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Climate change: implications for montane mammals of the Great Basin

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CLIMATE CHANGE: IMPLICATIONS FOR MONTANE MAMMALS OF THE GREAT BASIN

being

A Thesis Presented to the Graduate Faculty
of the Fort Hays State University in
Partial Fulfillment of the Requirements for
the Degree of Master of Science

by

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the Master of Science Degree

by

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PREFACE

The manuscript has been formatted in the style of the journal Conservation Biology.

Keywords: climate change, extinction, Great Basin, montane islands, montane mammals

ABSTRACT

Climate change threatens biodiversity; in particular, species with narrow distributions and specific habitat requirements. The Great Basin provides an excellent model system to evaluate the effects of climate change on species with isolated distributions and specific habitat requirements. I have evaluated the McDonald and Brown (1992) model that examined the effects of climate change on montane mammals of the Great Basin based on its underlying assumptions and model predictions. I have modeled the distributions of twelve montane mammal species found in the Great Basin and identified potential local extinctions by using maximum entropy modeling (Maxent) for two emission scenarios of changing climate for the year 2050: a minimum (b2a) and a maximum (a2a). Overall, a majority of Great Basin mammal species examined are predicted to experience reductions in distribution ranging from approximately 2-64% for a minimum emission scenario (b2a) and 39-79% for a maximum emission scenario (a2a). In particular, there was agreement between my model predictions and the MacDonald and Brown (1992) model predictions for four local extinctions for a minimum emission scenario (b2a), and five local extinctions for a maximum emission scenario (a2a). Instances in which model predictions relative to species distributions and abundances are consistent might provide a basis on which conservationists can develop generalities about biotic responses to changing environmental conditions. By understanding what environmental factors influence species occurrence, we can infer how climate change is likely to affect biodiversity and their spatial distributions, possibly allowing us to better manage and conserve populations.

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INTRODUCTION

Human population growth directly increases the pressure that humans exert on the Earth’s natural resources. As the human population continues to grow, it is expected that humans will have a growing impact on the Earth’s physical processes and the biological life that it sustains. In particular, the fragmentation of natural landscapes produces isolated patches of habitat surrounded and dominated by humans (Earn et al. 2000). Habitat fragmentation poses one of the greatest threats to the maintenance of biodiversity and ecosystem function (McKee et al. 2003). The altered habitat separating the patches of habitat, also referred to as matrix, might act as a filter or barrier to dispersal for some species. As a result, those species with specific habitat requirements and low dispersal abilities are isolated on patches of habitat commonly referred to as “habitat islands”.

Humans have not only altered terrestrial, aquatic and marine ecosystems, but have also had a significant impact on the composition of the Earth’s atmosphere largely as a result of burning of fossil fuels, which in turn has had a significant impact on the Earth’s climate (Vitousek et al. 1997). Climate directly and indirectly influences the distribution of vegetation and the associated fauna. Organisms respond to long-term changes in temperature and precipitation by moving to suitable habitats, and populations evolve in response to new conditions, or they become extinct (Holt 1990). As a result of historical changes in climate, species moved independently of one another into suitable habitats depending on their dispersal abilities. As a result, species assemblages were continually being formed and reassembled (Lovejoy & Hannah 2005). Human-induced changes in climate, in addition to the effects of habitat destruction and fragmentation, threaten biodiversity (McCarty 2001; Hannah et al. 2002). The altered and human-dominated landscape is a formidable challenge to the dispersal of species in response to climate change. Climate change is ranked second to habitat degradation among the current major threats to biodiversity in terrestrial ecosystems (Sala et al. 2000).

Changes in climate are occurring very rapidly (Houghton et al. 2001; IPCC 2001); therefore, species that are not able to move into suitable habitats might not be able to adapt quickly enough to changing conditions. If species are unable to adapt to the changing environmental conditions, they will go extinct. Human-induced climate change is likely to cause changes in species distributions, community structure, and ecosystem functions (Chapin et al. 2000; Williams & Jackson 2007; Williams et al. 2007).

Montane “islands” of the Great Basin

The Great Basin is an arid region in the western United States, consisting of isolated mountain ranges surrounded by desert valleys (Fig. 1A). The desert valleys of the Great Basin are located between 1220 and 1830 m in elevation and the dominant vegetation consists of sagebrush (*Artemisia* spp.) or saltbrush (*Atriplex* spp.); mountain habitat consists of subalpine conifers and alpine tundra (Brown 1978; Grayson & Livingston 1993). Montane “islands” are defined as areas having peaks above 2990 meters that are separated by valleys below 2280 meters (McDonald & Brown 1992). Nineteen mountain ranges in the Great Basin have been delineated based on these criteria (McDonald & Brown 1992) (Fig. 1B). Mammalian distributions in the Great Basin have been studied extensively in the past (Brown 1971; Grayson 1987). Community structure in insular habitats is thought to be driven by two biogeographic processes, immigration and extinction (MacArthur & Wilson 1963, 1967). Brown (1971, 1978) evaluated the processes that have shaped the community structure of montane mammals in the Great

Basin and determined that the only process that is operating in this system is extinction. The desert valleys below 2280 meters are considered barriers to dispersal, isolating the cool, mesic-adapted montane mammals on the mountain peaks (Brown 1971, 1978; McDonald & Brown 1992).

Climate change threatens the persistence of species found on isolated mountain ranges because of their insular nature. Distributions of species along elevational gradients are likely to shift up the slopes of the mountain in response to a warming climate (Peters & Lovejoy 1992). The Great Basin provides an excellent system to study the effects of climate change where immigration is limited. As species move up elevational gradients in response to climate change, these species are likely to experience reductions in the area of suitable habitat that might result in reductions in population size and possibly extinctions. Isolated faunas such as the montane mammals of the Great Basin, have served as model systems for studying non-equilibrial island biogeography and have influenced greatly our understanding of extinction in ecological time and the effects of climate change (Brown 1971, 1978; Thompson & Mead 1982; Grayson 1987; McDonald & Brown 1992; Grayson & Livingston 1993; Grayson 2000; Grayson & Madsen 2000).

Species that are highly sensitive to changes in temperature and precipitation are likely to have reduced dispersal abilities and narrow distributions. The American pika (*Ochotona princeps*) is an example of a species that is highly sensitive to changes in environmental conditions such as temperature and precipitation (Smith 1974; Smith & Weston 1990). Evaluation of the effects of climate change on the persistence of habitat-specific species, such as the American pika, is potentially important for conservation and management. Global changes in climate will result in regional changes in temperature and precipitation regimes which are likely to have a significant impact on the distributions of species with specific environmental and habitat requirements.

Most biogeographers agree that the natural distributions of species are primarily influenced by climate (Pearson & Dawson 2003). Expansions and contractions in the distributions of species have been documented in the fossil record (Grayson 1987; Davis & Shaw 2001); furthermore, there is extensive literature that attributes changes in the distribution and physiology of numerous taxonomic groups to recent anthropogenic changes in climate (Hughes 2000; Parmesan 2006).

The processes that threaten biodiversity are occurring at regional and global scales; therefore, in order to address these issues (habitat fragmentation and climate change), it is important to increase the scale of ecological studies beyond the local scale (Brown 1995). There is a wealth of information in the literature and museums that can be used to test conceptual and model-based hypotheses about large-scale patterns and processes (Barkley 1993). Data such as localities from museum records can be used in species distribution modeling programs to predict the environmental factors that are significant in determining the presence and absence of a species and to predict the effect of climate change on species distributions (Barkley 1993; Brown 1995; Graham et al. 2004; Elith et al. 2006; Pearce & Boyce 2006; Rotenberry et al. 2006; Rodríguez et al. 2007; Waltari & Guralnick 2008; but see Newbold 2010).

McDonald and Brown (1992) used a community level approach to model the effects of global warming on fourteen montane mammals of the Great Basin (Table 1). Table 2 lists the occurrence (1) or absence (0) of each species on nineteen isolated mountain ranges in the Great Basin. The McDonald and Brown (1992) model was based on three assumptions: 1) an increase in regional temperature of 3ºC by 2050, while assuming unchanged precipitation, 2) a 500 m upward shift in elevation of life zones for each mountain range, resulting in a decrease in total area, and 3) mammalian fauna exhibits the nested subset pattern. The species-area relationship (Arrhenius 1921; MacArthur & Wilson 1967) was used to estimate the number of species found on each mountain range based on reductions in the area of montane habitat resulting from climate changes. By comparing the number of species on each mountain with the number of species predicted to remain after climate change, McDonald and Brown (1992) predicted the number of local extinctions resulting from global warming. Local extinctions are defined as instances when a species no longer occurs within a defined region but persists in other regions (MacArthur & Wilson 1967). To determine which of the species would persist McDonald and Brown (1992) used the nested subset pattern (Patterson & Atmar 1986). The nested subset pattern occurs when the most species rich site contains all of the species and the less species rich sites contain a proper subset of the species found at more species rich sites (Patterson & Atmar 1986). McDonald and Brown (1992) applied the nested subset pattern to identify the species most likely to go extinct from each mountain range (Table 3). McDonald and Brown (1992) predicted that there would be a 35-96% decline in coniferous habitat throughout the Great Basin and a 9-62% decline in the mammalian fauna occurring on each of the mountain ranges in the Great Basin.

There are several potential errors associated with McDonald and Brown's (1992) approach. They used community level concepts such as the species-area relationship (Arrhenius 1921; MacArthur & Wilson 1967) and the nested subset pattern (Patterson &

Atmar 1986; Patterson 1987) to make population level predictions. Model details and the application of these approaches to conservation biology have been controversial (Grayson 1987, 1993; Grayson & Livingston 1993; Lawler 1998; Grayson & Madsen 2000). Skaggs and Boecklen (1996) concluded the McDonald and Brown (1992) model is not reliable for modeling extinctions caused by global warming because of its untenable assumptions and inadequate data base. Other criticisms stem from recently discovered species in habitats where they previously were thought to be absent, as well as evidence for species dispersal across desert valleys (Boecklen & Gotelli 1984; Grayson & Livingston 1993; Skaggs & Boecklen 1996; Lawler 1998; Grayson & Madsen 2000). In addition, Fischer and Lindenmayer (2005) have also questioned the application of the nested subset pattern in conservation. Their findings suggest that the occurrence of sensitive species could be affected by other ecological factors indirectly affected by habitat fragmentation.

Criticism of the McDonald and Brown (1992) model warrants the re-evaluation of the effects of climate change on the distributions and predicted extinctions of montane mammals in the Great Basin. I used species distribution modeling techniques and predicted climate data from general circulation models (GCM) to make predictions about the effects of climate change on species distributions. The objectives of my study were to 1) use a climate change model to predict the distribution of montane vegetation for two emission scenarios, 2) determine which current climatic and vegetation factors influence the distribution of Great Basin montane mammal species, 3) model the distributions of montane mammals for two emission scenarios, 4) compare the predicted species distributions from Maxent to the predictions of McDonald and Brown (1992), 5) test the predictions made by McDonald and Brown (1992), and 6) use the results of the climate change distribution models to develop conservation and management recommendations.

METHODS

Climate Data

Climate data were obtained as interpolated monthly climate surface layers with a 1 km x 1 km spatial resolution from WorldClim Version 1.4 (IPCC 2001; Hijmans et al. 2005). Historical climate data were derived using interpolations from observed conditions for the years 1950-2000 (Hijamns et al. 2005; IPCC 2001). Future climate data were statistically downscaled and calibrated from the Canadian Centre for Climate Modelling and Analysis (CCCma) Coupled Global Climate Model (CGCM3) using the IPCC Special Report on Emission Scenarios (SRES) (Flato & Boer 2001; IPCC 2001). I used two CCMA emission scenarios for the year 2050: a minimum (b2a, CCCma,) and a maximum (a2a, CCCma). Minimum (b2a, CCCma) emission scenario predictions are based on slower population growth (10.4 billion by 2100) and a developing economy with more emphasis on environmental protection, resulting in lower emissions and less warming. The maximum emission scenario (a2a, CCCma) is the “business as usual” scenario in which human populations will continue to increase (15 billion by 2100) with relatively slow economic and technological developments resulting in higher emissions and greater warming (Flato & Boer 2001; IPCC 2001; CCCma 2007).

Climatic variables used in my analyses included mean monthly minimum and maximum temperatures as well as mean total monthly precipitation. The average annual changes in temperature and precipitation were calculated relative to historical conditions. Minimum mean annual temperatures in the Great Basin are expected to increase by 2.2 ºC for the minimum emission scenario (b2a, CCCma) and 2.7 ºC for the maximum emission scenario (a2a, CCCma). Maximum mean annual temperatures in the Great

Basin are expected to increase by 2.1 ºC for a minimum emission scenario (b2a, CCCma) and 2.6 ºC for a maximum emission scenario (a2a, CCCma). Mean annual precipitation is expected to increase by 4.7 mm for a minimum emission scenario and 5.0 mm for a maximum emission scenario.

Vegetation Data

To generate better predictions of current and future species distributions, I also included vegetation data as an additional independent variable for modeling species distributions. Vegetation data for the western portion for the United States were obtained as land cover (dominant vegetation type) maps with a 30 meter grid resolution; the maps were derived from the GAP Analysis Project (GAP; see http://gapanalysis.nbii.gov). Regional GAP projects are based on distributions of vegetation mapped from the 2001 National Land Cover Dataset (NLCD) satellite imagery data. Land cover classes from several regional GAP programs, including the Northwest region GAP, Southwest region GAP and California region GAP, were compared and reclassified so that similar vegetation types were coded the same by using a Geographic Information System (GIS) (ArcGIS 9.2, Environmental Systems Research Institute, Redlands, California). This resulted in a consolidated land cover map that covers the majority of the western portion of the United States. The extent incorporated the entire state of Nevada as well as much of the neighboring states. This map included the vegetation within the study area as well as the surrounding areas. Montane vegetation was defined as land cover classes occurring at elevations above 2280 meters (Brown 1971; McDonald & Brown 1992). Using this definition with an elevation map of the extent (http://seamless.usgs.gov/) and the land cover map, eleven land cover classes in the Great Basin were identified as montane vegetation (Table 4). All of the remaining land cover classes (< 2280 meters) were reclassified as “other”. Vegetation classes indicated on the maps were sampled by randomly selecting 10,000 coordinates in decimal degrees within the extent of the study. The randomly selected points were then grouped based on the associated vegetation class at that point. Each montane vegetation class had 58-2802 random points associated with it. These groups were a representative sample of the distribution for each vegetation class and were used for modeling the historical distribution of montane vegetation throughout the Great Basin (Lawler et al. 2006).

Species Data

Specimen data for the fourteen mammal species were obtained from the Mammal Networked Information System (MaNIS; see http://manisnet.org/) and the Global Biodiversity Information Facility (GBIF; see http://www.gbif.org/). I obtained occurrence records for all fourteen species; in total 1813 museum records were downloaded. Locality descriptors were ranked based on the type of locality data associated with the species occurrences. Records with locality data in the form of geographic coordinates were ranked the highest, followed by legal descriptions, and finally descriptive locality. Records without locality data were removed from the sample and were not included in the data set. Locality points with only legal descriptions and descriptive locality data were georeferenced by using TRS Windows interface V1.1 (http://members.cox.net/azregion/trs/trs.htm) and BioGeomancer (http://biogeomancer.org/). To identify potential errors associated with georeferencing descriptive locality data, each point was verified to the correct mountain range and/or county and state by projecting the coordinates over a state and county map by using GIS.

I first verified the state where each specimen was collected; 11 points that did not match the locality descriptor were georeferenced by using TRS or BioGeomancer and eighteen specimens were eliminated from the sample due to incomplete data. 1795 coordinates were verified to the county where each specimen was captured, 190 points that did not match the locality descriptor were georeferenced by using TRS or BioGeomancer and 85 coordinates were removed from the sample due to incomplete data. After verifying each coordinate associated with a specimen record to the state and county where it was collected, I had 1710 specimen records with locality points in the form of coordinates for all species. Two species, the white-tailed jackrabbit (*Lepus townsendii*; n = 12) and the ermine (*Mustela ermine*; n = 4), had very few records with locality data, and were excluded (Table 1).

Approach

Climate change is likely to alter species distributions; therefore, my approach focuses on modeling the current distribution of the species and then projecting how climate change will alter that distribution. Models are abstract representations of an object, system, or process. There are a variety of methods for modeling species geographic distributions, each unique relative to model assumptions and techniques (Elith et al. 2006). Maximum entropy (Maxent) modeling is a technique that uses presence only locality data to estimate the potential distribution of a species based on environmental and habitat variables (Phillips et al. 2004, 2006). Models such as these build a function that estimates the probability of occurrence of a species within a grid cell based on a set of environmental conditions. Prior to developing the model, the points representing known occurrences are divided randomly into two groups; the training sample used to build the model equation and the test sample used to test the predictive power of the model equation. This technique is also referred to as cross-validation. Maximum entropy modeling has been implemented in several programs; I used Maxent (Version 3.3.1., http://www.cs.princeton.edu/~schapire/maxent/) because it has good predictive capabilities. Maxent has default settings and new extensions that optimize the predictive power of the model; this allows for the use of diverse datasets and does not require that the user have extensive statistical knowledge (Phillips & Dudík 2008). Models derived from Maxent are robust and it is also user friendly and equipped with several attractive properties including an efficient running time. The occurrence records must accurately represent the environmental space that is occupied by the species. The model assumes that the species distribution is at equilibrium. Therefore, the model does not take into account the dispersal abilities of the species. This technique is effective at determining habitat use and species distributions (Baldwin 2009). Maxent has been ranked among the highest performing programs relative to predictive power when compared to other species distribution modeling techniques (Elith et al. 2006; Pilar et al. 2006; Phillips & Dudík 2008).

Figures 2A and 2B illustrate a simplified view of how locality data and environmental data were utilized in this study. The technique uses historical environmental conditions and point locality data in the form of geographic coordinates to build a model equation that explains the distribution of the species (probability of occurrence). The technique uses the test sample to cross-validate the model equation that was developed with the training points and a binomial test to determine if a model generates predictions that are better than expected by chance. The proportion of points representing the population that were used to train and test the model were selected *a priori*. 85% of the locality points were used to train and build the model equation, while the remaining 15% were used to test model predictions. Errors of omission were measured by counting how many instances the model predicted that the species would be absent from areas where the species was known to occur. The model equation that was built for historical environmental conditions was then used with a set of predicted future environmental conditions to make predictions about changes in the distributions of the vegetation class or species. In modeling the distributions of montane vegetation classes, 36 independent environmental variables were selected including average monthly minimum temperature, average monthly maximum temperature, and average monthly precipitation. For modeling species distributions, 37 independent variables were included: average monthly minimum temperature, average monthly maximum temperature, average monthly precipitation, and the predicted distribution of montane vegetation. The model results are represented as a map indicating the probability of occurrence ranging from 0 to 1 (example in Fig. 3).

All vegetation data were processed in order to match the projection, grain size (1 x 1 km resolution) and extent of all layers. The historical distributions of eleven land cover classes were modeled by using historical environmental variables. Duplicate coordinates for a vegetation class were not included in the analysis. The distribution of each montane vegetation class was predicted using the model equation that was developed by Maxent and the environmental variables for a minimum (b2a, CCCma,) and maximum (a2a, CCCma) emission scenario. In total, three probability maps were generated by Maxent for each vegetation class; one predicted distribution for historical conditions, one for a minimum emission scenario (b2a, CCCma), and one for a maximum emission scenario (a2a, CCCma). The probability maps that Maxent generates represent the probability of occurrence ranging from 0 to1 that a vegetation class is likely to occur within a grid cell given a set of specified environmental conditions.

I selected a threshold value of 10%, in which 10% of the coordinates from the training sample would be excluded from the predicted distribution. In order to determine the 10% threshold value, the probabilities associated with the locality points used to build the model needed to be determined using GIS techniques. Once the probabilities were extracted they were ranked and the lowest 10% were eliminated. Based on the remaining points (90%), a new lower probability threshold was determined; this value is referred to as the “cumulative 10% threshold value”. Any probabilities above this threshold value were included in the distribution and reclassified as 1 (presence), while anything below the threshold value was not included in the distribution and was reclassified as 0 (absence). The probability maps for each vegetation class were then re-classified based on the cumulative 10% threshold value to generate the potential distribution of the vegetation class for historical conditions as well as for a minimum (b2a, CCCma) and a maximum (a2a, CCCma) emission scenario.

I calculated the effects of climate change on the distribution of montane vegetation throughout the Great Basin by comparing the historical distribution of each vegetation class to the predicted distribution for an emission scenario of changing climate. The distributions of all montane vegetation classes were overlaid and combined to produce a single vegetation map or mosaic illustrating the distribution of montane vegetation classes for historical conditions and a minimum (b2a, CCCma) and a maximum (a2a, CCCma) emission scenario (Fig. 4A, 4B, and 4C).

The historical distributions of twelve montane mammals were modeled by using occurrence records for each species and historical environmental data. In addition to environmental variables (temperature and precipitation), I also included the above derived vegetation layer for the eleven classes of montane vegetation. Duplicate coordinates of each species were not included in the analysis. 85% of the coordinates representing the species distribution were used to build the model equation, while the remaining 15% of the locality points were used to test the model equation relative to errors of omission. The distribution of montane mammals was predicted for each species by using the model equation that was developed by Maxent and the environmental variables for a minimum (b2a, CCCma) and maximum (a2a, CCCma) emission scenario. In total, three probability maps were generated by Maxent for each species; one predicted distribution for historical conditions, one for a minimum emission scenario (b2a, CCCma), and one for a maximum emission scenario (a2a, CCCma). The probability maps for each species were then re-classed based on the cumulative 10% threshold value for each species to determine the potential distribution of each species.

I calculated the effect of climate change on the distributions of each species throughout the Great Basin by comparing the historical distribution of each species to the predicted distribution for a scenario of changing climate. Species occurrence on a mountain range was determined by overlapping the predicted distribution of the species with a map of nineteen mountain ranges in the Great Basin. If the predicted distribution of each species overlapped with the location of the mountain range the species was predicted to occupy the mountain range. If the predicted distribution of the species did not overlap with the mountain range, the species was predicted to not occur at that site.

RESULTS

Predicted Distribution of Montane Vegetation

All of the models for the vegetation classes performed significantly better than expected by chance (Table 4). Vegetation classes are predicted to experience a 29-100 % reduction in distribution for a minimum emission scenario (b2a, CCCma) and a 37-100% reduction in distribution for a maximum emission scenario (a2a, CCCma). Rocky Mountain lodgepole pine forest is predicted to become extinct within the study area for both emission scenarios. In contrast, the Rocky Mountain montane dry-mesic mixed conifer forest and woodland vegetation class was predicted to expand its distribution by approximately 771% for a minimum and 612% for a maximum emission scenario. The inter-mountain west aspen-mixed conifer forest & woodland vegetation class showed a 103% increase in distribution for the minimum emission scenario and a 43% decrease in distribution for the maximum emission scenario. Combined, all montane vegetation in the Great Basin is estimated to contract by 65% for a minimum emission scenario and a 70% for a maximum emission scenario (Table 4). The distribution of all eleven montane vegetation classes throughout the Great Basin for historical conditions and a minimum emission scenario (b2a, CCCma) and a maximum emission scenario (a2a, CCCma) illustrate a mosaic of habitat types (Fig. 4).

Predicted Distribution of Montane Mammal Species

A majority of the models for the mammals performed significantly better than expected by chance (Table 5). The Western jumping mouse (*Zapus princeps*) (AUC = 0.742, P = 0.078) and the mountain cottontail (*Sylvilagus nuttallii*) (AUC = 0.963, P = 0.076) did marginally better than expected by chance of predicting the historical distribution. Three species did not perform better than expected by chance including the yellow-bellied marmot (*Marmota flaviventris*) (AUC = 0.550, P = 0.493), bushy-tailed Woodrat (*Neotoma cinerea*) (AUC = 0.697, P = 0.189), and water shrew (*Sorex palustris*) (AUC = 0.630, P = 0.461). These species were not included in further analyses. There was considerable variation between species relative to the variables that contributed the most in determining the probability of occurrence (Table 6). Caution should be used while interpreting the variable contributions when the predictor variables are correlated. All three independent variables; including temperature, precipitation, and vegetation, were likely correlated; therefore, it is difficult to determine the actual contribution of each variable to the distribution of a species.

I predicted that as environmental conditions become warmer, the distributions of montane vegetation and montane mammals would shift up elevational gradients. These shifts in distribution up the slopes of the mountains are likely to result in reductions in available suitable habitat for montane mammals. Reductions in suitable habitat are predicted to cause reductions in population sizes of montane species that might lead to extinctions (Brown 1995).

Overall, the mammal species examined are expected to experience reductions in distribution within the Great Basin ranging from approximately 2-64% for a minimum emission scenario and 39-79% for a maximum emission scenario (Table 5). The vagrant shrew (*Sorex vagrans*) is predicted to experience a 2% reduction in distribution for a minimum emission scenario and a 5% expansion in distribution for a maximum emission scenario. The cliff chipmunk (*Tamias dorsalis*) is predicted to experience a 58%

expansion in distribution for a minimum emission scenario and a 59% reduction in distribution for a maximum emission scenario. The mountain cottontail is predicted to experience a 131% and a 109% expansion in distribution for a minimum and a maximum emission scenario respectively. Three maps illustrating the distributions of each species for historical conditions, a minimum (b2a, CCCma) emission scenario, and a maximum (a2a, CCCma) emission scenario (Fig. 5-13).

Based on the predicted distribution of each species, the mountain ranges with environmental conditions suitable for each species to occur were identified. Table 7 illustrates a species by mountain range matrix indicating the predicted presences (1) and absences (0) of species on each mountain range based on their historical distributions. The matrix produced for historical distributions of species throughout mountain ranges in the Great Basin was then compared to the species by mountain matrix for historical distributions of species adapted from McDonald and Brown (1992). Comparisons made between different model predictions for historical conditions (Table 8 and 9) relative to unexpected occurrences (predicted as present in this study but absent in McDonald and Brown (1992) matrix) and errors of omission (absent in predicted historical distribution by Maxent but present in McDonald and Brown (1992) matrix). The presence and absence of a species on each mountain range was predicted for both a minimum (Table 10) and maximum (Table 11) emission scenario. The occurrences of species on each mountain range for a minimum (b2a, CCCma) and a maximum (a2a, CCCma) emission scenario were compared to the occurrence of species predicted for historical conditions in order to determine whether a species was predicted to persist or not for each emission scenario. Instances in which a species were not predicted to persist were considered to represent local extinctions. Brown (1971, 1978) examined the biogeographical processes that have shaped community structure on the isolated mountain ranges in the Great Basin, and determined that the only process operating in the Great Basin was extinction. Therefore, the Great Basin mammal community is considered to be a non-equilibrial system due to the inability of the montane mammals to cross the desert valleys. Therefore, based on the assumption that the system is nonequilibrial, instances when a species was not predicted to occur on a mountain range for historical conditions should not be on the mountain range in the future. As a result, the presence (1) of each species on nineteen mountain ranges in the Great Basin during historical conditions was compared to the presence (1) or absence (0) of a species on a mountain range in order to determine if the species was predicted to persist in the future for both a minimum (b2a, CCCma) (Table 12) and maximum (a2a, CCCma) (Table 13) emission scenario. Eleven local extinctions were predicted for a minimum emission scenario (b2a, CCCma). Belding's ground squirrel (*Urocitellus beldingi*) is not predicted to persist in the Desatoya Mountains, Roberts Creek, Toiyabe Range, and Toquima Range. The mountain cottontail was not predicted to persist in the Panamint Range, Sheep Range, and Spring Mountains. The Western jumping mouse was not predicted to persist in the Oquirrh Mountains, Sheep Range, Spring Mountains, and Stansbury Mountains. Twenty one local extinctions are predicted for a maximum emission scenario (a2a, CCCma). The American pika was not predicted to persist in Sheep Range. Belding's ground squirrel was not predicted to persist in the Desatoya Mountains, Robert's Creek, Toiyabe Range, and Toquima Range. The golden-mantled ground squirrel (*Callospermophilus lateralis*) was not predicted to persist in Sheep Range. The mountain cottontail was not predicted to persist in the Panamint Range, Sheep Range, and Spring Mountains. The cliff chipmunk was not predicted to persist in the Panamint Range, Pilot Range, Roberts Creek, Ruby Mountains, Sheep Range, Spring Mountains, Spruce Mountains, and Stansbury Mountains. The Uinta chipmunk (*Tamias umbrinus*) was not predicted to persist on the Panamint Range, Roberts Creek, and Sheep Range. The Western jumping mouse was not predicted to persist in Sheep Range. It is predicted that there will be an 8-30% decline and an 8-70% decline in species richness for a minimum emission scenario (b2a, CCCma) and a maximum emission scenario (a2a, CCCma) respectively. Overall, none of the species are predicted to go extinct throughout the entire Great Basin.

