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Use of a Climate Change Vulnerability Index for Assessing Species at Risk on Military Lands

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Abstract

Global climate change is seen as an emerging threat to wildlife species' population distribution and persistence. Climate change vulnerability indexes allow land managers to rapidly assess the vulnerability of species to climate change, and to predict a species persistence into the future. This work evaluated the NatureServe Climate Change Vulnerability Index as a tool for military land managers. The NatureServe Climate Change Vulnerability Index was applied to three high priority Species at Risk: (1) the Mohave ground squirrel (*Spermophilus mohavensis*) on Fort Irwin, CA; (2) the Columbia Basin distinct population segment of the greater sage-grouse (*Centrocercus urophasianus*) on the Yakima Training Center, WA; and (3) the gopher tortoise (*Gopherus polyphemis*) on Fort Stewart, GA. The Index predicted that the Mohave ground squirrel population was not vulnerable to climate change, and that the greater sage-grouse and gopher tortoise populations were moderately vulnerable. The Index was found to be easy to use; it included quantitative, spatially explicit data, and it identified needed research areas for species of conservation concern. However, Index outcome was found to be highly dependent on a single variable, historical hydrological niche, which varied greatly depending on size of assessment area.

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Preface

This study was conducted for Office of the Assistant Secretary of the Army for Acquisition, Logistics, and Technology, ASA(ALT) under program element 622720A896, "Army Environmental Quality Technology"; Work Unit 378CGB, "FY11 Prediction and Adaptation of Military Infrastructure to Unknown Futures." The technical monitor was Victor Diersing, DAIM-ISE.

This work was conducted by the Ecological Processes Branch (CN-N), Installations Division (CN), Construction Engineering Research Laboratory (CERL). The CERL principal investigators were Jinelle H. Sperry and Timothy Hayden. The HQDA ACSIM reviewer of the final draft report was Steven Sekscienski, DAIM-ISE. William d. Meyer is Chief, CEERD-CN-N, and Dr. John Bandy is Chief, CEERD-CN. The associated Technical Director was Alan Anderson, CEERD-CV-T. The Director of ERDC-CERL is Dr. Ilker R. Adiguzel.

CERL is an element of the US Army Engineer Research and Development Center (ERDC), US Army Corps of Engineers. The Commander and Executive Director of ERDC is COL Gary E. Johnston, and the Director of ERDC is Dr. Jeffery P. Holland.

1 Introduction

1.1 Background

The Department of Defense (DOD) is obligated by the Endangered Species Act (ESA) to take actions to conserve and manage threatened and endangered species (TES) that reside within its jurisdiction. The DOD maintains large tracts of contiguous land that provide habitat to a wide range of TES species. This is largely due to the fact that military lands remain largely in their natural state, and because they are not subject to commercial or residential development that fragments and reduces native TES habitat.

Consequently, of the 1373 species currently listed as threatened or endangered (USFWS 2011), over 188 species are known to inhabit Army lands (OACSIM 2009). Many more species found on military lands are considered “at-risk” for Federal listing as TES and recent DoD policies emphasize the need to proactively manage these species to prevent Federal listing (DOD 2011, p 18). For the military to fulfill its obligations set forth by the ESA and to prevent Species at Risk (SAR) from experiencing further population declines, it is necessary to understand the threats facing species of conservation concern.

Well-known threats, such as habitat fragmentation and loss, invasive species, and disease have been recognized and studied for many species found on DOD lands (e.g., Walton and Walls 1964; Guertin and Tess 2006, Peak 2007). Although climate change has been recognized as an emerging threat, only recently have studies begun to examine species vulnerability to climate change on military lands.

Globally, climate change is thought to be responsible for shifts in distribution and changes in abundance for many species (Parmesan and Yohe 2003; Perry et al. 2005) and may be responsible for at least one species’ extinction (Pounds et al. 1999). Ecological modeling efforts predict high levels of species extinction rates (e.g., 15–37%) by the year 2050, based on mid-range climate-warming scenarios (Thomas et al. 2004). If these predictions are accurate, unprecedented numbers of species on military lands could be listed as TES in the near future. In addition to the financial burden of conserving TES species, restrictions placed on the uses of lands containing TES habitat will negatively impact training on military lands. Therefore, it is critical to determine the species that are at the greatest risk of climate-mediated population decline and to identify any possible mechanisms to decrease that risk.

Numerous studies have attempted to model the vulnerability of a species or suite of species to climate change (e.g., Midgley et al. 2002, Chin et al. 2010). However, species vulnerability to climate change can vary both by species and by geographic area, making it difficult for land managers to use information garnered from previous studies when making management decisions. For example, while precipitation amounts are not predicted to change drastically in eastern coastal areas of the United States, the Midwest is predicted to experience substantially less precipitation (Nature conservancy 2011, Maurer et al. 2007). Because of such regional and species-specific responses, it becomes necessary to calculate vulnerability for a single species within a defined assessment area. Assessing species vulnerability requires extensive knowledge about a species life history, about population demographics, and about predicted climatic changes within the assessment area—which together make vulnerability assessments a daunting task for many land managers.

To simplify this task, several organizations (e.g., the US Environmental Protection Agency [USEPA]) have either already developed or are in the process of developing tools to assist land managers in assessing species vulnerability for species of interest. This work used the NatureServe* Climate Change Vulnerability Index to assess vulnerability for several species-at-risk on military lands.

The NatureServe Climate Change Vulnerability Index was created to address the need of land managers to quickly assess species vulnerability to provide information needed for wildlife management plans (Young et al. 2010). The Index incorporates key factors thought to influence species susceptibility to climate change, including indirect exposure to climate change, species-specific factors, and documented response to climate change. According to the NatureServe Guidelines (Young et al. 2010), some of the key characteristics of the Index are that:

1. The Index is programmed in a Microsoft Excel workbook.
2. It uses climate predictions provided by The Nature Conservancy's "Climate Wizard" (2009).
3. It requires knowledge about the distribution and life history of the focal species.

* www.natureserve.org

4. It predicts whether a species will decline, remain stable, or increase in numbers by the year 2050 within the assessment area.
5. It identifies key factors associated with the vulnerability of the focal species.

Note that the NatureServe Climate Change Vulnerability Index and associated guidelines for use are both available through the NatureServe website (www.natureserve.org).

1.2 Objectives

The primary objectives of this work were to:

1. Apply the NatureServe Climate Change Vulnerability Index to three SAR on military installations
2. Evaluate the NatureServe Index as a tool for military land managers
3. Provide instruction on using the Index for focal species on military lands
4. Identify needed research areas for species of conservation concern.

1.3 Approach

This work applied the NatureServe Climate Change Vulnerability Index to three species that, according to Army Species at Risk Policy, are considered high priority species for the Army and would have "significant impact on military readiness if Federally listed as threatened or endangered." These species are: the Mohave ground squirrel (*Spermophilus mohavensis*) on Fort Irwin, CA; the Columbia Basin distinct population segment of greater sage-grouse (*Centrocercus urophasianus*) on the Yakima Training Center, WA; and the gopher tortoise (*Gopherus polyphemis*) on Fort Stewart, GA.

1.4 Scope

This work used only data readily available for these species through the NatureServe Explorer website, primary literature, or government websites (e.g., USFWS 2011). Natural resources personnel at the installations were not contacted for further information; data were purposely limited to sources that would be readily available to any interested party. Many of the variables required by the Index can be either be visually estimated using figures provided by NatureServe or calculated using georeferenced data in a Geographic Information System (GIS). All three case studies used GIS (ESRI ArcMap 9.3), when the data were available, to improve accuracy. Appendix A to this report includes a detailed listing of factors included in analyses and justification for input data.

1.5 Mode of technology transfer

This and other related reports are being transmitted to military, land, and wildlife managers at Fort Hood, TX; The Army Environmental Command (AEC); and the Department of the Army for use in ESA and National Environmental Policy Act (NEPA) compliance efforts. This report will also be made accessible through the World Wide Web (WWW) at URL: http://www.cecer.army.mil

2 Results

The NatureServe Climate Change Vulnerability Index predicts that the Mohave ground squirrel population on Fort Irwin is stable and not vulnerable to climate change (Table 1). Fort Irwin is predicted to experience slightly warmer temperatures (approximately 4.89 °F) and only slightly less precipitation (−0.01% change) by the year 2050. The variables that indicated a greater risk for the species were climate change mitigation (due to wind/solar energy facilities on Fort Irwin), historical hydrological niche (but see comments below and in discussion), and physiological hydrological niche. All other variables indicated a neutral risk except for diet, which, due to the omnivorous diet of the ground squirrel, indicated a decreased risk (Table 1).

The greater sage-grouse population on the Yakima Training Center was predicted to be moderately vulnerable to climate change with abundance or range likely to decrease by 2050. Yakima training center was predicted to experience slightly warmer temperatures (4.11 °F) and drier conditions (−0.03 to −0.05% change) by the year 2050. Variables that contributed to greater sage-grouse vulnerability include anthropogenic barriers, climate change mitigation measures, historical hydrological niche, physiological hydrological niche, sensitivity to disturbance, dependence on other species for habitat, diet, and genetic variability (Table 1). Variables that decreased greater-sage grouse vulnerability were dispersal/movement capabilities and physical habitat (Table 1).

Finally, the gopher tortoise population on Fort Stewart was also predicted to be moderately vulnerable to climate change. Fort Stewart is predicted to experience slightly warmer (approximately 4.00 °F) and moderately drier (−0.06 to −0.07% change) conditions by 2050. Variables that contributed to gopher tortoise vulnerability include anthropogenic barriers, historical thermal niche, historical hydrological niche, and sensitivity to disturbance (Table 1).

For both the greater sage-grouse and gopher tortoise, the historical hydrological niche variable heavily influenced the outcome of the Index. Because military installations encompass a relatively small land area, the variability in hydrology across the installations was low, indicating high vulnerability to climate change.

Table 1. Factors contributing to species' vulnerability to climate change for three species at risk on military lands.

Species	Geographic Area	Anthropogenic Barriers	CC Mitigation	Dispersal/Movement	Historical thermal Niche	Historical hydrological Niche	Physiological Hydrological Niche	Disturbance	Phys habitat	Other spp for Habitat	Diet	Genetic variation	Index Score
Spermophilus mohavensis	Fort Irwin, CA	N	Inc	N	N	GI	SI	N	N	N	SD	U	PS
Centrocercus urophasianus	Yakima Training Center, WA	SI-N	SI	Dec	N	Inc	SI-N	Inc	SD	Inc-SI	SI	Inc	MV
Gopherus polyphemis	Fort Stewart, GA	Inc	N	N	SI	Inc	N	SI-N	N	N	N	U	MV

* Source: NatureServe Climate Change Vulnerability Index (www.natureserve.org).

** Factors that were considered neutral for all species were not included in table. For all vulnerability factors, Dec = decrease, SD = somewhat decrease, N = neutral, SI = somewhat increase, GI = greatly increase. Abbreviations for index score are PS = presumed stable, and MV = moderately vulnerable.

If variability across the entire range of the species was included, which may be a more realistic scenario, the vulnerability was decreased. For example, according to the moisture variation map provided by NatureServe, the moisture variation experienced by the Columbia Basin subpopulation of the greater sage-grouse is very large (approximately 1868 mm) across its entire range, indicating decreased vulnerability. Across the Yakima Training Center only, moisture variation is much lower (129 mm), indicating increased vulnerability. Although the instructions for this section specify the variation experienced only at level of the assessment area, we believe inclusion of the entire range is justified since this is a contiguous population and dispersal between military and non-military lands could be high. However, changing the input for this section causes a drastic change in results of the analysis with the population considered not vulnerable/presumed stable using range wide variation and moderately vulnerable using variation across the Yakima Training Center.

3 Assessment of the NatureServe Climate Change Vulnerability Index

The NatureServe Climate Change Vulnerability Index was successfully applied to three species at risk that reside on military lands. The Index was found to be relatively easy to apply. It included well-written, detailed guidelines and a user-friendly Microsoft Excel workbook format. Much of the data needed for all three test case species were available through NatureServe Explorer, including species range, temperature and precipitation maps. All other data were easily accessible either through standard primarily literature searches or by following links provided in the NatureServe Guidelines. (However, modeled future response to climate change was lacking for all three test species.)

A benefit of the Index was the option to calculate many of the input variables using spatially explicit GIS data. This allowed a more quantitative analysis of variables within the assessment area using historic and predicted climate variables. The Index also allowed the use of GIS maps to visually estimate anthropogenic barriers (e.g., urban development surrounding the assessment areas) and natural barriers (e.g., lakes, mountain ranges, etc).

One of the primary goals of this work was to use the Index to elucidate needed research areas for species of conservation concern. Even considering concerns with the validity of the Index for military installations (see below), this was found to be the most valuable use of the Index. Many species, such as the Desert Cymopterus (*Cymopterus deserticola*), would require more general natural history data (e.g., information on pollination) to be able to conduct a vulnerability assessment. For other species, key information may not be available. For the Mohave ground squirrel, for example, information on genetic variability was lacking. Although this deficiency may not prohibit an assessment, such information would be valuable for conservation and management.

General areas of potentially valuable research were also identified such as more comprehensive mapping of species ranges, importance of underground burrows and retreat sites for animal thermoregulation in a changing climate, and species' behavioral or physiological flexibility in reaction to phenological changes.

A primary concern relates to the Index's sensitivity to the size of assessment area. Although Index guidelines (Young et al. 2010) suggest that an area as small as a wildlife refuge would be suitable size for assessment, these results from military installations indicate that a larger assessment area may be needed. This concern was particularly evident with the historical hydrological niche variable, which attempts to measure the species' exposure to past variations in precipitation. The guidelines instruct the user to overlay the species' range map on an annual precipitation map and then to subtract the lowest pixel value from the highest pixel value within the assessment area. At such a small spatial scale, climatic variation across the assessment area is very low, which leads to a classification of high vulnerability for the species. However, variability across the broader range of the species is often much higher and likely reflects the true climatic variation that a species has historically experienced. In addition, range maps often include many areas that are not actually occupied (e.g., unoccupied elevational gradients), but that may vary greatly in precipitation.

A similar concern is that the Index outcome was heavily influenced by one or two variables. For example, the results of two of the three species included as case studies varied drastically depending on input for the historical hydrological niche variable. For both the greater sage-grouse and gopher tortoise, a change in input for historical hydrological niche resulted predictions of either "not vulnerable/stable" or "moderately vulnerable" to climate change. These two outcomes could result in very different management suggestions.

Finally, the predicted climate data rely on climatic averages across an area and does not take into account predicted increase in stochastic events (Katz and Brown 1992). For example, the gopher tortoise is highly vulnerable to drought with little to no reproduction in drought years (Harris and Leitner 2004, Delaney 2011). Although Fort Irwin is not predicted to experience drastic changes in temperature or precipitation, it is possible that several years of drought could extirpate the relatively small population present on the installation (D. Delany, pers. comm.). Although this concern is partly addressed with the disturbance regime variable, more emphasis could be placed on the impacts of stochastic events.

4 Conclusions and Recommendations

4.1 Conclusions

This work successfully applied the NatureServe Climate Change Vulnerability Index to three species, categorized as Species at Risk, which reside on military lands. The NatureServe Climate Change Vulnerability Index predicted that:

1. The Mohave ground squirrel population on Fort Irwin is stable and not vulnerable to climate change.
2. The greater sage-grouse population on the Yakima Training Center is moderately vulnerable to climate change with abundance or range likely to decrease by 2050.
3. The gopher tortoise population on Fort Stewart is moderately vulnerable to climate change.

