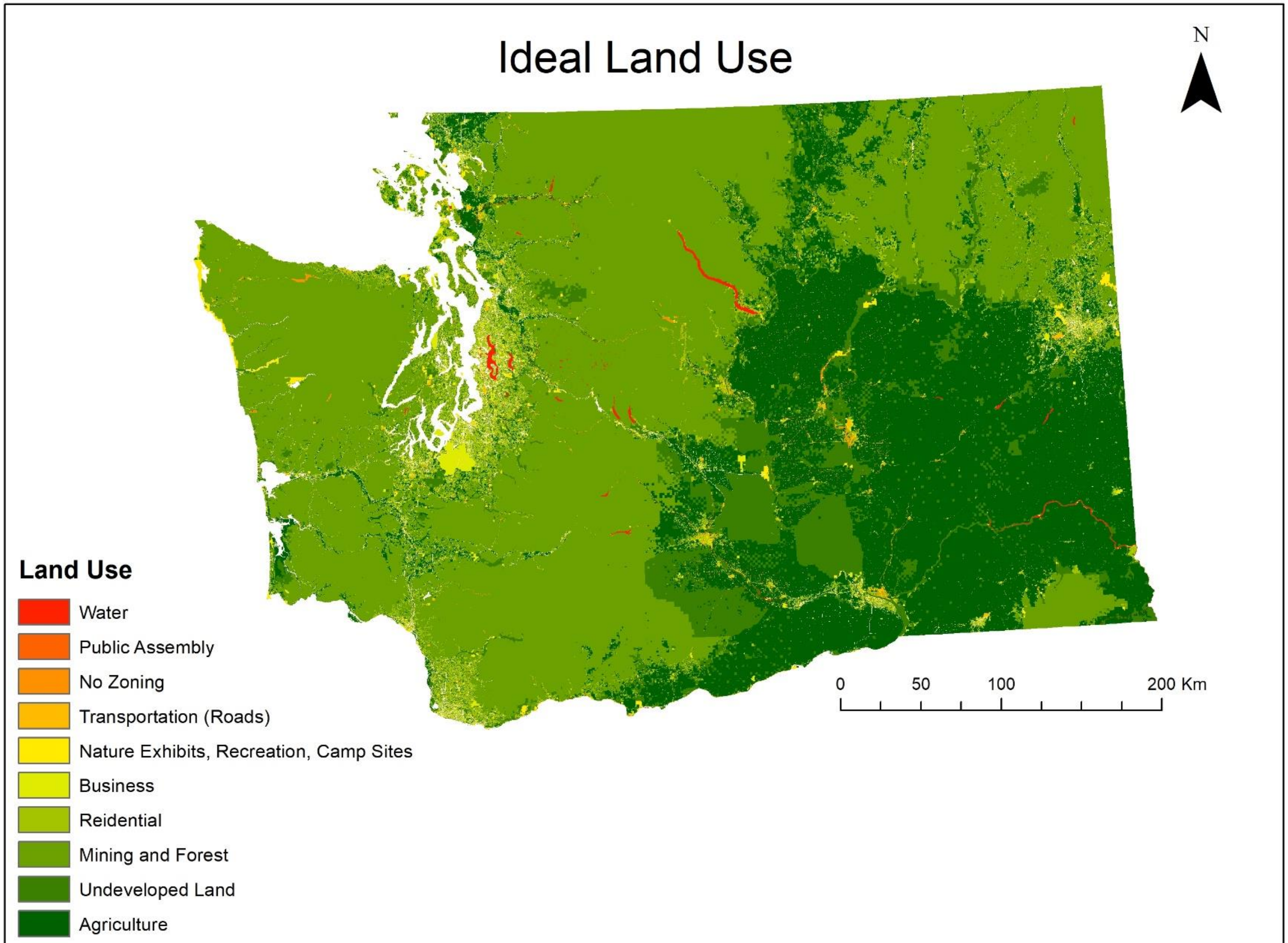

Figure 20: Land Use Classification