DISCUSSION

I predicted that there will be considerable changes in the distributions of montane vegetation classes throughout the mountain ranges of the Great Basin. Most vegetation classes showed a 29-100 % reduction in distribution for a minimum (b2a, CCCma) emission scenario and a 37-100% reduction in distribution for a maximum (a2a, CCCma) emission scenario throughout the Great Basin region. As environmental conditions become much hotter, it is expected that some vegetation classes will shift up elevational gradients, resulting in reductions in distributions. Reductions in montane habitat as a result of changes in climate are comparable to reductions in areas of oceanic islands that would result from rises in sea levels. Vegetation classes like the Rocky Mountain lodgepole pine forest restricted to northern latitudes or mountain peaks are predicted to be eliminated from the region due to the absence of suitable environmental conditions. Instances where vegetation classes are predicted to experience expansions in distributions such as the Rocky Mountain montane dry-mesic mixed conifer forest and woodland vegetation class could be due to shifts in distribution up the slopes of the mountain without reductions in distribution at lower elevations, indicating that these types of vegetations are more adapted to tolerate warmer environmental conditions. Shifts in the distribution of dominant vegetation types along elevational gradients of mountain ranges in southern California have been attributed to regional changes in climate (Kelly & Goulden 2008). I predicted that there will be considerable reductions in cool, mesic montane habitat throughout the Great Basin region for both emission scenarios as a result of warmer environmental conditions.

I predicted that there will be considerable changes in the distributions of montane mammals throughout the mountain ranges of the Great Basin. Montane species in the Great Basin are threatened by changes in habitat due to rapid changes in environmental conditions. The fourteen montane species that have been selected for my analysis are considered to be isolated on montane islands in the Great Basin because of their inability to cross desert valleys (Brown 1971, 1978; but see Grayson and Livingston 1993; Grayson et al. 1996; Lawler 1998). Climate change is predicted to cause shifts in the distributions of vegetation up the slopes of the mountains that will result in reductions in the availability of suitable montane habitat. In addition to the reduction in suitable montane habitat, montane mammals are also predicted to experience shifts in distributions along elevational gradients. These reductions in area are likely to cause reductions in population size which could lead to greater probabilities of extinction. Overall, most species were predicted to experience declines in distribution as a result of changes in climate.

The models for the yellow-bellied marmot, the bushy-tailed woodrat and the water shrew could potentially be improved if the number of points used to represent the populations was larger. The locality points of these species could potentially be associated with a particular vegetation class that represents a major component of the equation, when in reality it is limiting the model’s ability to accurately assess the contribution of the other environmental variables.

The model equations for the mountain cottontail and the Western jumping mouse performed marginally better than expected by chance. The distribution of the mountain cottontail was predicted to expand by 131% and 109% for both for both a minimum and maximum emission scenarios respectively. Grayson and Livingston (1993) have documented the occurrence of the mountain cottontail in areas where the species had not been documented in the past, suggesting inadequate sampling or that the species might be capable of dispersal across the desert valleys. The distribution of the Western jumping mouse is predicted to decrease by 51% and 49% for both minimum and maximum emission scenarios respectively. Model limitations associated with these species might be the small number of sample points used to represent the population; greater power and better predictions might be obtained by increasing sample size.

The model equations for the remaining seven species performed significantly better than expected by chance. Nine of the twelve species were predicted to experience reductions in distributions as a result of climate change. The exceptions were vagrant shrew, which was predicted to experience a 2% reduction in distribution for a minimum emission scenario and a 5% expansion in distribution for a maximum emission scenario, and the cliff chipmunk, which was predicted to experience a 58% expansion in distribution for a minimum emission scenario and a 59% reduction in distribution for a maximum emission scenario. The distributions of the vagrant shrew and cliff chipmunk are predicted to fluctuate for different emission scenarios, suggesting that environmental conditions are favorable for one scenario that allows for the expansion of their distribution, and alternatively for a different emission scenario, the conditions become unsuitable for the species and as a result the species distribution is reduced.

Of the six species that did show the predicted pattern, the American pika is particularly vulnerable to changes in climate due to lethal sensitivity to temperature increases (Smith & Weston 1990). The model's predictions suggest that the American pika will experience considerable reductions in distribution; including 61% for a minimum emission scenario (b2a, CCCma) and 71% for a maximum emission scenario (a2a, CCCma). The American pika was recently nominated as a candidate species for the Endangered Species Act (USFWS 2009). Due to this species sensitivity to high temperatures; petitioners suggest that the American pika is threatened by climate change and other factors (USFWS 2009). Based on available scientific information, the United States Fish and Wildlife Service (USFWS) determined that this species does not warrant protection as a threatened or endangered species under the Endangered Species Act (USFWS 2010). The percent reductions in distributions of the remaining five species showed the predicted pattern (Table 5). My results suggest that the persistence of habitat specific species, including montane mammals in the Great Basin and other species in general, are threatened by changes in climate. The application of this approach to broader scales might help us understand how climate change is likely to alter the distribution and abundance of species.

When comparing the species by mountain matrix predicted by McDonald and Brown (1992) to my predictions, there are some differences for both a minimum emission scenario (Table 14) and a maximum (Table 15) emission scenario. There is some disagreement between model predictions relative to species occurrence and persistence, these instances are noted with a 1^A, 0^B, 1^C, and 1^D. 1^A represents instances in which I predicted that the species will persist on the mountain range and McDonald and Brown (1992) predict that the species will become extinct on the mountain range (23, minimum (b2a) emission scenario; 24, maximum (a2a) emission scenario) (Tables 14 and 15). 0^B represented instances where I predicted that the species does not occur on the mountain range and McDonald and Brown (1992) predict that the species will become extinct on the mountain range (3, minimum (b2a) emission scenario; 3, maximum (a2a) emission scenario)(Tables 14 and 15). 1^C represents instances where I predicted that the species will become extinct on the mountain range and McDonald and Brown (1992) suggest that the species does not occur on the mountain range (7, minimum (b2a) emission scenario; 10, maximum (a2a) emission scenario) (Tables 14 and 15). 1^D indicated instances where I predicted that the species will become extinct on the mountain range and McDonald and Brown (1992) predict that the species will persist on the mountain range (0, minimum (b2a) emission scenario; 6, maximum (a2a) emission scenario) (Tables 14 and 15). Instances in which models disagree are noted on Tables 14 and 15. There is some agreement between model predictions relative to species extinctions, these instances are noted with a 1^E representing agreement on local extinctions of species. There was agreement between models on the predicted extinctions of four species for a minimum emission scenario (b2a, CCCma): Belding's ground squirrel was not predicted to persist on Toiyabe Range, the mountain cottontail was not predicted to persist on Panamint Range and Spring Mountains, and the Western jumping mouse was not predicted to persist on the Oquirrh Mountains. There was agreement between models on the predicted extinctions of five species for a maximum emission scenario (a2a, CCCma): Belding's ground squirrel was not predicted to persist on Toiyabe Range, the mountain cottontail was not predicted to persist on Panamint Range and Spring Mountains, and the cliff chipmunk wass not predicted to persist on Sheep Range and Spruce Mountains.

The model developed by McDonald and Brown (1992) evaluated how climate change was likely to affect extinction of montane mammals in the Great Basin.

McDonald and Brown (1992) used a community level approach to make predictions about processes such as extinction that operate at the population level; therefore, the concepts that were applied do not match the hierarchical level at which the process of acts upon. Species respond to environmental changes in temperature and precipitation independently of one another by adapting or moving into suitable habitats (Gleason 1939). To make more accurate predictions, I used a population level approach to predict the effects of climate change on species distributions. The assumption of the McDonald and Brown (1992) model that all of the zones of vegetation would shift up in elevation by 500 meters was flawed in that they neglected to consider that areas at higher latitudes are not likely to experience equal shifts in elevation when compared to areas at lower latitudes; therefore, this assumption is too general. Changes in temperature are likely to result in changes in precipitation patterns as well; the assumption that precipitation would remain constant under an assumed scenario for changing climate is not supported. Criticisms of the McDonald and Brown (1992) model include cross-valley dispersal due to recent finding that suggest species are able to tolerate the conditions that occur at lower elevations, indicating they might be able to disperse across desert valleys (Grayson & Livingston 1993; Grayson et al. 1996; Skaggs & Boecklen 1996; Lawler 1998). Another criticism regards the occurrence of species in areas in which they were not previously thought to occur, indicating this region is not as well described as previously suggested (Grayson & Livingston 1993; Grayson et al. 1996; Skaggs & Boecklen 1996; Lawler 1998). The bushy-tailed woodrat has been documented at low elevations and in habitat other than montane vegetation, suggesting that the species is not geographically restricted to the mountaintops of the Great Basin (Grayson et al. 1996, Grayson &

Madsen 2000). Although McDonald and Brown (1992) had some flaws associated with their model, this does not weaken its heuristic value.

Some causes for the difference in model predictions include the sources of data and how the data were applied to the model. There are three possible explanations for instances where unexpected presences might occur (noted as 1^U in Table 8). Unexpected presences suggest that some species have avoided detection in areas that have previously been surveyed (Grayson & Livingston 1993); this might occur as a result of temporal biases, survey biases, or the surveyor's ability to detect the species. Many species, including the American pika, continue to be discovered in areas in which they were not thought to occur in the past, suggesting that there is still a great need to document and study species distributions and their associated ecological and environmental requirements (Simpson 2009). Unexpected presences might also suggest that faunal relaxation is occurring at a faster rate than previously thought and as a result species are absent from areas where environmental conditions are suitable for the species to occur. Unexpected presences might also suggest that the model has made errors of commission in which the species is predicted to occur in an area where the species in fact does not occur.

One limitation associated with my approach is the use of highly correlated independent variables. Because temperature influences precipitation patterns, and both temperature and precipitation influence the distributions of vegetative associations, it is difficult to determine which variable contributed more to the model equation and as a result had a greater influence in determining the distribution of the species. The predicted distribution of a species might appear to be influenced more by one of many independent variables, but because the independent variables are highly correlated, it is difficult to determine the actual contribution of the variables.

The use of vegetation distributions along with environmental variables is useful in training the model to predict the distribution of a species based on environmental variables, but it might also negatively affect the model's ability to accurately make predictions about a distribution that best fits the sample points of the species. The inclusion of variables that are not relevant to the actual distribution of a species can appear to improve model predictions when in fact they have no effect on the real distribution. This can potentially result in over-fitting of the model which decreases the model's ability to accurately predict the distribution of the species.

The Great Basin is considered to be a non-equilibrial system (at least for some of the species), but my approach assumes that the system is equilibrial. As a result the model might predict reduced distributions. If a species was predicted to be absent from a mountain range for historical conditions it is assumed that the species is unlikely to successfully move into new areas where it did not occur previously but in which environmental conditions are appropriate. Violating the assumption of equilibrial distribution might yield predictions that underestimate the actual distributions of the species. Understanding model assumptions and limitations is beneficial in being able to accurately assess model predictions. Comparisons between model techniques and predictions is critical in understanding how climate change is likely to alter the patterns and processes that are operating both at a global scale and smaller scales.

Although it is unclear as to how anthropogenic changes in climate are likely to affect ecosystem functions and species across the globe, most researchers agree that climate change poses a serious threat to biodiversity (Thomas et al. 2004; Thomas et al. 2006; Massot et al. 2008; Rosenzweig et al. 2008). The effects of climate changes have been documented in several taxa including plants, insects, birds and mammals (Hoegh-Guldberg 1999; Parmesan et al. 1999; Peñuelas & Filella 2001; Pounds 2001; Walther et al. 2002; La Sorte & Thompson 2007; Kelly & Goulden 2008; Moritz et al. 2008). Changes in climate are likely to alter the distribution and abundance of species; therefore, some species will become increasingly vulnerable to extinctions (McLaughlin et al. 2002). Based on our results, it is predicted that changes in climate will cause geographically isolated montane species to move up elevational gradients which will result in considerable reductions in distribution, and as a result, species populations will decrease and will be pushed closer to the brink of extinction.

By applying models and understanding the advantages and limitations associated with each, we can infer something about patterns and processes that are operating in the systems. By comparing between model assumptions and predictions, researchers can gain a better understanding about how the system is likely to change as a result of climate change. Comparisons between model predictions provide a basis on which researchers can develop generalizations about the influence of climate change on species distributions in an effort to conserve biodiversity.

Understanding how climate change will affect the distribution and continued persistence of species across the globe can be better understood through the use of predictive modeling techniques. Modeling techniques provide a glimpse at the potential effects of climate change on species distributions and ecosystem functions. Although the predictions associated with the models are difficult to assess, there are generalities among models that are consistent throughout model predictions. These generalities provide some indications as to where conservation and management efforts should be focused to conserve species that are most vulnerable to changes in climate. Therefore it is imperative that we evaluate and understand how climate change is likely to alter species distributions, especially those species that have specific habitat requirements, are not as abundant, and are unable to move freely through a fragmented landscape.

The uncertainties associated with climate change make it very difficult to develop management and conservation practices that will help ensure the conservation of global biodiversity. Disciplines involved in management or conservation decisions often have to make decisions with very little understanding about the organism in question and with limited amounts of data (Starfield & Bleloch 1986). There is a wealth of information in the literature and museum records that can be used along with species distribution modeling programs to provide insight into how species are likely to respond to the changes in climate. Model predictions can help us better understand the uncertainties associated with climate change. Although model predictions are difficult to test, comparisons between model predictions can help develop generalities about species responses to climate change. Instances in which my model predictions agreed with the McDonald and Brown (1992) model suggest that we should pay particular attention to those species at those particular sites (Table 14 and 15). There was general agreement between both my models for a minimum (b2a) and maximum (a2a) emission scenarios and the McDonald and Brown (1992) model for three local extinctions of Belding's ground squirrel, mountain cottontail, and Western jumping mouse, indicating that we should monitor these species closely at those sites. The predictions that are produced by the models can then help develop a plan of action or help guide the establishment of new reserves and wildlife refuges in an effort to minimize the effects of habitat fragmentation and allow for the movement of organisms in response to climate change.

Humans have a significant impact on terrestrial, aquatic, and marine systems. Most notably, we have also had a significant impact on our atmosphere. Climate change is likely to become one of the greatest challenges for wildlife managers and conservation biologists and their ability to maintain sustainable populations and functional ecological process. Species with specific habitat requirements and low abundances are the most likely to be at risk due to changes in climate. It is important to conservation biologists that we identify species that are most susceptible to changes in climate and that conservation plans are developed in an effort to ensure that species will be able to move in response to the changing environmental conditions. Habitat corridors would provide suitable routes through that would allow species move into and out of habitats and reduce the negative impacts associated with habitat fragmentation and isolation. Species distribution modeling techniques provide a means by which researchers can evaluate what conditions allow for the persistence of species. These techniques could help guide the selection and development of future wildlife conservation reserves. These reserves would provide habitat that would be suitable for species to persist. In an effort to understand the effects of climate change on the persistence of biodiversity, it is crucial that we look to the future to try to gain a better understanding of how global anthropogenic changes are likely to affect the persistence of species. By studying the effects that humans have on global processes, we can develop new and innovative techniques to help reduce the human environmental footprint and, as a result, minimize the loss of biodiversity and maintain ecosystem function.

REFERENCES

Arrhenius, 0. 1921. Species and area. Journal of Ecology **9:**95-99.

Baldwin, R. A. 2009. Use of Maximum Entropy Modeling in Wildlife Research. Entropy **11:**854-866.

Barkley, T. M. 1993. Synthesis: A Historical Perspective. Annals of the Missouri Botanical Garden **80:**292-296.

Boecklen, W. J., and N. J. Gotelli. 1984. Island Biogeographic theory and conservation practice: species-area or specious-area relationship? Biological Conservation **29:**63-80.

Brown, J. H. 1971. Mammals on mountaintops: nonequilibrium insular biogeography. The American Naturalist **105:**467-478.

Brown, J. H. 1978. The theory of insular biogeography and the distribution of boreal birds and mammals. Great Basin Naturalist Memoirs **2:**209-228.

Brown, J. H. 1995. Macroecology. University of Chicago Press, Chicago.

Canadian Centre for Climate Modelling and Analysis (CCCma). 2007. Equivalent CO2 concentrations used in CCCma coupled global model simulations. Available from http://www.cccma.ec.gc.ca/data/cgcm/cgcm_forcing.shtml (accessed February 2009).

Chapin, F. S., et al. 2000. Consequences of changing biodiversity. Nature **405:**234-242.

Davis, M. B. and R. G. Shaw. 2001. Range shifts and adaptive responses to Quaternary climate change. Science **292:**673-679.

Earn, D. J. D., S. A. Levin, and P. Rohani. 2000. Coherence and conservation. Science **290:**1360-64.

Elith, J., C. Graham, and the NCEAS Species Distribution Modelling Group. 2006. Novel methods improve prediction of species' distributions from occurrence data. Ecography **29:**129-151.

Fischer, J., and D. B. Lindenmayer. 2005. Perfectly nested or significantly nested - an important difference for conservation management. Oikos **109:**485-494.

Flato, G.M., and G. J. Boer. 2001. Warming asymmetry in climate change simulations. Geophysical Research Letters **28:**195-198.

Gleason, H. A. 1939. The individualistic concept of the plant association. American Midland Naturalist **21:**92-110.

Graham, C. H., S. Ferrier, F. Huettman, C. Moritz, and A. T Peterson. 2004. New developments in museum-based informatics and applications in biodiversity analysis. Trends in Ecology and Evolution **19:**497–503.

Grayson, D. K. 1987. The biogeographic history of small mammals in the Great Basin: observations on the last 20,000 years. Journal of Mammalogy **68:**359-375.

Grayson, D. K. 1993. The deserts' past: a natural history of the Great Basin. Smithsonian Institute Press, Washington, D.C.

Grayson, D. K. 2000. Mammalian responses to Middle Holocene climate change in the Great Basin of the western United Sates. Journal of Biogeography **27:**181-192.

Grayson, D. K., and S. D. Livingston. 1993. Missing mammals on Great Basin mountains: Holocene extinctions and inadequate knowledge. Conservation Biology **7:**527-532.

Grayson, D. K., S. D. Livingston, E. Rickart, and M. W. Shaver. 1996. The biogeographic significance of low elevation records for *Neotoma cinerea* from the northern Bonneville Basin, Utah. Great Basin Naturalist **56:**191-196.

Grayson, D. K. and D. B. Madsen. 2000. Biogeographic implications of recent low-elevation recolonization by *Neotoma cinerea* in the Great Basin. Journal of Mammalogy **81:**1100-1105.

Hannah, L., G. F. Midgley, and D. Millar. 2002. Climate change-integrated conservation strategies. Global Ecology and Biogeography **11:**485-495.

Hijmans, R. J., S. E. Cameron, J. L. Parra, P. G. Jones, and A. Jarvis, 2005. Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology **25:**1965-1978.

Hoegh-Guldberg, O. 1999. Climate change, coral bleaching and the future of the world’s coral reefs. Marine Freshwater Research **50:**839–866.

Holt, R. D. 1990. The micro-evolutionary consequences of climate change. Trends in Ecology and Evolution **5:**311-315.

Houghton, J. T., et al. 2001. Climate Change 2001: The Scientific Basis. Contributions of Working Group I to the third assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom.

Hughes, L. 2000. Biological consequences of global warming: is the signal already apparent? Trends in Ecology and Evolution **15:**56-61.

Intergovernmental Panel on Climate Change (IPCC). 2001. Climate Change 2001: Impacts, Adaptation, and Vulnerability: Contribution of Working Group II to the

Third Assessment Report of the Intergovernmental Panel on Climate Change, edited by J. J. McCarthy et al., Cambridge University Press, New York.

Kelly A. E., and M. L. Goulden. 2008. Rapid shifts in plant distribution with recent climate change. Proceedings of the National Academy of Science of the United States of America **105:**11823-11826.

La Sorte, F. A., and F. R. Thompson. 2007. Poleward shifts in winter ranges of North American birds. Ecology **88:**1803-1812.

Lawler, T. E. 1998. Biogeography of Great Basin mammals: paradigm lost? Journal of Mammalogy **79:**1111-1130.

Lawler, J. J., D. White, R. P. Neilson, and A.R. Blaustein. 2006. Predicting climate-induced range shifts: model differences and model reliability. Global Change Biology **12:**1568-1584.

Lovejoy, T., and L. Hannah, editors. 2005. In Climate Change and Biodiversity. Yale University Press, New Haven, Connecticut.

MacArthur, R. H., and E. O. Wilson. 1963. An equilibrium theory of insular zoogeography. Evolution **17:**373–387.

MacArthur, R. H., and E. O. Wilson. 1967. The theory of island biogeography. Princeton University Press, Princeton, New Jersey.

Massot, M., J. Clobert, and R. Ferrière. 2008. Climate warming, dispersal inhibition and extinction risk. Global Change Biology **14:**461-469.

McCarty, J. P. 2001. Ecological consequences of recent climate change. Conservation Biology **15:**320-331.

McDonald, K. A. and J. H. Brown. 1992. Using montane mammals to model extinctions due to global change. Conservation Biology **6:**409-415.

McKee, J. K., P. W. Sciulli, C. D. Fooce, and T. A. Waite. 2003. Forecasting global biodiversity threats associated with human population growth. Biological Conservation **115:**161-64.

McLaughlin, J. F., J. J. Hellmann, C. L. Boggs, and P. R. Ehrlich. 2002. Climate change hastens population extinctions. Proceedings of the National Academy of Science of the United States of America **99:**6070-6074.

Moritz, C., J. L. Patton, C. J. Conroy, J. L. Parra, G. C. White, and S. R. Bessenger. 2008. Impact of a century of climate change on small mammal communities in Yosemite National Park, USA. Science **322:**261-264.

Newbold, T. 2010. Applications and limitations of museum data for conservation and ecology, with particular attention to species distribution models. Progress in Physical Geography **34:**3-22.

Parmesan, C., et al. 1999. Poleward shifts in geographical ranges of butterfly species associated with regional warming. Nature **399:**579-583.

Parmesan, C. 2006. Ecological and evolutionary responses to recent climate change. Annual Review of Ecology, Evolutions, and Systematics **37:**637-669.

Patterson, B. D. 1987. The principle of nested subsets and its implications for biological conservation. Conservation Biology **1:**323-335.

Patterson, B. D., and W. Atmar. 1986. Nested subsets and the structure of insular mammalian faunas and archipelagos. Biological Journal of the Linnean Society **28:**65-82.

Pearce, J. L., and M. S. Boyce. 2006. Modelling distribution and abundance with presence-only data. Journal of Applied Ecology **43:**405-412.

Pearson, R. G., and T. P. Dawson, 2003. Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful? Global Ecology and Biogeography **12:**361-371.

Peñuelas, J., and I. Filella,. 2001. Responses to a warming world. Science **294:**793–795

Peters R. L., and T. E. Lovejoy, editors. 1992. Global warming and biological diversity. Yale University Press, New Haven, Connecticut.

Phillips, S. and M. Dudík. 2008. Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. Ecography **31:**161-175.

Phillips, S. J., M. Dudik, and R. E. Schapire. 2004. A maximum entropy approach to species distribution modeling. Proceeding of the twenty-first international conference on machine learning **69:**83-90.

Phillips, S. J., R. P. Anderson, and R. E. Schapire. 2006. Maximum entropy modelling of species geographic distributions. Ecological Modelling **190:**231-259.

Pilar, H. A., C. H. Graham, L. L. Master, and D. L. Albert. 2006. The effect of sample of sample size and species characteristics on performance of different species distribution modeling methods. Ecography **29:**773-785.

Pounds, J. A. 2001. Climate and amphibian declines. Nature **410:**639-640

Rodríguez, J. P., L. Brotons, J. Bustamante, and J. Seoane. 2007. The application of predictive modelling of species distribution to biodiversity conservation. Diversity and Distributions **13:**243-251.

Rosenzweig C., et al. 2008. Attributing physical and biological impacts to anthropogenic climate change. Nature **453:**353-357.

Rotenberry, J. T., K. L. Preston, and S.T. Knick. 2006. GIS-based niche modeling for mapping species' habitat. Ecology **87:**1458-1464.

Sala, O. E., et al. 2000. Global biodiversity scenarios for the year 2100. Science **287:**1770-1774.

Simpson, W. G. 2009. American Pikas inhabiting low-elevation sites outside the species' previously described bioclimatic envelope. Western North American Naturalist **69:**243-250.

Skaggs, R. W., and W. J. Boecklen. 1996. Extinctions of montane mammals reconsidered: putting a global-warming scenario on ice. Biodiversity Conservation **5:**759-778

Smith, A. T. 1974. The distribution and dispersal of pika: consequences of insular population structure. Ecology **55:**1112-1119.

Smith, A. T., and M. L. Weston. 1990. *Ochotona princeps*. Mammalian Species **352:**1-8.

Starfield, A. M., and A. L. Bleloch. 1986. Building models for conservation and wildlife management. Macmillan, New York.

Thomas, C.D., et al. 2004. Extinction risk from climate change. Nature **427:**145-148.

Thomas, C. D., A. M. A. Franco, and J. K. Hill. 2006. Range retractions and extinctions in the face of climate warming. Trends in Ecology and Evolution **21:**415–416.

Thompson, R. S., and J.I. Mead. 1982. Late Quaternary environments and biogeography in the Great Basin. Quaternary Research **17:**39-55.

United States Fish and Wildlife Service (USFWS). 2009. Fish and Wildlife Service to conduct status review of the American pika. Available from http://www.fws.gov/nevada/highlights/news_releases/2009/050709_final_pika_nr.pdf (accessed March 2010).