As a tool for military land managers, the NatureServe Index was found to be relatively easy to apply. It includes well-written, detailed guidelines and a user-friendly Microsoft Excel workbook format. Much of the data needed for the test case species were available through NatureServe Explorer, through standard primarily literature searches, or through links provided in the NatureServe Guidelines.

Some benefits of using the Index with focal species on military lands are that:

1. It includes the option to calculate many of the input variables using spatially explicit GIS data, which allows a more quantitative analysis of variables within the assessment area using historic and predicted climate variables.
2. It allows the use of GIS maps to visually estimate anthropogenic barriers (e.g., urban development surrounding the assessment areas) and natural barriers (e.g., lakes, mountain ranges, etc).

Finally, the Index revealed several areas of potentially valuable research:

1. More comprehensive mapping of species ranges
2. Qualifying the importance of under-ground burrows and retreat sites for animal thermoregulation in a changing climate
3. Identifying species' behavioral or physiological flexibility in reaction to phenological changes.

4.2 Recommendations

This work recommends the use of the NatureServe Climate Change Vulnerability Index in its more common usage, with a suite of species assessed within a single assessment area. This method could offer a relative ranking of species' vulnerability and so provide a possible priority list for land managers. As the Index guidelines suggest, a listing of species vulnerability combined with species' conservation status (e.g., population size, range size, etc), could assist land managers in focusing their efforts on species that are at the most risk.

However, land managers are cautioned to take the concerns (delineated in Chapter 3) into account when applying the Index. For example, it would be advantageous to determine if one or two variables are driving the outcome, and to ensure that those inputs are correct and/or make biological sense for the focal species.

Acronyms and Abbreviations

Term	Spellout
AEC	Army Environmental Command
AET	actual evapotranspiration
AGU	American Geophysical Union
CC	climate change
CERL	Construction Engineering Research Laboratory
ESA	US Endangered Species Act
ESRI	Environmental Systems Research Institute, Inc.
GI	greatly increase
GIS	geographic information system
MV	moderately vulnerable.
NEPA	National Environmental Policy Act
PET	potential evapotranspiration
PS	presumed stable
SAR	Species at Risk
SD	somewhat decrease
SI	somewhat increase
TES	threatened and endangered species
TR	Technical Report
URL	Universal Resource Locator
US	United States
USDA	US Department of Agriculture
USEPA	US Environmental Protection Agency
USFWS	US Fish and Wildlife Service
WDFW	Washington Department of Fish and Wildlife
WWW	World Wide Web
YTC	Yakima Training Center

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Appendix A: Factors Included in the "NatureServe Climate Change Vulnerability Index"

This Appendix includes the list of factors included in NatureServe Climate Change Vulnerability Index (http://www.natureserve.org/climatechange), entered value for each factor, and justification for value. Language used to describe factors was taken directly from Guidelines for Using the NatureServe Climate Change Vulnerability Index (Young et al. 2010). Climate Wizard data provided were taken from: www.climatewizard.org. Note that all referenced figures are located at the end of this appendix.

I. Mohave Ground Squirrel (*Spermophilus mohavensis*) on Fort Irwin, CA

II. Exposure to Local Climate Change
   a. Temperature: Percent of species range, within Fort Irwin, which falls within provided categories of expected future climate change.
      i. Entered Value: 100% of range fell in area expected to be 4.5 to 5.0 °F warmer in 2050.
         1. According to Climate Wizard data, species range will be approximately 4.89 °F warmer (Figure A1).
   b. Hamon AET:PET* Moisture Metric: Percent of species range, within Fort Irwin, which falls within provided categories of expected future climate change.
      i. Entered Value: 100% of range fell in area expected to be > -0.028 change in precipitation by 2050.
         1. According to the Hamon AET:PET Moisture Map provided by NatureServe, species range will fall within the -0.01 metric, which indicates a slightly drier climate (Figure A2).

III. Indirect Exposure to Climate Change
   a. (B1) Exposure to sea level rise: Percent of species range subject to expected sea level rise.
      i. Entered Value: Neutral = <10% of species range occurs in area subject to sea level rise

* AET:PET (actual evapotranspiration : potential evapotranspiration)

ii. Justification: Interactive map on Department of Geosciences at University of Arizona website. Link to map provided by NatureServe Guidelines.

b. (B2) Distribution relative to barriers
   i. (A) Natural Barriers (e.g., lakes, mountain ranges)
      1. Entered Value: Neutral = Significant barriers do not exist.
         a. Justification: No significant natural barriers were detected using digital orthoimagery and aerial photos of Fort Irwin.
   ii. (B) Anthropogenic barriers (e.g., areas of development, fencing, roads)
      1. Entered Value: Neutral = Significant barriers do not exist.
         a. Justification: No significant anthropogenic barriers were detected using a map of roads/fragmentation (Silvis Wild-Urban Interface; Figure A3) or digital orthoimagery of Fort Irwin. Significant urban development exists south of the section of the species range that occurs off the military installation (Figure A3), but there is relatively little development directly around Fort Irwin.

c. (B3) Predicted impact of land use changes resulting from human responses to climate change (e.g., wind-farms, solar arrays, biofuels production).
   i. Entered Value: Increased vulnerability = the natural history/requirements of the species are known to be incompatible with mitigation-related land use changes that our likely to very likely to occur with its current and/or potential future range.
      1. Fort Irwin has been increasing and will continue to increase capabilities for both wind and solar power generation on site. Disturbance and habitat loss associated with these forms of alternative energy has been implicated as a conservation concern for the ground squirrel.

IV. Sensitivity to Climate Change

a. (C1) Dispersal and Movements: Known or predicted dispersal or movement capacities and characteristics and ability to shift location in the absence of barriers as conditions change over time as a result of climate change.
   i. Entered Value: Neutral = species is characterized by moderate dispersal or movement capability. A significant percentage of individuals disperse approximately 100 – 1000m per dispersal event (rarely further).

1. Justification: According to NatureServe Explorer, “Harris and Leitner (2004) found that radio-tagged adult male Mohave ground squirrels in the western Mojave Desert of California made extensive movements during the mating season (mid-February to mid-March). ... Males made long movements (up to at least 1.5 km) during the mating season. The maximum straight-line distance moved within days for males during the mating season (median 391 m, range 274-1491 m) was greater than for the postmating season, (median 130 m, range 46-427 m). Maximum within-day movements by females during the mating season (median 138 m, range 96-213 m) did not differ significantly from postmating movements (median 205 m, range 24-371 m). Furthermore, Harris and Leitner (2005) documented long-distance movements by juveniles (commonly more than 1 kilometer, up to 3.9 kilometers in females and 6.3 kilometers in males.”

b. (C2) Predicted Sensitivity to Temperature and Moisture Changes: Breadth of temperature and moisture conditions, at both broad and local scales, within which a species is known to be capable of reproducing, feeding, growing, or otherwise existing. Species with narrow environment tolerances/requirements may be more vulnerable to habitat loss from climate change than are species that thrive under diverse conditions.
   i. (a) Predicted sensitivity to changes in temperature, based on current/recent past temperature tolerance
      1. (i) Historical thermal niche (exposure to past variations in temperature): Large scale temperature variation that a species has experienced in recent historical timeframes (i.e., the past 50 years), as approximated by mean seasonal temperature variation (difference between highest mean monthly maximum temperature and lowest mean monthly minimum temperature) for occupied cells within the assessment area.
         a. Entered Value: Neutral = the species has experienced average (57.1 to 77 °F) temperature variation in the past 50 years.
         b. Justification: According to the temperature variation map provided by NatureServe, the temperature variation experienced by this species is approximately 67 °F (see Figure A4).
      2. (ii) Physiological thermal niche: The degree to which a species is restricted to relatively cool or cold above-ground ter-

restrial or aquatic environments that are thought to be vulnerable to loss or significant reduction as a result of climate change.

a. Entered Value: Neutral = species distribution is not significantly affected by thermal characteristics of the environment in the assessment area.

   i. Justification: Mohave ground squirrels are not “restricted to relatively cool or cold environments” as required by the other categories. I was concerned that their use of burrows in the summer would constitute use of cool environments, although the introduction to this section specifically requires these habitats to be above-ground environments.

ii. (b) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime.

1. (i) Historical hydrological niche (exposure to past variations in precipitation): Large-scale precipitation variation that a species has experienced in recent historical times (i.e., the past 50 years), as approximated by mean annual precipitation variation across occupied cells within the assessment area.

   a. Entered Value: Neutral OR Greatly Increase Vulnerability = considering the range of mean annual precipitation across the range of the population, the species has experienced average (509 to 1016 mm) precipitation variation in the past 50 years, indicating neutral vulnerability (Figure A5). However, the variation experienced only within Fort Irwin is very small (< 100 mm), indicating a greatly increased vulnerability (Figure A5).

   b. Justification: According to the moisture variation map provided by NatureServe, the moisture variation experienced by this species is average (approximately 611 mm) across its entire range (see Figure A6). However, the instructions for this section specify inclusion of the variation experienced only at level of the assessment area. On Fort Irwin, the variation is approximately 73 mm, indicating greatly increased vulnerability. The results of the analyses are the same whether or not I input data for the entire range of the species or only for Fort Irwin.

2. (ii) Physiological hydrological niche: A species dependence on a narrowly defined precipitation/hydrological regime, in-

cluding strongly seasonal precipitation patterns and/or specific aquatic/wetland habitats.

a. Entered Value: Somewhat increase vulnerability = somewhat (10 – 50%) dependent on a strongly seasonal hydrologic regime or localized moisture regime that is highly vulnerable to loss or reduction with climate change and the expected direction of moisture change (drier or wetter) is likely to reduce the species' distribution.

i. Justification: Ground squirrel reproduction dependent on early winter precipitation and precipitation expected to decrease with climate change. According to NatureServe Explorer, "no reproduction occurs during the driest years; for example, Harris and Leitner (2004) found that no reproduction occurred at their study site when early winter precipitation (October-January) was less than 30 mm."

iii. (c) Dependence on a specific disturbance regime likely to be impacted by climate change: Species response to specific disturbance regimes such as fires, floods, severe winds, pathogen outbreaks, or similar events.

1. Entered Value: Neutral = little or no response to a specific disturbance regime or climate change is unlikely to change the frequency, severity, or extant of that disturbance regime in a way that affects the range or abundance of the species.

a. Justification: I could not find any evidence that Mohave Ground Squirrels show negative response to specific disturbance regimes.

iv. (d) Dependence on ice, ice-edge, or snow cover habitats

1. Entered Value: Neutral = little dependence on ice- or snow-associated habitats.

c. (C3) Restriction to uncommon geological features or derivatives: Species' need for a particular soil/substrate, geology, water chemistry, or specific physical feature (e.g., caves, cliffs, active sand dunes) for reproduction, feeding, growth, or otherwise existing for one or more portions of the life cycle.

i. Entered Value: Neutral = having clear preference for (> 85% of occurrences found on) a certain geological feature or derivative, where the feature is among the dominant types within the species range. ... Many species whose habitat descriptions specify one pH category and/or one soil particle size (e.g., rocky, sandy, or loamy) will probably fall here, upon confirmation that the substrate type is not particularly uncommon within the species range.

ii. Justification: Species found in areas with sandy soil or sand mixed with gravel (Best 1995). This soil type does not seem to be particularly uncommon within the species range.

d. (C4) Reliance on interspecific interactions

i. (a) Dependence on other species to generate habitat
1. Entered Value: Neutral = required habitat generated by more than a few species or does not involve species-specific processes.
2. Justification: According to NatureServe Explorer, Mohave ground squirrels are associated with a variety of habitats including creosotebush association, shadscale association, alkali sink association, and Joshua tree association.

ii. (b) Dietary versatility: Diversity of food types consumed by the animal species
1. Entered Value: Somewhat decrease = omnivorous diet including numerous species of both plants and animals.
2. Justification: Mohave ground squirrel's diet consists of forbs, seeds, and invertebrates of many species (Best 1995).

iii. (d) Dependence on other species for propagule dispersal
1. Entered Value: Neutral = Disperses on its own (most animals).

iv. (e) Forms part of an interspecific interaction not covered by C4a-d.
1. Entered Value: Neutral = Does not require an interspecific interaction or, if it does, many potential candidate partners are available.

e. (C5) Genetic Factors

i. (a) Measured genetic variation
1. Entered Value: Unknown = I could not find data on the genetic variation of Mohave ground squirrels in comparison to related taxa.

ii. (b) Occurrence of bottlenecks in recent evolutionary history
1. Entered Value: Unknown = I could not find any previous studies that examined recent bottlenecks.

f. (C6) Phenological response to changing seasonal temperature or precipitation dynamics

i. Entered Variable: Unknown = I could not find any previous studies that have examined changing phenology in the ground squirrel.

V. Documented or Modeled Response to Climate Change
   a. (D1) Documented response to recent climate change
      i. Entered Value: Unknown = I could not find any documentation regarding species response to climate change.
   b. (D2) Modeled future (2050) change in range or population size
      i. Entered Value: Unknown = I could not find any documentation regarding species response to climate change.
   c. (D3) Overlap of modeled future (2050) range with current range
      i. Entered Value: Unknown = I could not find any documentation regarding species response to climate change.
   d. (D4) Occurrence of protected areas in modeled future (2050) distribution
      i. Entered Value: Unknown = I could not find any documentation regarding species response to climate change.

VI. Results: The NatureServe Climate Change Vulnerability Index predicts that the Mohave ground squirrel is **not vulnerable/presumed stable**. According to the index, "the available evidence does not suggest that abundance and/or range extent within the geographical area assessed (Fort Irwin) will change (increase/decrease) substantially by 2050. Actual range boundaries may change." The confidence in the assessment is very high with all iterations of the Monte Carlo simulation indicating a stable population.

VII. Greater Sage-grouse (*Centrocercus urophasianus*) on Yakima Training Center, WA

VIII. Exposure to Local Climate Change
   a. Temperature: Percent of species range, within Yakima Training Center, which falls within provided categories of expected future climate change.
      i. Entered Value: 100% of range fell in area expected to be 3.9 to 4.4 °F warmer in 2050.
         1. According to Climate Wizard data, species range will be approximately 4.11 °warmer (Figure A6).
   b. Hamon AET:PET Moisture Metric: Percent of species range, within Fort Irwin, which falls within provided categories of expected future climate change.
      i. Entered Value: 100% of range fell in area expected to be -0.028—0.050 change in precipitation by 2050.
         1. According to the Hamon AET:PET Moisture Map provided by NatureServe, species range will fall within the -0.05 to -0.03 metric, which indicates a slightly drier climate (Figure A7).

IX. Indirect Exposure to Climate Change

a. (BI) Exposure to sea level rise: Percent of species range subject to expected sea level rise.

i. Entered Value: Neutral = <10% of species range occurs in area subject to sea level rise

ii. Justification: Interactive map on Department of Geosciences at University of Arizona website. Link to map provided by NatureServe.

b. (B2) Distribution relative to barriers

i. (A) Natural Barriers (e.g., lakes, mountain ranges)

1. Entered Value: Neutral = Significant barriers do not exist.

a. Justification: No significant natural barriers were detected using digital orthoimagery of Fort Irwin (see Figure A8)

ii. (B) Anthropogenic barriers (e.g., areas of development, fencing, roads)

1. Entered Value: Somewhat Increase Vulnerability/Neutral = barriers border the current distribution such that climate change-caused distributional shifts in the assessment area are likely to be significantly but not greatly or completely impaired/Significant barriers do not exist.

a. Justification: There is extensive habitat fragmentation and urban development surrounding the Yakima Training Center. However, this species has extensive dispersal capabilities that may decrease the risk.

c. (B3) Predicted impact of land use changes resulting from human responses to climate change (e.g., wind-farms, solar arrays, biofuels production).

i. Entered Value: Somewhat Increased vulnerability = the natural history/requirements of the species are known to be incompatible with mitigation-related land use changes that may possibly occur with its current and/or potential future range.