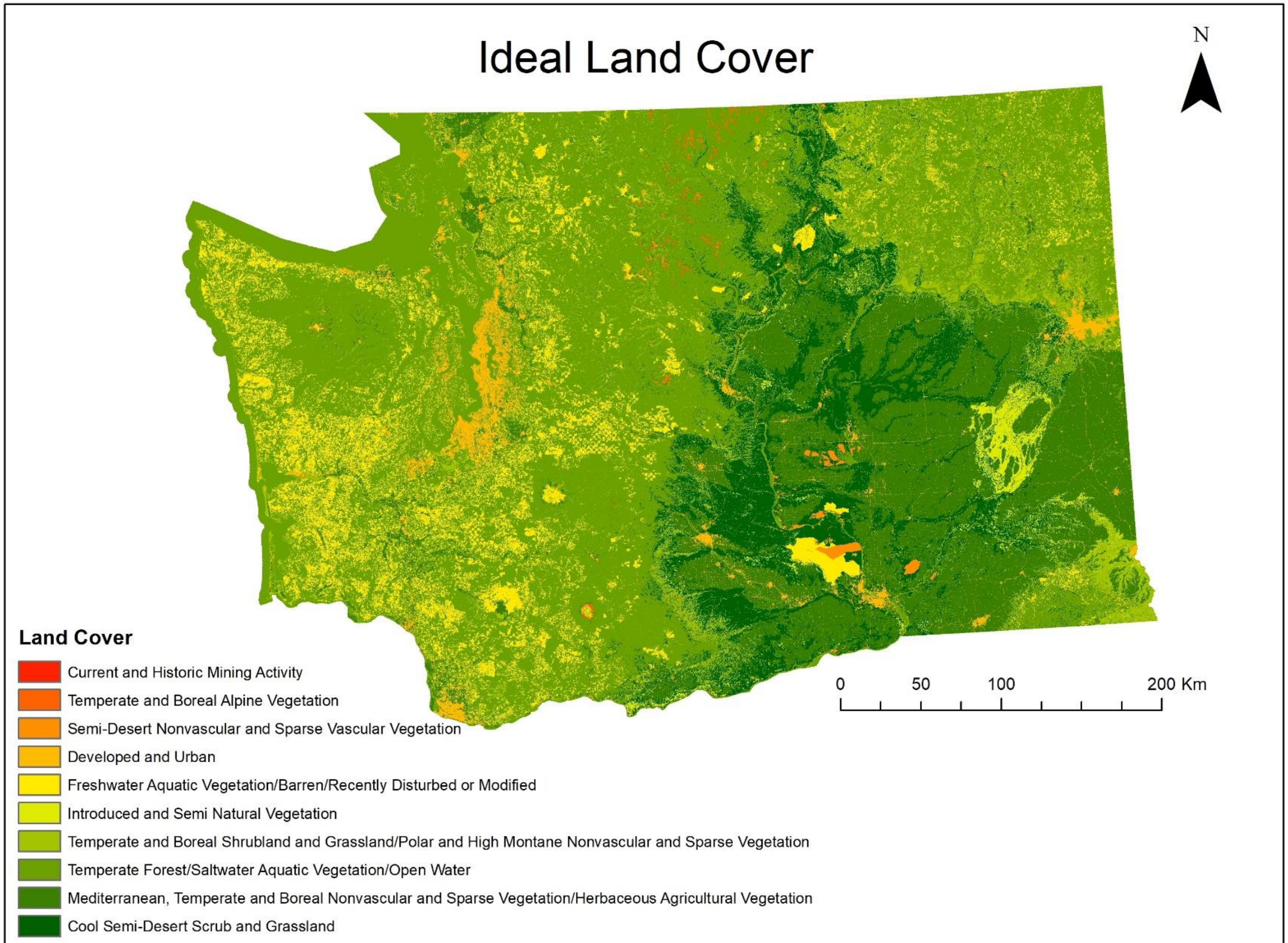

Figure 21: Land Cover Classification

