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Idaho Department
of Fish and Game
PO Box 25
Boise, Idaho
83707

Slickspot Peppergrass (*Lepidium papilliferum*) Field Survey and Predictive Distribution Modeling

Beth Colket

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ABSTRACT

Slickspot peppergrass (*Lepidium papilliferum*) is a rare annual or biennial forb endemic to sagebrush steppe in southwestern Idaho (Moseley 1994). Targeting potential slickspot peppergrass habitat for field inventory requires substantial planning of where suitable habitat might occur. Predictive distribution modeling is a tool to find suitable habitat and better prioritize survey efforts for rare plant species (Hernandez et al. 2006, Pearson et al. 2007). GIS layers of continuous environmental data and existing slickspot peppergrass location data were used with the MaxEnt algorithmic model to create a GIS layer that predicts the distribution of slickspot peppergrass in the Owyhee Uplands ecological section buffered by 50 km (14,135,497 ha). Model performance was evaluated using omission vs. predicted area and receiver operating curve (ROC) plot analyses.

The highest probability areas for suitable slickspot peppergrass habitat using the MaxEnt model occurred between Glenn's Ferry northwest to New Plymouth and beyond across the Idaho-Oregon state line; and Grasmere east past the U.S. Air Force Juniper Butte Training Range. I consulted with USFWS personnel about prioritizing survey efforts using model results and based on this meeting, randomly selected polygons were surveyed near the Emmett and Grasmere areas in Idaho. No new slickspot peppergrass locations were discovered, although new locations of Davis' peppergrass (*Lepidium davisii*), another rare plant species, were discovered.

Based on the model results, an area near Emmett was surveyed and it appeared quite suitable for slickspot peppergrass, except that the land had been highly disturbed by fire and non-native species. Several predicted areas near Grasmere were also surveyed, but these had variable habitat suitability. The physical appearance of most slickspots near Grasmere seemed slightly different from slickspots occupied by slickspot peppergrass. Many slickspots in the Grasmere area had black or red cinders or cobbles scattered across and were associated with different shrub steppe communities than occupied slickspots. Overlaying the model with geology maps helped better focus the model results, although the Grasmere area still remained strongly predicted even after overlaying similar geology. As they become available, higher quality geology or soils maps that are classified continuously across county lines could elucidate the geological differences between the Grasmere area and other areas in Idaho where slickspot peppergrass is known to occur.

BLM, private, and state lands had the largest proportion of high probability suitable habitat for slickspot peppergrass, although much of the private land had been cultivated or developed. USFS lands had a negligible amount of high probability suitable habitat for slickspot peppergrass—these were east of Twin Falls far from known slickspot peppergrass locations. The slickspot peppergrass model provides biologists and land managers information to prioritize future surveys and conservation planning efforts for slickspot peppergrass.

KEY WORDS

Slickspot peppergrass, *Lepidium papilliferum*, sagebrush steppe, MaxEnt, modeling, habitat, abundance, rare plant conservation, Idaho.

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Idaho Department of Fish and Game (IDFG) personnel B. Colket and A. Schmidt prepared input data used for modeling. B. Colket developed the model, produced the maps, and wrote the report. B. Colket, J. Granton, and N. Wade conducted field surveys. B. Bosworth and L. Svancara provided technical advice. The report was reviewed by IDFG personnel L. Svancara and R. Sallabanks, U.S. Fish and Wildlife Service personnel B. Chaney, G. Glenne, and J. Wood, and U.S. Forest Service personnel K. Beall.

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lepa_223pts_25per.csv (model test points)
lepa_223pts_75per.csv (model training points)

ASC (.asc format, study area; used for MaxEnt)

ao1000_ddemag.asc (digital elevation model)
ao1kmslpdeg.asc (slope [degrees])
ao_pt_a_pa.asc (total precipitation)
ao_rt_a_pa_1km.asc (daily shortwave radiation)
aoclay.asc (% clay)
aosilt1.asc (% silt)

VECTOR
studyarea.shp (Owyhee Uplands ecological section buffered by 50 km)
studyarea_1kmgrid.shp (1-km cells used for filtering point data)
lepa_223pts_25per.shp (model test points)
lepa_223pts_75per.shp (model training points)

OUTPUT

RAW MODEL OUTPUT
maxent_223pts (original model results)

MODEL SHAPEFILES (.shp format)
maxent223pts.shp (model converted to .shp format)
maxent223pts_coarsegeol_similar.shp (maxent223pts.shp, model clipped by similar 1:2,500,000 geology in study area)
maxent223pts_1978geol_similar.shp (maxent223pts.shp, model clipped by similar 1:500,000 geology in Idaho)

SURVEYED AREAS (.shp format)
surveyedareas.shp (areas surveyed for slickspot peppergrass in 2008)
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INTRODUCTION

Slickspot peppergrass (*Lepidium papilliferum*) is a rare annual or biennial forb endemic to sagebrush steppe in southwestern Idaho (Moseley 1994). Concern for declining slickspot peppergrass trends in abundance and habitat quality led to slickspot peppergrass being proposed as an endangered species in 2002 (U.S. Fish and Wildlife Service [USFWS]). The USFWS withdrew the proposed rule in 2004 and 2007, but the U.S District Court for the District of Idaho subsequently reversed each of these decisions in 2005 and 2008, respectively. Since June 2008, slickspot peppergrass has had proposed endangered status under the Endangered Species Act (USFWS 2008).

Slickspot peppergrass is highly specific to slickspots that have developed on remnant Pleistocene surfaces (Fisher et al. 1996). Slickspots, also known as mini-playas or natric sites, are defined as small soil inclusions with a silt loam surface crust, a restrictive hardpan, and a subsurface argillic horizon (high clay content; Sandoval et al. 1959, Lewis and White 1964, Fisher et al. 1996). Slickspots are associated with shrub interspaces in sagebrush steppe and are visually distinct, due to their high albedo and sparsely vegetated surface (Fisher et al. 1996). When slickspot peppergrass has been found in the past, it has occurred on a fraction of slickspots present. For example, the percentage of occupied slickspots discovered relative to the total number of slickspots surveyed ranged between 0.3% in 2005 (Colket and Crymes 2006), 3.0% in 2004 (Mancuso 2005), 8.8% in 2003 (Mancuso 2003), and 9.0% in 2007 (ERO Resources Corp. 2008).

Targeting potential slickspot peppergrass habitat for field inventory requires substantial planning of where suitable habitat might occur. Predictive distribution modeling is a tool to find suitable habitat and better prioritize survey efforts for rare plant species (Hernandez et al. 2006, Pearson et al. 2007). GIS layers of continuous environmental data (i.e., elevation, climate, soils) and existing slickspot peppergrass location data are used with an appropriate algorithmic model (i.e., CART, DOMAIN, MaxEnt) to create a GIS layer that predicts the distribution of the target species. The accuracy of the predictive distribution model is then evaluated using a randomly selected subset of independent species location data. Model evaluation can be further evaluated by assessing its accuracy in the field.

Algorithmic models are differentiated by algorithm class, absence data (Pearce and Boyce 2006), sample size requirements (Stockwell and Peterson 2002, Hernandez et al. 2006, Pearson et al. 2007), and overall robustness (Elith et al. 2006, Ward 2007). Robustness is measured using rates of omission (false-negative) and commission (false-positive) and receiver operating curve (ROC) analyses (Hernandez et al. 2006, Phillips et al. 2006). MaxEnt runs multiple iterations that cumulatively increase probability until a convergence threshold is reached (maximum entropy). MaxEnt does not require absence data and is considered to be robust (Beauvais et al. 2006, Elith et al. 2006, Hernandez et al. 2006, Phillips et al. 2006, Guisan et al. 2007, Ward 2007).

The objective of this project was to develop a high-quality predictive distribution model of slickspot peppergrass to identify potential habitat.

STUDY AREA

The study area used for defining model extent was the Owyhee Uplands ecological section buffered outward by 50 km (14,135,497 ha), using 1-km scale data (studyarea.shp, Appendix A). Over 99% of all known slickspot locations occur in the Owyhee Uplands ecological section. The remaining locations occur in the Northwestern Basin and Range Section and within 869 m of the Owyhee Uplands ecological section. These points being placed outside the Owyhee Uplands ecological section was likely associated with the coarse scale of the map. The 50 km buffer was used to include these locations and model areas adjacent to these areas.

METHODS

Model procedures

Slickspot peppergrass point location data for Idaho were accessed from the Idaho Natural Heritage Program (IDNHP) BIOTICS Database (2008). Polygon data and low precision point data not taken with a GPS unit were excluded from this dataset. Oversampling bias was corrected for point data collected at the U.S. Air Force Juniper Butte Training Area, also known as Management Area (MA 12; Idaho Conservation Data Center 2008). This was done by calculating the density of points in adjacent MA 11, and reducing the number of points in MA 12 to the same density (155 pts/4892 ha). The 2,740 points in MA 12 were selected randomly so that only 155 points remained.

The remaining 2,007 points were further filtered to 321 points using a 1-km cell grid across the study area (studyarea_1kmgrid.shp, Appendix A), so that not more than 1 point occurred within each 1-km cell. There was still a disproportionately higher density of points in MAs 11-12 compared MAs 1-10. We calculated the density of points in MAs 1-10 (137 points/52,249 ha) to reduce the density of points in MAs 11-12 from 196 to 86 points/32,985 ha. Twenty-five percent (n=62) of these 223 points were randomly selected to be excluded for testing the model (lepa_223pts_25per.asc, .shp); the remaining 161 points were used for training the model (lepa_223pts_75per.asc, .shp; Appendix A).