1. Wind power development is taking place near the Yakima Training Center and the installation has been suggested as a possible area for wind farms. Wind farms were discussed as an issue of conservation concern for the species in the Washington Fish and Wildlife Species Recovery Plan (Stinson, Hays, and Schroede 2004).

X. Sensitivity to Climate Change

a. (C1) Dispersal and Movements: Known or predicted dispersal or movement capacities and characteristics and ability to shift location in the absence of barriers as conditions change over time as a result of climate change.

i. Entered Value: Decreased Vulnerability= species is characterized by excellent dispersal or movement capability. Species has propagules or dispersing individuals that readily move more than 10 km from natal or source areas.
ii. Justification: According to NatureServe Explorer, "populations can be defined by their migration habit. Populations are either non-migratory, or undertake a 1-stage migration or two-stage migration. One-stage migrants move between distinct summer and winter ranges, often 15–48 km apart. Two-stage migrants move between breeding habitat, summer range, and winter range, and their annual movements can exceed 80 to 100 km (Connelly 1999)."

b. (C2) Predicted Sensitivity to Temperature and Moisture Changes: Breadth of temperature and moisture conditions, at both broad and local scales, within which a species is known to be capable of reproducing, feeding, growing, or otherwise existing. Species with narrow environment tolerances/requirements may be more vulnerable to habitat loss from climate change than are species that thrive under diverse conditions.
   i. (a) Predicted sensitivity to changes in temperature, based on current/recent past temperature tolerance
      1. (i) Historical thermal niche (exposure to past variations in temperature): Large scale temperature variation that a species has experienced in recent historical timeframes (i.e., the past 50 years), as approximated by mean seasonal temperature variation (difference between highest mean monthly maximum temperature and lowest mean monthly minimum temperature) for occupied cells within the assessment area.
         a. Entered Value: Neutral = the species has experienced average (57.1 to 77 °F) temperature variation in the past 50 years.
         b. Justification: According to the temperature variation map provided by NatureServe, the temperature variation experienced by this species is approximately 62 °F (see Figure A9).
      2. (ii) Physiological thermal niche: The degree to which a species is restricted to relatively cool or cold above-ground terrestrial or aquatic environments that are thought to be vul-

nerable to loss or significant reduction as a result of climate change.

a. Entered Value: Neutral = species distribution is not significantly affected by thermal characteristics of the environment in the assessment area.
b. Justification: Sage-grouse are not “restricted to relatively cool or cold environments” as required by the other categories.

ii. (b) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime.

1. (i) Historical hydrological niche (exposure to past variations in precipitation): Large-scale precipitation variation that a species has experienced in recent historical times (i.e., the past 50 years), as approximated by mean annual precipitation variation across occupied cells within the assessment area.
    a. Entered Value: Somewhat Decrease Vulnerability OR Increase vulnerability= considering the range of mean annual precipitation across the range of the population, the species has experienced very large (< 1016 mm) precipitation variation in the past 50 years, indicating decreased vulnerability. However, the variation experienced only within the Yakima Training Center is small (100 – 254 mm), indicating an increased vulnerability.
        i. Justification: According to the moisture variation map provided by NatureServe, the moisture variation experienced by this species is very large (approximately 1868 mm) across its entire range (see Figure A10), indicating decreased vulnerability. On the Yakima Training Center only, moisture variation is much lower (129 mm), indicating increased vulnerability. Although the instructions for this section specify the variation experienced only at level of the assessment area, I believe inclusion of the entire range is justified since this is a contiguous population and dispersal between military and non-military lands could be high. However, changing the input for this section causes a drastic change in results of the analysis with the population considered “Not Vulnerable/Presumed Stable” with a “Somewhat Decreased Vulnerability” input and

"Moderately Vulnerable" with an "Increase Vulnerability" input.

2. (ii) Physiological hydrological niche: A species dependence on a narrowly defined precipitation/hydrological regime, including strongly seasonal precipitation patterns and/or specific aquatic/wetland habitats.
   a. Entered Value: Neutral/Somewhat Increased Vulnerability= Species has little or no dependence on a strongly seasonal hydrologic regime and/or specific aquatic/wetland habitat/ somewhat (10 – 50%) dependent on a strongly seasonal hydrologic regime or localized moisture regime that is highly vulnerable to loss or reduction with climate change and the expected direction of moisture change (drier or wetter) is likely to reduce the species' distribution.
   b. Justification: There is some evidence that reproduction may be affected by winter/spring precipitation (Gill 1966, Peterson 1970), although adult survival does not appear to be affected (Zablan et al. 2003).

iii. (c) Dependence on a specific disturbance regime likely to be impacted by climate change: Species response to specific disturbance regimes such as fires, floods, severe winds, pathogen outbreaks, or similar events.

1. Entered Value: Increased Vulnerability = strongly affected by specific disturbance regime, and climate change is likely to change the frequency, severity, or extent of that disturbance regime in a way that reduces the species' distribution, abundance, or habitat quality. For example, many sagebrush-associated species in regions predicted to experience increased fire frequency/intensity would be scored here due to the anticipated deleterious effects of increased fire on their habitat.
   a. Justification: Fire has been shown to negatively affect populations (Connelly et al. 2000) and climate change is predicted to increase fire frequency within the assessment area (Krawchuk et al. 2009).

iv. (d) Dependence on ice, ice-edge, or snow cover habitats

1. Entered Value: Neutral = little dependence on ice- or snow-associated habitats. Sage grouse prefer areas with low snow accumulation.

c. (C3) Restriction to uncommon geological features or derivatives: Species' need for a particular soil/substrate, geology, water chemistry, or specific physical feature (e.g., caves, cliffs, active sand dunes) for reproduction, feeding, growth, or otherwise existing for one or more portions of the life cycle.
   i. Entered Value: Somewhat Decreased Vulnerability= somewhat flexible, but not highly generalized in dependence on geological features or derivatives. ... [T]his category also encompasses species not strongly tied to any specific geological feature or derivative, such as many birds and mammals.
   ii. Justification: Sage-grouse not strongly tied to any specific geological feature.
d. (C4) Reliance on interspecific interactions
   i. (a) Dependence on other species to generate habitat
      1. Entered Value: Somewhat increase/increased vulnerability = Required habitat generated primarily by one or more of not more than a few species/required habitat generated primarily by one species, and that species is at most moderately vulnerable to climate change within the assessment area.
      2. Justification: The required habitat of sage-grouse is generated by no more than a few species (several species of sagebrush), but primarily by big sagebrush (*A. tridentata*) at YTC. The response of sagebrush to climate change is not clear. Perfors et al. (2003) expect an increase in sagebrush with climate change, but Poore et al. (2009) predicts a decrease.
   ii. (b) Dietary versatility: Diversity of food types consumed by the animal species
      1. Entered Value: Somewhat increase vulnerability = completely or almost completely (>90%) dependent during any part of the year on a few species from a single guild that may respond similarly to climate change.
      2. Justification: Sage-grouse feed exclusively on sagebrush during the winter. The number of sagebrush species eaten depends on availability in the area.
   iii. (d) Dependence on other species for propagule dispersal
      1. Entered Value: Neutral = Disperses on its own (most animals).
   iv. (e) Forms part of an interspecific interaction not covered by C4a-d.

1. Entered Value: Neutral = Does not require an interspecific interaction or, if it does, many potential candidate partners are available.

e. (C5) Genetic Factors

i. (a) Measured genetic variation

1. Entered Value: Increased Vulnerability = genetic variation reported as "very low" compared to findings using similar techniques on related taxa.
2. Justification: Variation is low in the Columbia Basin population (Oyler-McCance, Taylor, and Quinn 2005) and low diversity was mentioned as a conservation concern in the Washington Department of Fish and Wildlife Sage Grouse Recovery Plan.

f. (C6) Phenological response to changing seasonal temperature or precipitation dynamics

i. Entered Variable: Unknown = I could not find any previous studies that have examined changing phenology in the sage-grouse.

XI. Documented or Modeled Response to Climate Change

a. (D1) Documented response to recent climate change

i. Entered Value: Unknown = I could not find any documentation regarding species response to climate change.

b. (D2) Modeled future (2050) change in range or population size

i. Entered Value: Unknown = I could not find any documentation regarding species response to climate change.

c. (D3) Overlap of modeled future (2050) range with current range

i. Entered Value: Unknown = I could not find any documentation regarding species response to climate change.

d. (D4) Occurrence of protected areas in modeled future (2050) distribution

i. Entered Value: Unknown = I could not find any documentation regarding species response to climate change.

XII. Results: The NatureServe Vulnerability Index predicts that Greater Sage-grouse are "Moderately Vulnerable" with "abundance and/or range extent within geographical area assessed likely to decrease by 2050." However, as noted above, if I categorize historical hydrological niche as "somewhat decreased vulnerability" based on the range of the entire Columbia basin population, the Index predicts that Greater Sage-grouse are "Not Vulnerable/Presumed Stable."

XIII. <u>Gopher Tortoise (*Gopherus polyphemis*) on Fort Stewart, GA</u>

XIV. [Note: I could not find a range map for this species that was compatible with ArcGis. However, Fort Stewart falls entirely within the range of gopher tortoise (Figure A11) and so the boundaries of the installation were used in all analyses.]

XV. Exposure to Local Climate Change
- a. Temperature: Percent of species range, within Fort Stewart, which falls within provided categories of expected future climate change.
  - i. Entered Value: 100% of range fell in area expected to be 3.9 to 4.4 °(F) warmer in 2050.
    - 1. According to Climate Wizard data, species range will be approximately 4.00 °F warmer (Figure A12).
- b. Hamon AET:PET Moisture Metric: Percent of species range, within Fort Irwin, which falls within provided categories of expected future climate change.
  - i. Entered Value: 100% of range fell in area expected to be -0.051 t0 -0.073 change in precipitation by 2050.
    - 1. According to the Hamon AET:PET Moisture Map provided by NatureServe, species range will fall within the -0.06 to -0.07 metric, which indicates a slightly drier climate (Figure A13).

XVI. Indirect Exposure to Climate Change
- a. (BI) Exposure to sea level rise: Percent of species range subject to expected sea level rise.
  - i. Entered Value: Neutral = <10% of species range occurs in area subject to sea level rise
  - ii. Justification: Interactive map on Department of Geosciences at University of Arizona website (Figure A14). Link to map provided by NatureServe.
- b. (B2) Distribution relative to barriers
  - i. (A) Natural Barriers (e.g., lakes, mountain ranges)
    - 1. Entered Value: Neutral = Significant barriers do not exist.
      - a. Justification: No significant natural barriers were detected using aerial photos of Fort Stewart.
  - ii. (B) Anthropogenic barriers (e.g., areas of development, fencing, roads)
    - 1. Entered Value: Increase Vulnerability = barriers border the current distribution such that climate change-caused distributional shifts in the assessment area are likely to be greatly but not completely or almost completely impaired. Anthro-

pogenic example: Intensive urbanization surrounds 75% of the range of a salamander species.

2. Justification: There is extensive urban development surrounding Fort Stewart and major highways north and east of the Fort (Figure A15).

c. (B3) Predicted impact of land use changes resulting from human responses to climate change (e.g., wind-farms, solar arrays, biofuels production).

i. Entered Value: Neutral = The species is unlikely to be significantly affected by mitigation-related land use changes that may occur within its current and/or potential future range, including any of the above; OR it is unlikely that any mitigation-related land use change will occur within the species' current and/or potential future range.

1. Like many military installations, Fort Stewart appears to be pursuing alternative energy sources. However, this does not seem to be an imminent threat to the Gopher Tortoise population on the installation.

XVII. Sensitivity to Climate Change

a. (C1) Dispersal and Movements: Known or predicted dispersal or movement capacities and characteristics and ability to shift location in the absence of barriers as conditions change over time as a result of climate change.

i. Entered Value: Neutral= Species is characterized by moderate dispersal or movement capability. A significant percentage (at least 5%) of individuals disperse approximately 100-1000 m per dispersal event ... note that these short-distance migratory animals may exhibit strong fidelity to natal areas, but nevertheless generally include individuals that colonize or move into other nearby areas.

ii. Justification: According to NatureServe Explorer, "in northern Florida, the calculated mean moved distance from and between burrows was 37.0 m (SD = 37.0 m) for adult females and 79.0 m (SD = 69.0 m) for adult males (Diemer 1992b)." However, "using radio-telemetry, Diemer (1992b) found that of her radio-tagged animals the longest movement made was 0.74 km by an emigrating subadult. Juveniles also may make long distance movements, usually following some type of disturbance to the resident burrow (Diemer 1992b, Wilson et al. 1991). Two adult males in Georgia dispersed 1.2 km and 1.5 km (straight-line distance to final known location) (Eubanks et al. 2003)."

b. (C2) Predicted Sensitivity to Temperature and Moisture Changes: Breadth of temperature and moisture conditions, at both broad and local scales, within which a species is known to be capable of reproducing, feeding, growing, or otherwise existing. Species with narrow environment tolerances/requirements may be more vulnerable to habitat loss from climate change than are species that thrive under diverse conditions.
   i. (a) Predicted sensitivity to changes in temperature, based on current/recent past temperature tolerance
      1. (i) Historical thermal niche (exposure to past variations in temperature): Large scale temperature variation that a species has experienced in recent historical timeframes (i.e., the past 50 years), as approximated by mean seasonal temperature variation (difference between highest mean monthly maximum temperature and lowest mean monthly minimum temperature) for occupied cells within the assessment area.
         a. Entered Value: Somewhat Increased Vulnerability = the species has experienced slightly lower than average (47.1 to 57 °F) temperature variation in the past 50 years.
         b. Justification: According to the temperature variation map provided by NatureServe, the temperature variation experienced by this species is approximately 54 to 55 °F (see Figure A16).
      2. (ii) Physiological thermal niche: The degree to which a species is restricted to relatively cool or cold above-ground terrestrial or aquatic environments that are thought to be vulnerable to loss or significant reduction as a result of climate change.
         a. Entered Value: Neutral = species distribution is not significantly affected by thermal characteristics of the environment in the assessment area.
         b. Justification: Gopher tortoises are not "restricted to relatively cool or cold environments" as required by the other categories. As with the Mohave ground squirrel, I feel that burrows may be considered a "relatively cool environment," however, the instructions specify "above-ground" habitats.
   ii. (b) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime.
      1. (i) Historical hydrological niche (exposure to past variations in precipitation): Large-scale precipitation variation that a

species has experienced in recent historical times (i.e., the past 50 years), as approximated by mean annual precipitation variation across occupied cells within the assessment area.

a. Entered Value: Somewhat Decrease Vulnerability OR Increase vulnerability= considering the range of mean annual precipitation across the range of the population, the species has experienced very large (< 1016 mm) precipitation variation in the past 50 years, indicating decreased vulnerability. However, the variation experienced only within Fort Stewart is small (100 – 254 mm), indicating an increased vulnerability.
   i. Justification: According to the moisture variation map provided by NatureServe, the moisture variation experienced by this species is very large (approximately 1110 mm) across its entire range (see Figure A17), indicating decreased vulnerability. On Fort Stewart only, moisture variation is much lower (108 mm), indicating increased vulnerability. This variable greatly impacts the results of the analysis with the population considered "Not Vulnerable/Presumed Stable" with a "Somewhat Decreased Vulnerability" input and "Moderately Vulnerable" with an "Increase Vulnerability" input.