United States Fish and Wildlife Service (USFWS). 2010. Endangered Species Act Protection for the American pika is not warranted. Available from http://www.fws.gov/mountain-prairie/species/mammals/americanpika/PressRelease02052010.pdf (accessed March 2010)

Vitousek, P. M., H. A. Mooney, J. Lubchenco, and J. M. Melillo. 1997. Human domination of Earth's ecosystems. Science **277:**494-499.

Waltari, E., and R. Guralnick. 2008. Ecological niche modelling of montane mammals in the Great Basin, North America: Examining past and present connectivity of species across basins and ranges. Journal of Biogeography **36 :**148-161.

Walther, G. R., E. Post, P. Convey, A. Menzel, C. Parmesan, T. J. C. Beebee, J. M. Fromentin, O. Hoegh-Guldberg, and F. Bairlein. 2002. Ecological responses to recent climate change. Nature **416:**389–395.

Williams, J. W., and S. T. Jackson. 2007. Novel climates, no-analog communities, and ecological surprises. Frontiers in Ecology and the Environment **5:**475-482.

Williams, J. W., S. T. Jackson, and J. E. Kutzbach. 2007. Projected distributions of novel and disappearing climates by 2100 AD. Proceedings of the National Academy of Sciences of the United States of America **104:**5738-5742.

Table 1. Montane mammal species of the Great Basin (adapted from McDonald & Brown 1992). The list indicates the identity of the species that were under consideration for this analysis. *Indicate species that were excluded from the sample due to an insufficient number of locality points. ** indicates species whose model did not perform statistically better than expected by chance and as a result were removed from the analysis.

SCIENTIFIC NAME	COMMON NAME	ABBREVIATION
Callospermophilus lateralis	Golden-mantled Ground Squirrel	CALA
Microtus longicaudus	Long-tailed Vole	MILO
Ochotona princeps	American Pika	OCPR
Sorex vagrans	Vagrant Shrew	SOVA
Sylvilagus nuttallii	Mountain Cottontail	SYNU
Tamias dorsalis	Cliff Chipmunk	TADO
Tamias umbrinus	Uinta Chipmunk	TAUM
Urocitellus beldingi	Belding’s Ground Squirrel	URBE
Zapus princeps	Western Jumping Mouse	ZAPR
*Marmota flaviventris***	Yellow-bellied Marmot	MAFL
*Neotoma cinerea***	Bushy-tailed Woodrat	NECI
*Sorex palustris***	Water Shrew	SOPA
*Lepus townsendii**	White-tailed Jackrabbit	LETO
*Mustela erminea**	Ermine	MUER

Table 2. Historical occurrence records of twelve small boreal mammal species among nineteen isolated mountain ranges in the Great Basin (adapted from McDonald & Brown 1992). 1 = species occurs on mountain range. 0 = species do not occur on mountain range.

RANGE	SPECIES												Number of species present
	CALA	MAFL	MILO	NECI	OCPR	SOPA	SOVA	SYNU	TADO	TAUM	URBE	ZAPR	
Deep	1	1	1	1	0	0	1	1	1	1	0	0	8
Desatoya	1	1	1	1	1	0	0	1	1	1	0	0	8
Diamond	1	0	0	1	0	0	0	0	1	1	0	0	4
Grant	1	0	1	0	0	0	0	1	1	1	0	0	5
Oquirrh	0	1	1	1	0	1	1	0	1	1	0	1	8
Panamint	0	0	0	1	0	0	0	1	1	0	0	0	3
Pilot	1	0	0	1	0	0	0	0	1	0	0	0	3
Roberts	0	0	1	0	0	1	0	0	0	1	0	1	4
Ruby	1	1	1	1	1	1	1	1	0	1	1	1	11
Schell	1	1	1	1	0	0	1	1	1	1	0	0	8
Sheep	0	0	0	1	0	0	0	0	1	1	0	0	3
Snake	1	1	1	1	0	1	1	1	1	1	0	0	9
Spring	1	0	0	1	0	0	1	1	1	1	0	0	6
Spruce	1	0	0	1	0	0	0	0	1	1	0	0	4
Stansbury	0	1	1	1	0	1	1	0	1	1	0	0	7
Toiyabe	1	1	1	1	1	1	1	1	1	1	1	1	12
Toquima	1	1	1	1	1	1	1	1	1	1	0	1	11
White Pine	1	1	1	1	0	0	0	1	1	1	0	0	7
White-Inyo	1	1	1	1	1	1	1	1	1	1	0	0	10
Number of ranges inhabited	14	11	13	17	5	8	10	12	17	17	2	5	

Table 3. Predicted distribution of twelve small boreal mammal species among nineteen isolated mountain ranges in the Great Basin for an assumed scenario of climate change (Adapted from McDonald & Brown 1992). 1 = species occurs on mountain range. 0 = species do not occur on mountain range. 1^E = Species predicted to go extinct for an assumed scenario of changing climate.

RANGE	SPECIES												Number of species present
	CALA	MAFL	MILO	NECI	OCPR	SOPA	SOVA	SYNU	TADO	TAUM	URBE	ZAPR	
Deep	1	1^E	1	1	0	0	1^E	1^E	1	1	0	0	5
Desatoya	1^E	1^E	1^E	1	1^E	0	0	1^E	1	1	0	0	3
Diamond	1^E	0	0	1	0	0	0	0	1^E	1	0	0	2
Grant	1	0	1^E	0	0	0	0	1^E	1	1	0	0	3
Oquirrh	0	1	1	1	0	1	1	0	1	1	0	1^E	7
Panamint	0	0	0	1	0	0	0	1^E	1	0	0	0	2
Pilot	1^E	0	0	1	0	0	0	0	1	0	0	0	2
Roberts	0	0	1	0	0	1^E	0	0	0	1	0	1^E	2
Ruby	1	1	1	1	1^E	1	1	1	0	1	1^E	1^E	8
Schell	1	1^E	1	1	0	0	1^E	1^E	1	1	0	0	5
Sheep	0	0	0	1	0	0	0	0	1^E	1	0	0	2
Snake	1	1	1	1	0	1^E	1	1	1	1	0	0	8
Spring	1	0	0	1	0	0	1^E	1^E	1	1	0	0	4
Spruce	1^E	0	0	1	0	0	0	0	1^E	1	0	0	2
Stansbury	0	1	1	1	0	1^E	1	0	1	1	0	0	6
Toiyabe	1	1	1	1	1	1	1	1	1	1	1^E	1^E	10
Toquima	1	1	1	1	1^E	1	1	1	1	1	0	1^E	9
White Pine	1	1^E	1^E	1	0	0	0	1^E	1	1	0	0	4
White-Inyo	1	1	1	1	1^E	1	1	1	1	1	0	0	9
Number of ranges inhabited	10	7	10	17	1	5	7	5	14	17	0	0	

Table 4. GAP map land cover classes defined as montane vegetation occurring at elevations above 2280 meters. Results indicating model performance relative to predicting the distributions of montane vegetation classes as measured by errors of omission. The historical distribution of each montane vegetation class is listed along with the predicted distributions for a minimum (b2a, CCCma) and maximum (a2a, CCCma) emission scenario.

Code #	VEGETATION CLASS	Test data AUC	P-value	Historical (km^2)	Future b2a (km^2)	% Change in distribution	Future a2a (km^2)	% Change in distribution
1	Rocky Mountain Aspen Forest and Woodland	0.954	< 0.001	43222	11282	-74	14259	-67
2	Inter-Mountain Basins Subalpine Limber-Bristlecone Pine Woodland	0.996	< 0.001	3060	2176	-29	678	-78
3	Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest & Woodland	0.974	< 0.001	3260	125	-96	575	-82
4	Northern Pacific Mesic Subalpine Woodland	0.996	< 0.001	15979	11093	-31	9411	-41
5	Rocky Mountain Subalpine Mesic Spruce-Fir Forest & Woodland	0.965	< 0.001	12076	8143	-33	4586	-62
6	Rocky Mountain Lodgepole Pine Forest	0.977	< 0.001	3624	0	-100	13	-100
7	Rocky Mountain Montane Dry-Mesic Mixed Conifer Forest & Woodland	0.98	< 0.001	4858	42293	771	34586	612
8	Rocky Mountain Montane Mesic Mixed Conifer Forest & Woodland	0.976	< 0.001	11366	4412	-61	7128	-37
9	Inter-Mountain West Aspen-Mixed Conifer Forest & Woodland	0.993	< 0.001	1647	3348	103	940	-43
10	Inter-Mountain Basins Mountain Mahogany Woodland & Shrubland	0.953	< 0.001	65682	6004	-91	2870	-96
11	Inter-Mountain Basins Montane Sagebrush Steppe	0.926	< 0.001	119964	9446	-92	9107	-92

Table 5. Results indicating model performance relative to predicting the distributions of montane mammals as measured by errors of omission. The historical distribution of each montane mammal is listed along with the predicted future distributions for a minimum (b2a, CCCma) and a maximum (a2a, CCCma) emission scenario. Negative signs represent reductions in distribution and positive signs represent expansions in distribution. Models for species that did not perform significantly better than expected by chance are indicated with ** after the scientific name, these species were not included in subsequent analyses. Models for species that performed marginally better than expected by chance are indicated with ♦ after the scientific name.

SPECIES	Test data AUC	P-value	Historical (km^2)	Future b2a (km^2)	% change in distribution	Future a2a (km^2)	% change in distribution
Callospermophilus lateralis	0.75	0.011	216819	78647	-64	49220	-77
*Marmota flaviventris***	0.55	0.493	446881	185247	-59	130104	-71
Microtus longicaudus	0.741	0.001	246142	194499	-21	149043	-39
*Neotoma cinerea***	0.697	0.189	240418	434489	81	485830	102
Ochotona princeps	0.942	< 0.001	111815	43716	-61	32675	-71
*Sorex palustris***	0.63	0.461	521830	274259	-47	220916	-58
Sorex vagrans	0.869	< 0.001	288577	283632	-2	302400	5
Sylvilagus nuttallii◆	0.963	0.076	210232	485985	131	438581	109
Tamias dorsalis	0.948	< 0.001	81598	128687	58	33887	-59
Tamias umbrinus	0.837	0.001	160838	77449	-52	56056	-65
Urocitellus beldingi	0.872	< 0.001	158232	74477	-53	33504	-79
Zapus princeps◆	0.742	0.078	186560	91768	-51	95436	-49

Table 6. Percent contribution of the five most significant environmental variables in each of the species distribution models ranked from highest importance (1) to least importance (5) along with the percent contribution of each to the training of the data set. Variables include minimum monthly temperature (tmin), maximum monthly temperature (tmax), and monthly precipitation (prec). 1 = Jan, 2 = Feb, 3 = Mar, 4 = Apr, 5 = May, 6 = Jun, 7 = Jul, 8 = Aug, 9 = Sep, 10 = Oct, 11 = Nov, 12 = Dec.

SPECIES	Environmental variables ranked by % Contribution									
	1		2		3		4		5	
Callospermophilus lateralis	tmin03	17	veg	16	prec03	12	prec11	12	prec06	9.9
Microtus longicaudus	veg	23	prec01	20	prec03	14	tmin10	9.4	tmax08	9.3
Ochotona princeps	veg	41	tmax08	34	tmax04	6.4	prec02	5.9	tmin11	1.9
Sorex vagrans	prec12	52	veg	9.6	prec04	6.5	prec05	4.5	tmax02	4.4
Sylvilagus nuttallii	tmin10	26	prec03	18	prec06	18	prec12	18	prec11	4.4
Tamias dorsalis	prec07	53	tmin07	9.3	tmax12	8.1	prec06	7.9	prec02	5.5
Tamias umbrinus	veg	46	prec07	16	tmin12	7.8	prec06	6.6	tmin02	3.2
Urocitellus beldingi	veg	19	prec06	11	prec12	9.9	prec11	9.8	tmin09	8.6
Zapus princeps	veg	35	prec01	12	prec12	11	prec05	8.6	tmin08	6.5

Table 7. Distribution of nine small boreal mammal species among nineteen isolated mountain ranges in the Great Basin predicted by Maxent modeling for historical conditions.

	SPECIES									Number of species present
RANGE	CALA	MILO	OCPR	SOVA	SYNU	TADO	TAUM	URBE	ZAPR	
Deep	1	1	1	1	0	1	1	0	1	7
Desatoya	1	1	1	1	1	1	1	1	1	9
Diamond	1	1	1	1	1	1	1	0	1	8
Grant	1	1	1	0	1	1	1	0	1	7
Oquirrh	1	1	1	1	0	0	1	0	1	6
Panamint	1	1	1	1	1	1	1	0	1	8
Pilot	0	1	1	1	0	1	1	0	1	6
Roberts	1	1	1	1	0	1	1	1	1	8
Ruby	1	1	1	1	0	1	1	1	1	8
Schell	1	1	1	1	1	1	1	0	1	8
Sheep	1	1	1	0	1	1	1	0	1	7
Snake	1	1	1	1	1	1	1	0	1	8
Spring	1	1	1	0	1	1	1	0	1	7
Spruce	1	1	1	1	0	1	1	0	1	7
Stansbury	1	1	1	1	0	1	1	0	1	7
Toiyabe	1	1	1	1	1	1	1	1	1	9
Toquima	1	1	1	1	1	1	1	1	1	9
White Pine	1	1	1	1	1	1	1	0	1	8
White-Inyo	1	1	1	1	1	1	1	1	1	9
Number of ranges inhabited	18	19	19	16	12	18	19	6	19	

Table 8. Historical distributions of nine montane mammals predicted by Maxent compared to the species distribution documented by McDonald and Brown (1992). Unexpected presences are when a species is predicted to be present (1) on a mountain range, but the species is not noted as occurring on that mountain range by McDonald and Brown (1992). 1^U = Unexpected presences.

	SPECIES									Number of species present
RANGE	CALA	MILO	OCPR	SOVA	SYNU	TADO	TAUM	URBE	ZAPR	
Deep	1	1	1^U	1	0	1	1	0	1^U	7
Desatoya	1	1	1	1^U	1	1	1	1^U	1^U	9
Diamond	1	1^U	1^U	1^U	1^U	1	1	0	1^U	8
Grant	1	1	1^U	0	1	1	1	0	1^U	7
Oquirrh	1^U	1	1^U	1	0	0	1	0	1	6
Panamint	1^U	1^U	1^U	1^U	1	1	1^U	0	1^U	8
Pilot	0	1^U	1^U	1^U	0	1	1^U	0	1^U	6
Roberts	1^U	1	1^U	1^U	0	1^U	1	1^U	1	8
Ruby	1	1	1	1	0	1^U	1	1	1	8
Schell	1	1	1^U	1	1	1	1	0	1^U	8
Sheep	1^U	1^U	1^U	0	1^U	1	1	0	1^U	7
Snake	1	1	1^U	1	1	1	1	0	1^U	8
Spring	1	1^U	1^U	0	1	1	1	0	1^U	7
Spruce	1	1^U	1^U	1^U	0	1	1	0	1^U	7
Stansbury	1^U	1	1^U	1	0	1	1	0	1^U	7
Toiyabe	1	1	1	1	1	1	1	1	1	9
Toquima	1	1	1	1	1	1	1	1^U	1	9
White Pine	1	1	1^U	1^U	1	1	1	0	1^U	8
White-Inyo	1	1	1	1	1	1	1	1^U	1^U	9
Number of ranges inhabited	18	19	19	16	12	18	19	6	19	

Table 9. Historical distributions of nine montane mammals predicted by Maxent compared to the species distribution documented by McDonald and Brown (1992). Errors of omission are referred to as instances where a species is predicted to be absent on a mountain range (0), but the species is noted as occurring on that mountain range by McDonald and Brown (1992). 0^{O} = Error of Omission.

	SPECIES									Number of species present
RANGE	CALA	MILO	OCPR	SOVA	SYNU	TADO	TAUM	URBE	ZAPR	
Deep	1	1	1	1	0^{O}	1	1	0	1	7
Desatoya	1	1	1	1	1	1	1	1	1	9
Diamond	1	1	1	1	1	1	1	0	1	8
Grant	1	1	1	0	1	1	1	0	1	7
Oquirrh	1	1	1	1	0	0^{O}	1	0	1	6
Panamint	1	1	1	1	1	1	1	0	1	8
Pilot	0^{O}	1	1	1	0	1	1	0	1	6
Roberts	1	1	1	1	0	1	1	1	1	8
Ruby	1	1	1	1	0^{O}	1	1	1	1	8
Schell	1	1	1	1	1	1	1	0	1	8
Sheep	1	1	1	0	1	1	1	0	1	7
Snake	1	1	1	1	1	1	1	0	1	8
Spring	1	1	1	0^{O}	1	1	1	0	1	7
Spruce	1	1	1	1	0	1	1	0	1	7
Stansbury	1	1	1	1	0	1	1	0	1	7
Toiyabe	1	1	1	1	1	1	1	1	1	9
Toquima	1	1	1	1	1	1	1	1	1	9
White Pine	1	1	1	1	1	1	1	0	1	8
White-Inyo	1	1	1	1	1	1	1	1	1	9
Number of ranges inhabited	18	19	19	16	12	18	19	6	19	

Table 10. Distribution of nine small boreal mammal species among nineteen isolated mountain ranges in the Great Basin predicted by Maxent for a minimum emission scenario (b2a, CCCma).

	SPECIES									Number of species present
RANGE	CALA	MILO	OCPR	SOVA	SYNU	TADO	TAUM	URBE	ZAPR	
Deep	1	1	1	1	1	1	1	0	1	8
Desatoya	1	1	1	1	1	1	1	0	1	8
Diamond	1	1	1	1	1	1	1	0	1	8
Grant	1	1	1	0	1	1	1	0	1	7
Oquirrh	1	1	1	1	0	0	1	0	0	5
Panamint	1	1	1	1	0	1	1	0	1	7
Pilot	1	1	1	1	0	1	1	0	1	7
Roberts	1	1	1	1	1	1	1	0	1	8
Ruby	1	1	1	1	1	1	1	1	1	9
Schell	1	1	1	1	1	1	1	0	1	8
Sheep	1	1	1	0	0	1	1	0	0	5
Snake	1	1	1	1	1	1	1	0	1	8
Spring	1	1	1	0	0	1	1	0	0	5
Spruce	1	1	1	1	0	1	1	0	1	7
Stansbury	1	1	1	1	1	1	1	0	0	7
Toiyabe	1	1	1	1	1	1	1	0	1	8
Toquima	1	1	1	1	1	1	1	0	1	8
White Pine	1	1	1	1	1	1	1	0	1	8
White-Inyo	1	1	1	1	1	1	1	1	1	9
Number of ranges inhabited	19	19	19	16	13	18	19	2	15	

Table 11. Distribution of nine small boreal mammal species among nineteen isolated mountain ranges in the Great Basin predicted by Maxent for a maximum emission scenario (a2a, CCCma).

	SPECIES									Number of species present
RANGE	CALA	MILO	OCPR	SOVA	SYNU	TADO	TAUM	URBE	ZAPR	
Deep	1	1	1	1	1	1	1	0	1	8
Desatoya	1	1	1	1	1	1	1	0	1	8
Diamond	1	1	1	1	1	1	1	0	1	8
Grant	1	1	1	1	1	1	1	0	1	8
Oquirrh	1	1	1	1	0	0	1	0	1	6
Panamint	1	1	1	1	0	0	0	0	1	5
Pilot	1	1	1	1	0	0	1	0	1	6
Roberts	1	1	1	1	0	0	0	0	1	5
Ruby	1	1	1	1	0	0	1	1	1	7
Schell	1	1	1	1	1	1	1	0	1	9
Sheep	0	1	0	0	0	0	0	0	0	1
Snake	1	1	1	1	1	1	1	0	1	8
Spring	1	1	1	0	0	0	1	0	1	5
Spruce	1	1	1	1	0	0	1	0	1	6
Stansbury	1	1	1	1	1	0	1	0	1	7
Toiyabe	1	1	1	1	1	1	1	0	1	8
Toquima	1	1	1	1	1	1	1	0	1	8
White Pine	1	1	1	1	1	1	1	0	1	8
White-Inyo	1	1	1	1	1	1	1	1	1	9
Number of ranges inhabited	18	19	18	17	11	10	16	2	18	

Table 12. Extinctions predicted by Maxent for the minimum emission scenario (b2a, CCCma). Instances where species are predicted to be absent for historical conditions are unlikely to occur on the same mountain range for an assumed emission scenario due to the assumption that the system is nonequilibrial (Brown 1971). 1^E = Predicted extinctions, 0^I = Species absent for historical conditions but present for a minimum emission scenario.

	SPECIES									Number of species present
RANGE	CALA	MILO	OCPR	SOVA	SYNU	TADO	TAUM	URBE	ZAPR	
Deep	1	1	1	1	0^I	1	1	0	1	7
Desatoya	1	1	1	1	1	1	1	1^E	1	8
Diamond	1	1	1	1	1	1	1	0	1	8
Grant	1	1	1	0	1	1	1	0	1	7
Oquirrh	1	1	1	1	0	0	1	0	1^E	5
Panamint	1	1	1	1	1^E	1	1	0	1	7
Pilot	0^I	1	1	1	0	1	1	0	1	6
Roberts	1	1	1	1	0^I	1	1	1^E	1	7
Ruby	1	1	1	1	0^I	1	1	1	1	8
Schell	1	1	1	1	1	1	1	0	1	8
Sheep	1	1	1	0	1^E	1	1	0	1^E	5
Snake	1	1	1	1	1	1	1	0	1	8
Spring	1	1	1	0	1^E	1	1	0	1^E	5
Spruce	1	1	1	1	0	1	1	0	1	7
Stansbury	1	1	1	1	0^I	1	1	0	1^E	6
Toiyabe	1	1	1	1	1	1	1	1^E	1	8
Toquima	1	1	1	1	1	1	1	1^E	1	8
White Pine	1	1	1	1	1	1	1	0	1	8
White-Inyo	1	1	1	1	1	1	1	1	1	9
Number of ranges inhabited	18	19	19	16	9	18	19	2	15	

Table 13. Extinctions predicted by Maxent for the maximum emission scenario (a2a, CCCma). Instances where species are predicted to be absent for historical conditions are unlikely to occur on the same mountain range for an assumed emission scenario due to the assumption that the system is nonequilibrial (Brown 1971). 1^E = Predicted extinctions, 0^I = Species absent for historical conditions but present for a minimum emission scenario.

	SPECIES									Number of species present
RANGE	CALA	MILO	OCPR	SOVA	SYNU	TADO	TAUM	URBE	ZAPR	
Deep	1	1	1	1	0^I	1	1	0	1	7
Desatoya	1	1	1	1	1	1	1	1^E	1	8
Diamond	1	1	1	1	1	1	1	0	1	8
Grant	1	1	1	0^I	1	1	1	0	1	7
Oquirrh	1	1	1	1	0	0	1	0	1	6
Panamint	1	1	1	1	1^E	1^E	1^E	0	1	5
Pilot	0^I	1	1	1	0	1^E	1	0	1	5
Roberts	1	1	1	1	0	1^E	1^E	1^E	1	5
Ruby	1	1	1	1	0	1^E	1	1	1	7
Schell	1	1	1	1	1	1	1	0	1	8
Sheep	1^E	1	1^E	0	1^E	1^E	1^E	0	1^E	1
Snake	1	1	1	1	1	1	1	0	1	8
Spring	1	1	1	0	1^E	1^E	1	0	1	5
Spruce	1	1	1	1	0	1^E	1	0	1	6
Stansbury	1	1	1	1	0^I	1^E	1	0	1	6
Toiyabe	1	1	1	1	1	1	1	1^E	1	8
Toquima	1	1	1	1	1	1	1	1^E	1	8
White Pine	1	1	1	1	1	1	1	0	1	8
White-Inyo	1	1	1	1	1	1	1	1	1	9
Number of ranges inhabited	17	19	18	16	9	10	16	2	18	

Table 14. Comparison between the predicted extinctions by Maxent for a minimum emission scenario (b2a, CCCma) and the predicted extinctions for the McDonald and Brown (1992) model. 1 = The species is predicted to persist on the mountain range, 0 = The species is not predicted to occur on the mountain range, 1[A] = Maxent predicts that the species will persist on the mountain range and McDonald and Brown (1992) predict that the species will become extinct on the mountain range, 0[B] = Maxent predicts that the species did not occur on the mountain range and McDonald and Brown (1992) predict that the species will become extinct on the mountain range, 1[C] = Maxent predicts that the species will become extinct on the mountain range and McDonald and Brown (1992) suggests that the species did not occur on the mountain range, 1[D] = Maxent predicts that the species will become extinct on the mountain range and McDonald and Brown (1992) predict that the species will persist on the mountain range, 1[E] = Maxent and McDonald and Brown (1992) predict that the species will become extinct on the mountain range.