Environmental variables were assessed for the study area using MaxEnt (Phillips et al. 2004) to compare the following environmental variables: elevation, slope (°), aspect, silt (%), sand (%), clay (%), total precipitation of each quarter (summer/fall/winter/spring), isothermality, coefficient of variation of total monthly precipitation, daily total shortwave radiation, number of frost days, rock fragment volume, daily average air temperature of the warmest quarter, total annual precipitation, depth to bedrock, daily average air temperature, and pH. These variables were assessed because precipitation, temperature, solar radiation, and substrate seemed to be biologically important for where slickspot peppergrass occurred. Climate variables were accessed from DAYMET (Thornton et al. 1997, Thornton and Running 1999, Thornton et al. 2000) and soil variables were accessed from Miller and White (1998). The resulting jackknife tests of variable importance were evaluated and variables providing the least unique information to the model were excluded. MaxEnt was rerun and additional variables were excluded until there were only 6 remaining variables. These environmental variables used for modeling were: elevation (ao1000_ddemag.asc), slope (°;

ao1kmslpdeg.asc), silt (%; aosilt1.asc), clay (%; aoclay.asc), daily total shortwave radiation (ao_rt_a_pa_1km.asc), and total annual precipitation (ao_pt_a_pa.asc; Appendix A).

All model training points (n=161) and test points (n=62) were run in MaxEnt using the 6 environmental variables. Model performance was evaluated using omission vs. predicted area and ROC plot analyses. All plant nomenclature is from the U.S. Department of Agriculture (2004).

Geology

Model values were selected within similar geology in Idaho using the 1:500,000-scale Geologic Map of Idaho (Bond 1978, Johnson and Raines 1996). Similar geology at this scale was based on geologic formations where slickspot peppergrass is known to occur (Table 2; Appendix D.2). Model values were also selected within similar geology across the 4-state study area, The Geology of the Conterminous United States at 1:2,500,000 Scale—A Digital Representation of the 1974 P.B. King and H.M. Beikman Map (Schruben et al. 1994). Similar geology at this scale was based on geologic formations that intersect known slickspot peppergrass locations, except for Cretaceous granitic rocks (Table 1; Appendix D.1). Cretaceous granitic rocks were excluded because a single slickspot peppergrass location occurred 1 km within its boundary. This point being placed inside the Cretaceous granitic rocks was due to the coarse scale of the geologic map, as evidenced by the higher-quality 1:500,000-scale geologic map of Idaho. Soils were not used because the data available were not classified continuously across county lines.

Land ownership

Land ownership overlays were created for the model and private, BLM, state, and USFS lands, with and without 1:500,000-scale geology in Idaho. Cultivated, developed, and urban lands were overlaid with these maps because these lands are no longer considered suitable habitat.

Field survey preparation

Model values were selected that had ≥ 15% probability, public land ownership (state and federal), and similar geology using the 1:500,000-scale Geologic Map of Idaho. The 15% value was arbitrarily based on the cumulative threshold value where >95% of test points were predicted. Model values <1 km from known locations were excluded so that areas where slickspot peppergrass was not known to occur were targeted. One hundred polygons were randomly selected from the remaining selection for field survey. USFWS personnel were consulted about prioritizing survey efforts using model results—based on this meeting, polygons were surveyed near the Emmett and Grasmere areas in Idaho (surveyedareas.shp, Appendix A). Track log data were recorded on a Trimble Nomad GPS unit (tracklog.shp, Appendix A).

RESULTS

Model performance

Figure 1a shows how test and training data omission and predicted area vary with the cumulative threshold value selected. Optimally, the cumulative threshold value

represents the lowest fraction of background predicted and the lowest omission of samples. These cumulative threshold values were >15% and >27% based on test and training data, respectively. However, we did not select a cumulative threshold value to encourage the reader to assess the entire spectrum of model values themselves.

Figure 1b shows how the test and training data fit the model using ROC plots. The ROC plot for test data evaluates the model's predictive power by calculating how much better than random the test points fit the model. The further the line representing test data is to the top left of the graph, the better the model predicts the test data. The line representing the test data curves in the far upper left corner of the ROC plot and has an area under the curve (AUC) of 0.978, indicating the test points strongly predict the model.

Field survey

The highest probability areas for suitable slickspot peppergrass habitat using the MaxEnt model occurred between Glenn's Ferry northwest to New Plymouth and beyond across the Idaho-Oregon state line; and Grasmere east past the U.S. Air Force Juniper Butte Training Range (Fig. 2; maxent223pts.shp, Appendix A). The model results were narrowed down by similar geology (Tables 1-2; Appendices D.1 and D.3) at the 1:500,000 scale (Appendix D.2; maxent223pts_1978geol_similar.shp, Appendix A) and the 1:2,500,000 scale (Appendix D.4; maxent223pts_coarsegeol_similar.shp, Appendix A). Predicted distribution of slickspot peppergrass in Idaho was further narrowed down by land use (i.e., cultivated, developed, and urban lands; Fig. 3).

Surveys were conducted on 24 July in the Emmett area and 5-7 August 2008 in the Grasmere area. No new slickspot peppergrass locations were discovered, although new Davis' peppergrass (*Lepidium davisii*) locations were discovered at polygons #1-2 on 7 August 2008 (lepasurvey_lepdavlocationsfound.shp, Appendix A). The following describes our survey efforts in the areas targeted:

<u>Surveyed 24 July 2008, polygon #1 (Emmett)</u>

B. Colket and N. Wade surveyed for slickspot peppergrass southwest of Emmett (Fig. 2). This area had been completely burned and was dominated by cheatgrass (*Bromus tectorum*) and rush skeletonweed (*Chondrilla juncea*; Fig. 4). Additional species, all non-native, that were observed during the survey were medusahead (*Taeniatherum caput-medusae*), crested wheatgrass (*Agropyron cristatum*), tall tumblemustard (*Sisymbrium altissimum*), clasping pepperweed (*Lepidium perfoliatum*), Russian thistle (*Salsola tragus*), bur buttercup (*Ceratocephala testiculata*), and moth mullein (*Verbascum blattaria*). Big sagebrush (*Artemisia tridentata*) was not observed, although there were a few small stands of rubber rabbitbrush (*Ericameria nauseosa*). There were many slickspots on the ridgelines and fewer slickspots on the flats, some with good biological crust development. The slickspots appeared similar to slickspots that support slickspot peppergrass in the New Plymouth and Eagle foothills areas.

<u>Surveyed 5 August 2008, polygon #1 (Grasmere)</u>

B. Colket and J. Granton surveyed for slickspot peppergrass immediately south of Grasmere, east of Highway 51 (Fig. 2). This area was unburned and had Wyoming big sagebrush (*A. t.* ssp. *wyomingensis*) habitat with varying non-native species cover

comprising the understory (Fig. 5). Additional species present included broom snakeweed (*Gutierrezia sarothrae*), Indian ricegrass (*Achnatherum hymenoides*), bluebunch wheatgrass (*Pseudoroegnaria spicata*), Sandberg bluegrass (*Poa secunda*), and clasping pepperweed. Some of the slickspots appeared capable of supporting slickspot peppergrass, but there were few slickspots in the general area.

Surveyed 5 August 2008, polygon #2 (Grasmere)

B. Colket and J. Granton surveyed for slickspot peppergrass immediately northeast of Grasmere, east of Highway 51 (Fig. 2). This area was unburned and had Wyoming big sagebrush habitat with a bluebunch wheatgrass understory and very low non-native cover. However, halogeton (*Halogeton glomeratus*) occurred on nearby two-track roads (Fig. 6). Some of the slickspots appeared capable of supporting slickspot peppergrass, although there were few slickspots in the general area. Based on the uniform black or red gravel cinders or basalt cobbles spread across the formation, some of these slickspots may have been playettes, which is unusual for slickspots occupied by slickspot peppergrass. However, some slickspots appeared similar to those occupied by slickspot peppergrass at the Orchard Training Area.

Surveyed 6 August 2008, polygon #1 (Grasmere)

B. Colket and J. Granton surveyed for slickspot peppergrass south of Grasmere, east of Highway 51 (Fig. 2). This area was unburned and had Wyoming big sagebrush habitat with a bluebunch wheatgrass understory (Fig. 7). Some of the slickspots appeared capable of supporting slickspot peppergrass, although there were few slickspots in the general area (except east of the main gravel road used to access the area). Some of these slickspots may have been playettes, based on the uniform black or red gravel cinders or basalt cobbles spread across the formation. These slickspots (or playettes) had high cover of Hood's phlox (*Phlox hoodii*) and sometimes Bruneau milkvetch (*Astragalus camptopus*), neither of which has been associated with slickspots occupied by slickspot peppergrass. Halogeton also occurred on nearby two-track roads.

Surveyed 6 August 2008, polygon #2 (Grasmere)

B. Colket and J. Granton surveyed for slickspot peppergrass south of Grasmere, east of Highway 51 (Fig. 2). This area was unburned and had Wyoming big sagebrush habitat with a Sandberg bluegrass understory (Fig. 8). The terrain had basalt outcrops with gentler slopes below. Some of the slickspots appeared capable of supporting slickspot peppergrass, although there were even fewer slickspots in the general area compared to other areas surveyed up to this point. Based on the uniform black or red gravel cinders or basalt cobbles spread across the formation, some of these slickspots may have been playettes.