2. (ii) Physiological hydrological niche: A species dependence on a narrowly defined precipitation/hydrological regime, including strongly seasonal precipitation patterns and/or specific aquatic/wetland habitats.
   a. Entered Value: Neutral = Species has little or no dependence on a strongly seasonal hydrologic regime and/or specific aquatic/wetland habitat.
   b. Justification: I could not find evidence that Gopher Tortoises are dependent on a specific hydrological regime.

iii. (c) Dependence on a specific disturbance regime likely to be impacted by climate change: Species response to specific disturbance regimes such as fires, floods, severe winds, pathogen outbreaks, or similar events.

1. Entered Value: Neutral = little or no response to a specific disturbance regime or climate change is unlikely to change the frequency, severity, or extent of that disturbance regime in a way that affects the range or abundance of the species.

a. Justification: Although fire has generally been shown to improve habitat for Gopher Tortoise, fire frequency within the assessment area is predicted to exhibit little change or decline (Krawchuk et al. 2009). Possible increase in mortality due to hurricane caused flooding?

iv. (d) Dependence on ice, ice-edge, or snow cover habitats

1. Entered Value: Neutral = little dependence on ice- or snow-associated habitats.

c. (C3) Restriction to uncommon geological features or derivatives: Species' need for a particular soil/substrate, geology, water chemistry, or specific physical feature (e.g., caves, cliffs, active sand dunes) for reproduction, feeding, growth, or otherwise existing for one or more portions of the life cycle.

i. Entered Value: Neutral = having clear preference for (> 85% of occurrences found on) a certain geological feature or derivative, where the feature is among the dominant types within the species range. ... Many species whose habitat descriptions specify one pH category and/or one soil particle size (e.g., rocky, sandy, or loamy) will probably fall here, upon confirmation that the substrate type is not particularly uncommon within the species range.

ii. Justification: Species found in areas with well-drained, sandy soil (NatureServe Explorer). This soil type does not seem to be particularly uncommon within the species range.

d. (C4) Reliance on interspecific interactions

i. (a) Dependence on other species to generate habitat

1. Entered Value: Neutral = required habitat generated by more than a few species or does not involve species-specific processes.
2. Justification: Species found a variety of habitats including sandhill (pine-turkey oak), sand pine scrub, xeric hammock, pine flatwoods, dry prairie, coastal grasslands and dunes, and mixed hardwood-pine communities (Landers and Speake 1980, Auffenberg and Franz 1982, Kushlan and Mazzotti 1984, Diemer 1986, 1992a).

ii. (b) Dietary versatility: Diversity of food types consumed by the animal species

1. Entered Value: Neutral = Diet flexible; not dependent on one or a few species.
2. Justification: Gopher tortoise forage on a wide range of plant species (MacDonald and Mushinksy 1988).

iii. (d) Dependence on other species for propagule dispersal
    1. Entered Value: Neutral = Disperses on its own (most animals).

iv. (e) Forms part of an interspecific interaction not covered by C4a-d.
    1. Entered Value: Neutral = Does not require an interspecific interaction or, if it does, many potential candidate partners are available.

e. (C5) Genetic Factors
  i. (a) Measured genetic variation and (b) Occurrence of bottlenecks in recent evolutionary history.
    1. Entered Value: Unknown
    2. Justification: Studies suggest that the western populations of Gopher Tortoise have low genetic diversity compared to the eastern (which would include Fort Stewart; Ennen et al. 2010) and that several populations have experienced bottlenecks (again, not the Georgia population; Schwartz and Karl 2005). However, I cannot find evidence that the Eastern populations have particularly low genetic diversity compared to related taxa or that they've experienced population bottlenecks.

f. (C6) Phenological response to changing seasonal temperature or precipitation dynamics
  i. Entered Variable: Unknown = I could not find any previous studies that have examined changing phenology in the gopher tortoise.

XVIII. Documented or Modeled Response to Climate Change

a. (D1) Documented response to recent climate change
  i. Entered Value: Unknown = I could not find any documentation regarding species response to climate change.

b. (D2) Modeled future (2050) change in range or population size
  i. Entered Value: Unknown = I could not find any documentation regarding species response to climate change.

c. (D3) Overlap of modeled future (2050) range with current range
  i. Entered Value: Unknown = I could not find any documentation regarding species response to climate change.

d. (D4) Occurrence of protected areas in modeled future (2050) distribution
  i. Entered Value: Unknown = I could not find any documentation regarding species response to climate change.

XIX. Results: The NatureServe Vulnerability Index predicts that the Gopher Tortoise is "**Moderately Vulnerable**" with "abundance and/or range extent within geographical area assessed likely to decrease by 2050." However, as noted above, if I categorize historical hydrological niche as "somewhat decreased vulnerability" based on the range of the entire gopher tortoise population, the Index predicts that gopher tortoise are "**Not Vulnerable/Presumed Stable**."

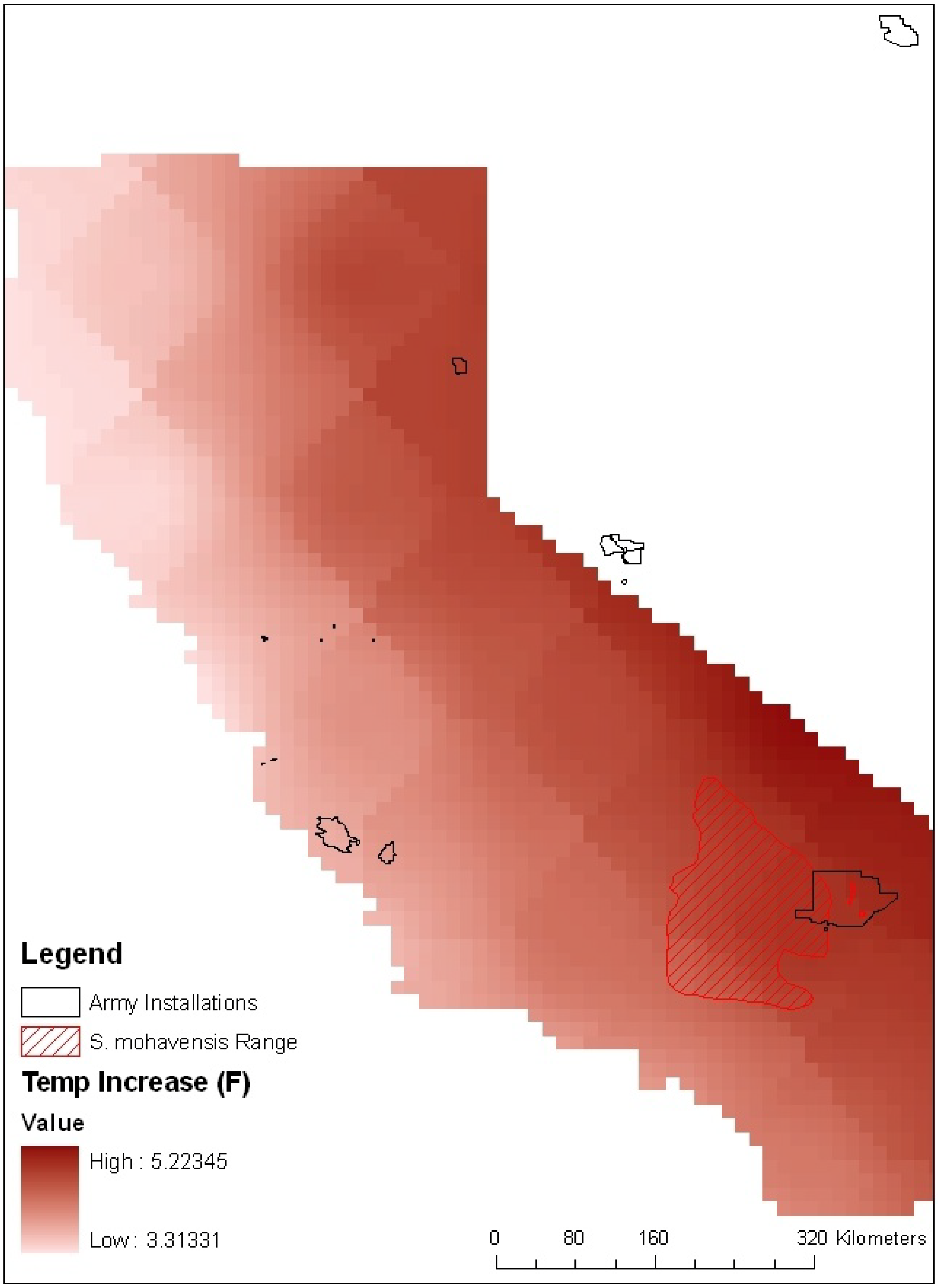

Figure A1. Mohave ground squirrel (*Spermophilus mohavensis*) range distribution in California, in relation to projected future (2050) temperature increase. Temperature data provided by Climate Wizard (www.climatewizard.org; Maurer et al. 2007) given a Medium A1B emission scenario and Ensemble Average Global Circulation Model. Red hatched polygon indicates ground squirrel range distribution and black polygon indicates US Army military installations (Fort Irwin overlaps *S. mohavenis* range).

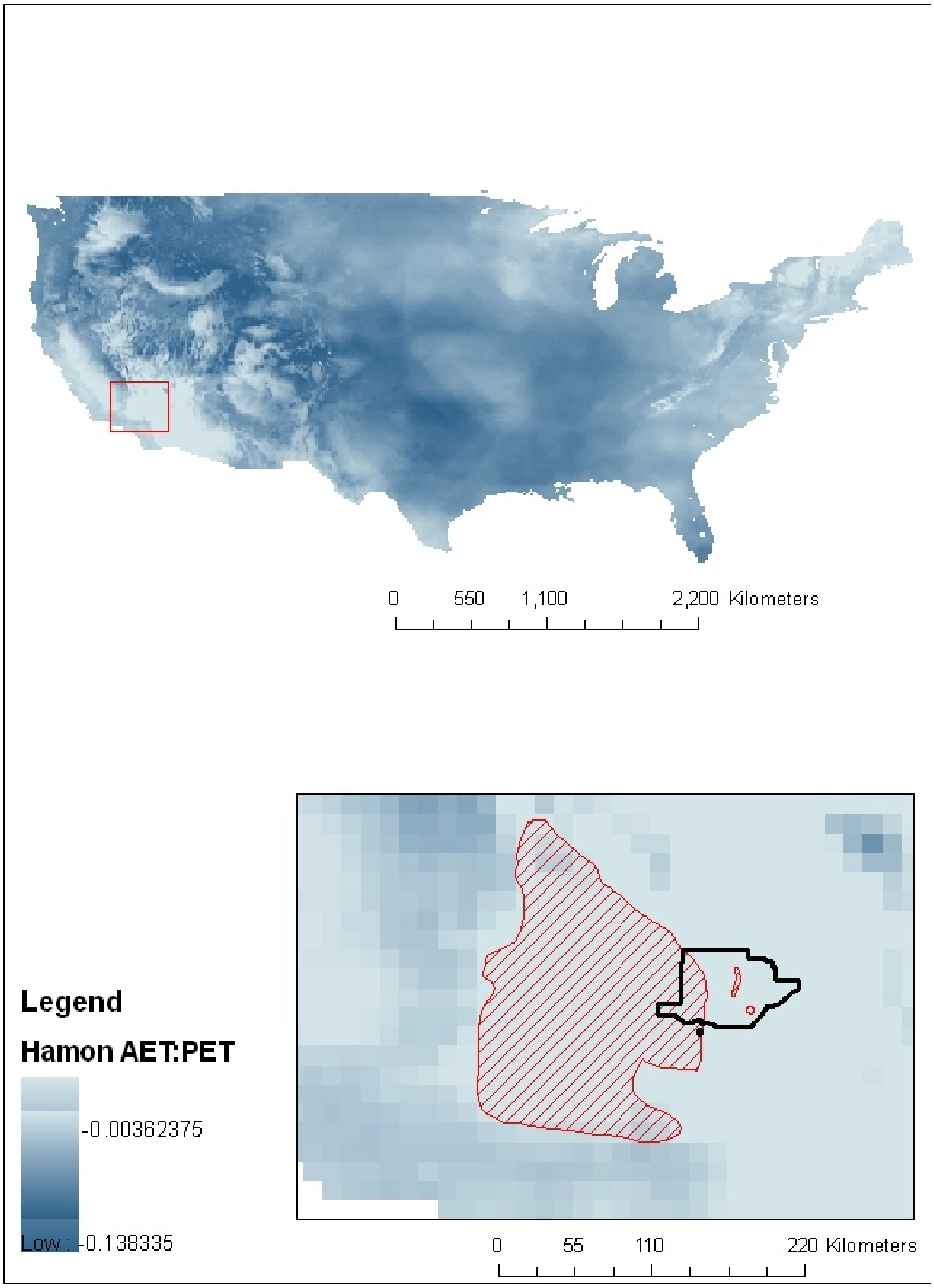

Figure A2. Mohave ground squirrel (*Spermophilus mohavensis*) range distribution in California, in relation to projected future (2050) change in precipitation (Hamon AET:PET moisture index). Precipitation data provided by NatureServe (**www.natureserve.org/climatechange**). Red hatched polygon indicates ground squirrel range distribution and black polygon indicates US Army military installations (Fort Irwin overlaps *S. mohavenis* range).