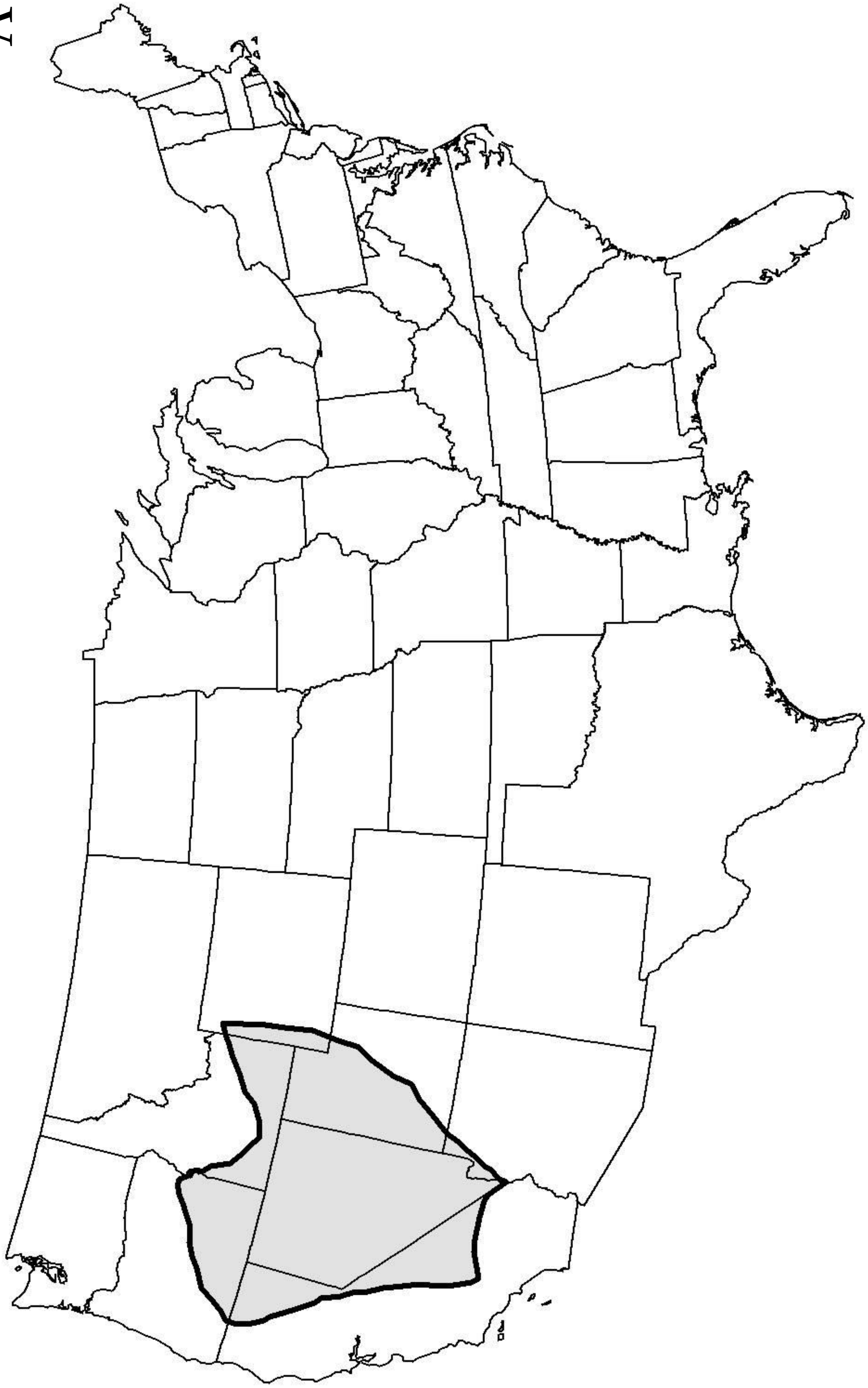
	SPECIES									Number of species present
RANGE	CALA	MILO	OCPR	SOVA	SYNU	TADO	TAUM	URBE	ZAPR	
Deep	1	1	1	1^A	0^B	1	1	0	1	7
Desatoya	1^A	1^A	1^A	1	1^A	1	1	1^C	1	9
Diamond	1^A	1	1	1	1	1^A	1	0	1	8
Grant	1	1^A	1	0	1^A	1	1	0	1	7
Oquirrh	1	1	1	1	0	0	1	0	1^E	5
Panamint	1	1	1	1	1^E	1	1	0	1	7
Pilot	0^B	1	1	1	0	1	1	0	1	6
Roberts	1	1	1	1	0	1	1	1^C	1^A	7
Ruby	1	1	1^A	1	0	1	1	1^A	1^A	8
Schell	1	1	1	1^A	1^A	1	1	0	1	8
Sheep	1	1	1	0	1^C	1^A	1	0	1^C	5
Snake	1	1	1	1	1	1	1	0	1	8
Spring	1	1	1	0^B	1^E	1	1	0	1^C	5
Spruce	1^A	1	1	1	0	1^A	1	0	1	7
Stansbury	1	1	1	1	0	1	1	0	1^C	6
Toiyabe	1	1	1	1	1	1	1	1^E	1^A	8
Toquima	1	1	1^A	1	1	1	1	1^C	1^A	8
White Pine	1	1^A	1	1	1^A	1	1	0	1	8
White-Inyo	1	1	1^A	1	1	1	1	1	1	9
Number of ranges inhabited	18	19	19	16	9	18	19	2	15	

Table 15. Comparison between the predicted extinctions by Maxent for a maximum emission scenario (a2a, CCCma) and the predicted extinctions for the McDonald and Brown (1992) model. 1 = The species is predicted to persist on the mountain range, 0 = The species is not predicted to occur on the mountain range, 1^A = Maxent predicts that the species will persist on the mountain range and McDonald and Brown (1992) predict that the species will become extinct on the mountain range, 0^B = Maxent predicts that the species did not occur on the mountain range and McDonald and Brown (1992) predict that the species will become extinct on the mountain range, 1^C = Maxent predicts that the species will become extinct on the mountain range and McDonald and Brown (1992) suggests that the species did not occur on the mountain range, 1^D = Maxent predicts that the species will become extinct on the mountain range and McDonald and Brown (1992) predict that the species will persist on the mountain range, 1^E = Maxent and McDonald and Brown (1992) predict that the species will become extinct on the mountain range.

	SPECIES									Number of species present
RANGE	CALA	MILO	OCPR	SOVA	SYNU	TADO	TAUM	URBE	ZAPR	
Deep	1	1	1	1^{A}	0^{B}	1	1	0	1	7
Desatoya	1^{A}	1^{A}	1^{A}	1	1^{A}	1	1	1^{C}	1	8
Diamond	1^{A}	1	1	1	1	1^{A}	1	0	1	8
Grant	1	1^{A}	1	0	1^{A}	1	1	0	1	7
Oquirrh	1	1	1	1	0	0	1	0	1^{A}	6
Panamint	1	1	1	1	1^{E}	1^{D}	1^{C}	0	1	5
Pilot	0^{B}	1	1	1	0	1^{D}	1	0	1	5
Roberts	1	1	1	1	0	1^{C}	1^{D}	1^{C}	1^{A}	5
Ruby	1	1	1^{A}	1	0	1^{C}	1	1^{A}	1^{A}	7
Schell	1	1	1	1^{A}	1^{A}	1	1	0	1	8
Sheep	1^{C}	1	1^{C}	0	1^{C}	1^{E}	1^{D}	0	1^{C}	1
Snake	1	1	1	1	1	1	1	0	1	8
Spring	1	1	1	0^{B}	1^{E}	1^{D}	1	0	1	5
Spruce	1^{A}	1	1	1	0	1^{E}	1	0	1	6
Stansbury	1	1	1	1	0	1^{D}	1	0	1	6
Toiyabe	1	1	1	1	1	1	1	1^{E}	1^{A}	8
Toquima	1	1	1^{A}	1	1	1	1	1^{C}	1^{A}	8
White Pine	1	1^{A}	1	1	1^{A}	1	1	0	1	8
White-Inyo	1	1	1^{A}	1	1	1	1	1	1	9
Number of ranges inhabited	17	19	18	16	9	10	16	2	18	

Figure 1. A) The Great Basin (indicated with the solid fill) is an arid region in the western portion of the United States. B) Nineteen isolated mountain ranges in the Great Basin with intervening desert valleys that are surrounded by the Sierra Nevada mountains to the West and the Rocky mountains to the East (Adapted from Brown 1971, Grayson & Livingston 1993). Two mountain ranges; DE and SR (shaded in dark grey), were not included in the original analysis by Brown (1971), but were included in the analysis by McDonald and Brown (1992). (Site abbreviations: DC = Deep Creek Range, DE = Desatoya Mountains, DM = Diamond Mountains, GR = Grant Range, OD = Oquirrh Mountains, PM = Panamint Range, PR = Pilot Range, RC = Roberts Creek, RB = Ruby Mountains, SC = Schell Creek Range, SR = Sheep Range, SN = Snake Range, SP = Spring Mountains, SU = Spruce Mountains, ST = Stansbury Mountains, TO = Toiyabe Range, TQ = Toquima Range, WP = White Pine Range, WI = White-Inyo Range).

A



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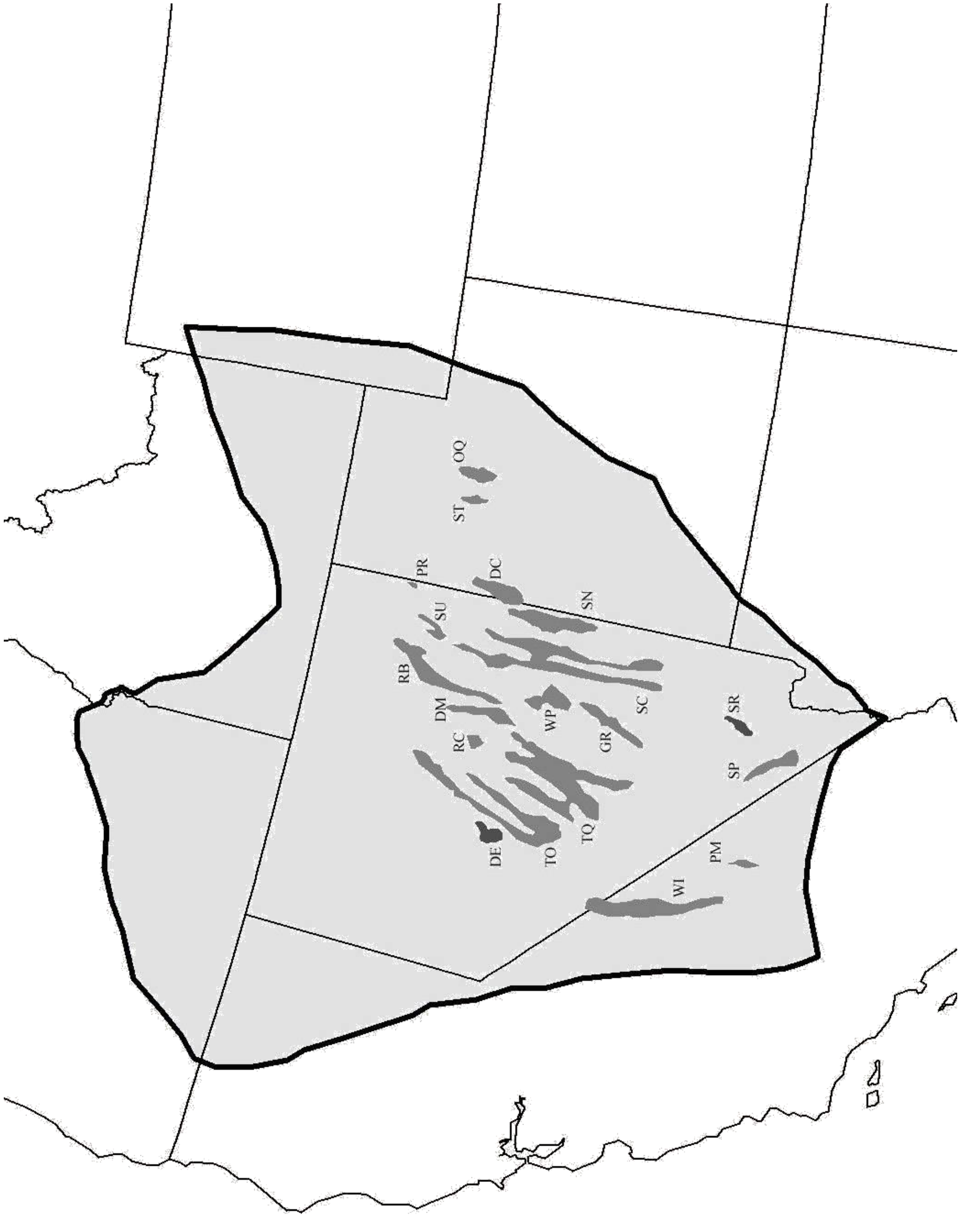
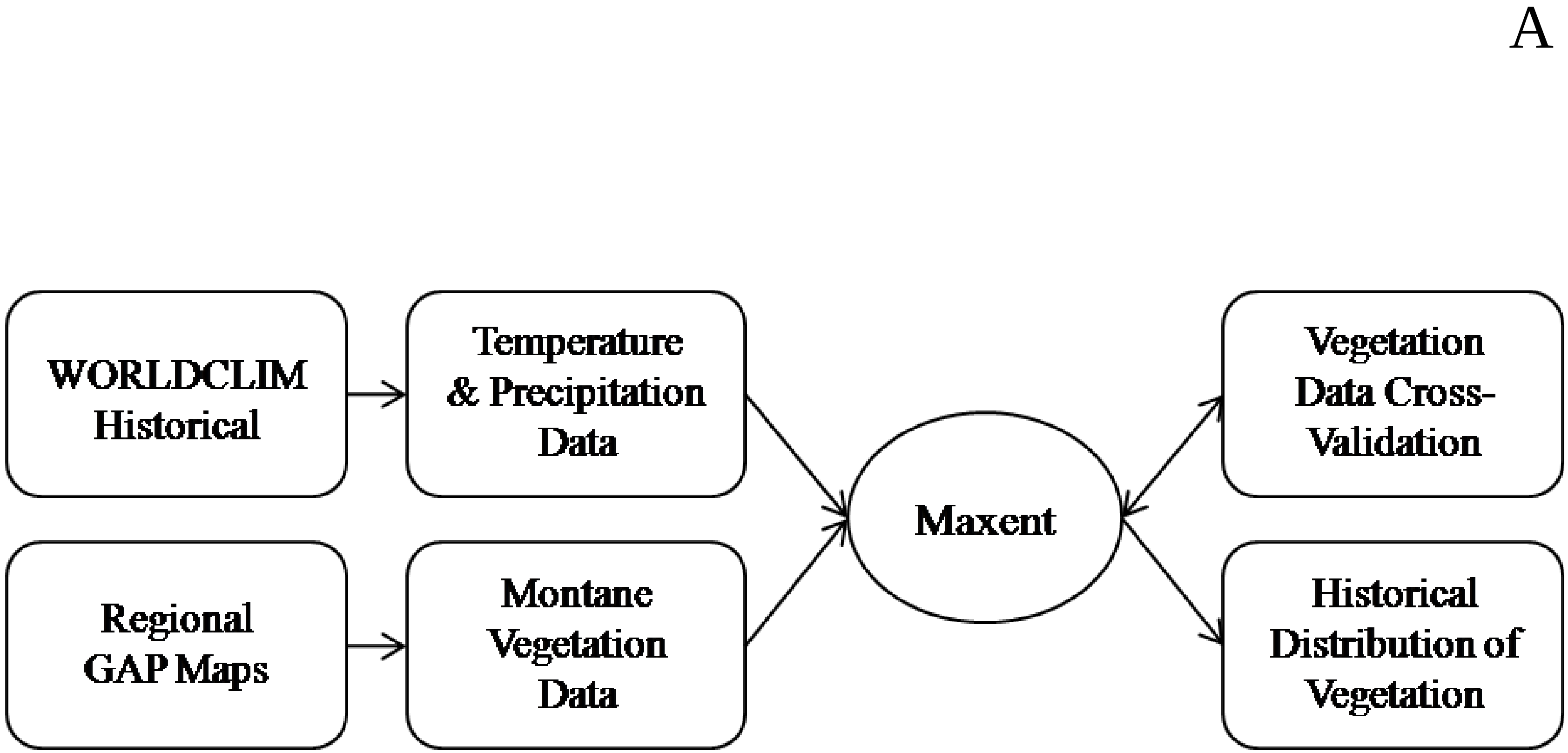


Figure 2. A) Model of the historical distribution of montane vegetation throughout the Great Basin for historical conditions. B) Model of the future distribution of montane vegetation for a climate change emission scenario. C) Model of the historical distribution of montane mammals throughout the Great Basin for historical conditions. D) Model of the future distribution of montane mammals for a climate change emission scenario.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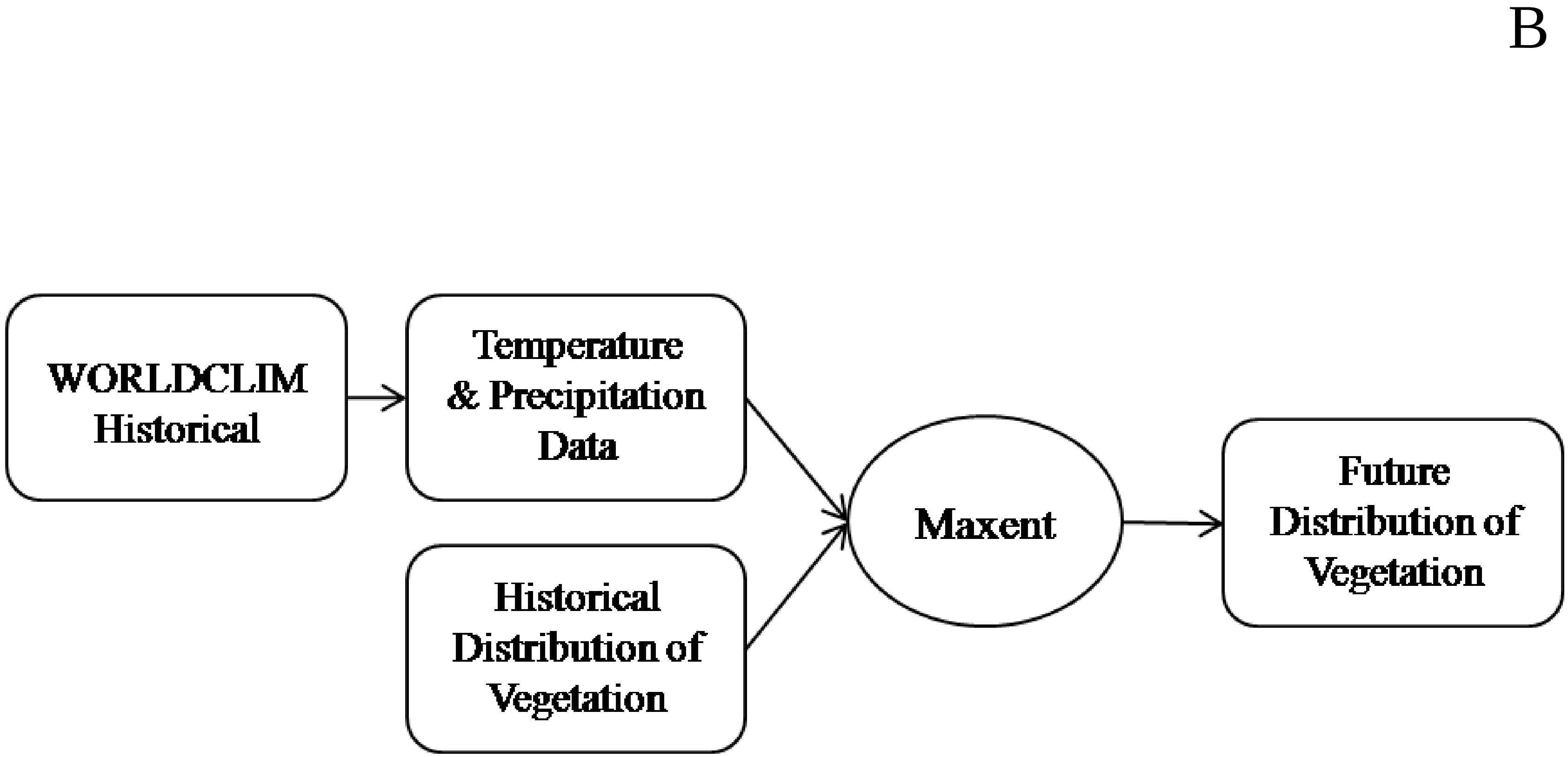
Montane Vegetation Data
Maxent
Vegetation Data Cross-Validation
Historical Distribution of Vegetation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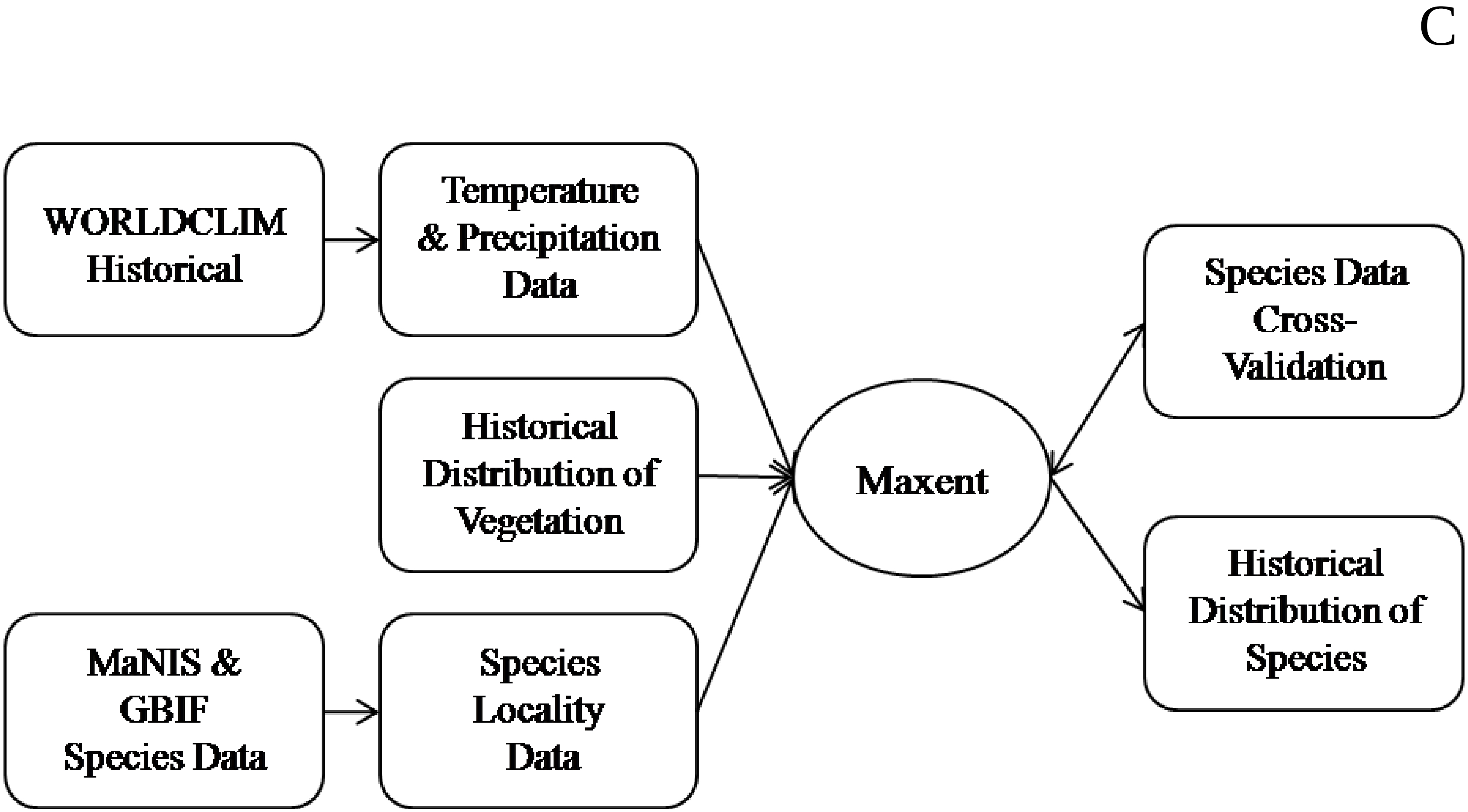
Maxent
Future Distribution of Vegetation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Temperature & Precipitation Data
Historical Distribution of Vegetation
MaNIS & GBIF Species Data
Species Locality Data
Maxent
Species Data Cross-Validation
Historical Distribution of Species

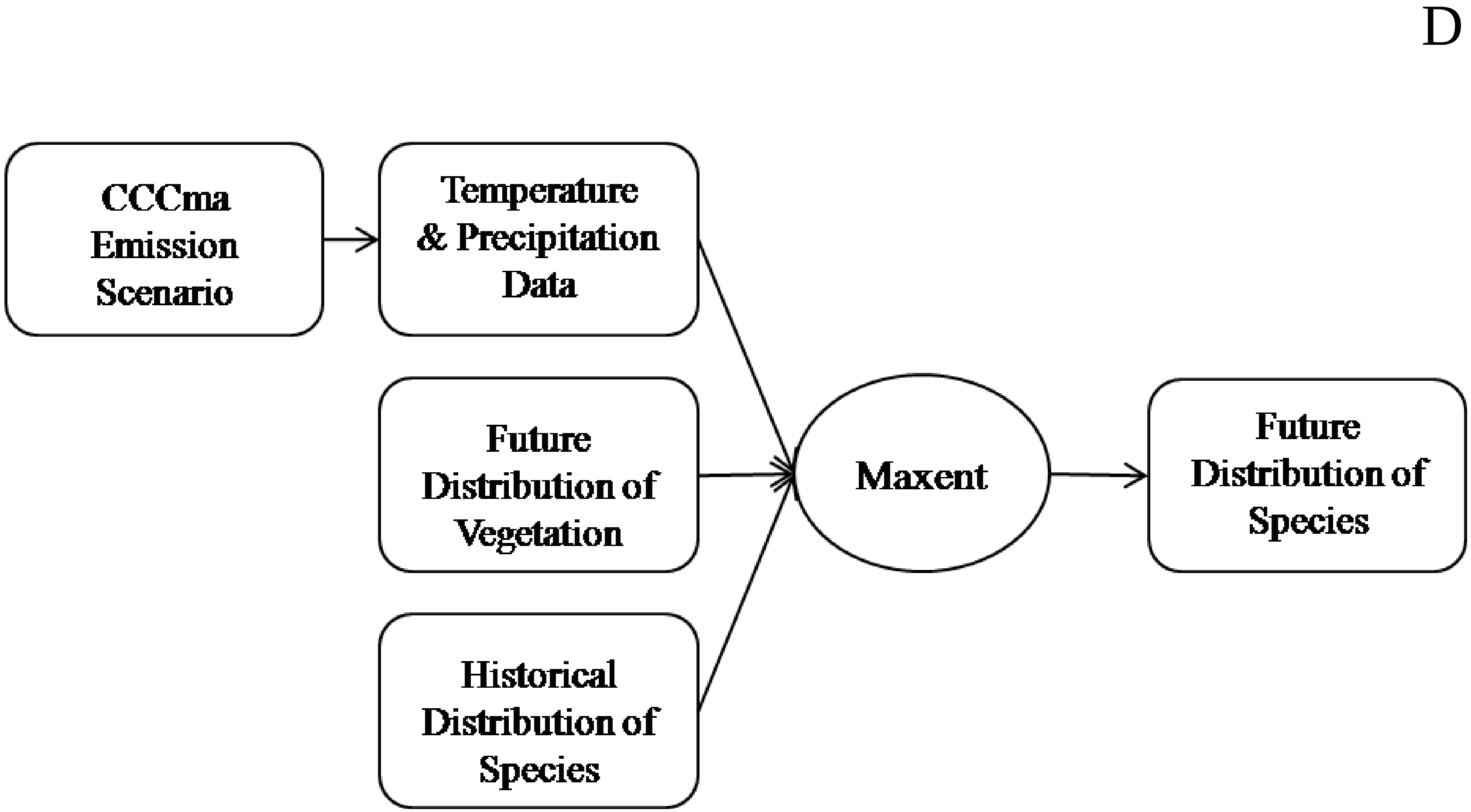

D
CCCma Emission Scenario
Temperature & Precipitation Data
Future Distribution of Vegetation
Historical Distribution of Species
Maxent
Future Distribution of Species

Figure 3. A) Maxent results: probability map of occurrence for the historical distribution of the American pika (*Ochotona princeps*). Warm colors indicate high probability of occurrence and cool colors indicate low probability of occurrence.