Surveyed 7 August 2008, polygon #1 (Grasmere)

B. Colket and J. Granton surveyed for slickspot peppergrass south of Grasmere, east of Highway 51 (Fig. 2). This area was unburned and had Wyoming big sagebrush habitat with a Sandberg bluegrass understory (Fig. 9). There were both slickspots and playas and they had soils with high albedo and sometimes black basalt rocks that formed symmetrical circles. Some playettes appeared capable of supporting slickspot peppergrass, although this would depend on whether the chemical composition and soil

structure were suitable. A new Davis' peppergrass location was discovered during the survey, representing an extension of element occurrence (EO) 116 (lepasurvey_lepdavlocationsfound.shp, Appendix A). An EO is a specific geographic location where "a species or natural community is, or was, present" (NatureServe 2002:10). Associated photos and the EO update form for this extension are stored in Appendices B and C, respectively.

Surveyed 7 August 2008, polygon #2 (Grasmere)

B. Colket and J. Granton surveyed for slickspot peppergrass northwest of Grasmere, west of Highway 51 (Fig. 2). This area was unburned and had Wyoming big sagebrush habitat with a Sandberg bluegrass understory (Fig. 10). Some of the slickspots appeared capable of supporting slickspot peppergrass. However, the area was primarily characterized by playas, including a 50x40 m playa with >1,000 Davis' peppergrass plants and 3 additional playas occupied by Davis' peppergrass (lepasurvey_lepdavlocationsfound.shp, Appendix A). These discoveries represent new Davis' peppergrass EO 176. Associated photos and the EO update form for new EO 176 are stored in Appendices B and C, respectively.

DISCUSSION

The slickspot peppergrass model was a useful tool to help select survey areas, although no new slickspot peppergrass locations were discovered as a result of this work (Fig. 2; maxent223pts.shp, Appendix A). It is possible that we missed slickspots occupied by slickspot peppergrass since it can remain dormant in the seed bank for at least 12 years (Meyer et al. 2005). In addition, we were surveying relatively late in the season when many slickspot peppergrass plants are desiccated. However, it is unlikely that we overlooked any slickspot peppergrass locations containing more than a few plants.

Based on the model results, the area surveyed near Emmett appeared quite suitable for slickspot peppergrass, except that the land had been highly disturbed by fire and non-native plant species. The soil color and overall appearance of its slickspots were similar to slickspots occupied by slickspot peppergrass in the New Plymouth and Eagle areas. Slickspot peppergrass can occur in areas that have been highly disturbed by fire and non-native species, but high quality habitat is characterized by intact sagebrush steppe, low abundance of non-native species, and low levels of anthropogenic disturbances (Moseley 1994, U.S. Fish and Wildlife Service 2003, Colket et al. 2006).

Several predicted areas near Grasmere were also surveyed, but these had variable habitat suitability. There were fewer slickspots across the landscape in the Grasmere area than areas known to support slickspot peppergrass. Most slickspots near Grasmere were physically different from slickspots occupied by slickspot peppergrass. For example, these slickspots had black or red cinders or cobbles scattered across and were in big sagebrush communities with different plant associates (i.e., broom snakeweed, Indian ricegrass, Bruneau milkvetch) than slickspots occupied by slickspot peppergrass. Slickspot peppergrass might occur in the Grasmere area, but additional survey efforts would be required.

Overlaying the model with geology and land use helped better focus the model results, although the Grasmere area remained strongly predicted even after doing this (Fig. 3;

Appendices D.2 and D.4). Geological formations intersected by the largest proportion of slickspot peppergrass points (Tables 1-2) could be used to better target strongly predicted areas for slickspot peppergrass. For example, the formation Tpb was intersected by 81 points compared to QTs (1 point), out of a total of 223 points (Table 1). Given limited survey resources, strongly predicted areas in the Tpb formation would likely be the better target compared to QTs, although QTs should not be excluded. As they become available, higher quality geology or soils maps that are classified continuously across county lines could elucidate the geological differences between the Grasmere area and other areas in Idaho where slickspot peppergrass is known to occur.

Areas where slickspot peppergrass was not strongly predicted should not necessarily be discounted from future surveys, and vice versa, particularly if biologists familiar with the species believe otherwise. This project provides a broadscale assessment of the predicted distribution of slickspot peppergrass. Modeling at a finer scale (i.e., 30-m or better) would probably better relate to this species' predicted distribution, although it was not possible in this case, given the environmental variable data available for the multi-state study area. There are also likely subtle geological-related differences that influence the suitability of a slickspot for slickspot peppergrass that are not being picked up by the model. Finer environmental variable data, especially for geology or soils, would probably improve the model's ability to detect the suitability of a given slickspot.

MANAGEMENT IMPLICATIONS

This slickspot peppergrass model is a tool for biologists and managers to use in coordination with their knowledge of the species' habitat requirements and known distribution. This model can be used to prioritize future surveys and conservation planning efforts for slickspot peppergrass.

BLM, private, and state lands had the largest proportion of high probability suitable habitat for slickspot peppergrass, although much of the private land has already been cultivated or developed (Appendices D.5-D.7). USFS lands had a negligible amount of high probability suitable habitat—these were east of Twin Falls far from known slickspot peppergrass locations (Appendix D.8).

I recommend that model values selected by similar 1:500,000-scale geology be used in Idaho (Fig. 3; maxent223pts_1978geol_similar.shp, Appendix A; Appendix D.2). Model values selected by similar 1:2,500,000-scale geology should be used outside of Idaho (Appendix D.4; maxent223pts_ coarsegeol_similar, Appendix A). Finer scale environmental variable data, especially for geology or soils, should be evaluated for future use if they become available.

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Table 1. Geological formations intersecting known slickspot peppergrass (*Lepidium papilliferum*) locations, based on The Geology of the Conterminous United States at 1:2,500,000 Scale—A Digital Representation of the 1974 P.B. King and H.M. Beikman Map (Schruben et al. 1994).

Time period	Formation	Description	Points[a]
Pliocene	Tpv	Pliocene volcanic rocks	74
Pleistocene-Recent	Qv	Quaternary volcanic rocks	62
Pliocene	Tpc	Pliocene continental	45
Pleistocene-Recent	Q	Quaternary	29
Pliocene	Tpf	Pliocene felsic volcanic rocks	12
Cretaceous	Kg	Cretaceous granitic rocks	1

Table 2. Geological formations intersecting known slickspot peppergrass (*Lepidium papilliferum*) locations, based on the Geologic Map of Idaho at the 1:500,000 scale (Bond 1978; Johnson and Raines 1996).

Time period	Formation	Description	Source	Points[a]
Pliocene	Tpb	Pliocene olivine basalt flows and associated tuff and detritus of southern Idaho	Sedimentary rock, continental deposits, Cenozoic units	81
Pleistocene	Qpmb	Middle Pleistocene plateau and canyon-filling basalt in and near the Snake Plain	Igneous rock, extrusions, Cenozoic units, basalt	46
Pleistocene	Qpa	Pleistocene waterlaid detritus; may be distal deposits of glacial floods and outwash	Sedimentary rock, continental deposits, Cenozoic units	36
Pliocene	Tpd	Pliocene stream and lake deposits; may be due to volcanic and block-faulting events	Sedimentary rock, continental deposits, Cenozoic units	28
Pleistocene	Qpmd	Middle Pleistocene lava-dammed Snake Plain lake beds of silt, clay, and diatomite	Sedimentary rock, continental deposits, Cenozoic units	13
Pleistocene-Recent	Qa	Quaternary alluvium; may contain some glacial deposits and colluvium in uplands	Sedimentary rock, continental deposits, Cenozoic units	6
Pliocene	Tpf	Pliocene silicic welded tuff, ash, and flow rock; most common in southwestern Idaho	Igneous rock, extrusions, Cenozoic units, felsite	5
Pleistocene	Qpg	Pleistocene outwash, fanglomerate, flood and terrace gravels	Sedimentary rock, continental deposits, Cenozoic units	4
Pleistocene	Qpu1b	Upper Pleistocene Snake Plain lava flows; local stratigraphic position is at bottom (older)	Igneous rock, extrusions, Cenozoic units, basalt	2
Pleistocene	Qpu?b	Upper Pleistocene Snake Plain lava flows; local stratigraphic position unknown	Igneous rock, extrusions, Cenozoic units, basalt	1
Miocene-Pleistocene	QTs	Pleistocene and Pliocene stream and lake deposits	Sedimentary rock, continental deposits, Cenozoic units	1

a=Points represent the number of the 223 filtered slickspot peppergrass points used for modeling (both training and test data) that intersect each geological formation.