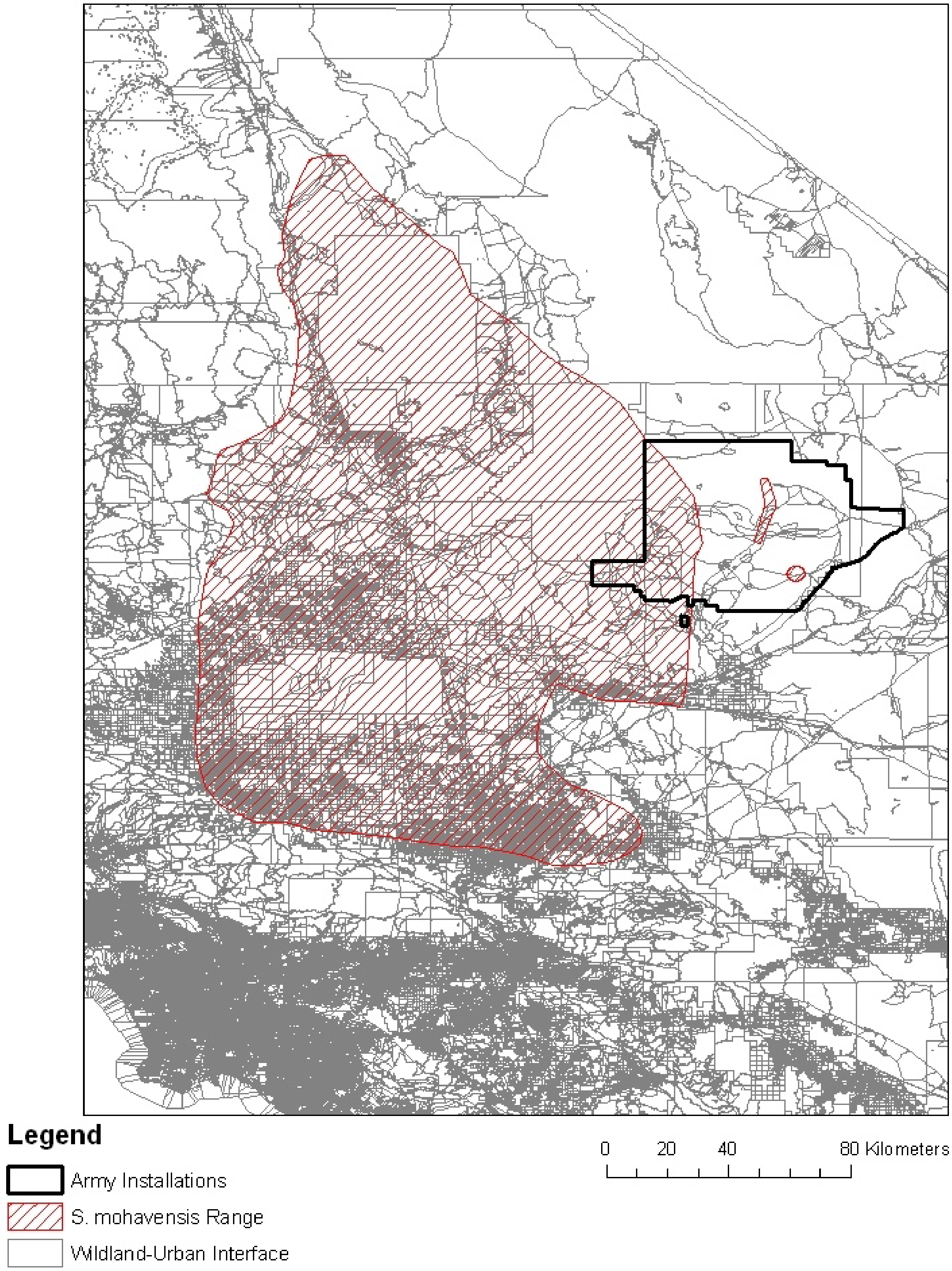

Figure A3. Mohave ground squirrel (*Spermophilus mohavensis*) range distribution in California, in relation to urban development and habitat fragmentation. Development map provided by Wildland-Urban Interface data (Silvis Lab, University of Wisconsin-Madison and US Department of Agriculture (USDA) Forest Service North Central Research Station). Red hatched polygon indicates ground squirrel range distribution and black polygon indicates US Army military installations (Fort Irwin overlaps *S. mohavenis* range).

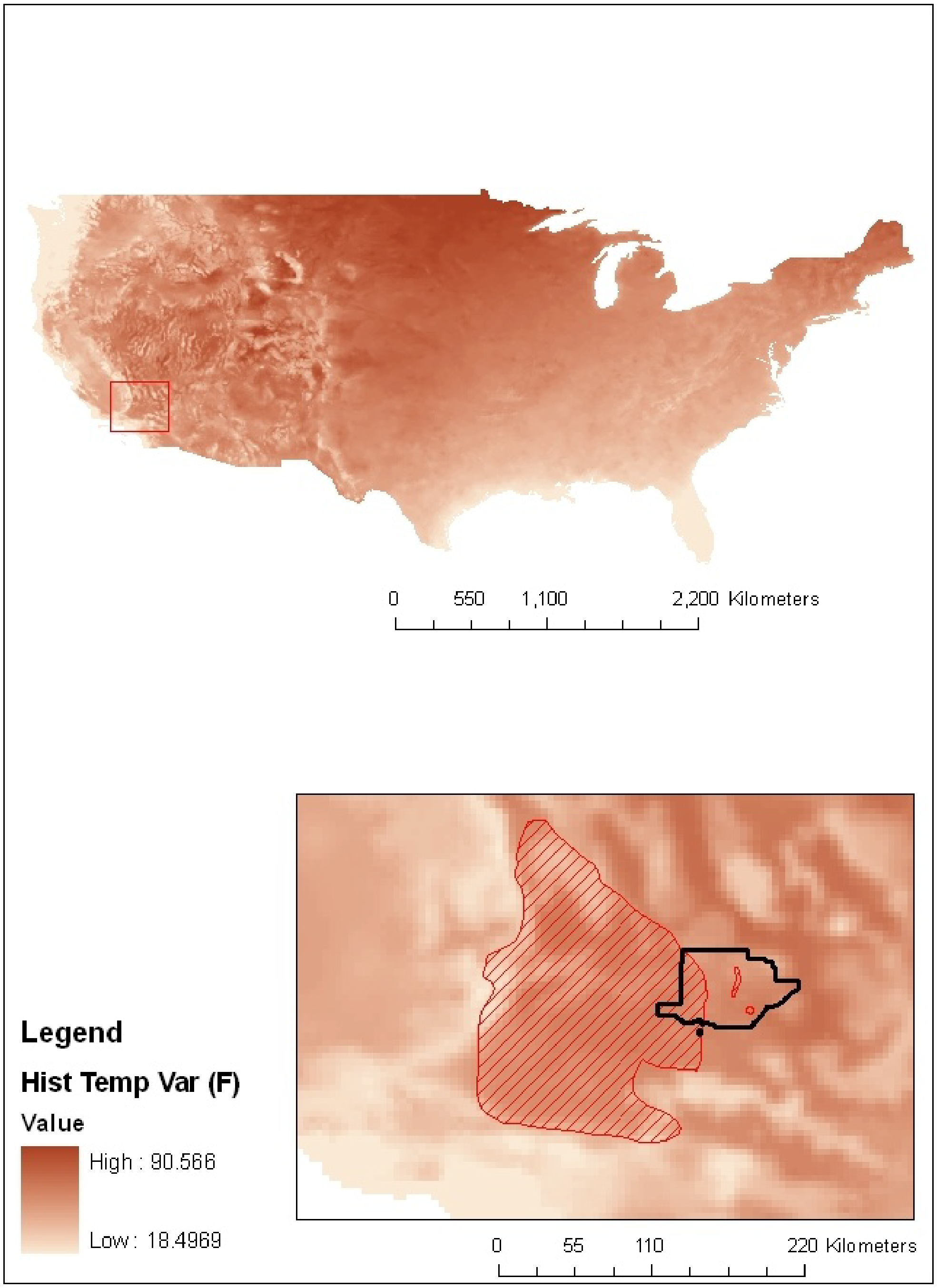

Figure A4. Mohave ground squirrel (*Spermophilus mohavensis*) range distribution in California, in relation to mean seasonal temperature variation experienced over the last 50 years. Temperature variation data provided by NatureServe (**www.natureserve.org/climatechange**). Red hatched polygon indicates ground squirrel range distribution and black polygon indicates US Army military installations (Fort Irwin overlaps *S. mohavenis* range).

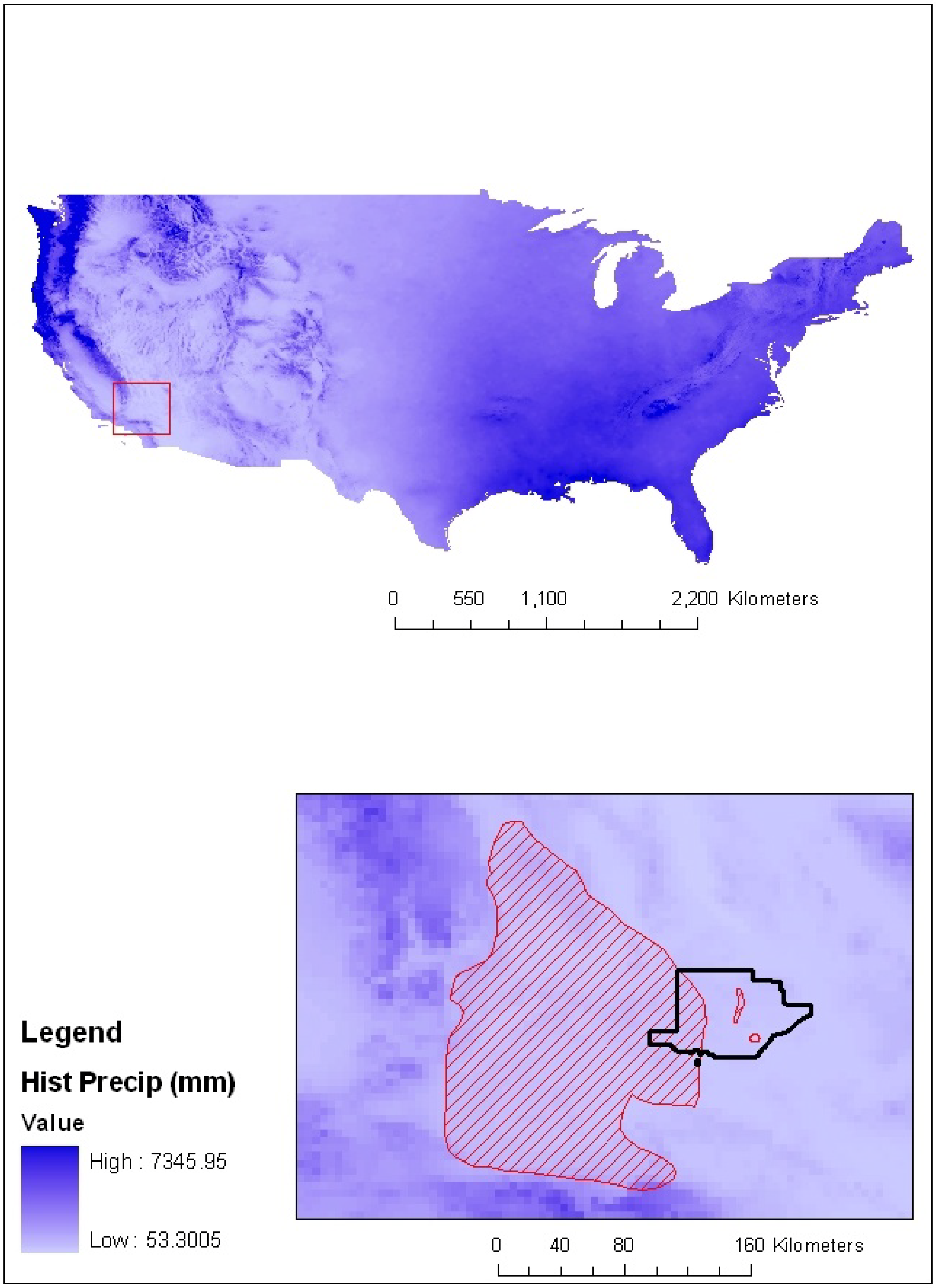

Figure A5. Mohave ground squirrel (*Spermophilus mohavensis*) range distribution in California, in relation to mean annual precipitation variation experienced over the last 50 years. Precipitation variation data provided by NatureServe (**www.natureserve.org/climatechange**). Red hatched polygon indicates ground squirrel range distribution and black polygon indicates US Army military installations (Fort Irwin overlaps *S. mohavenis* range).

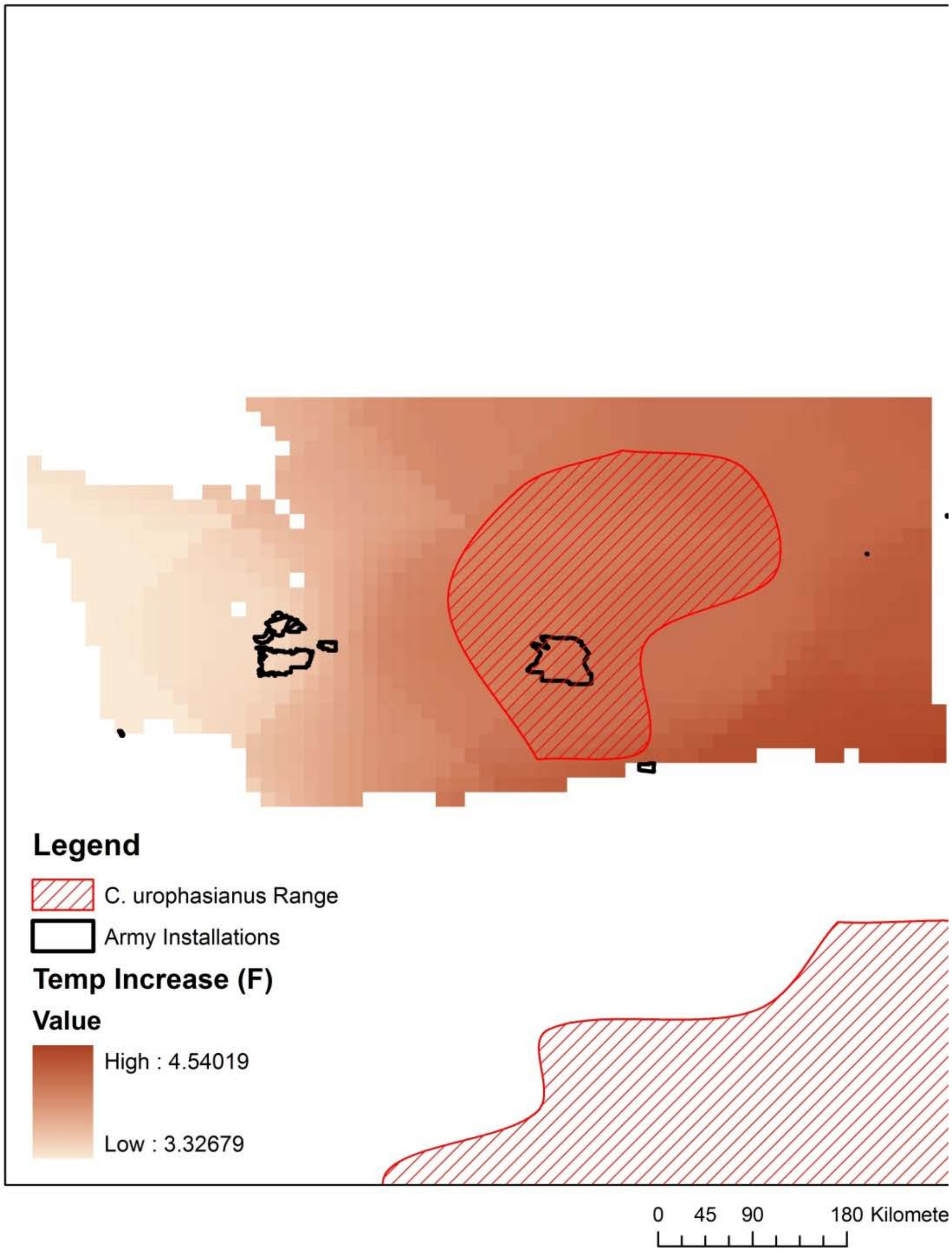

Figure A6. Greater Sage-grouse (*Centrocercus urophasianus*) range distribution in Washington, in relation to projected future (2050) temperature increase. Temperature data provided by Climate Wizard (www.climatewizard.org; Maurer et al. 2007) given a Medium A1B emission scenario and Ensemble Average Global Circulation Model. Red hatched polygon indicates sage-grouse range distribution and black polygon indicates US Army military installations (Yakima Training Center overlaps *C. urophasianus* range).