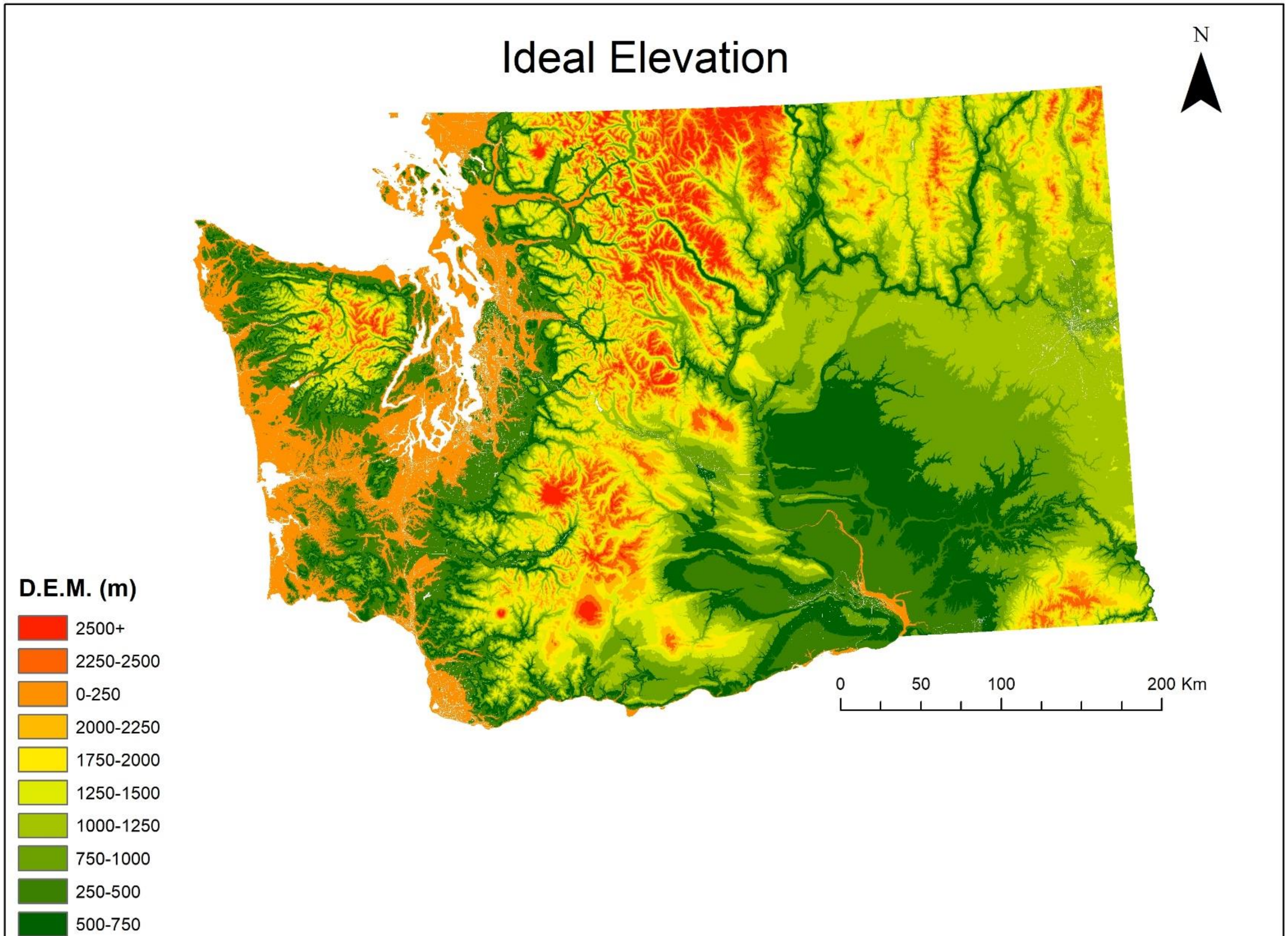

Figure 22: Elevation Classification

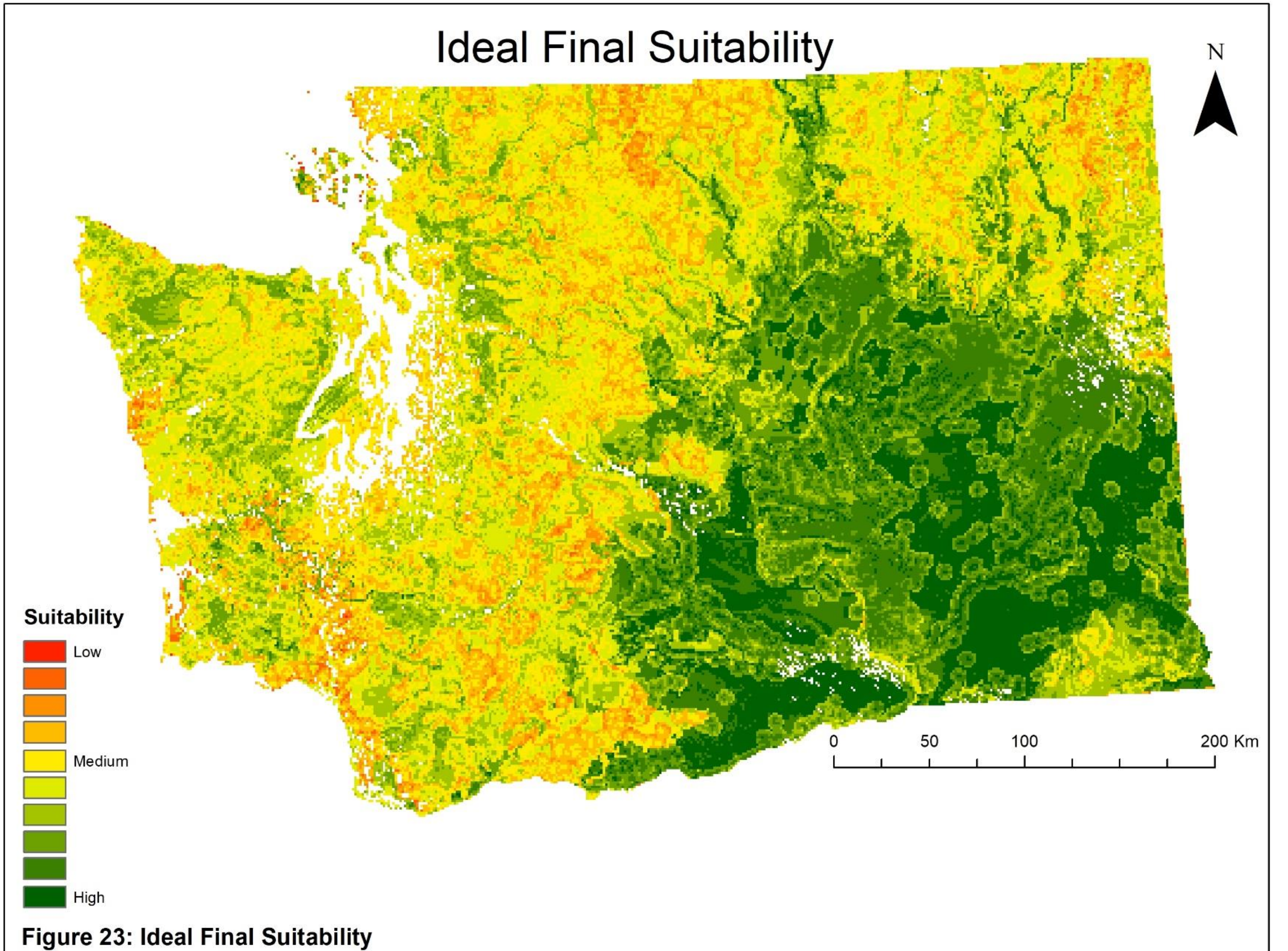