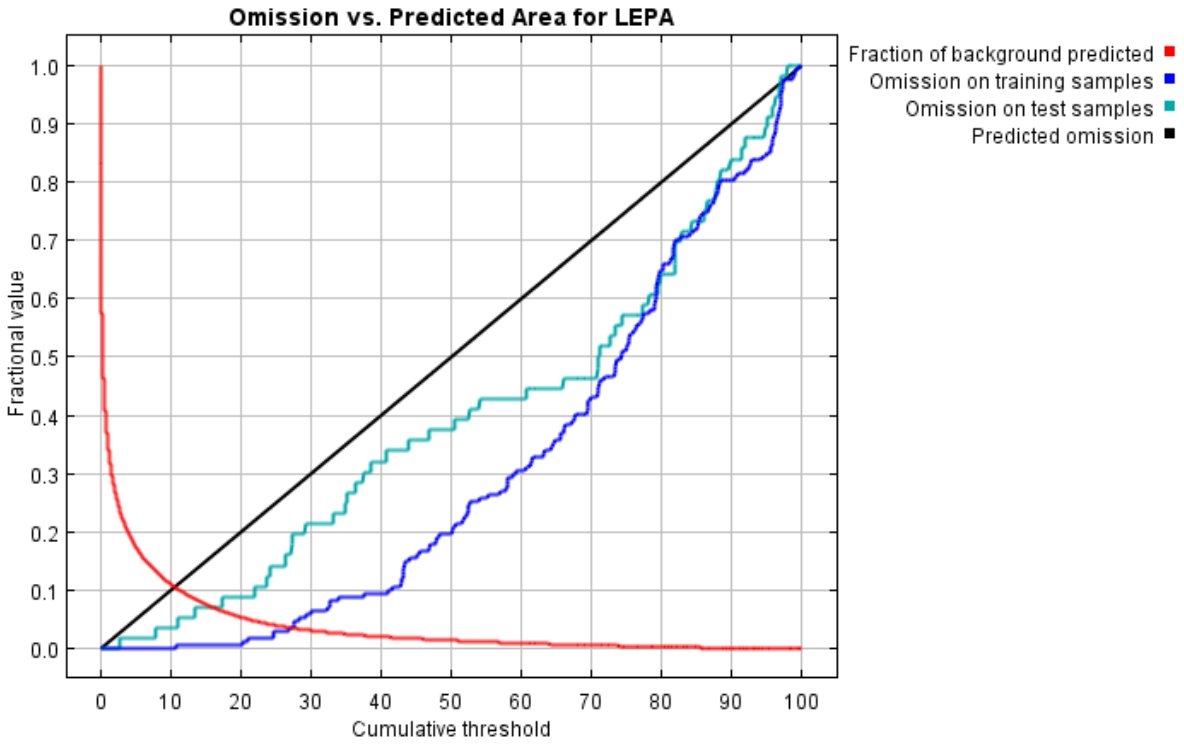


Figure 1a. Analysis of omission versus predicted area for the slickspot peppergrass (*Lepidium papilliferum*; LEPA) predictive distribution model developed using MaxEnt.

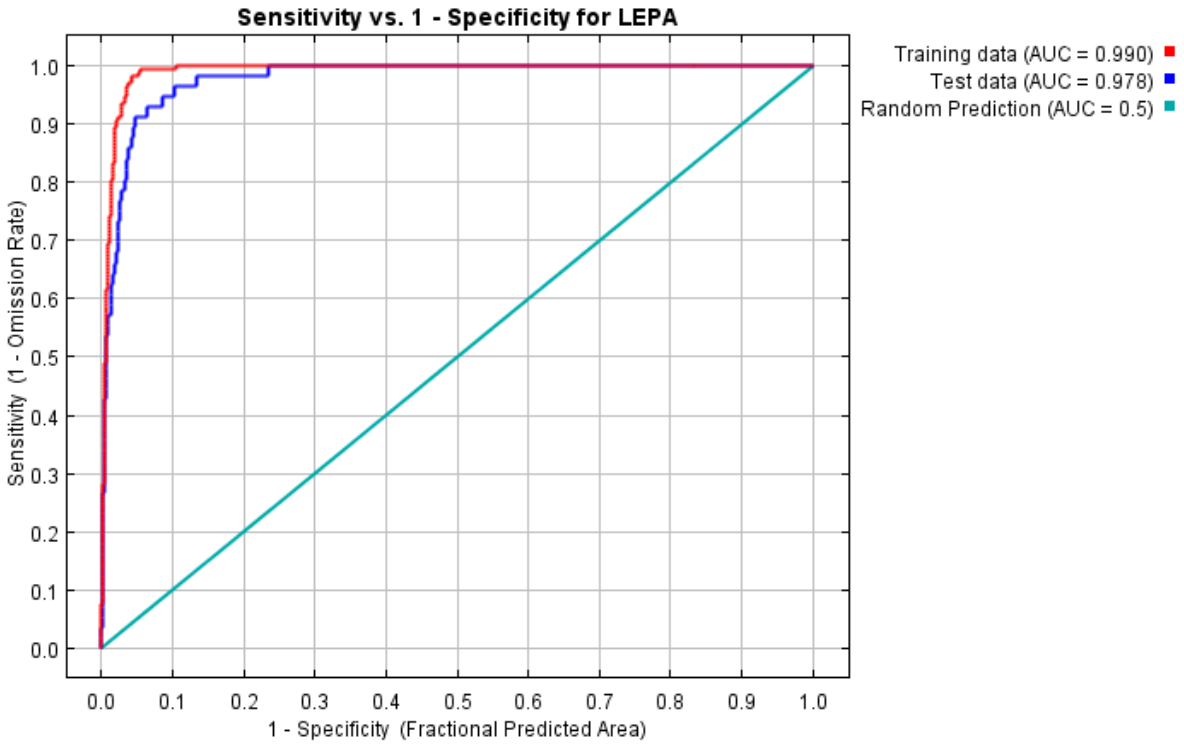


Figure 1b. Receiver operating characteristic (ROC) plot analyses for the slickspot peppergrass (*Lepidium papilliferum*; LEPA) predictive distribution model developed using MaxEnt.

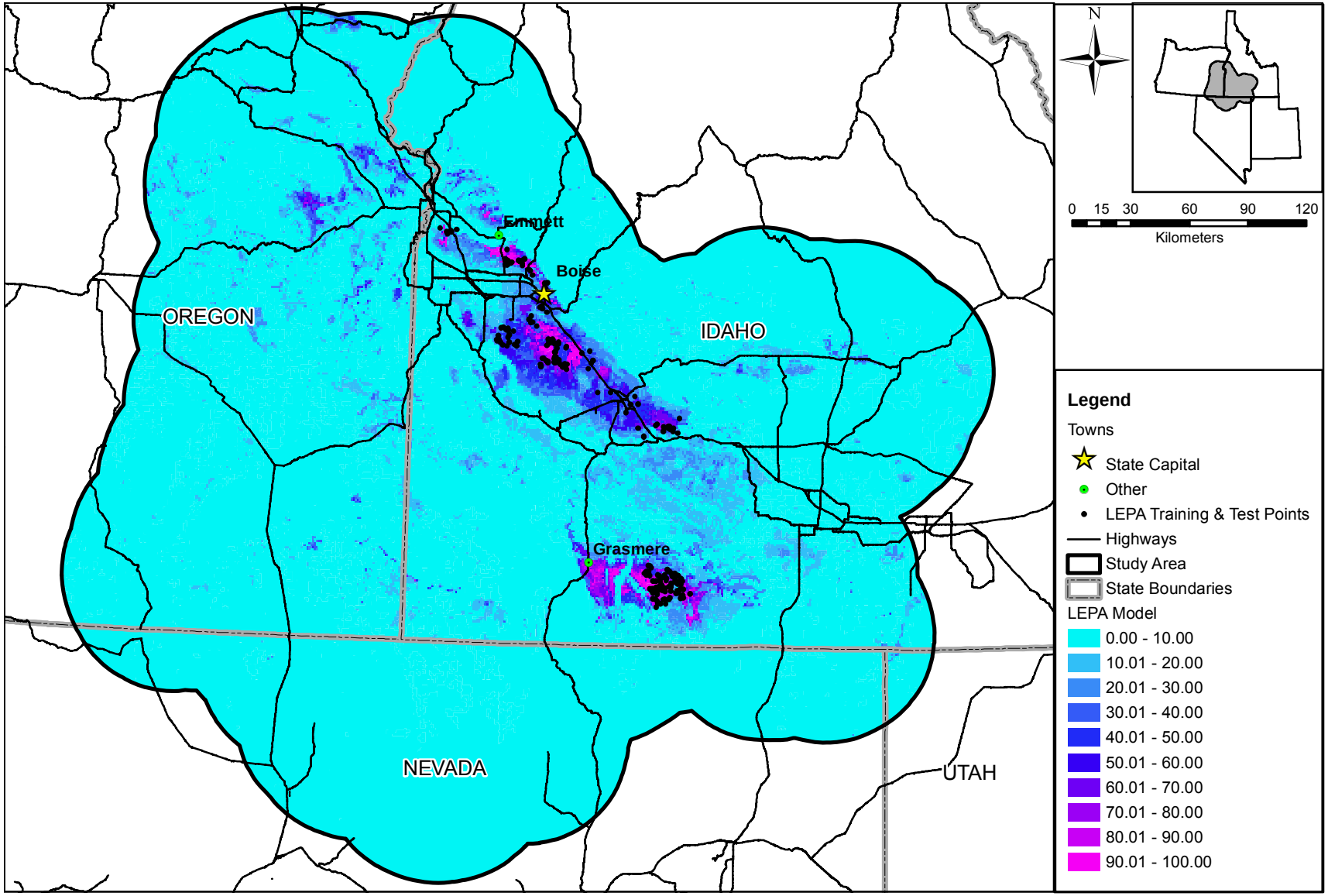


Figure 2. Predicted distribution of slickspot peppergrass (*Lepidium papilliferum*; LEPA) using MaxEnt. See poster version in Appendix E.