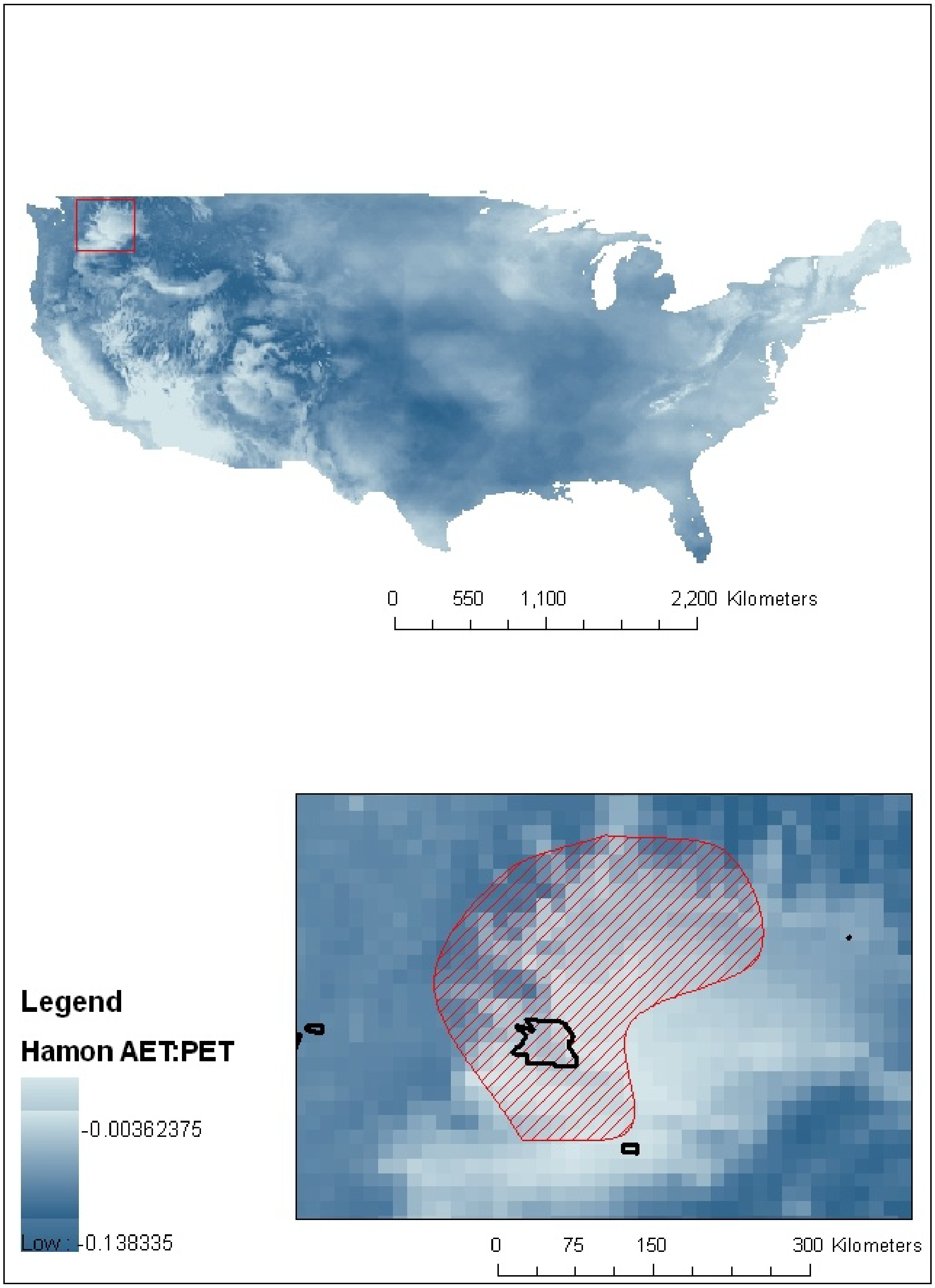

Figure A7. Greater Sage-grouse (*Centrocercus urophasianus*) range distribution in Washington, in relation to projected future (2050) change in precipitation (Hamon AET:PET moisture index). Precipitation data provided by NatureServe (**www.natureserve.org/climatechange**). Red hatched polygon indicates sage-grouse range distribution and black polygon indicates US Army military installations (Yakima Training Center overlaps *C. urophasianus* range).

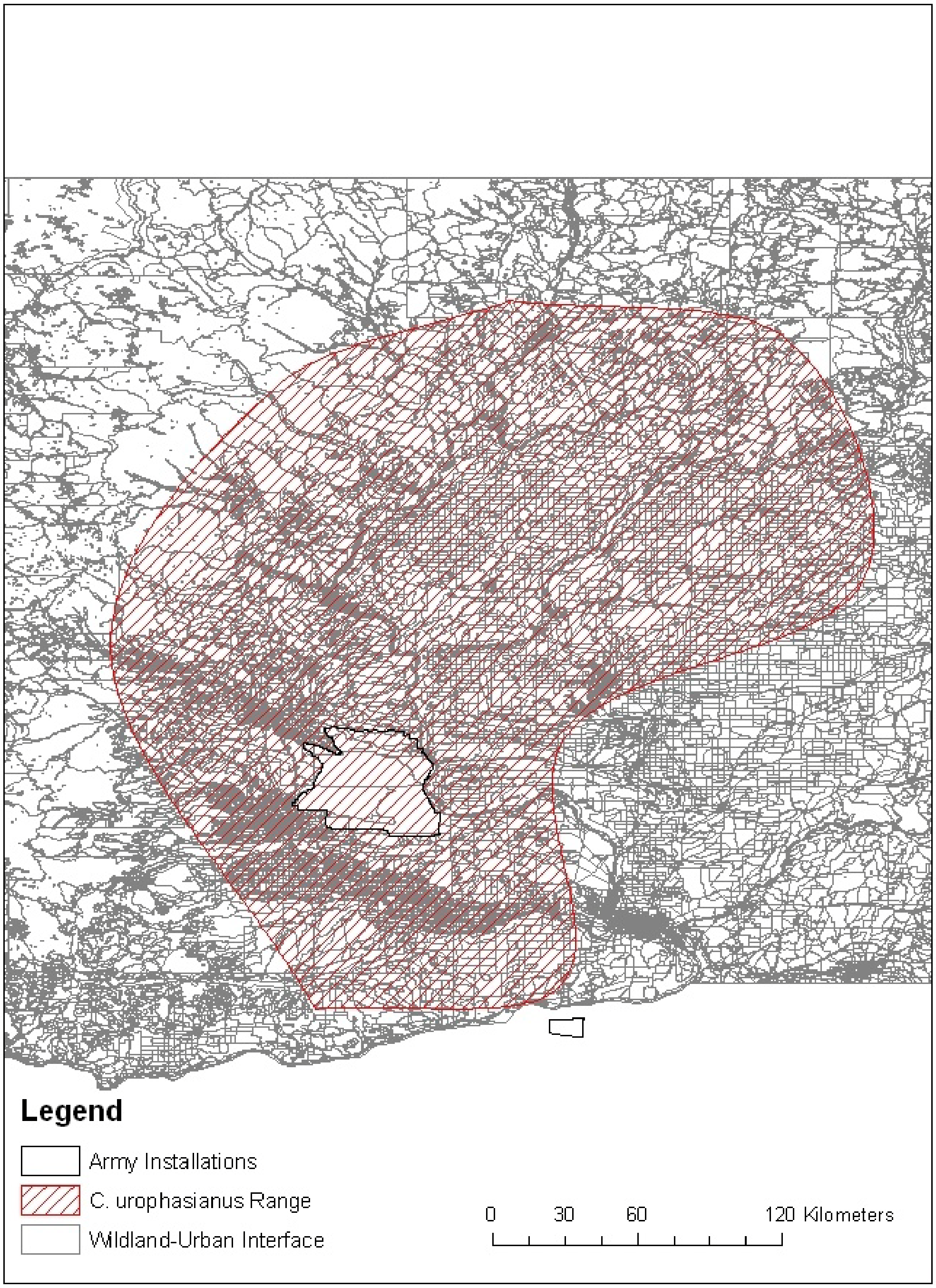

Figure A8. Greater Sage-grouse (*Centrocercus urophasianus*) range distribution in Washington, in relation to urban development and habitat fragmentation. Development map provided by Wildland-Urban Interface data (Silvis Lab, University of Wisconsin-Madison and USDA Forest Service North Central Research Station). Red hatched polygon indicates sage-grouse range distribution and black polygon indicates US Army military installations (Yakima Training Center overlaps *C. urophasianus* range).

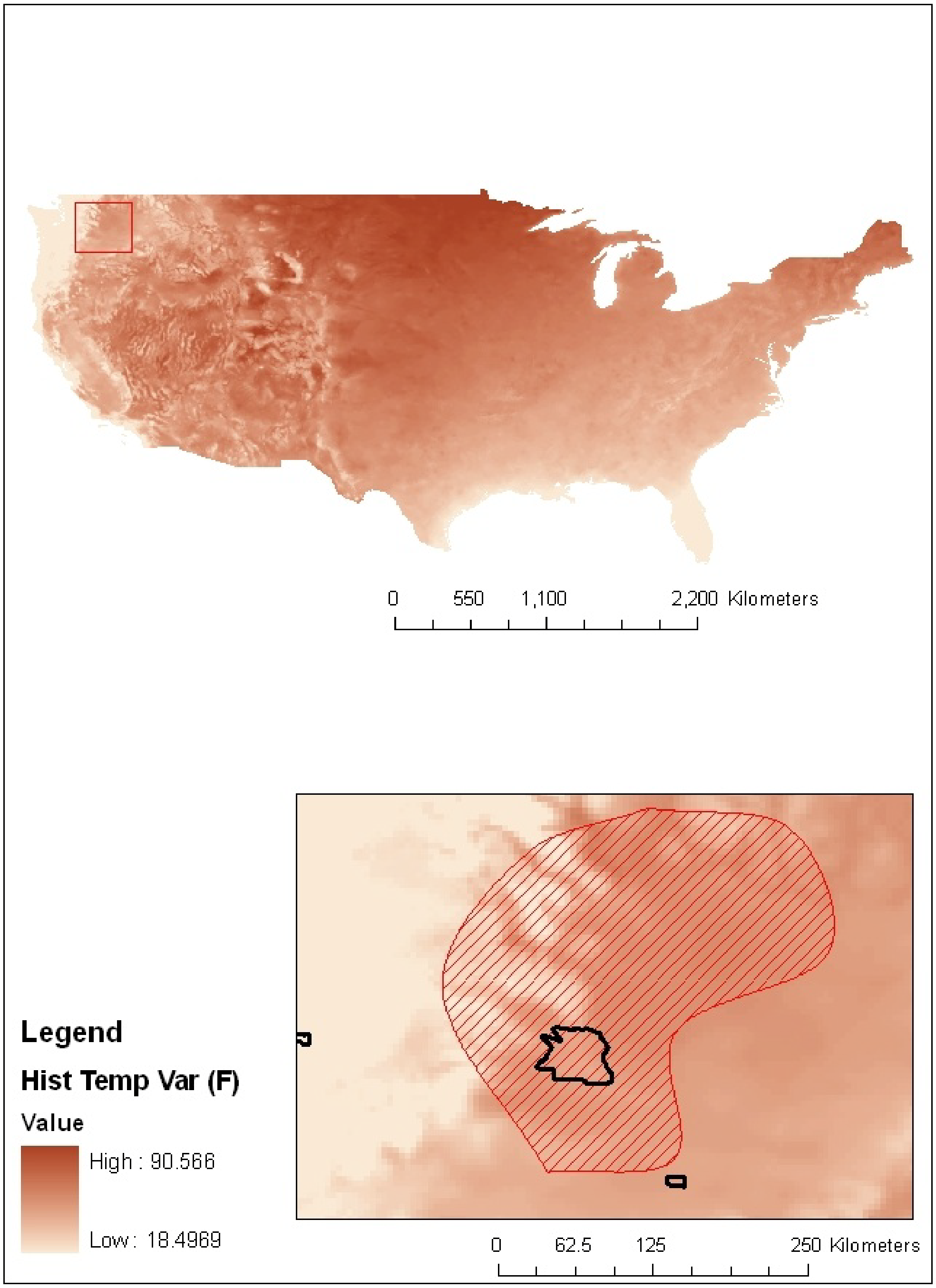

Figure A9. Greater Sage-grouse (*Centrocercus urophasianus*) range distribution in Washington, in relation to mean seasonal temperature variation experienced over the last 50 years. Temperature variation data provided by NatureServe (**www.natureserve.org/climatechange**). Red hatched polygon indicates sage-grouse range distribution and black polygon indicates US Army military installations (Yakima Training Center overlaps *C. urophasianus* range).

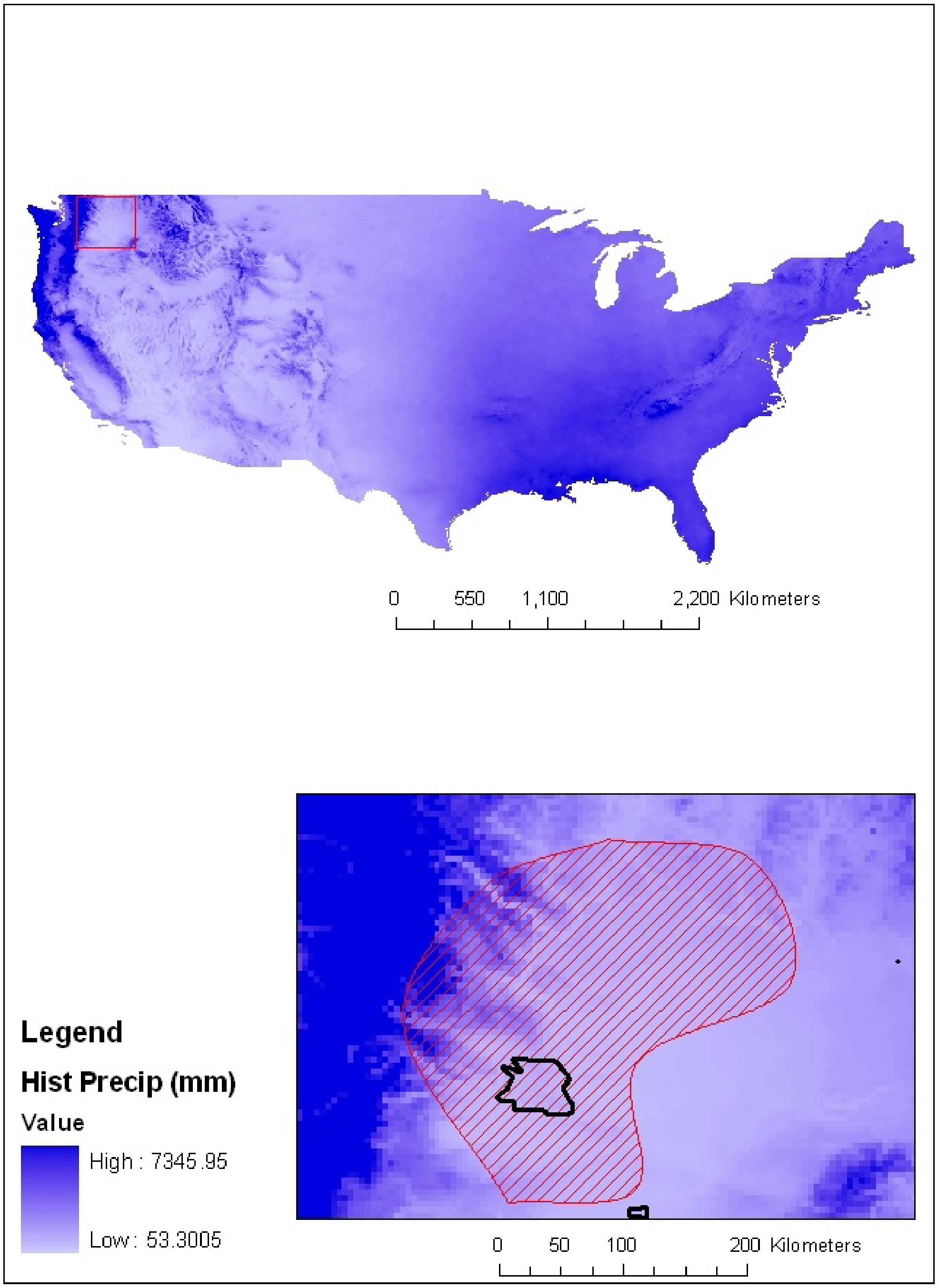

Figure A10. Greater Sage-grouse (*Centrocercus urophasianus*) range distribution in Washington, in relation to mean annual precipitation variation experienced over the last 50 years. Precipitation variation data provided by NatureServe (www.natureserve.org/climatechange). Red hatched polygon indicates sage-grouse range distribution and black polygon indicates US Army military installations (Yakima Training Center overlaps *C. urophasianus* range).