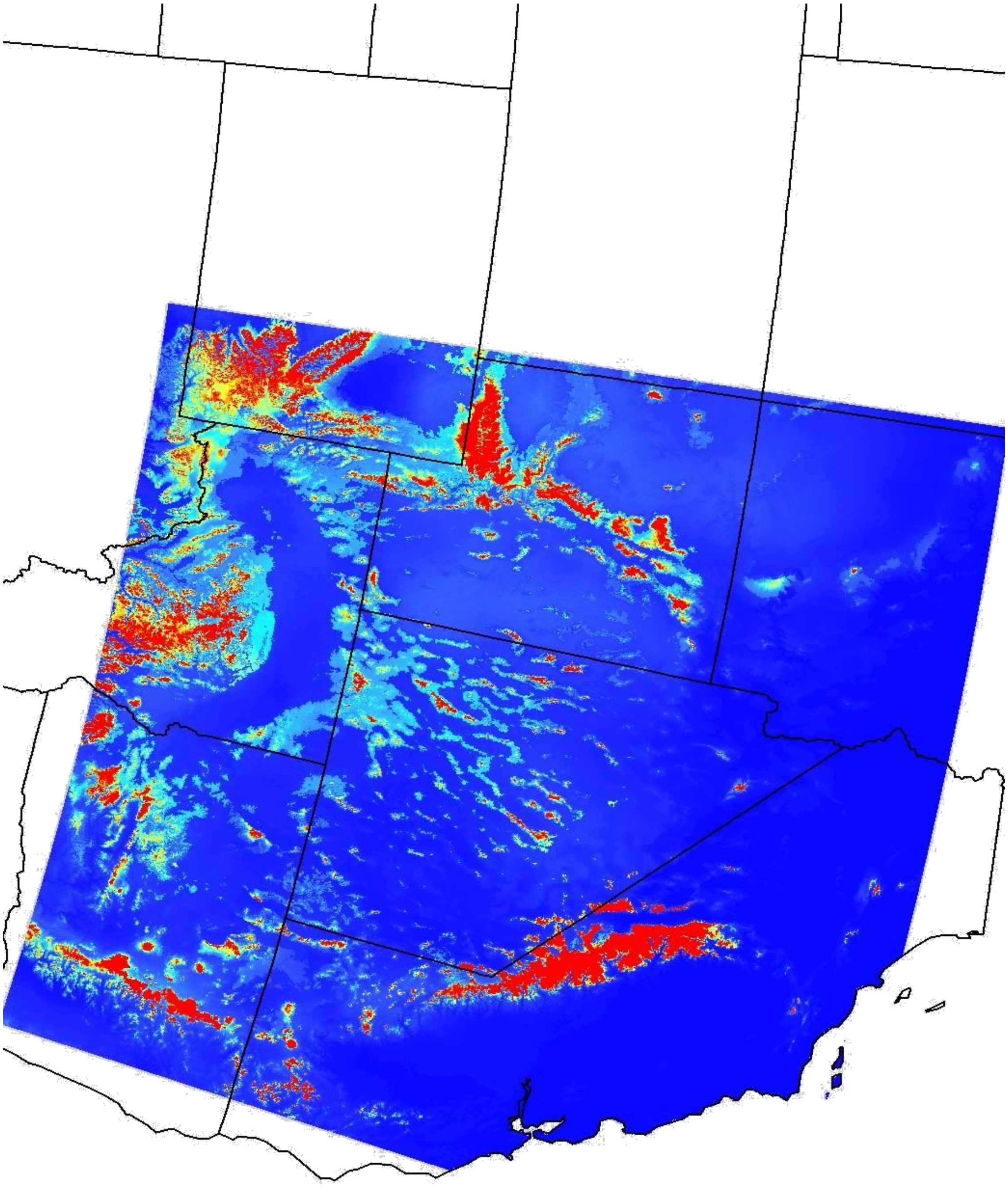
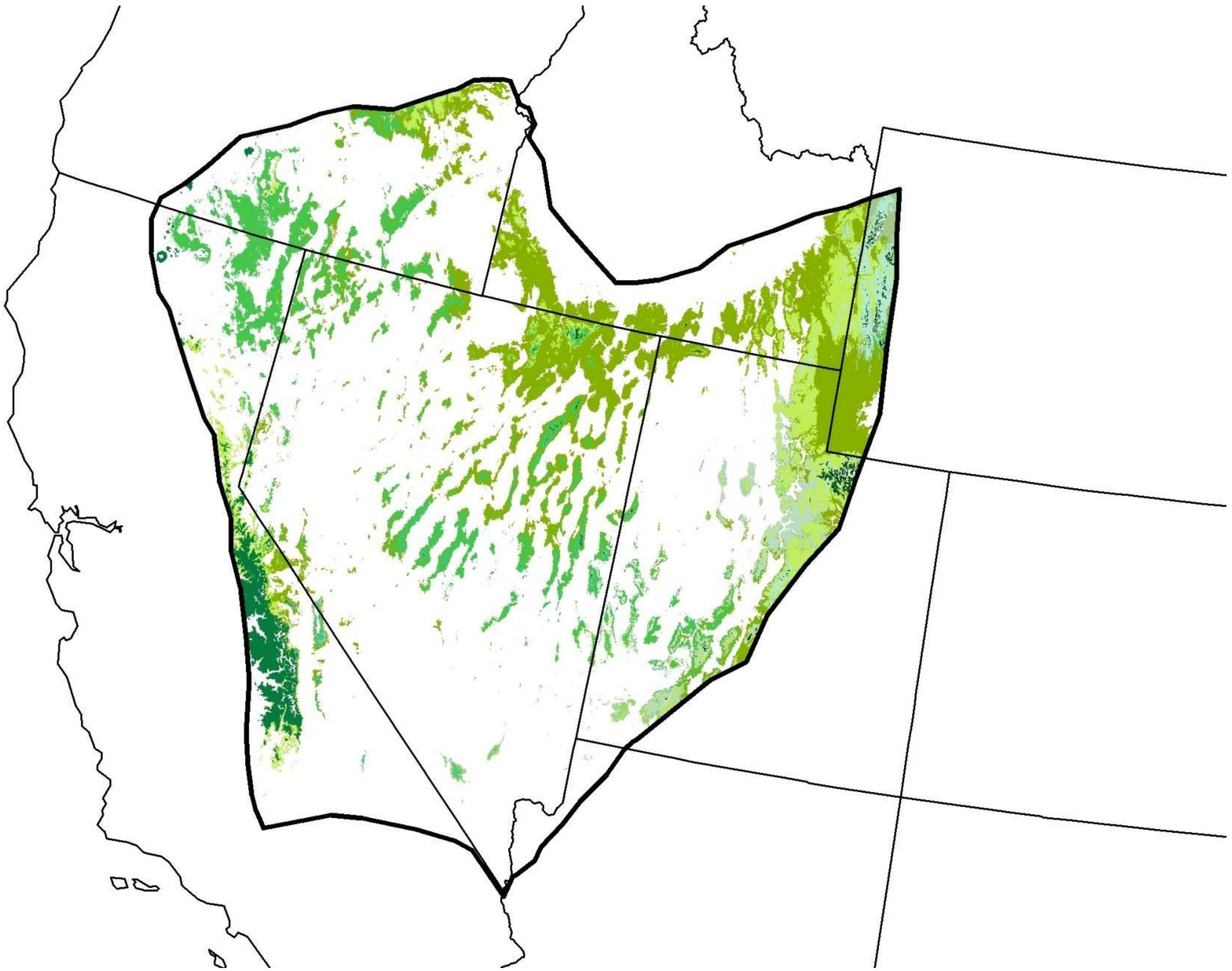


Figure 4. A) Mosaic of the predicted distributions by Maxent of montane habitat throughout the Great Basin for historical conditions. B) Mosaic of the predicted distributions by Maxent of montane habitat throughout the Great Basin for a minimum emission scenario (b2a, CCCma). C) Mosaic of the predicted distributions by Maxent of montane habitat throughout the Great Basin for a maximum emission scenario (a2a, CCCma). Colors used in vegetation maps referring to the distribution of each vegetation class by code number (see Table 4). GB = Extent of the Great Basin.

🟩 1	🟩 2	🟩 3	🟩 4	🟩 5	🟩 6
🟩 7	🟩 8	🟩 9	🟩 10	🟩 11	□ GB

A



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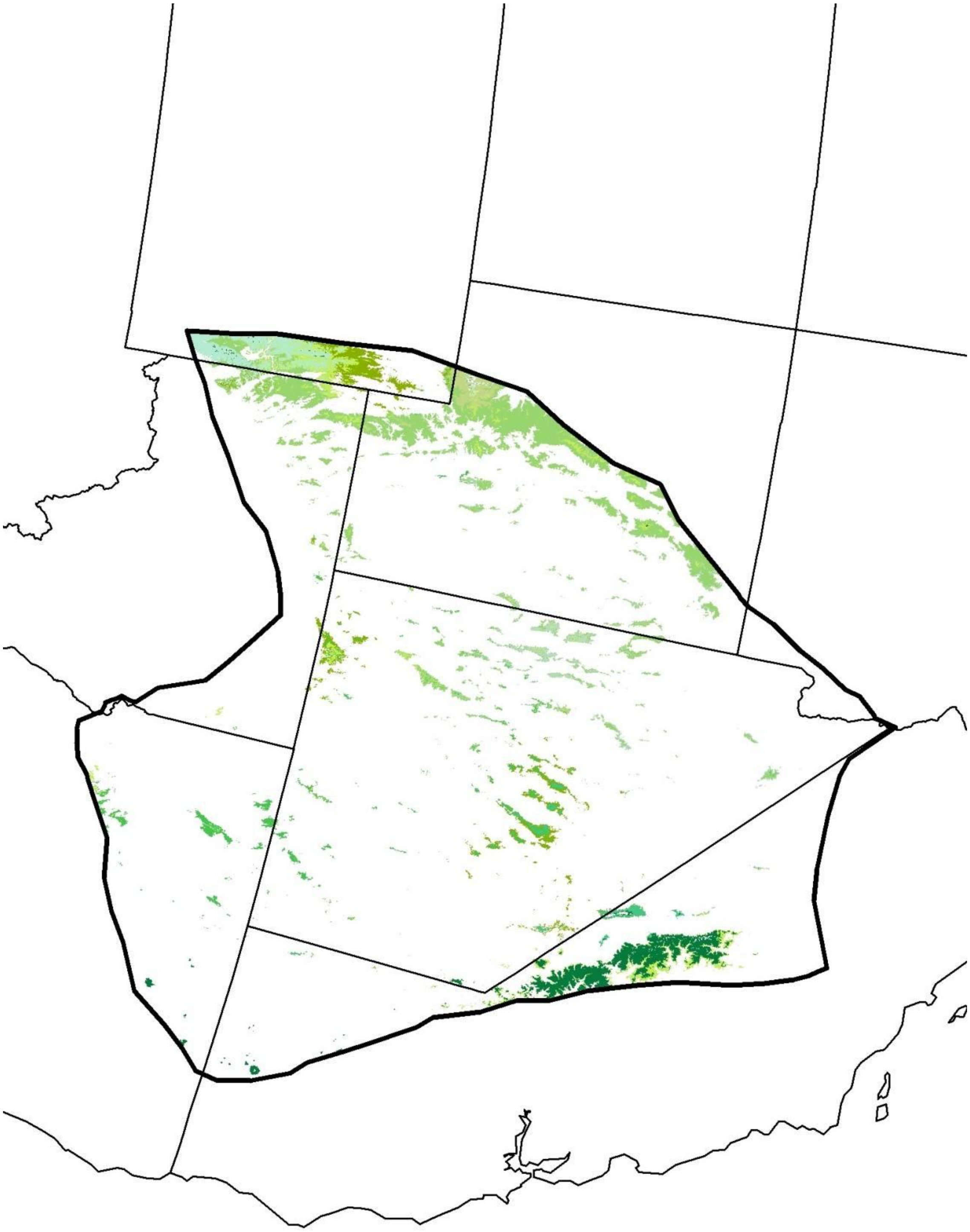

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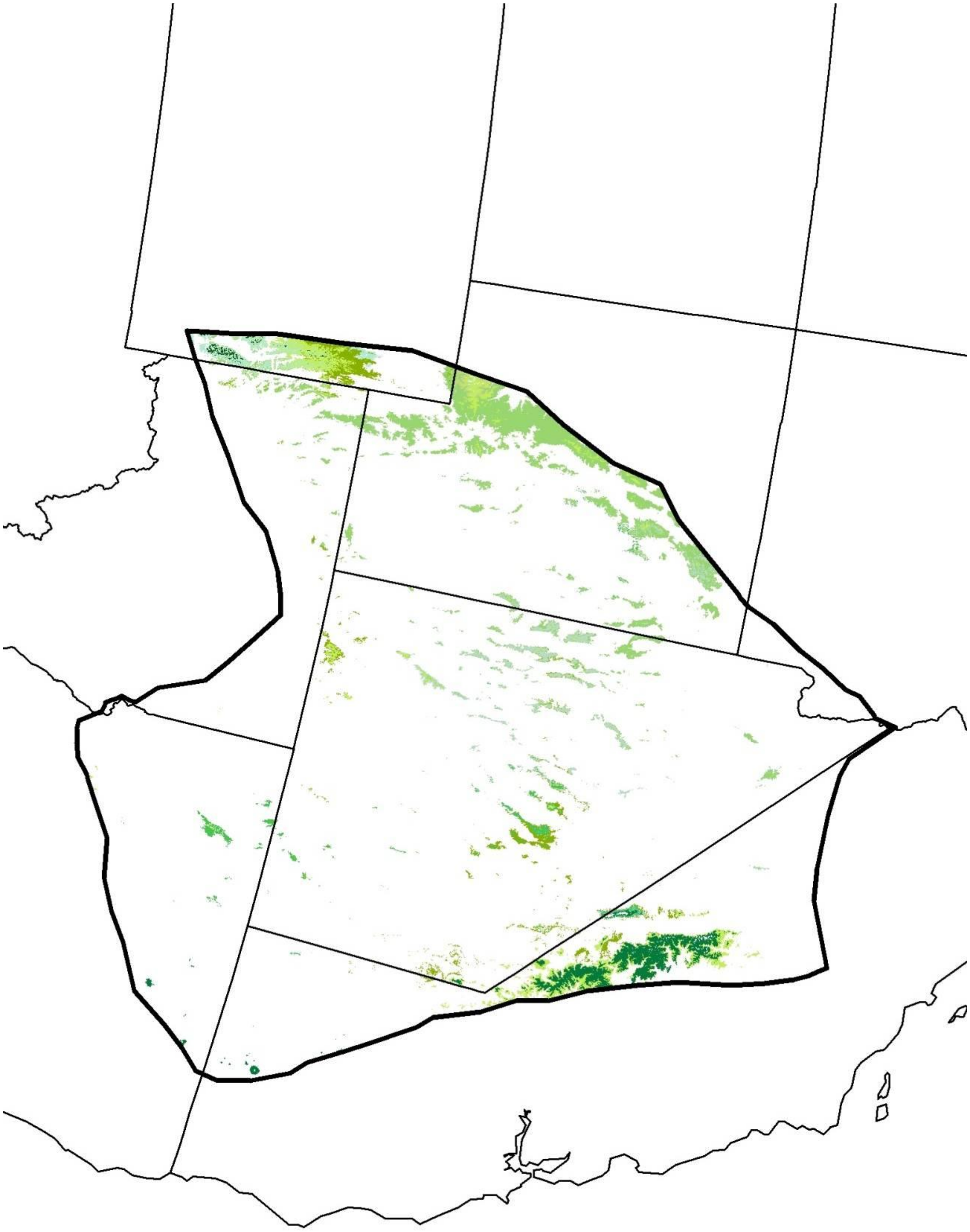
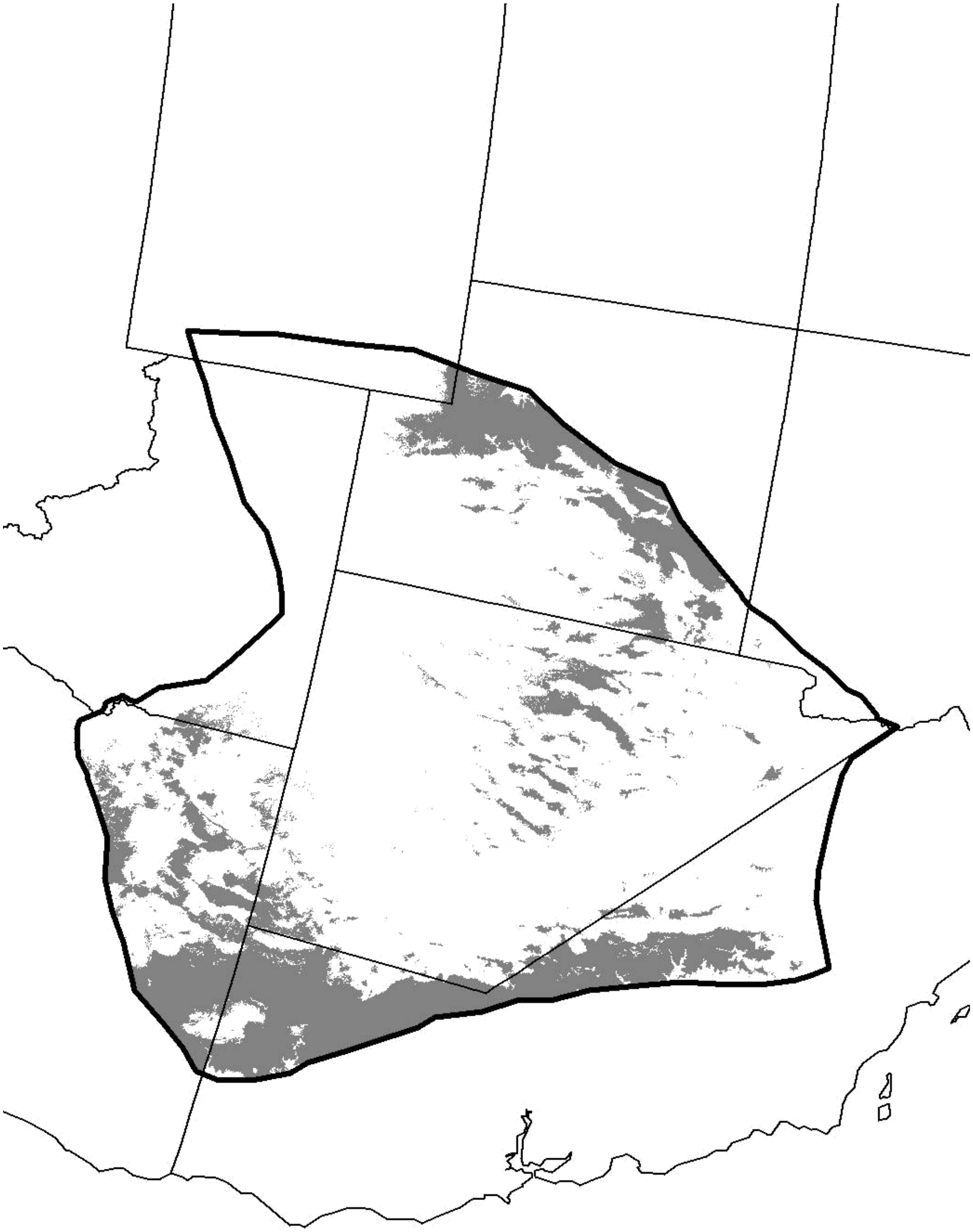


Figure 5. A) Distribution of the Golden-mantled ground squirrel (*Callospermophilus lateralis*) in the Great Basin predicted by Maxent for historical conditions. B) Distribution of the Golden-mantled ground squirrel in the Great Basin predicted by Maxent for minimum emission scenario (b2a, CCCma). C) Distribution of the Golden-mantled ground squirrel in the Great Basin predicted by Maxent for maximum emission scenario (a2a, CCCma). Shaded areas indicate the predicted distribution of the species.

A



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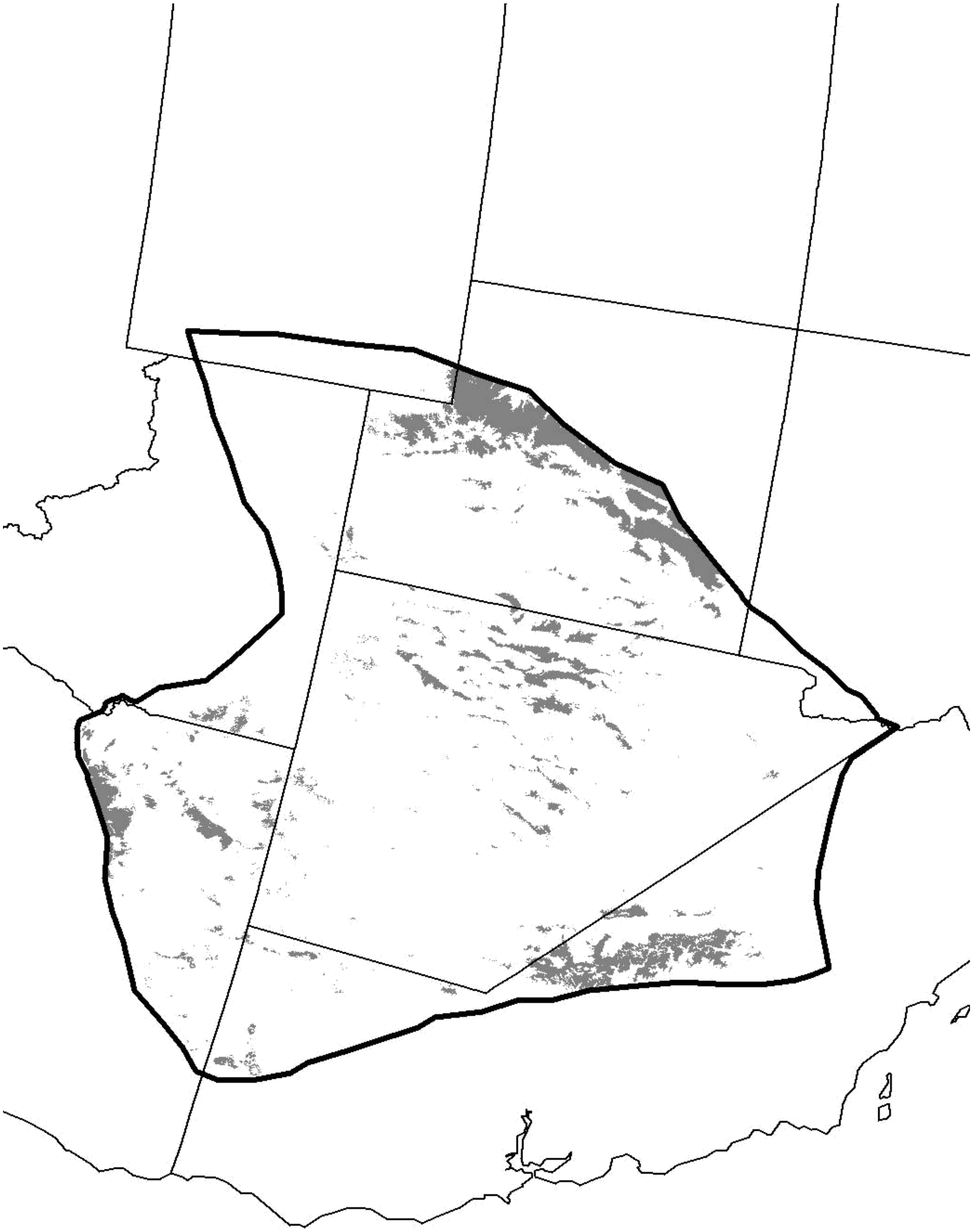

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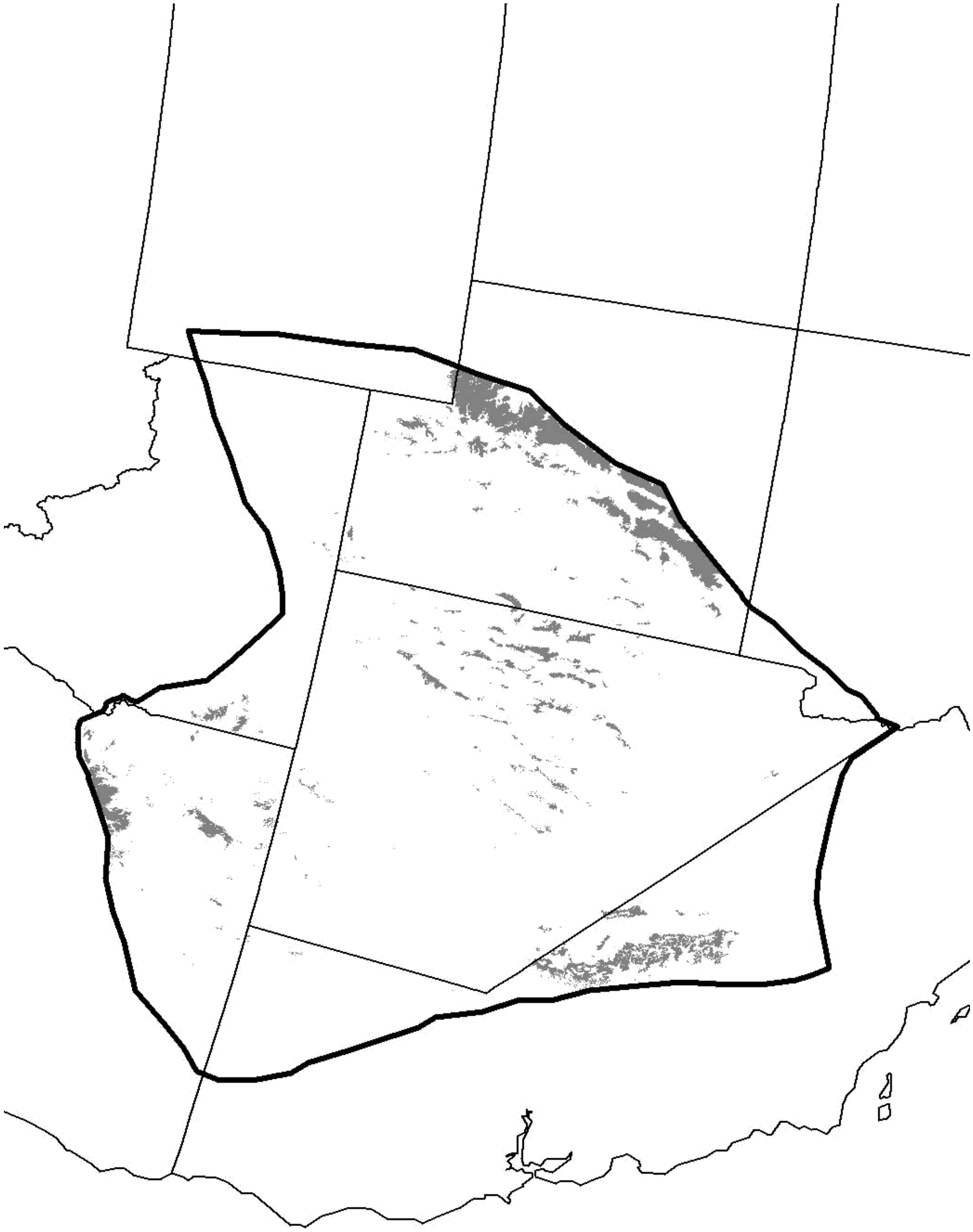
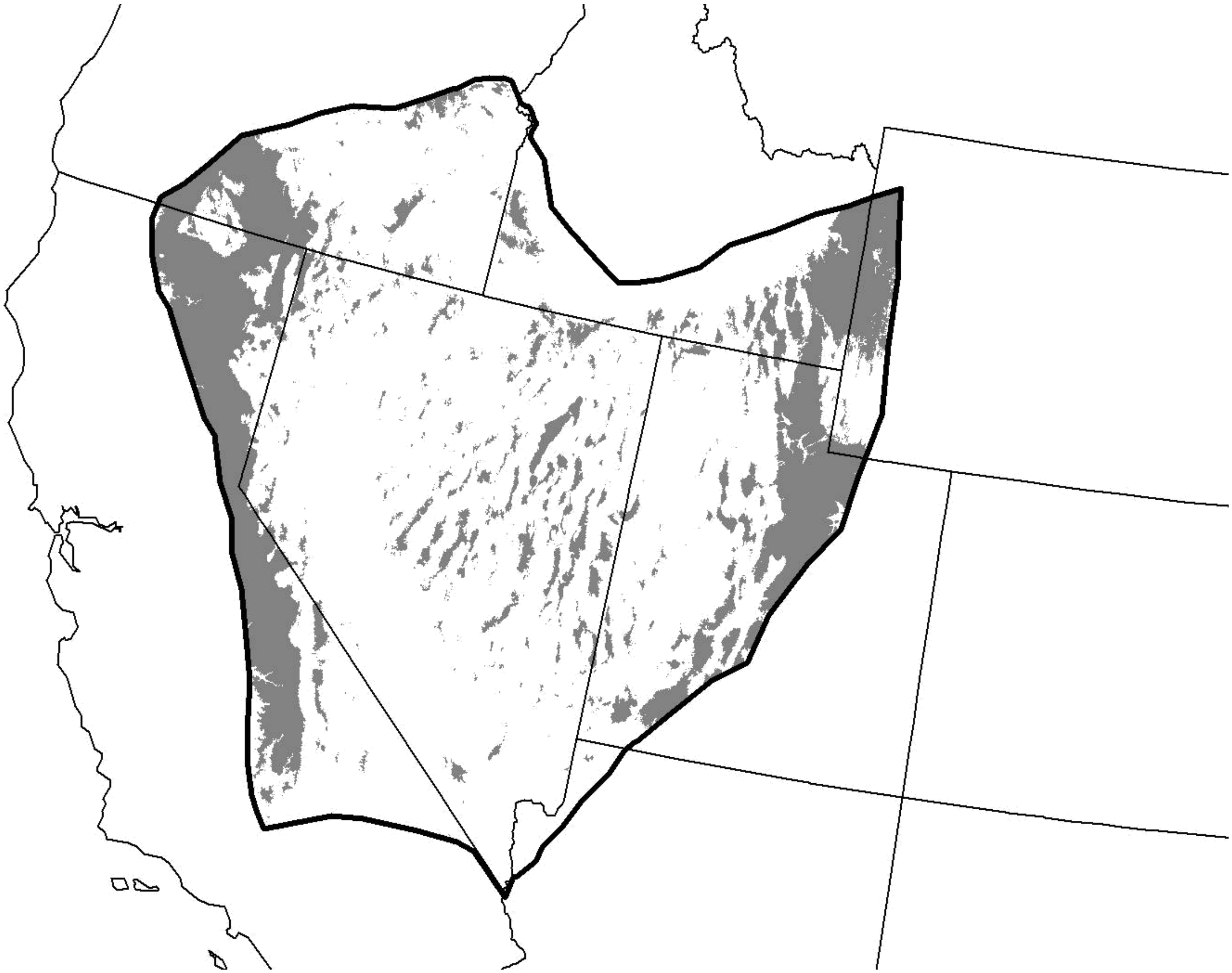


Figure 6. A) Distribution of the Long-tailed vole (*Microtus longicaudus*) in the Great Basin predicted by Maxent for historical conditions. B) Distribution of the Long-tailed vole in the Great Basin predicted by Maxent for minimum emission scenario (b2a, CCCma). C) Distribution of the Long-tailed vole in the Great Basin predicted by Maxent for maximum emission scenario (a2a, CCCma). Shaded areas indicate the predicted distribution of the species.