Figure 23: Ideal Final Suitability

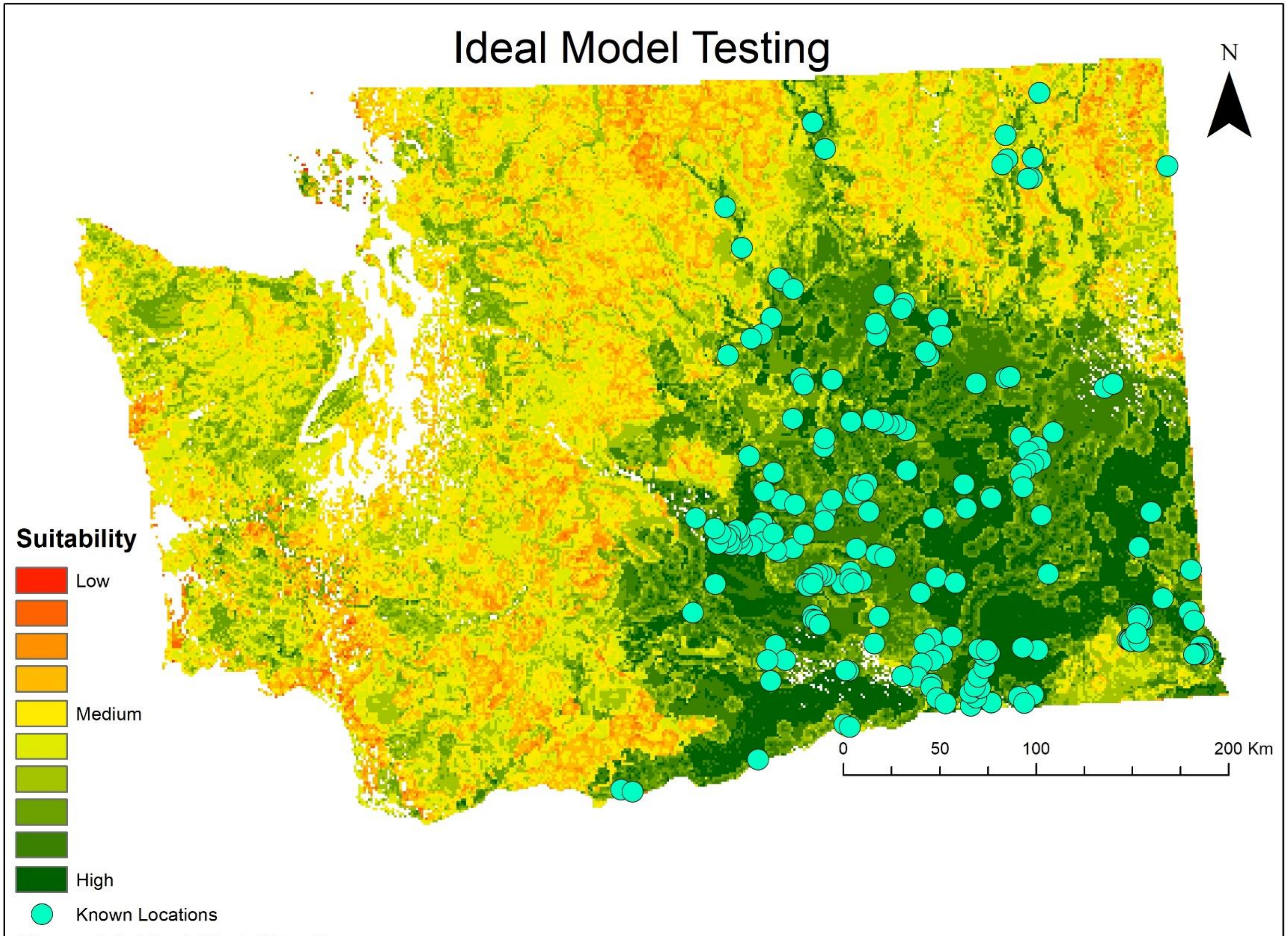

Figure 24: Ideal Model Testing

Table 3 Predicted model known location testing.