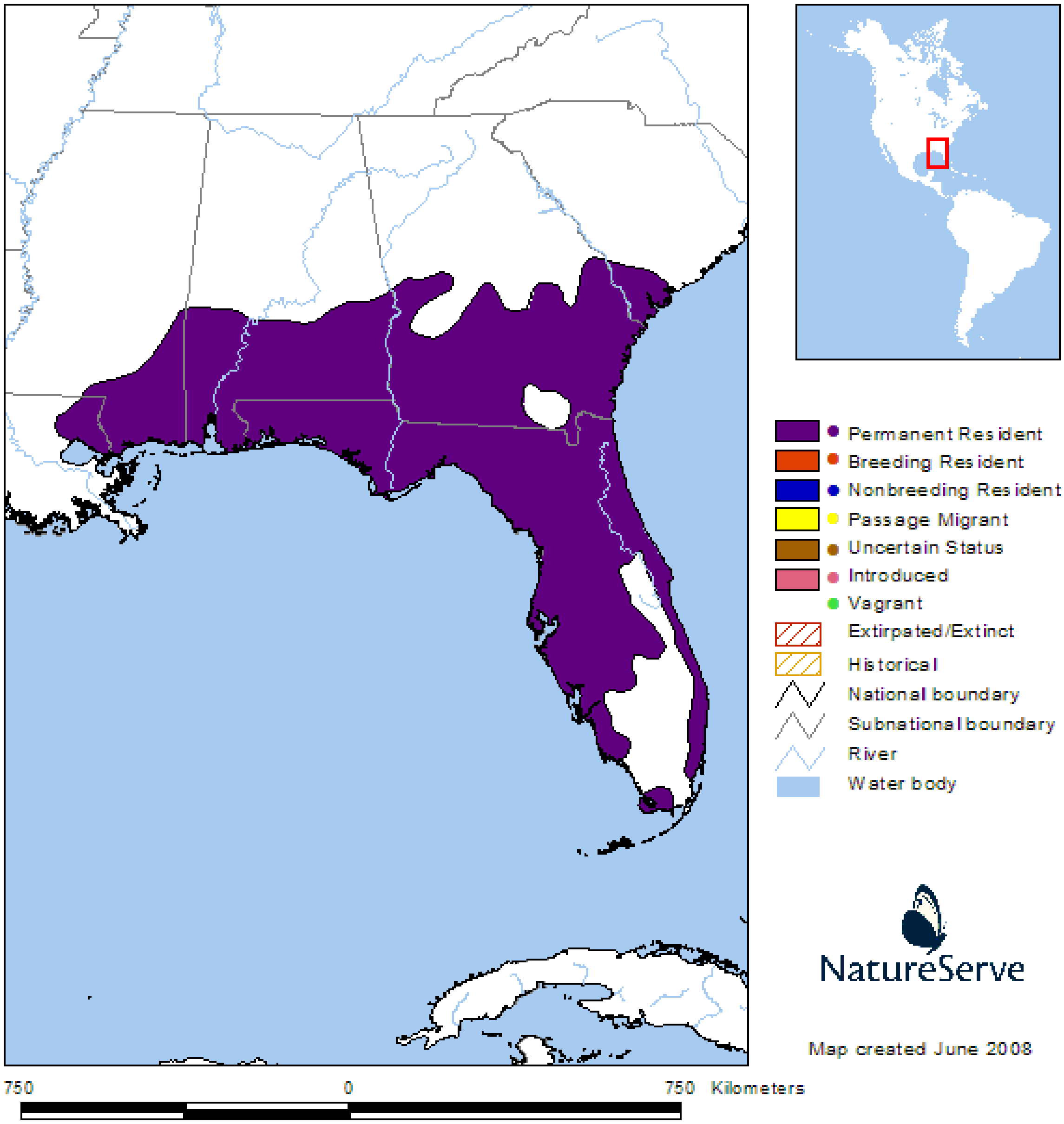

Figure A11. Gopher tortoise (*Gopherus polyphemis*) range distribution. Map provided by NatureServe Explorer (**www.natureserve.org/explorer**).

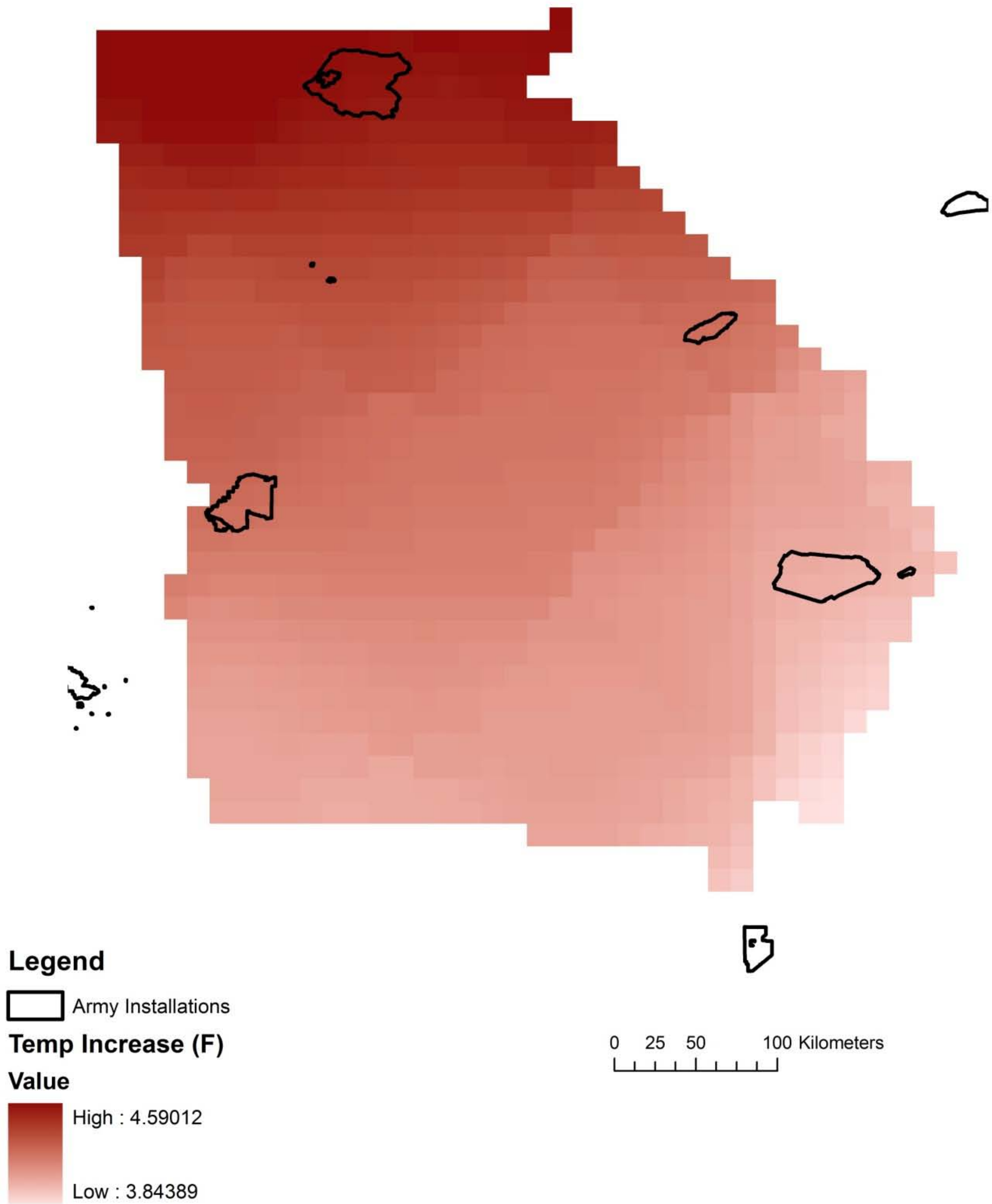

Figure A12. Georgia, in relation to projected future (2050) temperature increase. Temperature data provided by Climate Wizard (www.climatewizard.org; Maurer et al. 2007) given a Medium A1B emission scenario and Ensemble Average Global Circulation Model. Black polygon indicates US Army military installations (Fort Stewart, which is encompassed within Gopher Tortoise [*Gopherus polyphemis]* distribution, is the large installation near the eastern seaboard).

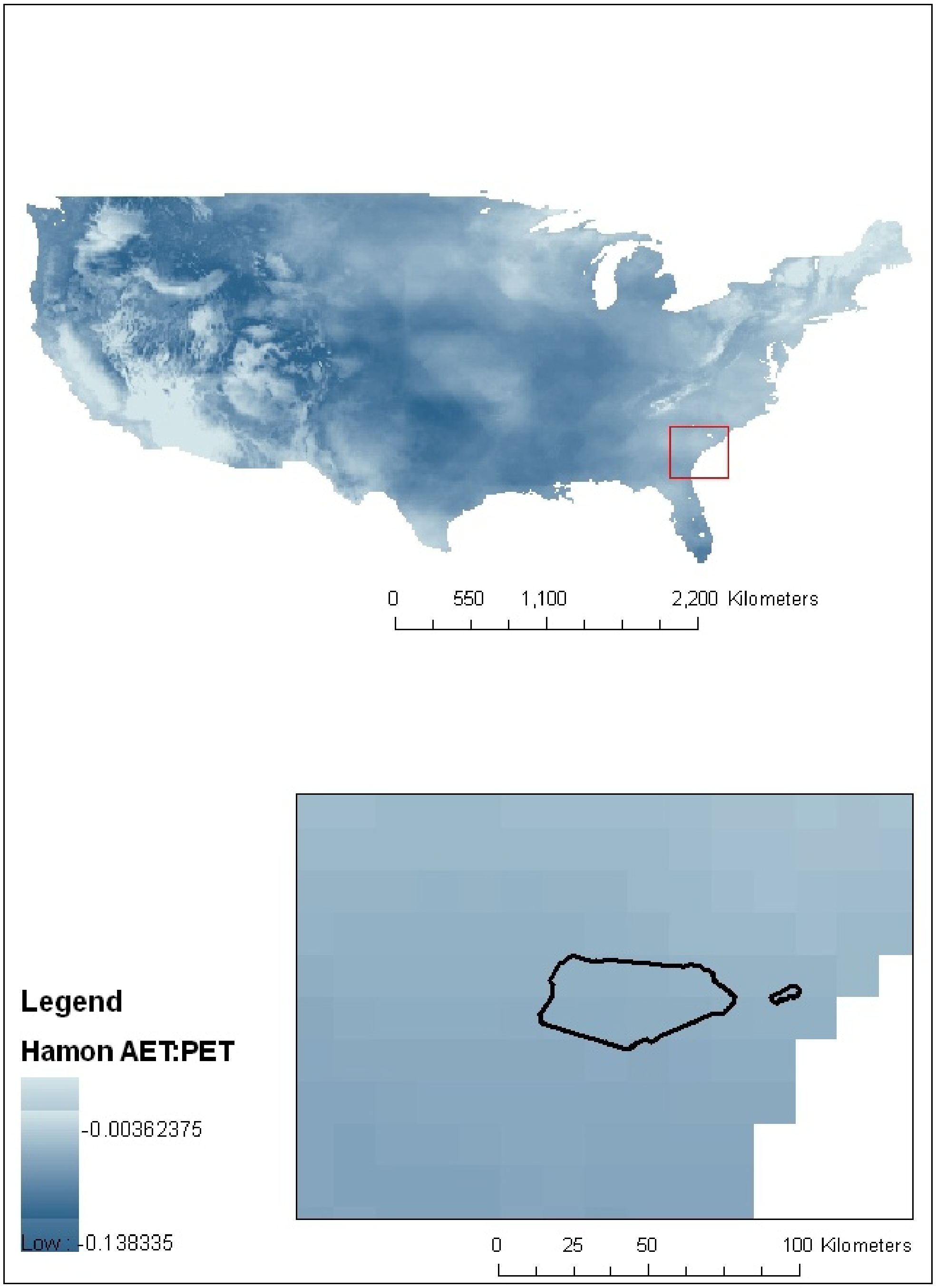

Figure A13. Georgia, in relation to projected future (2050) change in precipitation (Hamon AET:PET moisture index). Greater negative numbers indicate drier conditions. Precipitation data provided by NatureServe (www.natureserve.org/climatechange). Black polygon indicates US Army military installations (Fort Stewart, which is encompassed within Gopher Tortoise [*Gopherus polyphemis]* distribution, is the large installation near the eastern seaboard).

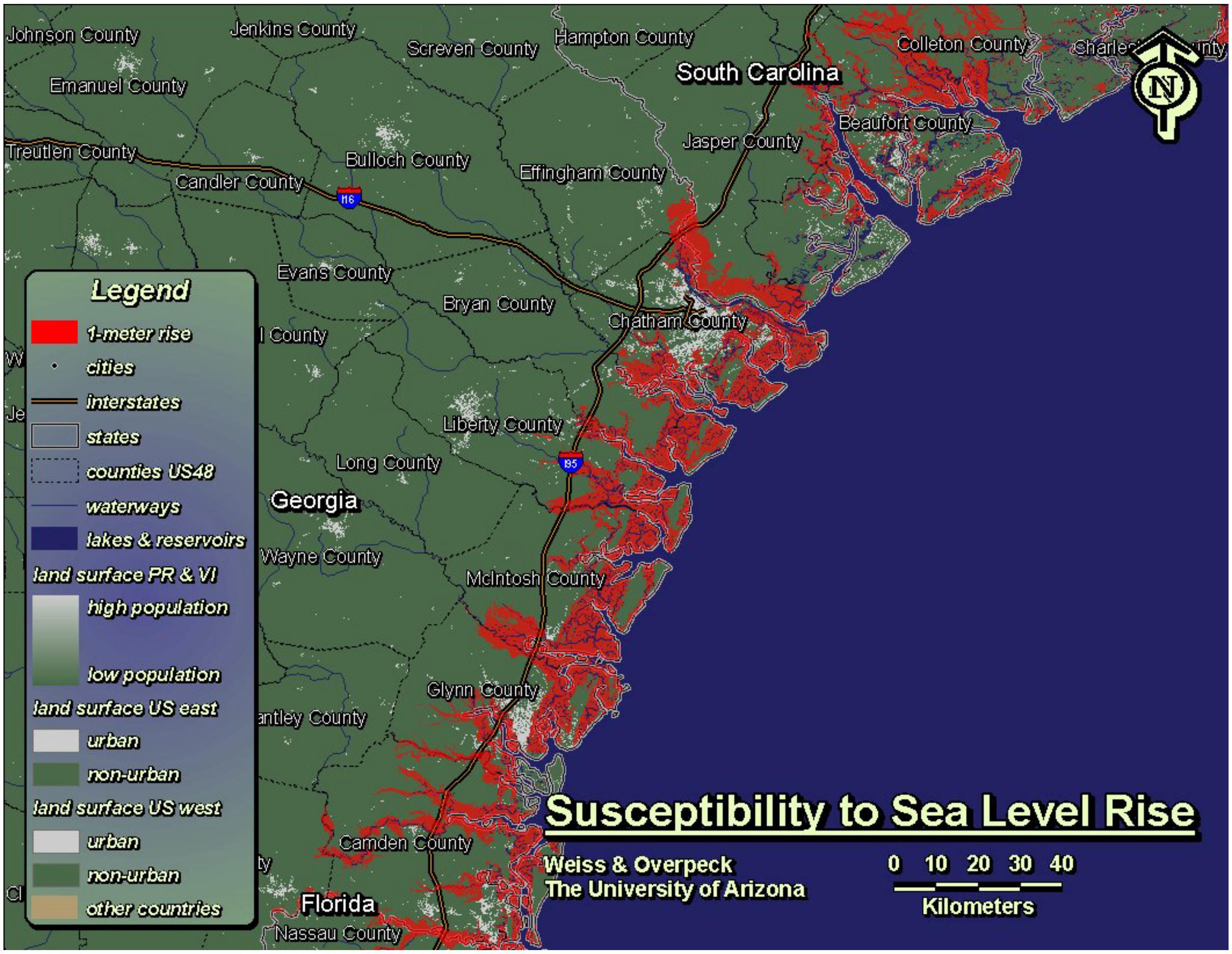

Figure A14. Map of land areas expected to be impacted by 1 m rise in sea level. Map provided by Department of Geosciences at University of Arizona.