A



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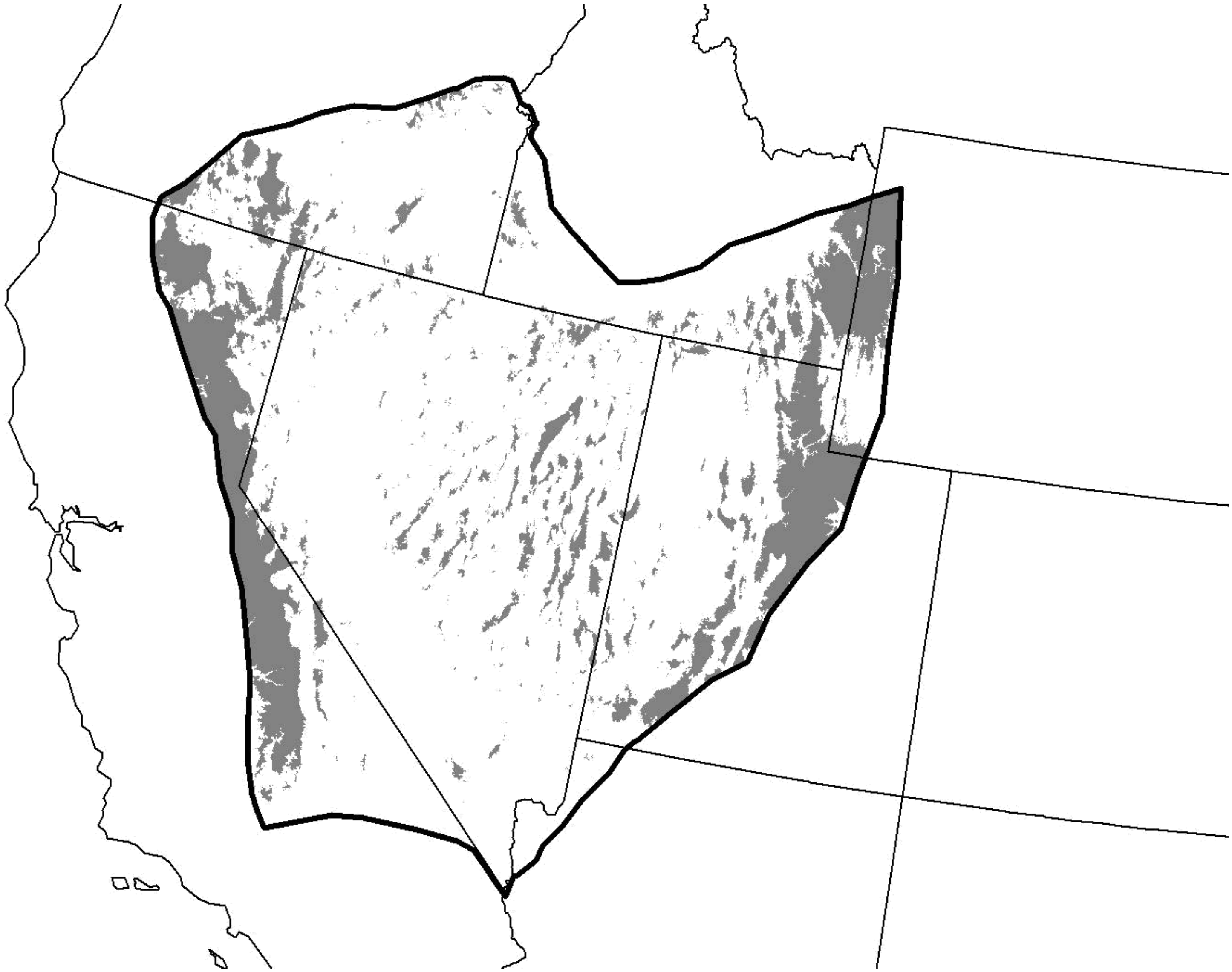

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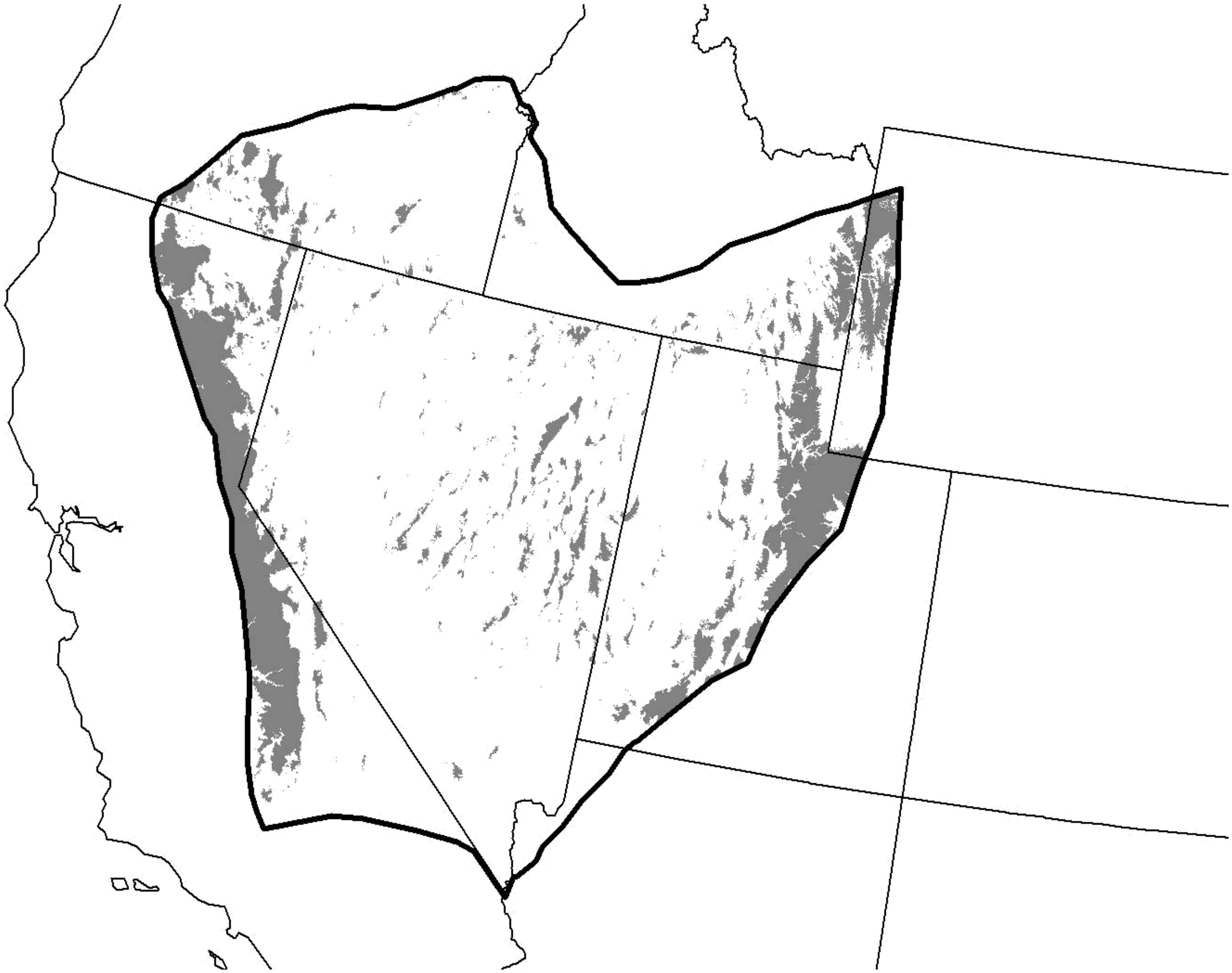
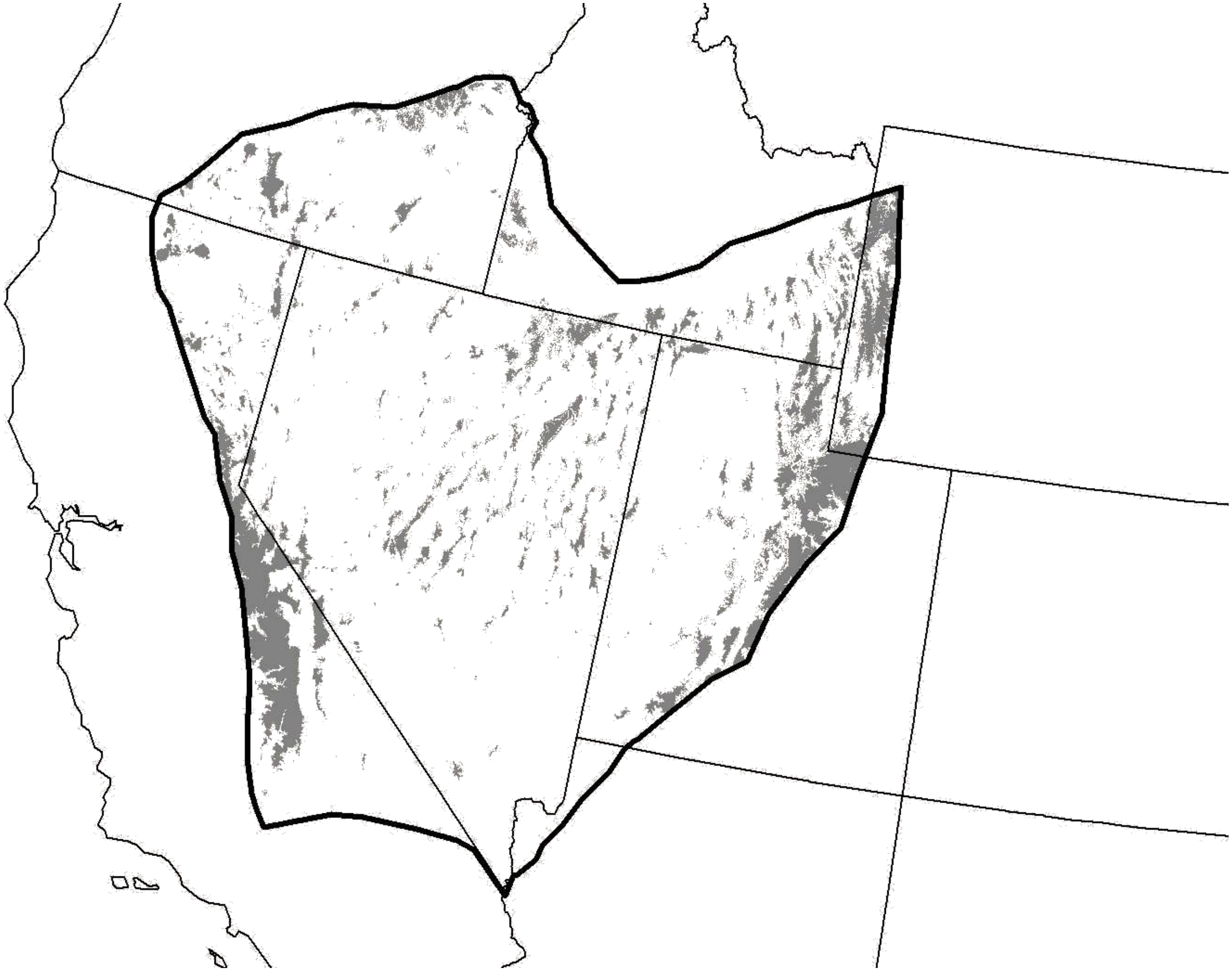


Figure 7. A) Distribution of the American pika (*Ochotona princeps*) in the Great Basin predicted by Maxent for historical conditions. B) Distribution of the American pika in the Great Basin predicted by Maxent for minimum emission scenario (b2a, CCCma). C) Distribution of the American pika in the Great Basin predicted by Maxent for maximum emission scenario (a2a, CCCma). Shaded areas indicate the predicted distribution of the species.

A



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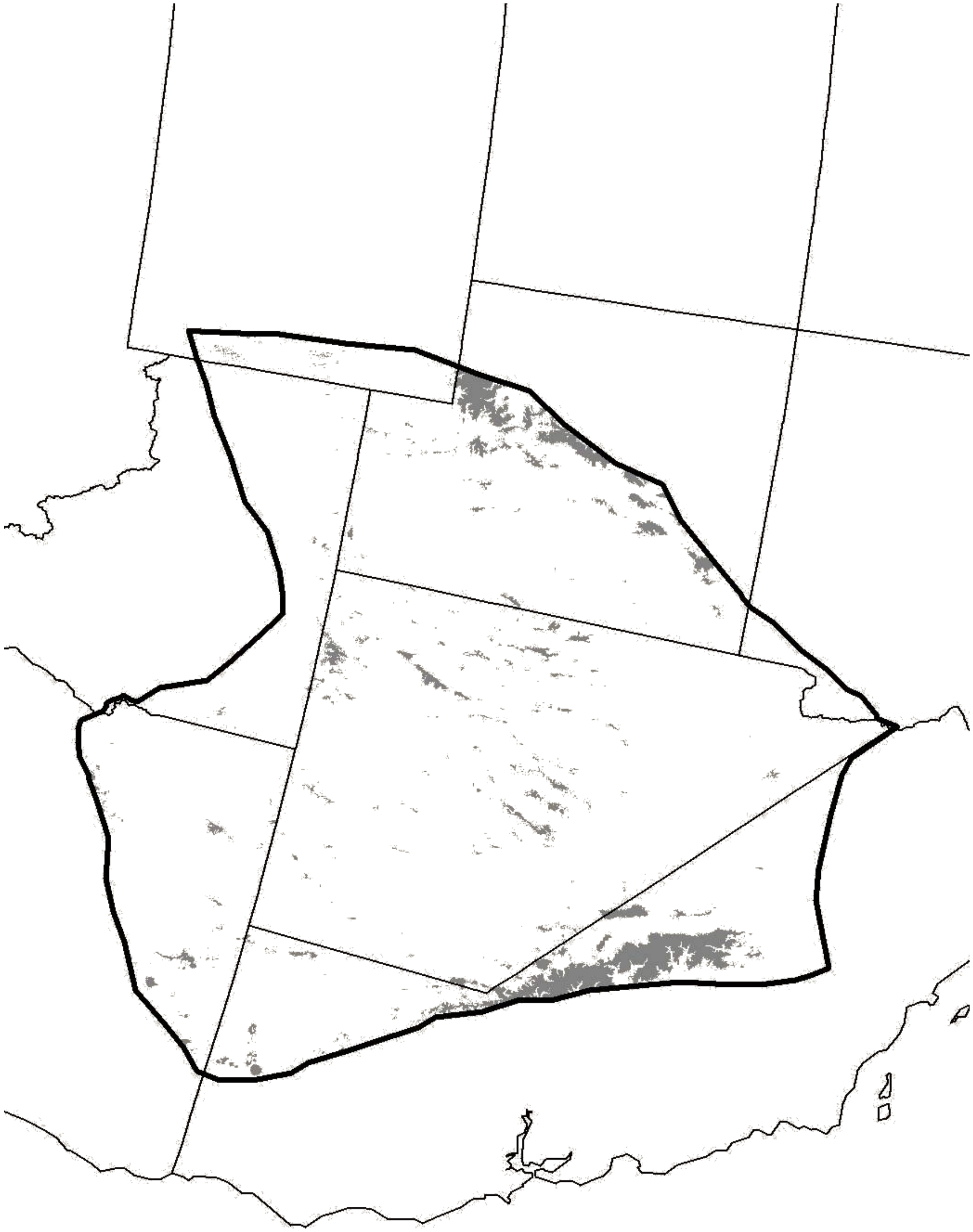

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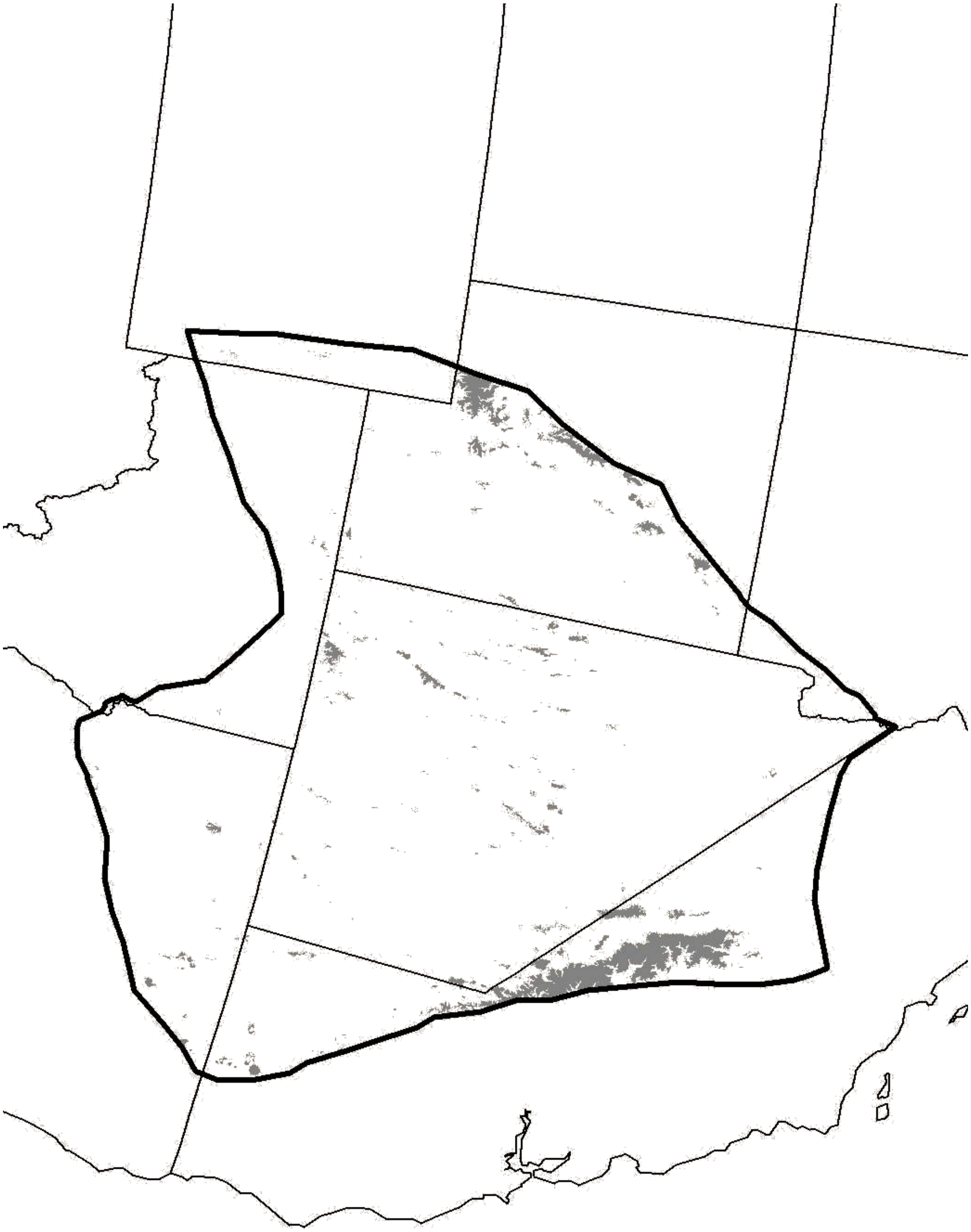
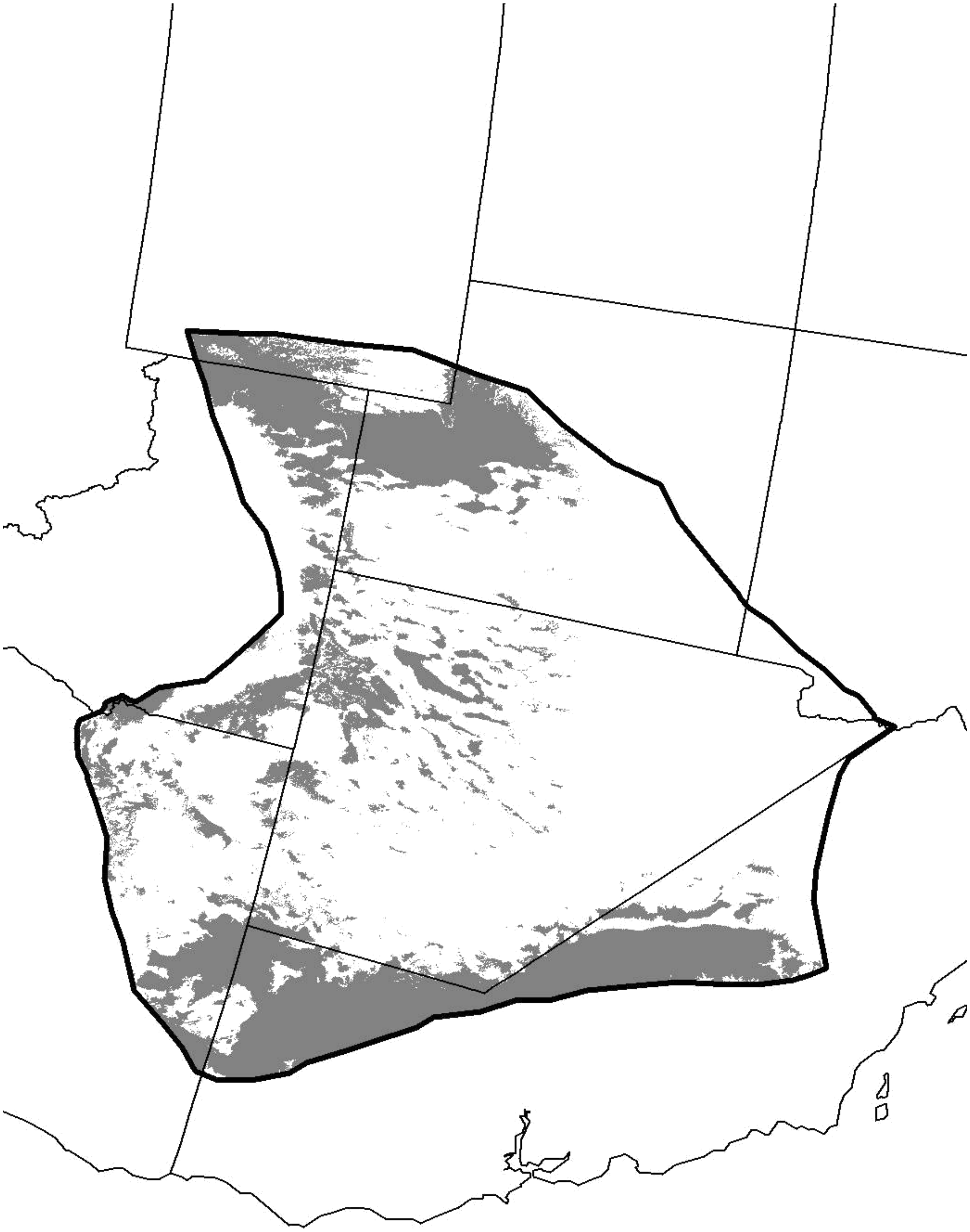


Figure 8. A) Distribution of the vagrant shrew (*Sorex vagrans*) in the Great Basin predicted by Maxent for historical conditions. B) Distribution of the vagrant shrew in the Great Basin predicted by Maxent for minimum emission scenario (b2a, CCCma). C) Distribution of the vagrant shrew in the Great Basin predicted by Maxent for maximum emission scenario (a2a, CCCma). Shaded areas indicate the predicted distribution of the species.