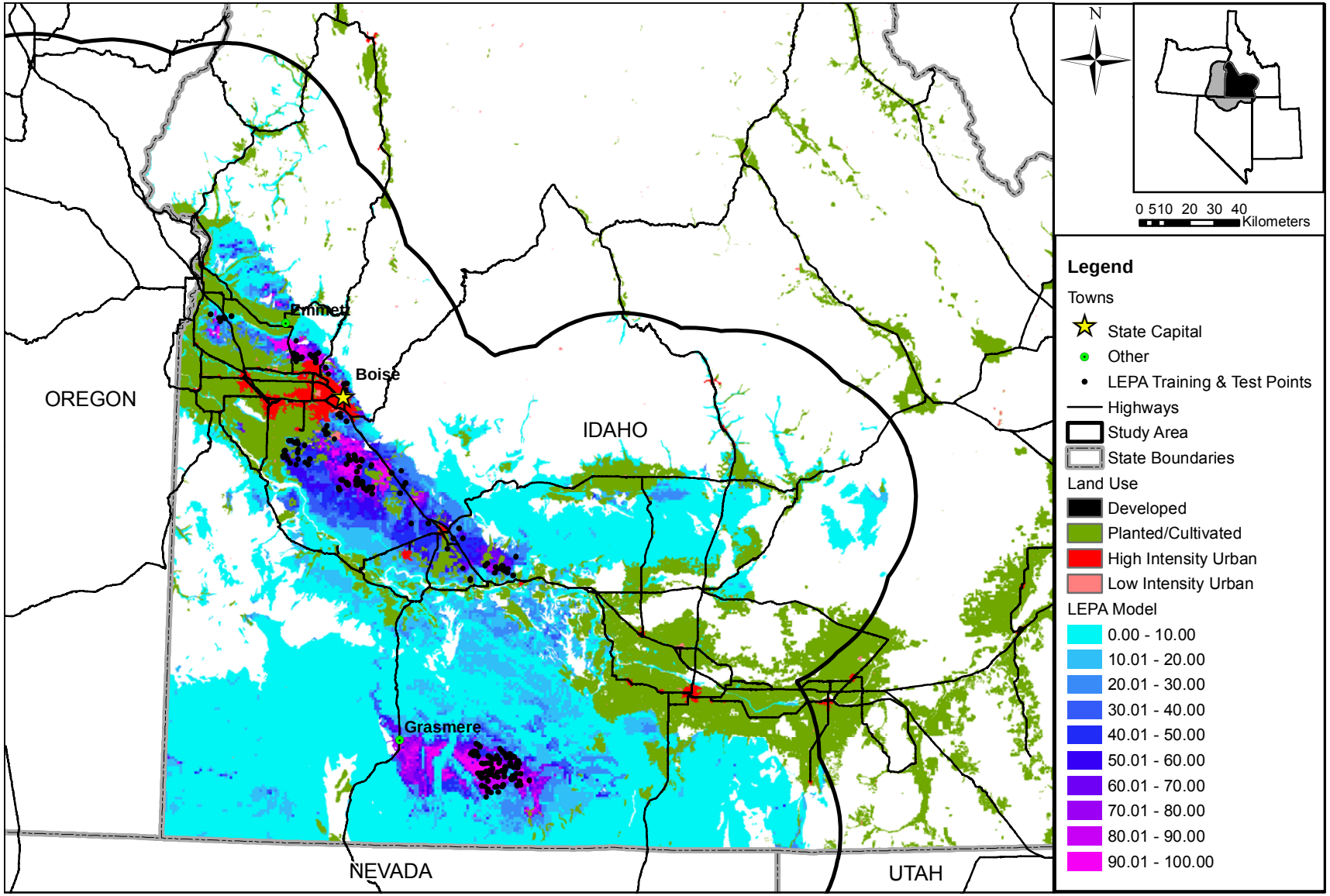


Figure 3. Land use and predicted distribution of slickspot peppergrass (*Lepidium papilliferum*; LEPA) using MaxEnt and 1:500,000 geology in Idaho (Bond 1978; Johnson and Raines 1996). Similar geology is based on geological formations selected in Appendix D.1. See poster version in Appendix E.

Figure 4. Habitat surveyed at polygon #1 on 24 July 2008 (Emmett area; see Figures 2-3 for location).

Figure 5. Habitat surveyed at polygon #1 on 5 August 2008 (Grasmere area; see Figures 2-3 for location).

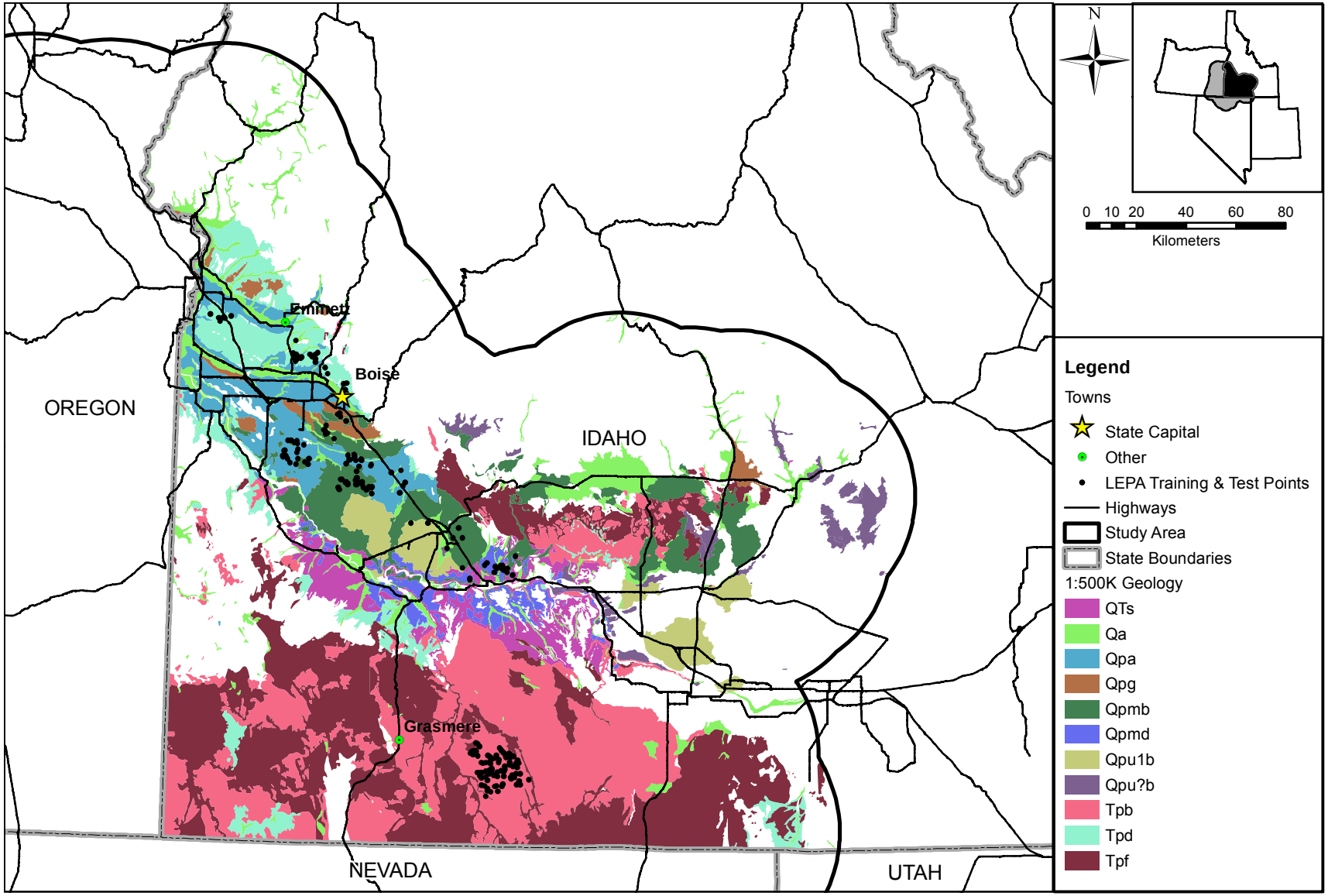
Figure 6. Habitat surveyed at polygon #2 on 5 August 2008 (Grasmere area; see Figures 2-3 for location).

Figure 7. Habitat surveyed at polygon #1 on 6 August 2008 (Grasmere area; see Figures 2-3 for location).