Classifcation	Count	Percent
1	0	0
2	1	0.52
3	4	2.06
4	5	2.58
5	7	3.61
6	2	1.03
7	16	8.25
8	36	18.56
9	84	43.30
10	39	20.10

Table 4 Ideal model known location testing.

Classifcation	Count	Percent
1	0	0
2	0	0
3	0	0
4	0	0
5	2	1.03
6	8	4.14
7	34	17.61
8	39	20.21
9	72	37.31
10	38	19.70

RESULTS:

The predictive model shows areas that are close to bodies of water, low elevations, in shrub steppe habitats with arid soils are the most suitable. Once the predictive model was created, field checks were used to validate the model. Based on data from the Washington State Department of Fish and Wildlife and personal field checks, it is seen that 81.96% fall within the 8-10 classifications for habitat suitability in the predictive model and 77.22% fall within the 8-10 category in the ideal model (Table 2-3).

The final output for the predictive model shows locations around Washington State that are suitable for spadefoot toads given the variables used (Figure 16). The output shows suitable locations on both the eastern and western side of Washington. This is due to the chosen classification scheme and the factors provided show good habitat and there is no way for ArcMap to know that the Cascade Mountain Range is a huge geographical barrier for spadefoot toads.

The final output for the ideal model shows that most of Washington State is deemed suitable habitat (Figure 23). The ideal suitability output shows fewer unsuitable locations than the predictive model.

DISCUSSION:

Using a single population, we were able to create a predictive model for *S. intermontane.* Through both field checks and the use of other known locations we were able to test the validity of our model. The use of suitability maps for predicting species distribution is often avoided due to the inaccuracy that can occur (Austin 2007). The success of our model is most likely due to the coarse scale of which we are looking at. When we compare our predicted model versus our ideal model, we see a large number of similarities and differences. Both models show similar patterns of suitable habitat throughout Washington State. The major differences appeared with how detailed they are with where to look. The coarse scale of the predictive model shows very general areas to begin looking, which would be ideal for a species that has few known locations. However, as you add more known locations and begin to get a more ideal distribution, you can better pinpoint where within those locations to search.

Creating suitability maps have some dependencies for being successful or even possible. First, a researcher needs to have access to GIS and data or at least the ability to create layers for each variable if there is none previously made. This means that remote areas with little data could be hard to use. Second, some data can be very expensive to obtain. If the researcher needs to obtain satellite images to create variable layers, the total cost could become very high. Our model could easily be adapted to include other variables, such as: distance to roads or cities, climate data (upon availability), water table depths, and many others. To further studies the use of aerial photos and remote sensing techniques could be used in order to supplement or refine suitability maps for cryptic or endangered species (Shealer and Alexander 2013).

Some species have very little natural history information available. A researcher could create a preliminary predictive model, similar to ours, using a single population and basic natural history. Then as more individuals are found you can use count data from each layer to reclassify and tighten or broaden each layer. This will slowly create a more accurate model over time.

Predictive suitability maps can be beneficial in areas where animals are becoming a concern. One example is in Wyoming, *S. intermontana* is now a species of concern and they are having trouble finding populations. By using past and current data, a predictive model could be made to assess where populations may be located or even moving to. With continuing climate change, we are seeing drastic changes over time in available habitats for many species causing the management and monitoring of endangered or cryptic species to be increasingly more difficult.

Using a predictive model to begin looking for a cryptic species is very useful. As researchers discover new individuals or populations a more ideal model can be created. When comparing our predictive and ideal models, the predictive model shows more of the geographic barriers, where the ideal model shows more detail in areas of high suitability that could make finding individuals easier within a given area.

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