A



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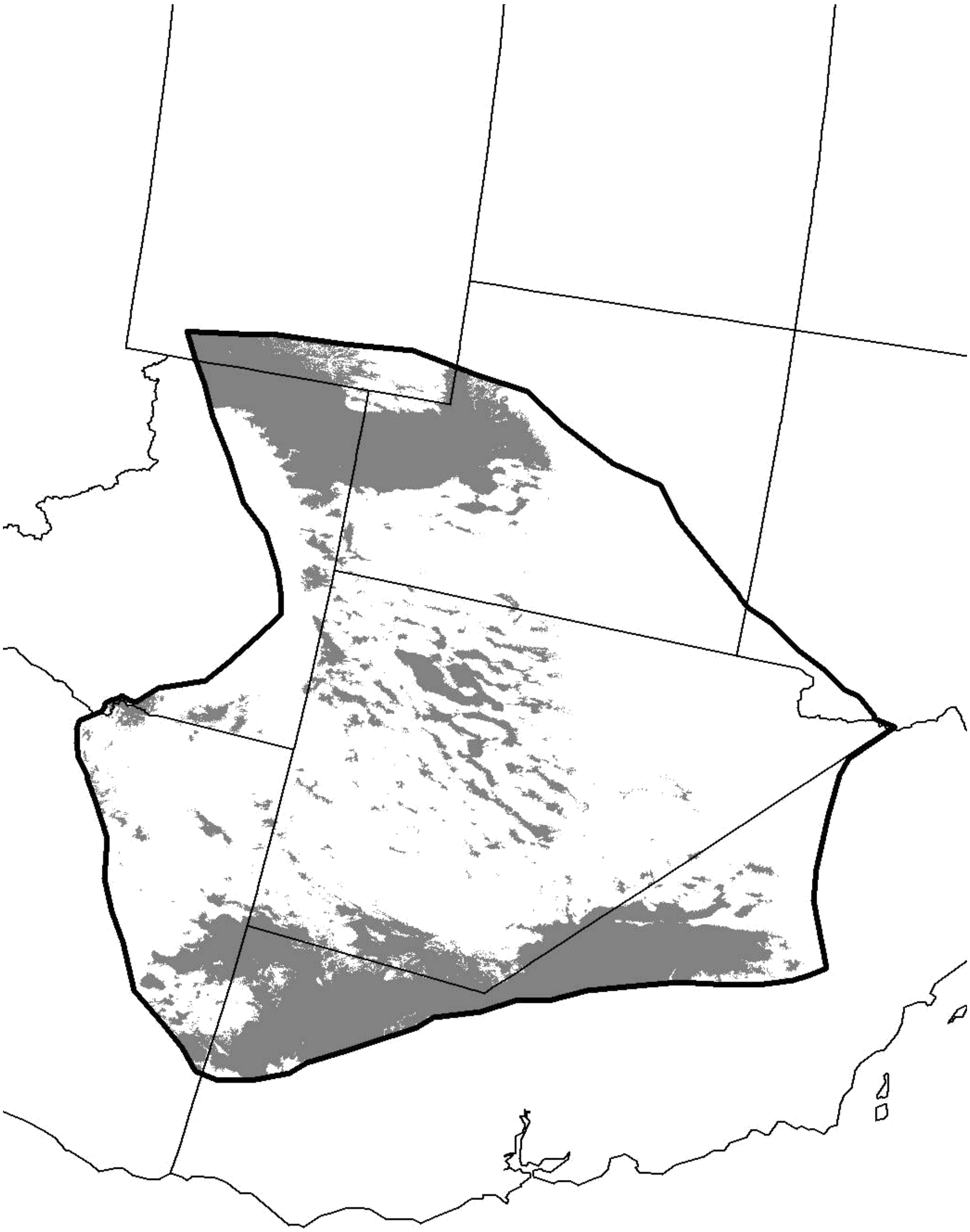


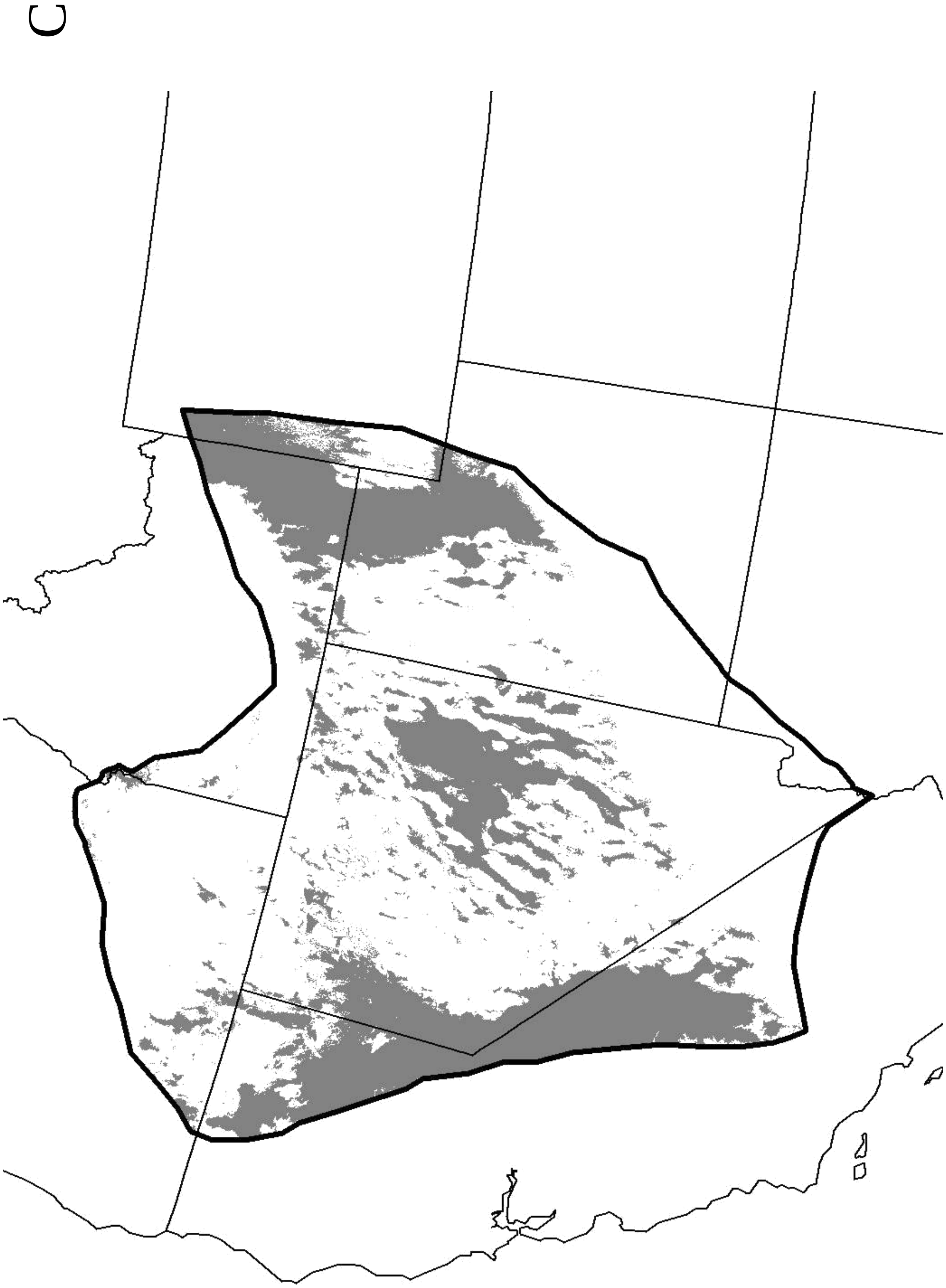
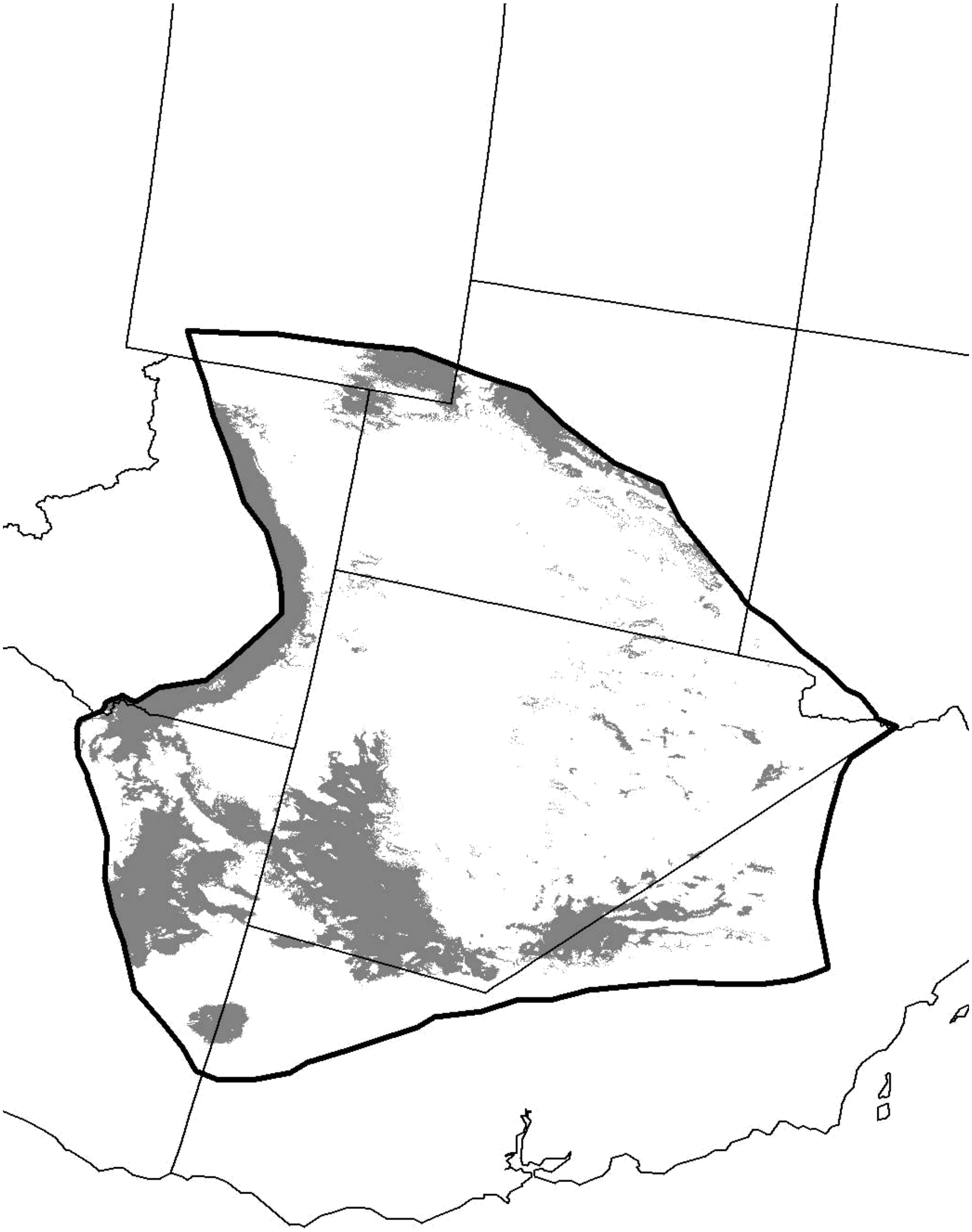
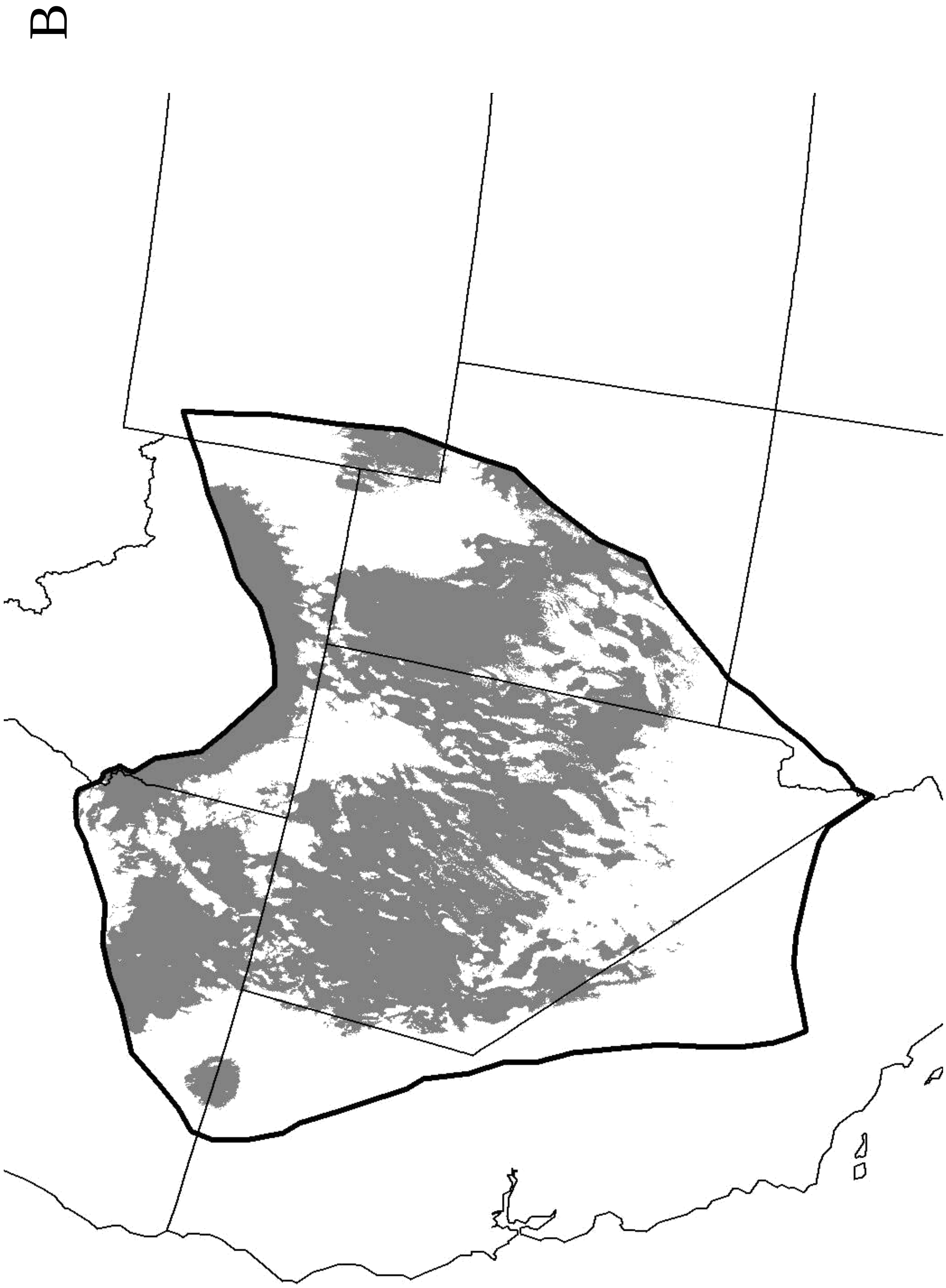

C

Figure 9. A) Distribution of the mountain cottontail (*Sylvilagus nuttallii*) in the Great Basin predicted by Maxent for historical conditions. B) Distribution of the mountain cottontail in the Great Basin predicted by Maxent for minimum emission scenario (b2a, CCCma). C) Distribution of the mountain cottontail in the Great Basin predicted by Maxent for maximum emission scenario (a2a, CCCma). Shaded areas indicate the predicted distribution of the species.

A

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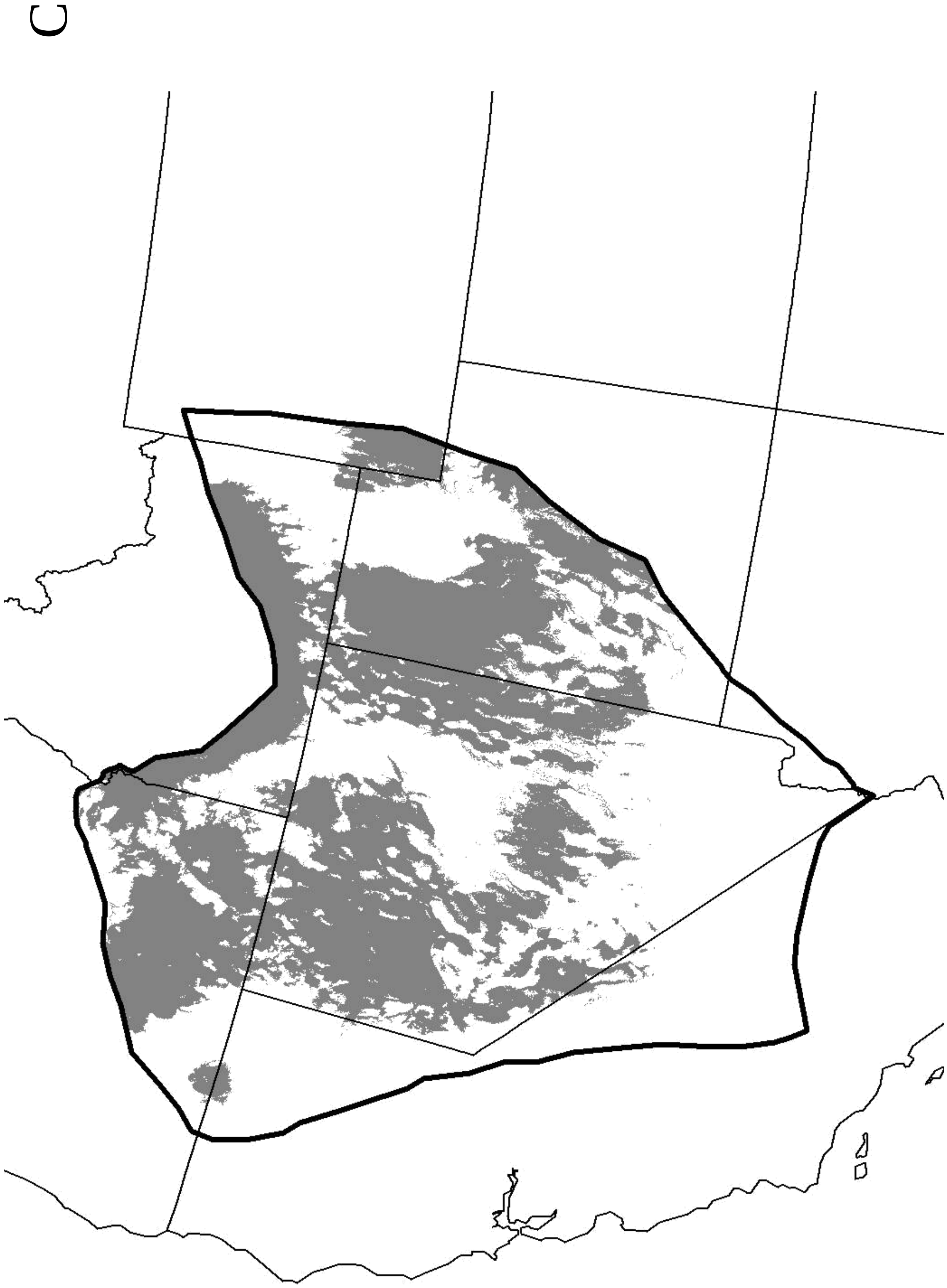
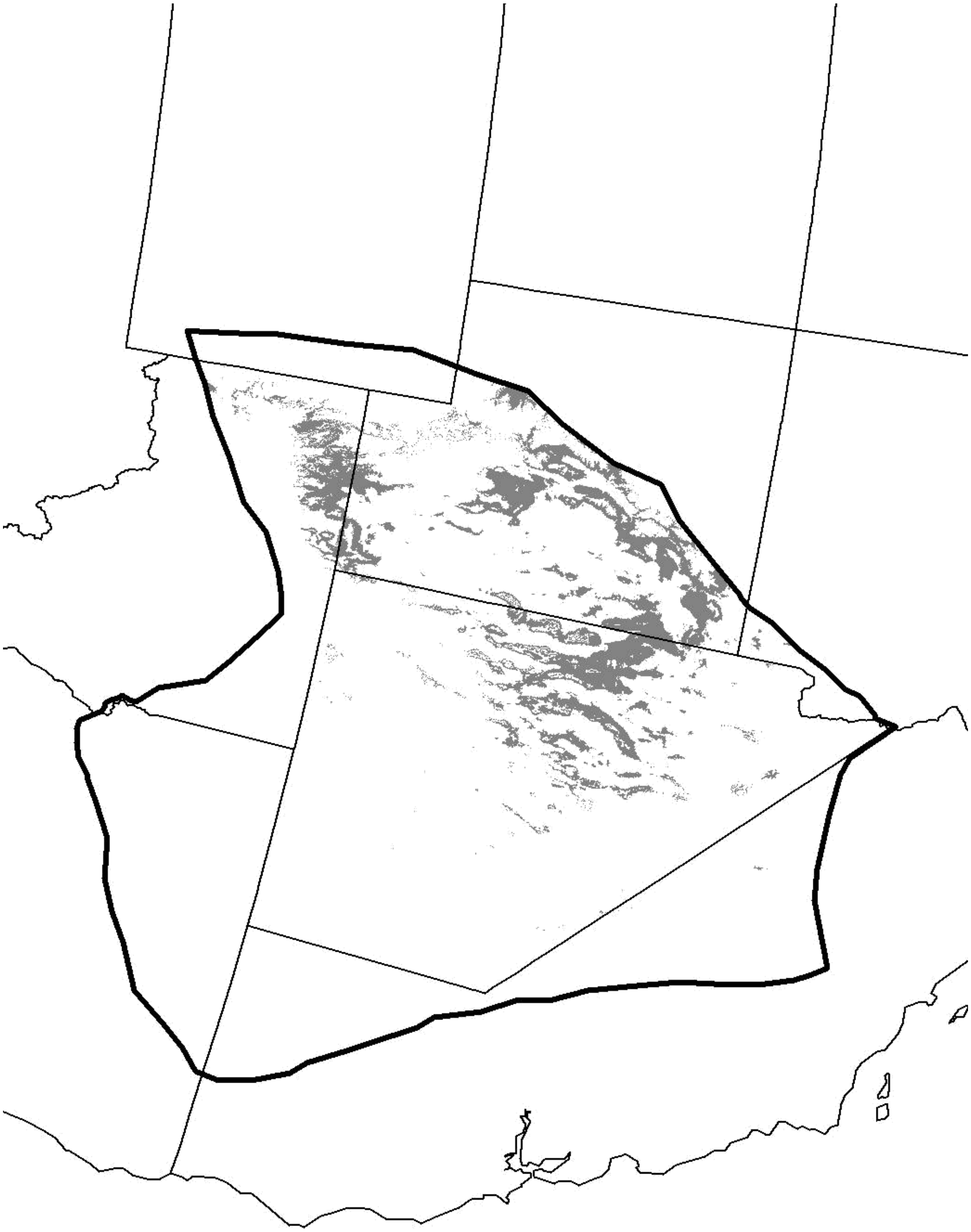

C

Figure 10. A) Distribution of the cliff chipmunk (*Tamias dorsalis*) in the Great Basin predicted by Maxent for historical conditions. B) Distribution of the cliff chipmunk in the Great Basin predicted by Maxent for minimum emission scenario (b2a, CCCma). C) Distribution of the cliff chipmunk in the Great Basin predicted by Maxent for maximum emission scenario (a2a, CCCma). Shaded areas indicate the predicted distribution of the species.