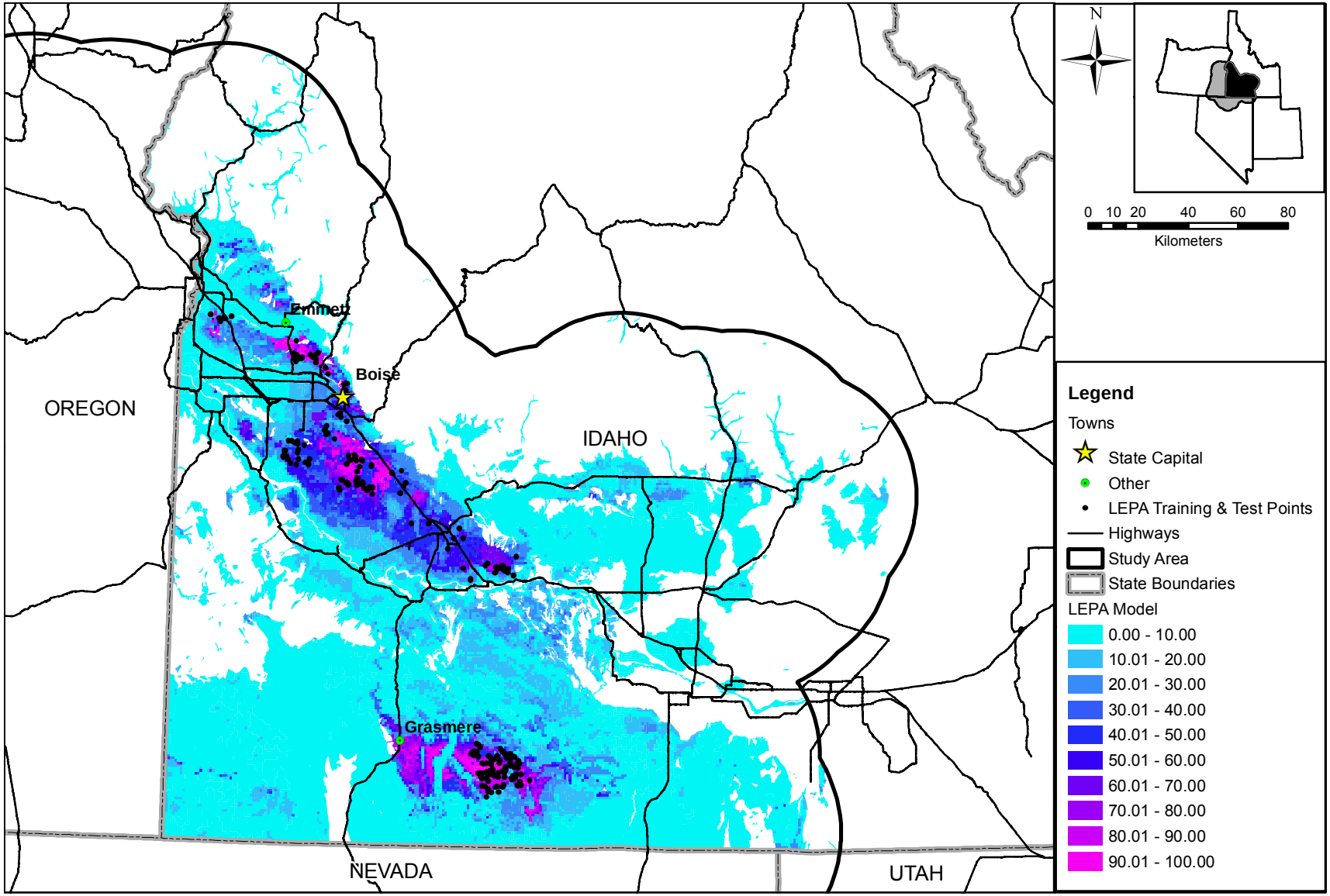
Figure 8. Habitat surveyed at polygon #2 on 6 August 2008 (Grasmere area; see Figures 2-3 for location).

Figure 9. Habitat surveyed at polygon #1 on 7 August 2008 (Grasmere area; see Figures 2-3 for location).

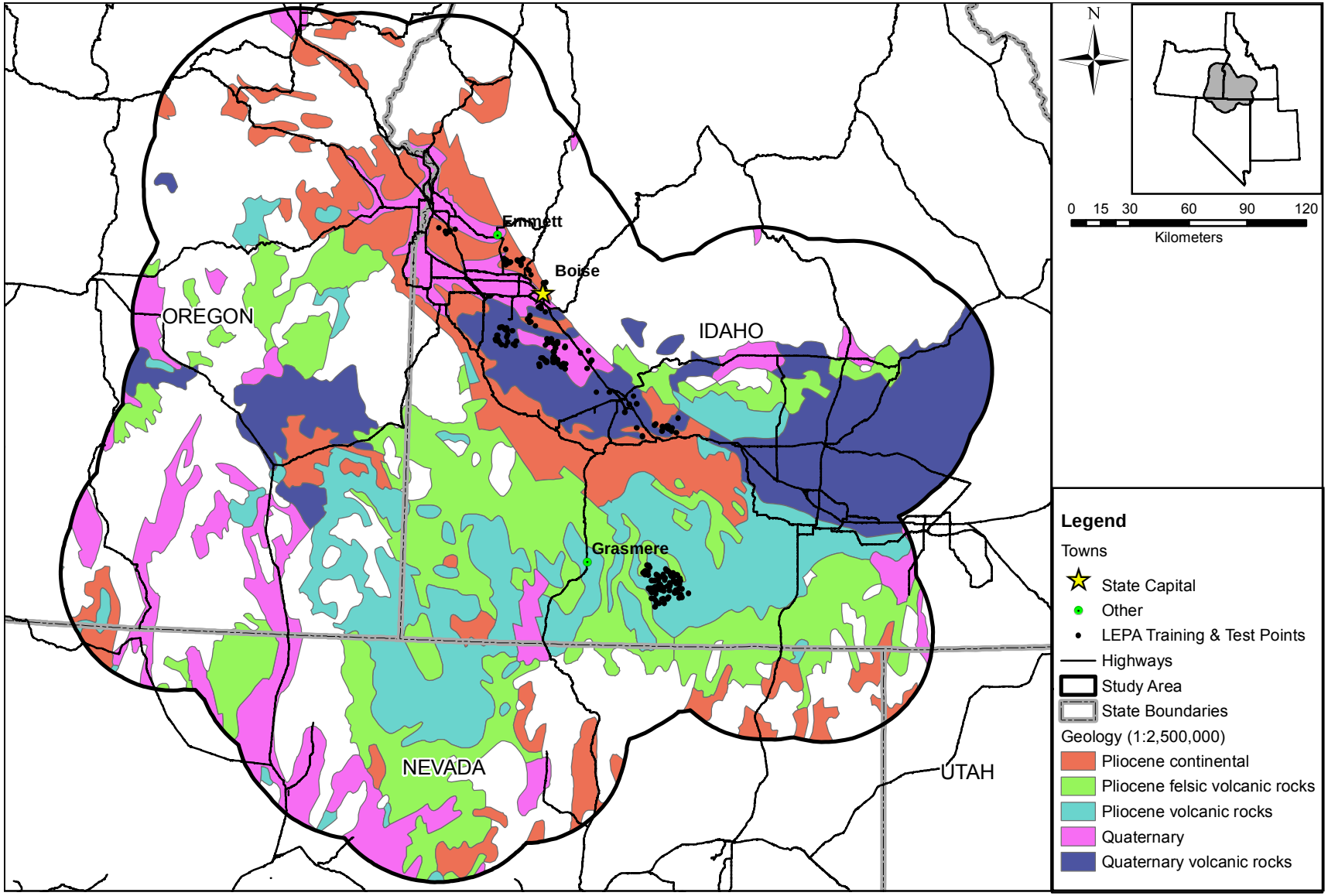
Figure 10. Habitat surveyed at polygon #2 on 7 August 2008 (Grasmere area; see Figures 2-3 for location).



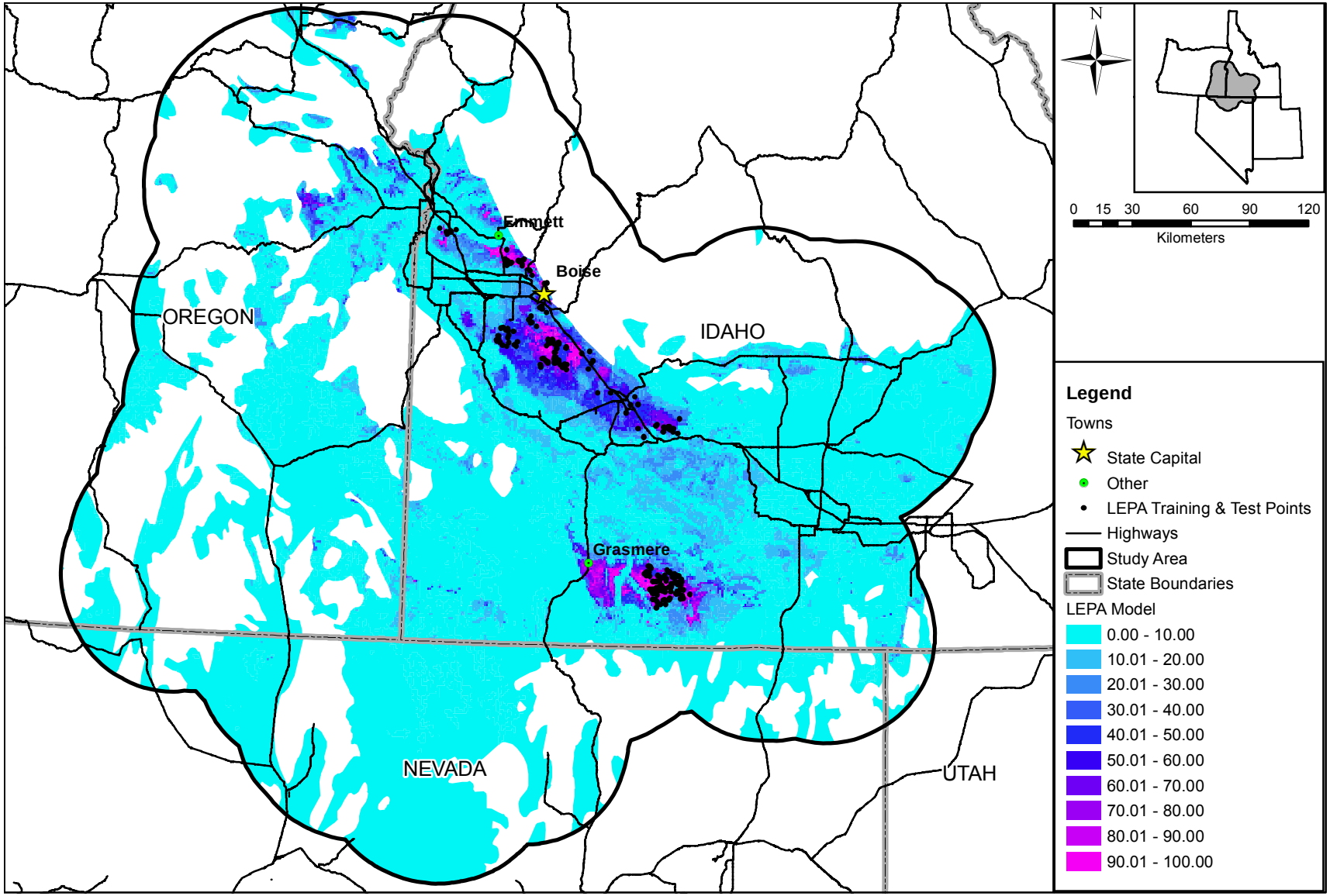
Appendix D.1. Geological formations intersecting known slickspot peppergrass (*Lepidium papilliferum*) locations, based on the Geologic Map of Idaho at the 1:500,000 scale (Bond 1978; Johnson and Raines 1996).