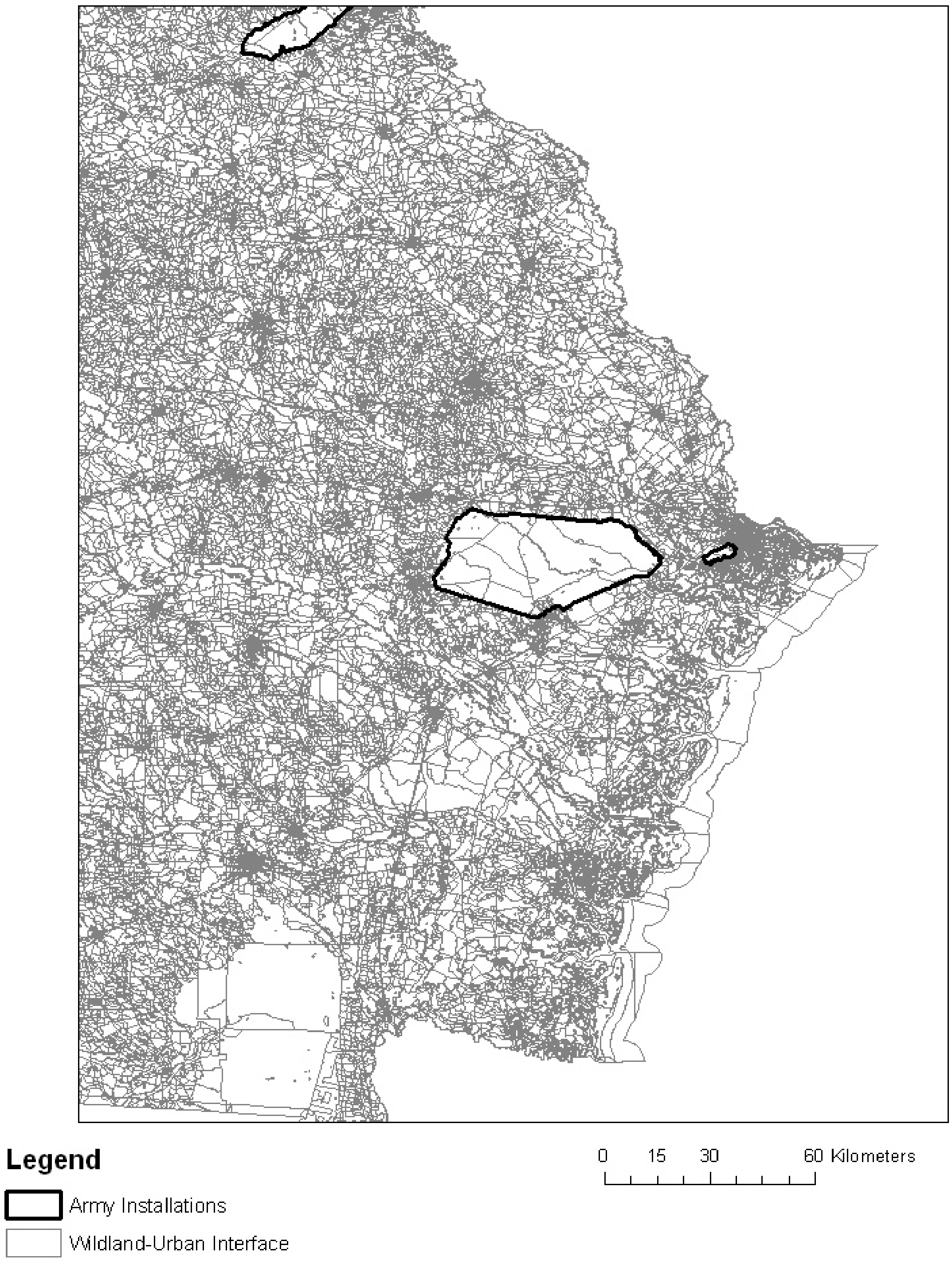

Figure A15. Georgia, in relation to urban development and habitat fragmentation. Development map provided by Wildland-Urban Interface data (Silvis Lab, University of Wisconsin-Madison and USDA Forest Service North Central Research Station). Black polygon indicates US Army military installations (Fort Stewart, which is encompassed within Gopher Tortoise [*Gopherus polyphemis]* distribution, is the large installation near the eastern seaboard).

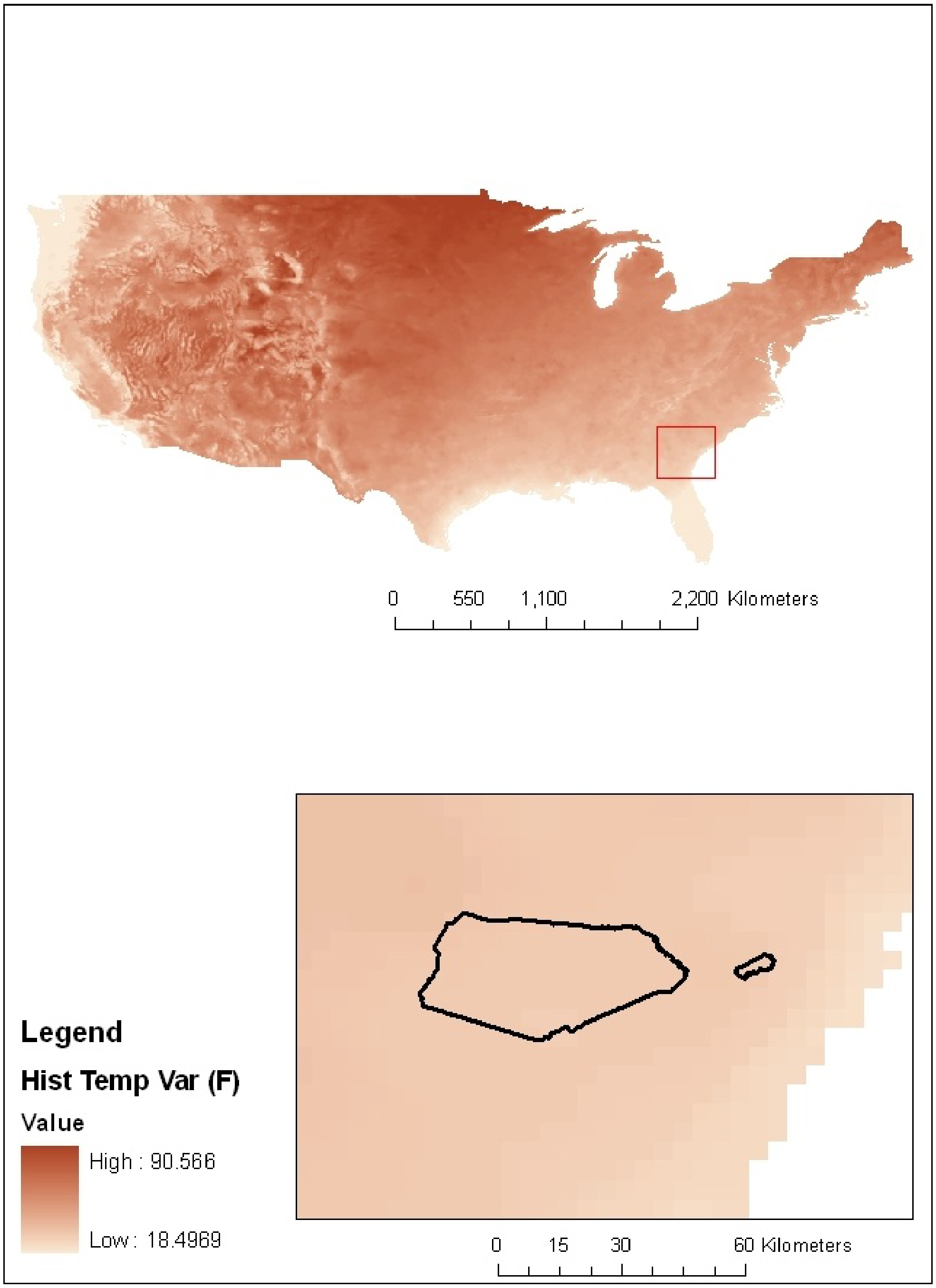

Figure A16. Georgia, in relation to mean seasonal temperature variation experienced over the past 50 years. Temperature variation data provided by NatureServe (**www.natureserve.org/climatechange**). Black polygon indicates US Army military installations (Fort Stewart, which is encompassed within Gopher Tortoise [Gopherus polyphemis] distribution, is the large installation near the eastern seaboard).

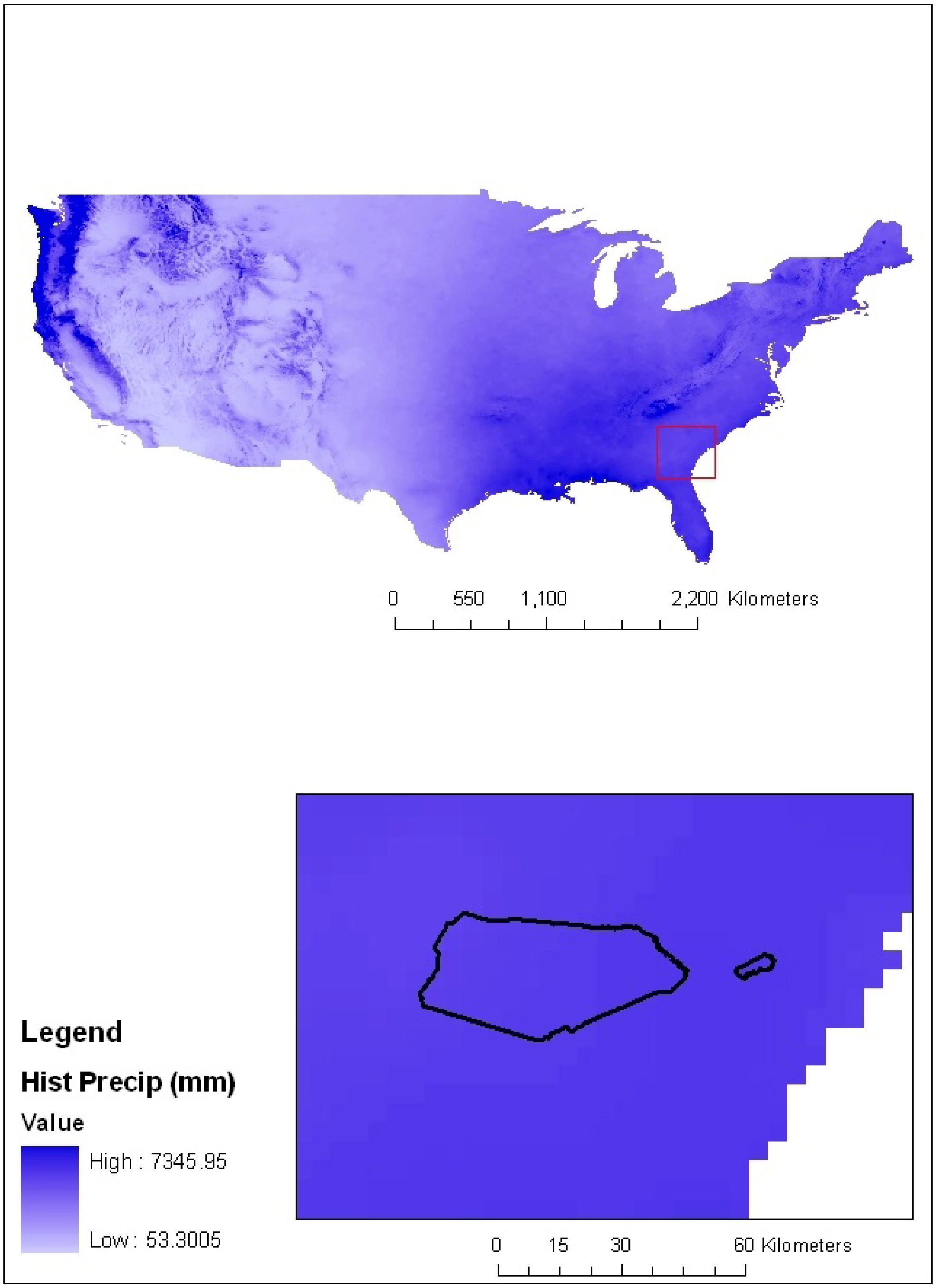

Figure A17. Georgia, in relation to mean annual precipitation variation experienced over the last 50 years. Precipitation variation data provided by NatureServe (www.natureserve.org/climatechange). Black polygon indicates US Army military installations (Fort Stewart, which is encompassed within Gopher Tortoise [*Gopherus polyphemis]* distribution, is the large installation near the eastern seaboard).

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14. ABSTRACT
Global climate change is seen as an emerging threat to wildlife species' population distribution and persistence. Climate change vulnerability indexes allow land managers to rapidly assess the vulnerability of species to climate change, and to predict a species persistence into the future. This work evaluated the NatureServe Climate Change Vulnerability Index as a tool for military land managers. The NatureServe Climate Change Vulnerability Index was applied to three high priority Species at Risk: (1) the Mohave ground squirrel (*Spermophilus mohavensis*) on Fort Irwin, CA; (2) the Columbia Basin distinct population segment of the greater sage-grouse (*Centrocercus urophasianus*) on the Yakima Training Center, WA; and (3) the gopher tortoise (*Gopherus polyphemis*) on Fort Stewart, GA. The Index predicted that the Mohave ground squirrel population was not vulnerable to climate change, and that the greater sage-grouse and gopher tortoise populations were moderately vulnerable. The Index was found to be easy to use; it included quantitative, spatially explicit data, and it identified needed research areas for species of conservation concern. However, Index outcome was found to be highly dependent on a single variable, historical hydrological niche, which varied greatly depending on size of assessment area.

15. SUBJECT TERMS
climate change, land management, natural resources management, threatened and endangered species

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