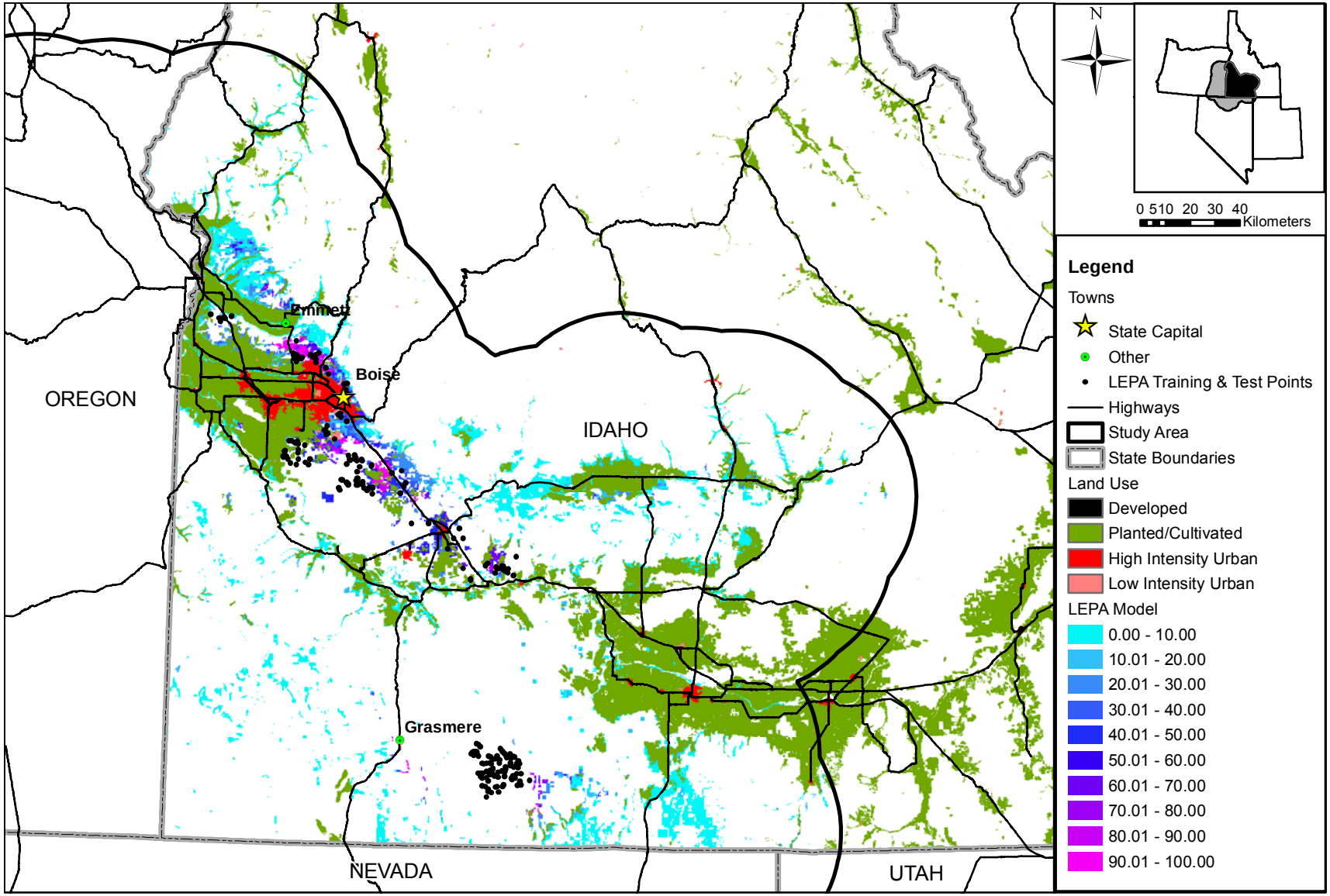
Appendix D.2. Predicted distribution of slickspot peppergrass (*Lepidium papilliferum*; LEPA) using MaxEnt and 1:500,000 geology in Idaho (Bond 1978; Johnson and Raines 1996). Similar geology is based on geological formations selected in Appendix D.1.



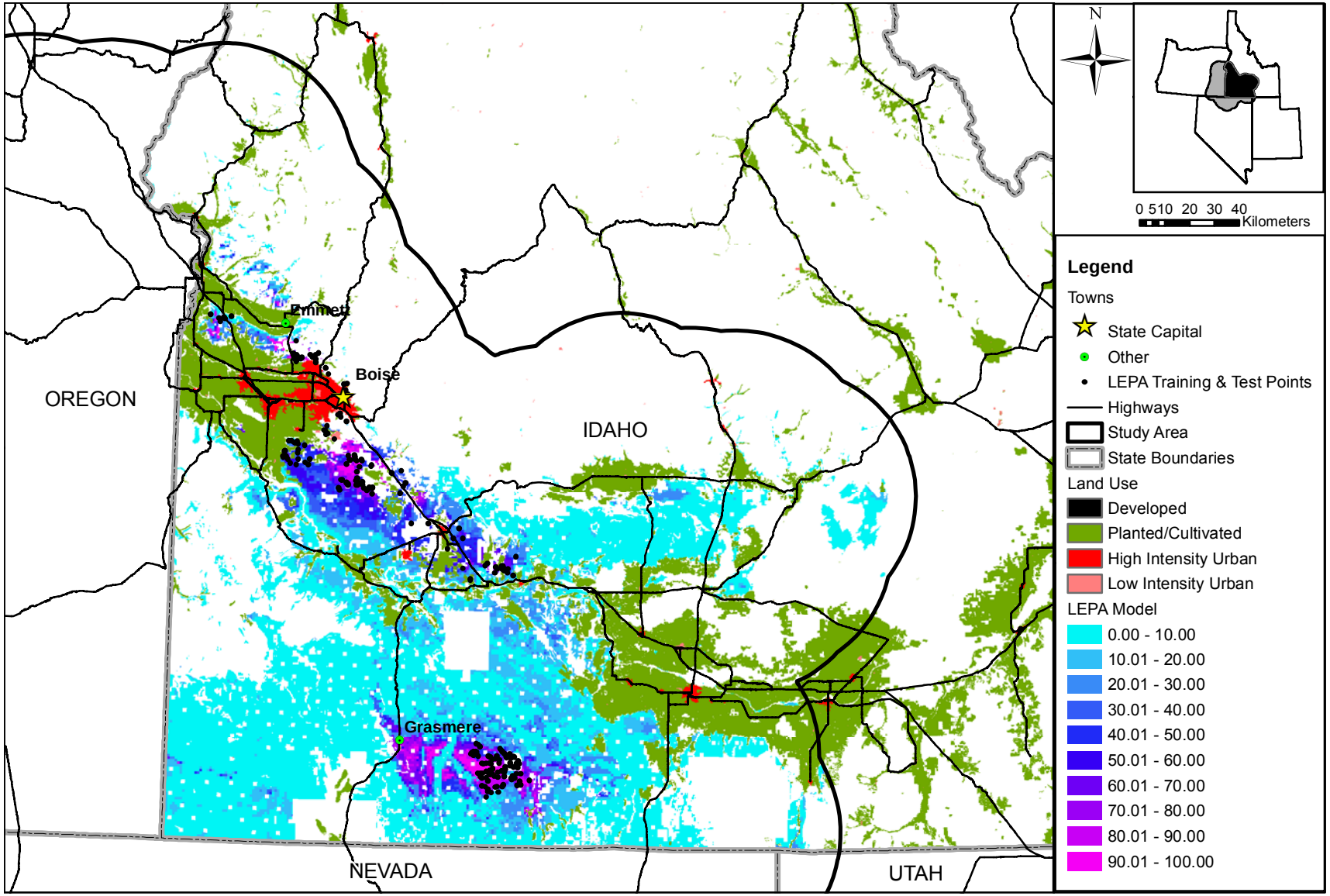
Appendix D.3. Geological formations intersecting known slickspot peppergrass (*Lepidium papilliferum*) locations, based on The Geology of the Conterminous United States at 1:2,500,000 Scale—A Digital Representation of the 1974 P.B. King and H.M. Beikman Map (Schruben et al. 1994).



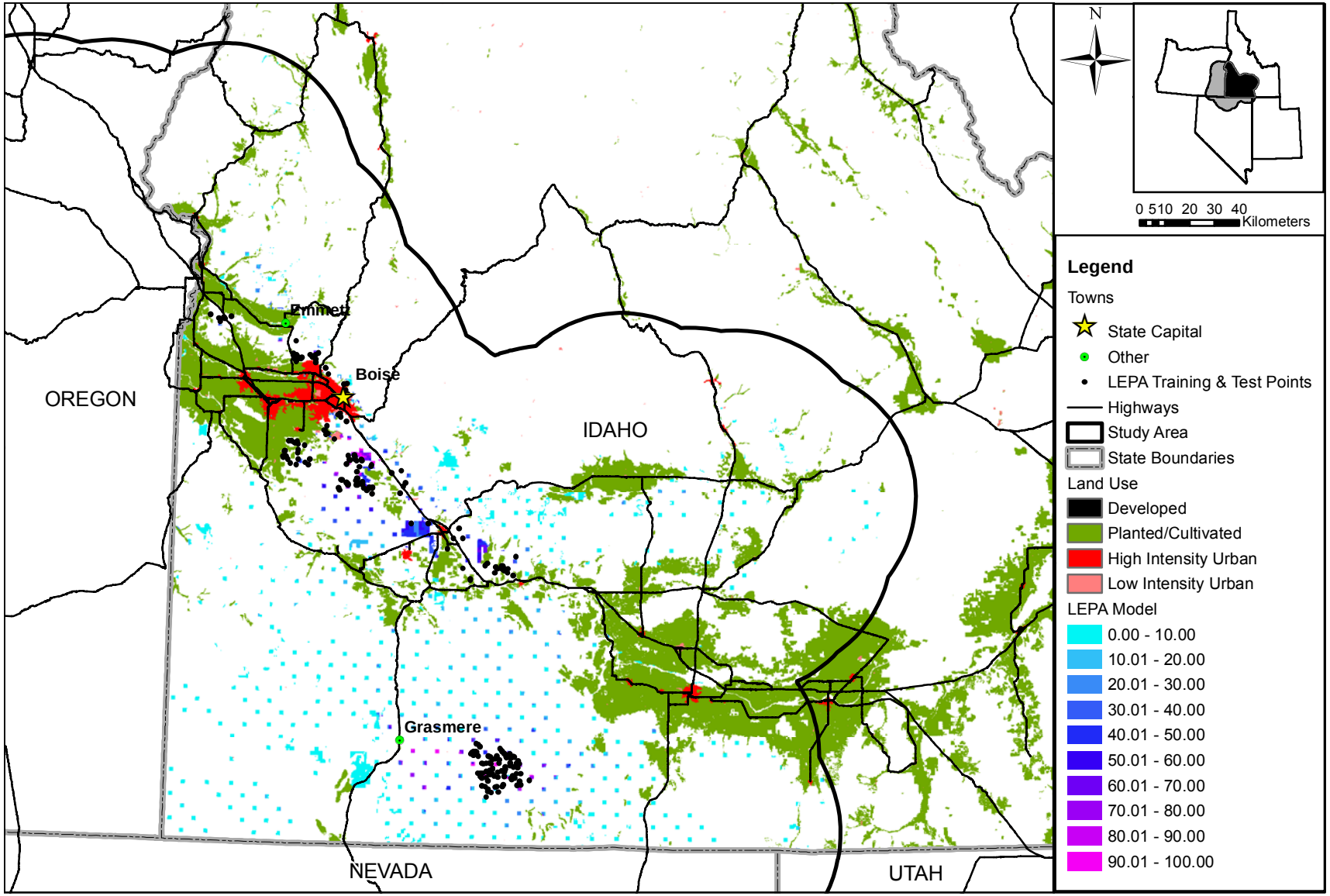
Appendix D.4. Predicted distribution of slickspot peppergrass (*Lepidium papilliferum*; LEPA) using MaxEnt and 1:2,500,000 geology in the four-state study area (Schruben et al. 1994). Similar geology is based on geological formations selected in Appendix D.3.



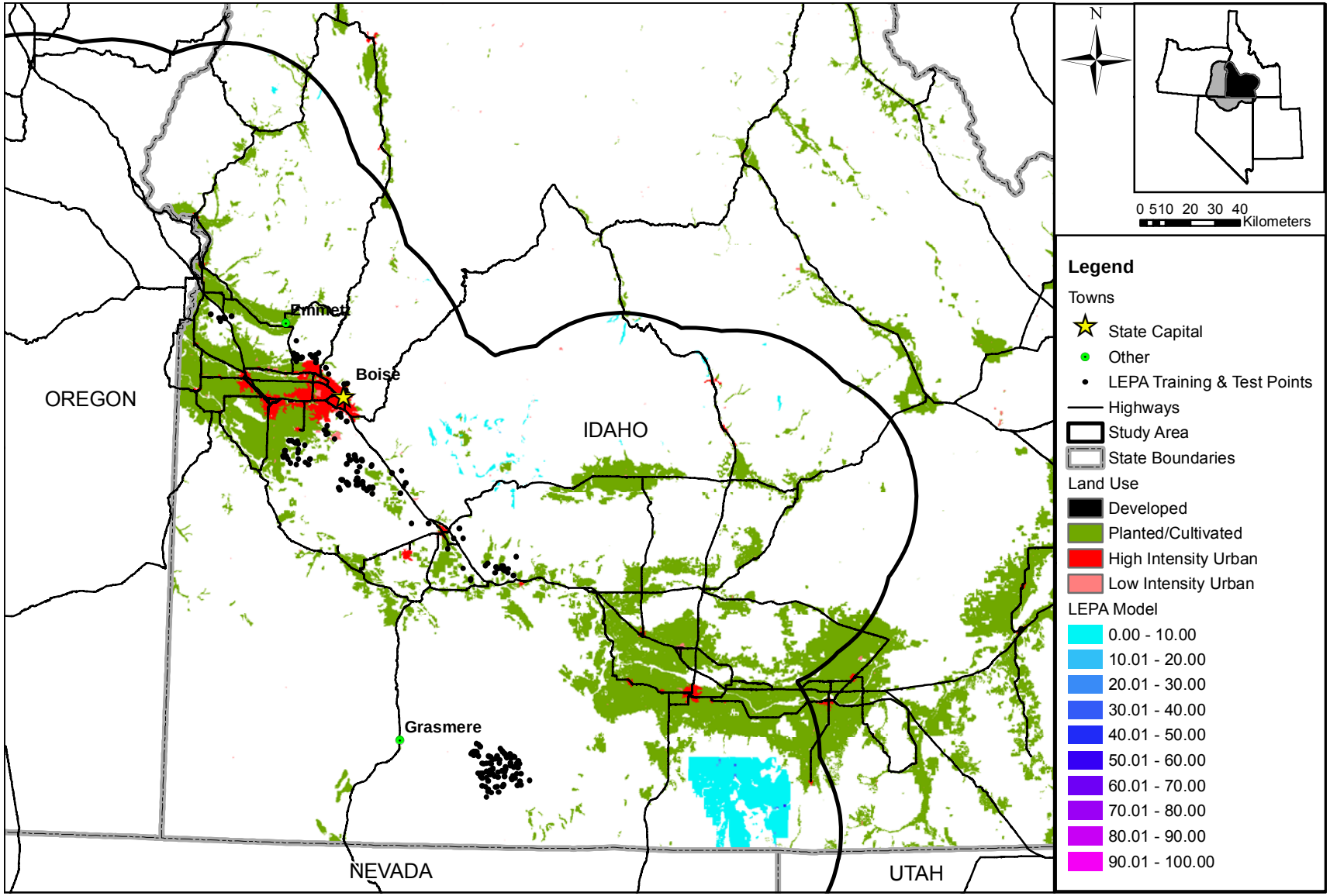
Appendix D.5. Land use and predicted distribution of slickspot peppergrass (*Lepidium papilliferum*) on private lands using MaxEnt and 1:500,000 geology of Idaho (see Appendix D.1).



Appendix D.6. Land use and predicted distribution of slickspot peppergrass (*Lepidium papilliferum*) on BLM lands using MaxEnt and 1:500,000 geology of Idaho (see Appendix D.1).



Appendix D.7. Land use and predicted distribution of slickspot peppergrass (*Lepidium papilliferum*) on state lands using MaxEnt and 1:500,000 geology of Idaho (see Appendix D.1).



Appendix D.8. Land use and predicted distribution of slickspot peppergrass (*Lepidium papilliferum*) on USFS lands using MaxEnt and 1:500,000 geology of Idaho (see Appendix D.1).