A



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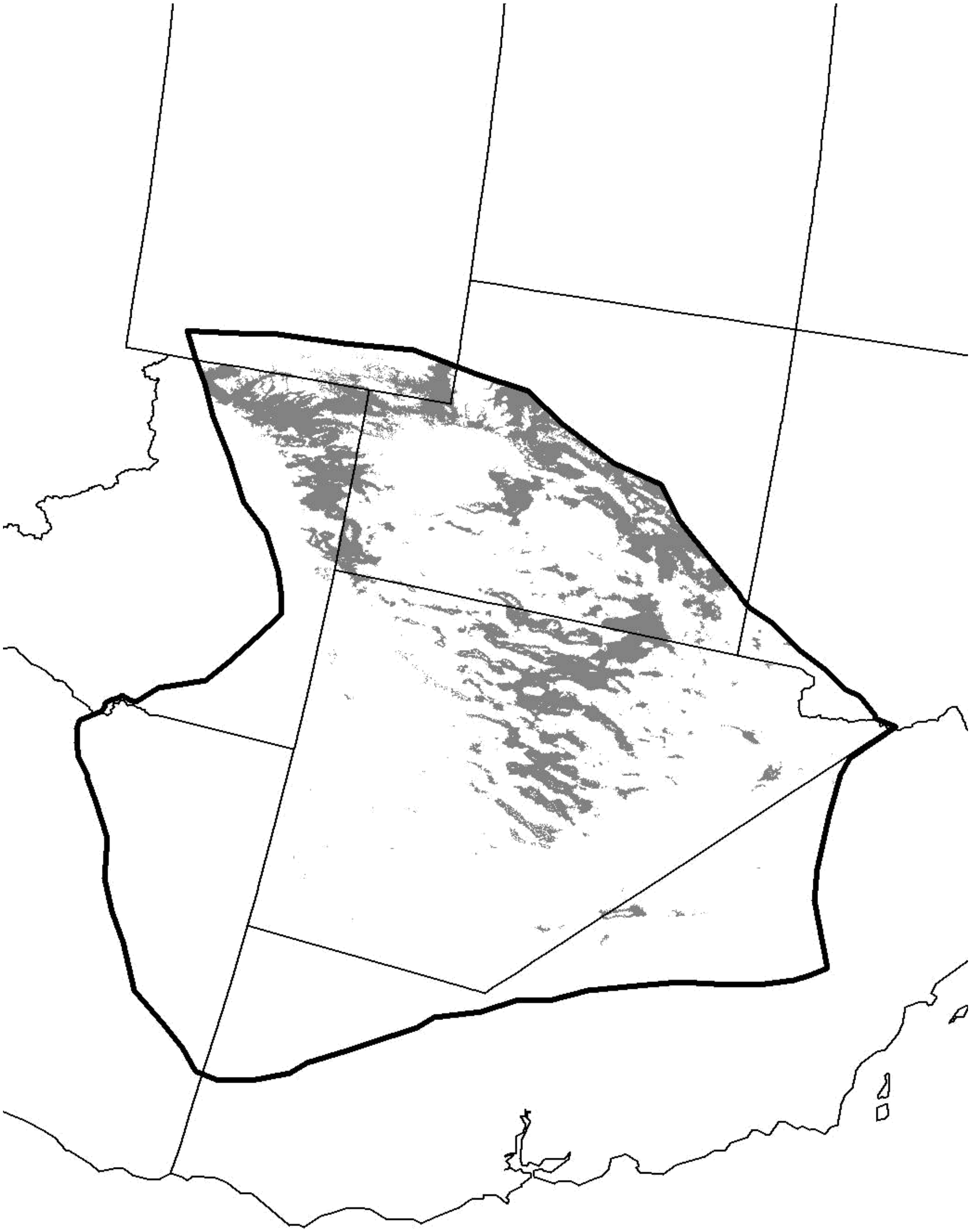


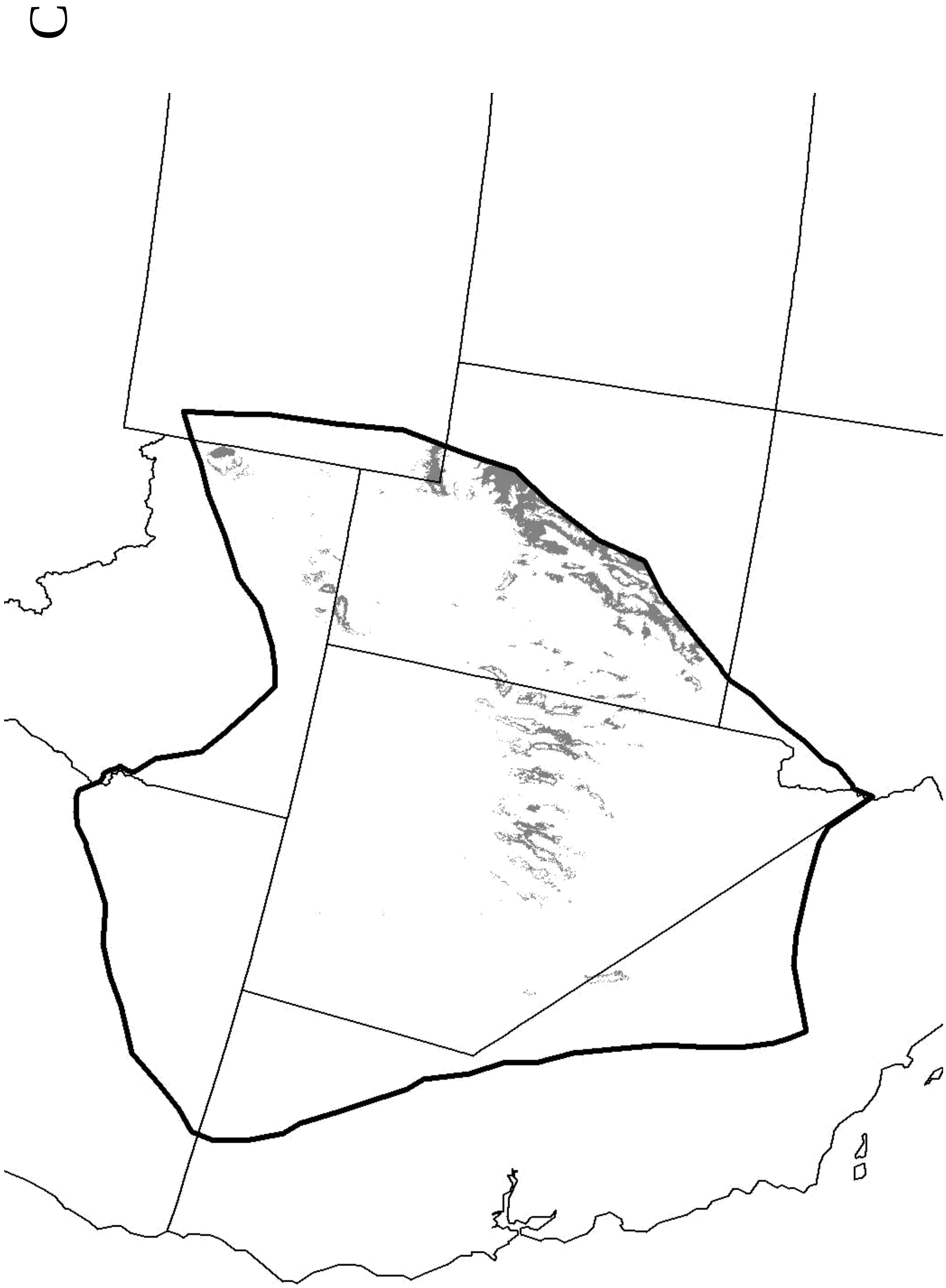
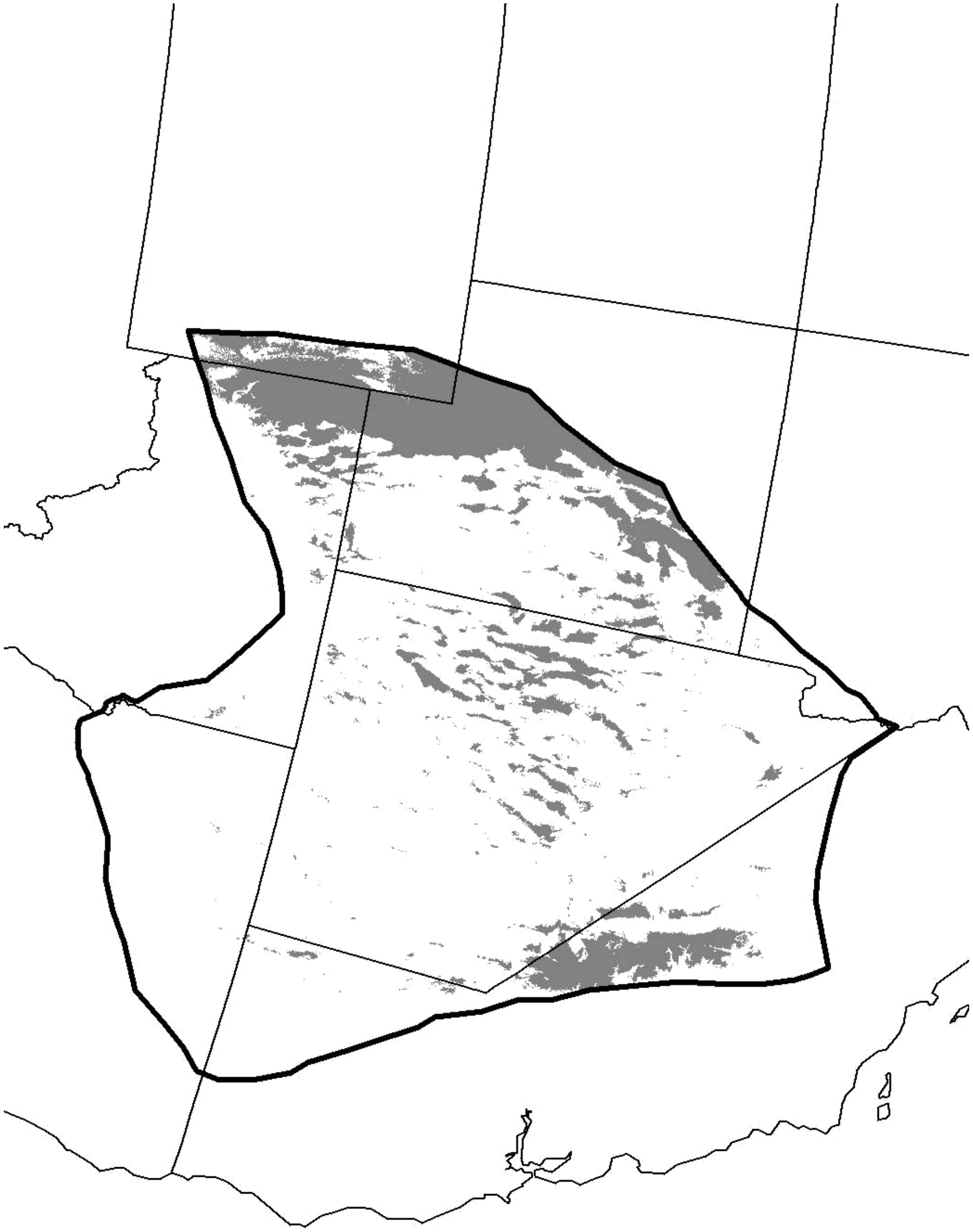

C

Figure 11. A) Distribution of the Uinta chipmunk (*Tamias umbrinus*) in the Great Basin predicted by Maxent for historical conditions. B) Distribution of the Uinta chipmunk in the Great Basin predicted by Maxent for minimum emission scenario (b2a, CCCma). C) Distribution of the Uinta chipmunk in the Great Basin predicted by Maxent for maximum emission scenario (a2a, CCCma). Shaded areas indicate the predicted distribution of the species.

A



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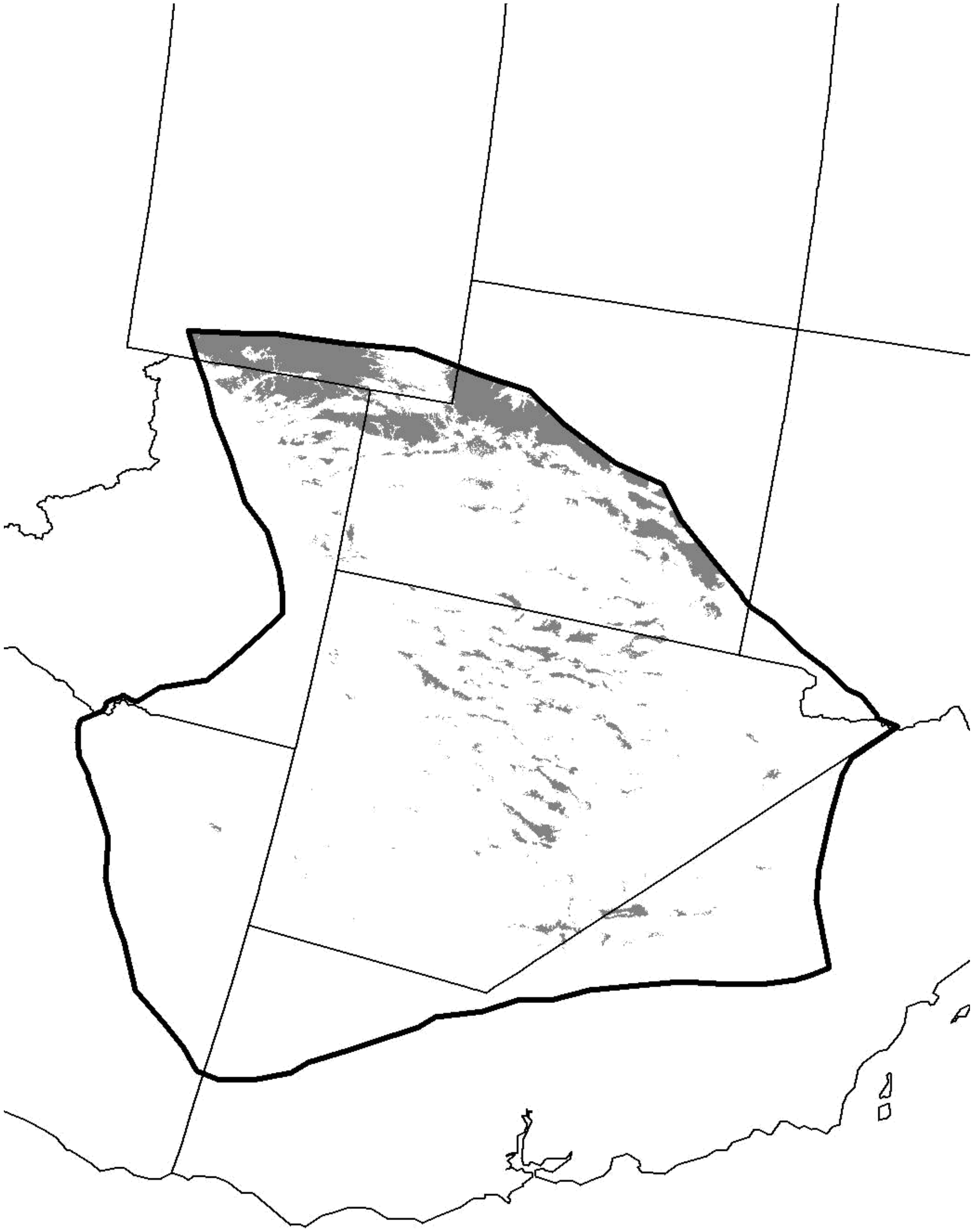

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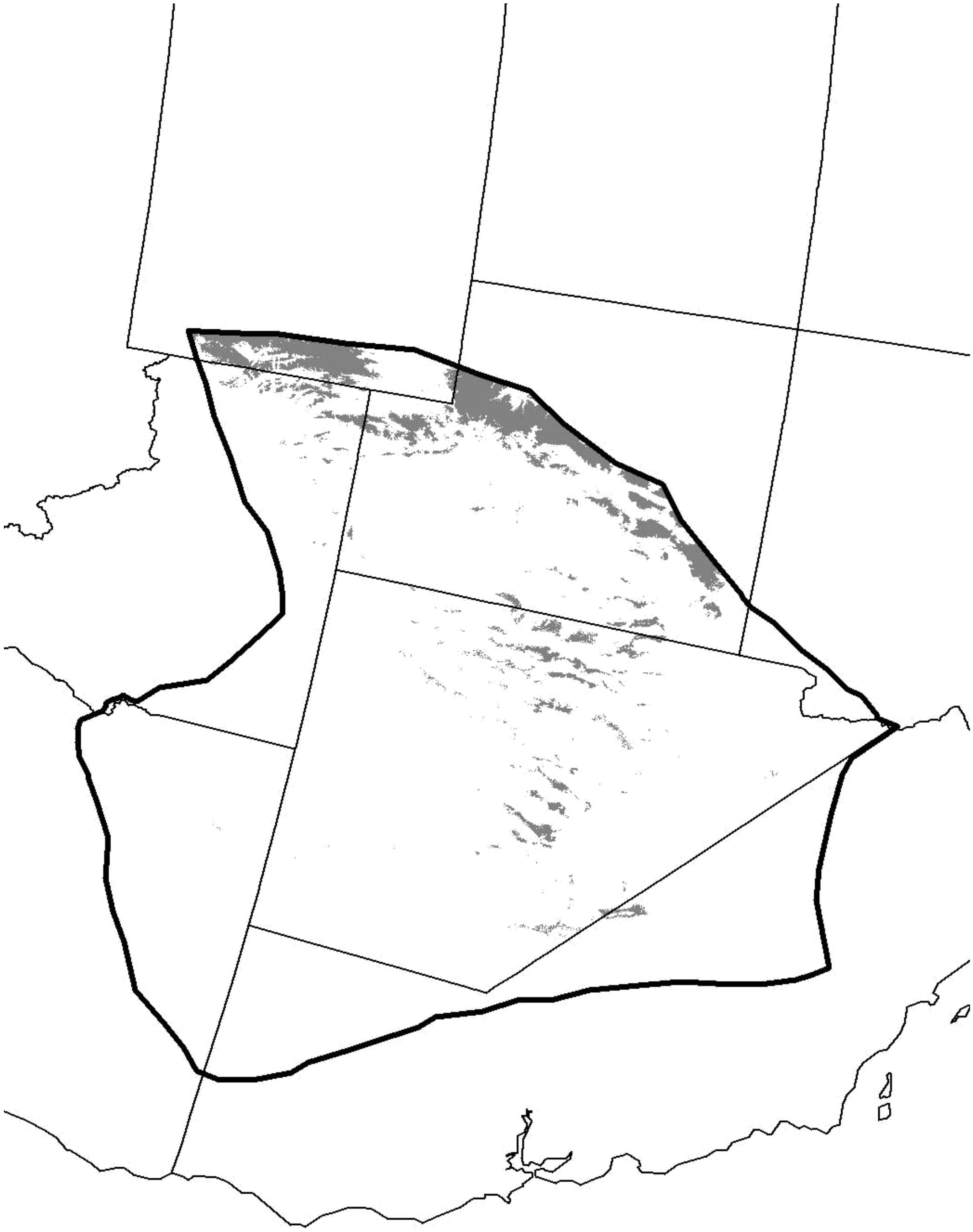
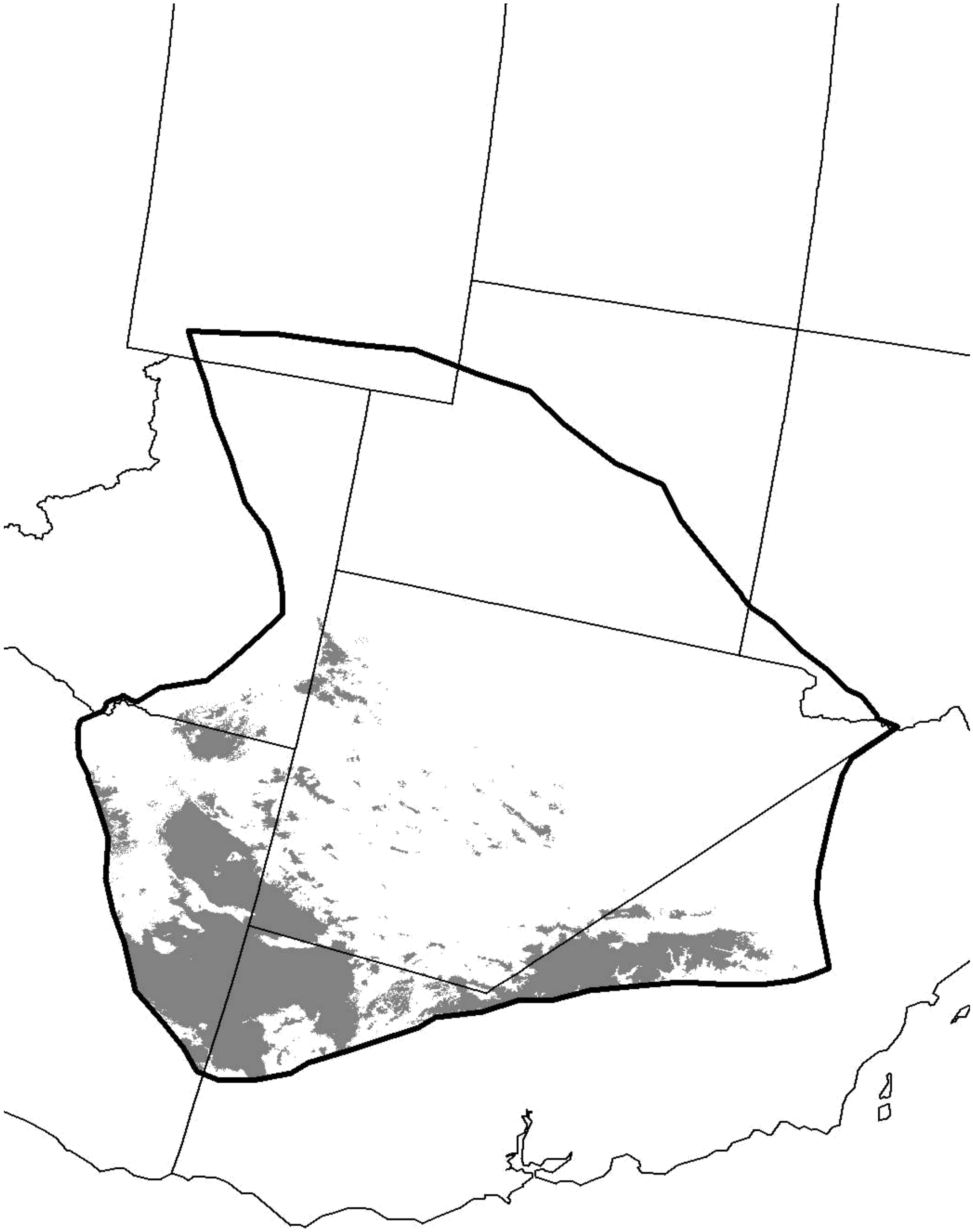


Figure 12. A) Distribution of the Belding’s ground squirrel (*Urocitellus beldingi*) in the Great Basin predicted by Maxent for historical conditions. B) Distribution of the Belding’s ground squirrel in the Great Basin predicted by Maxent for minimum emission scenario (b2a, CCCma). C) Distribution of the Belding’s ground squirrel in the Great Basin predicted by Maxent for maximum emission scenario (a2a, CCCma). Shaded areas indicate the predicted distribution of the species.

A



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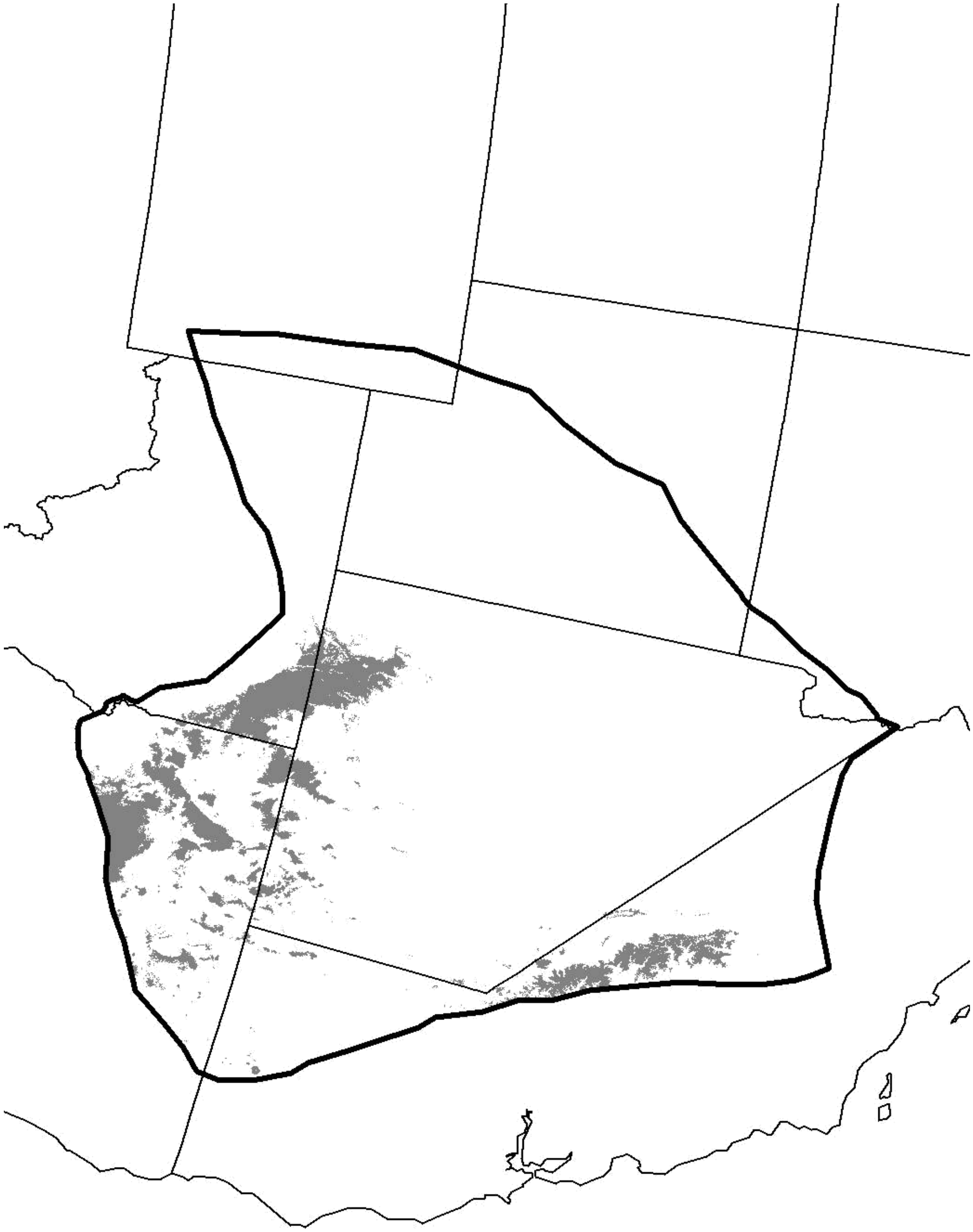

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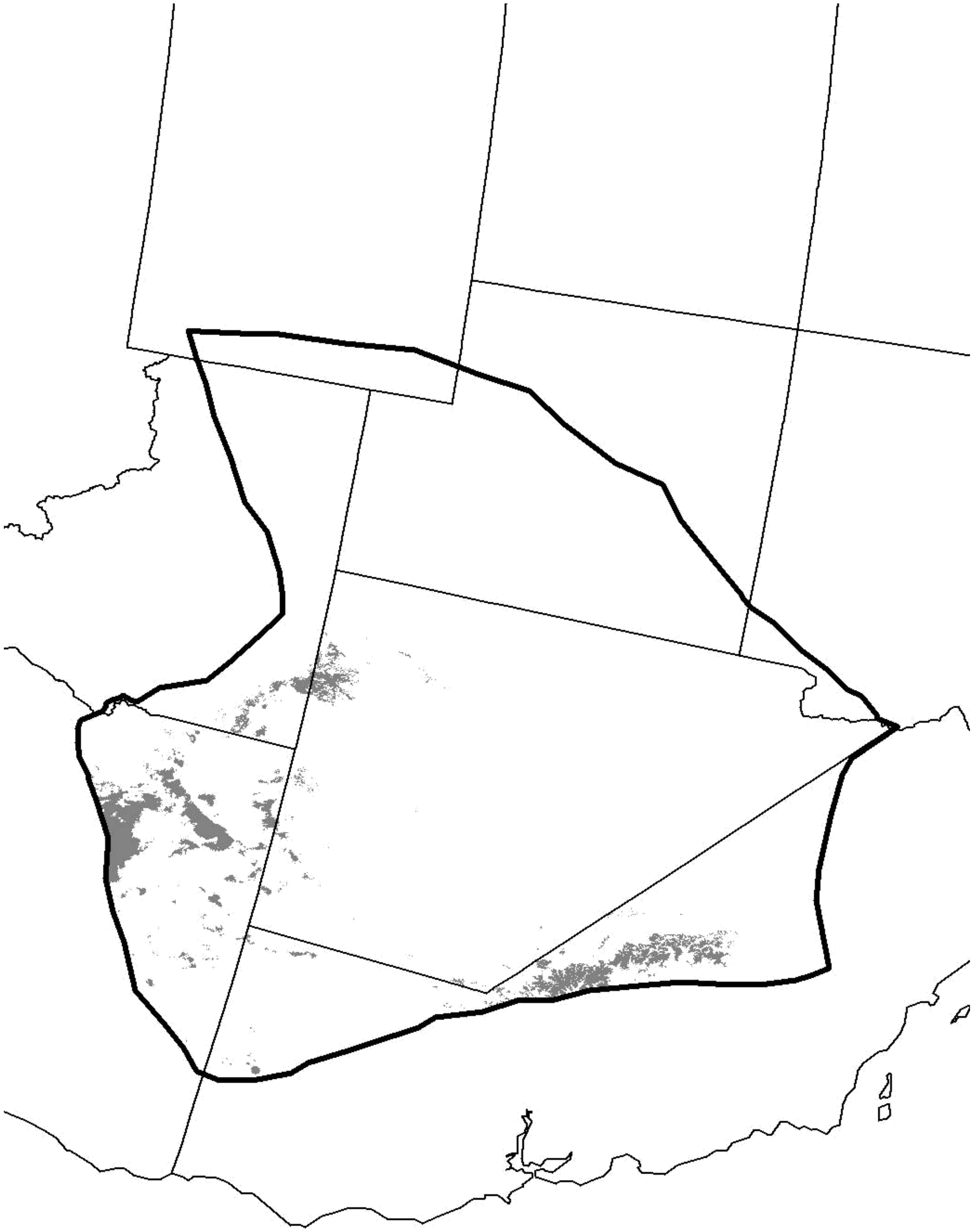
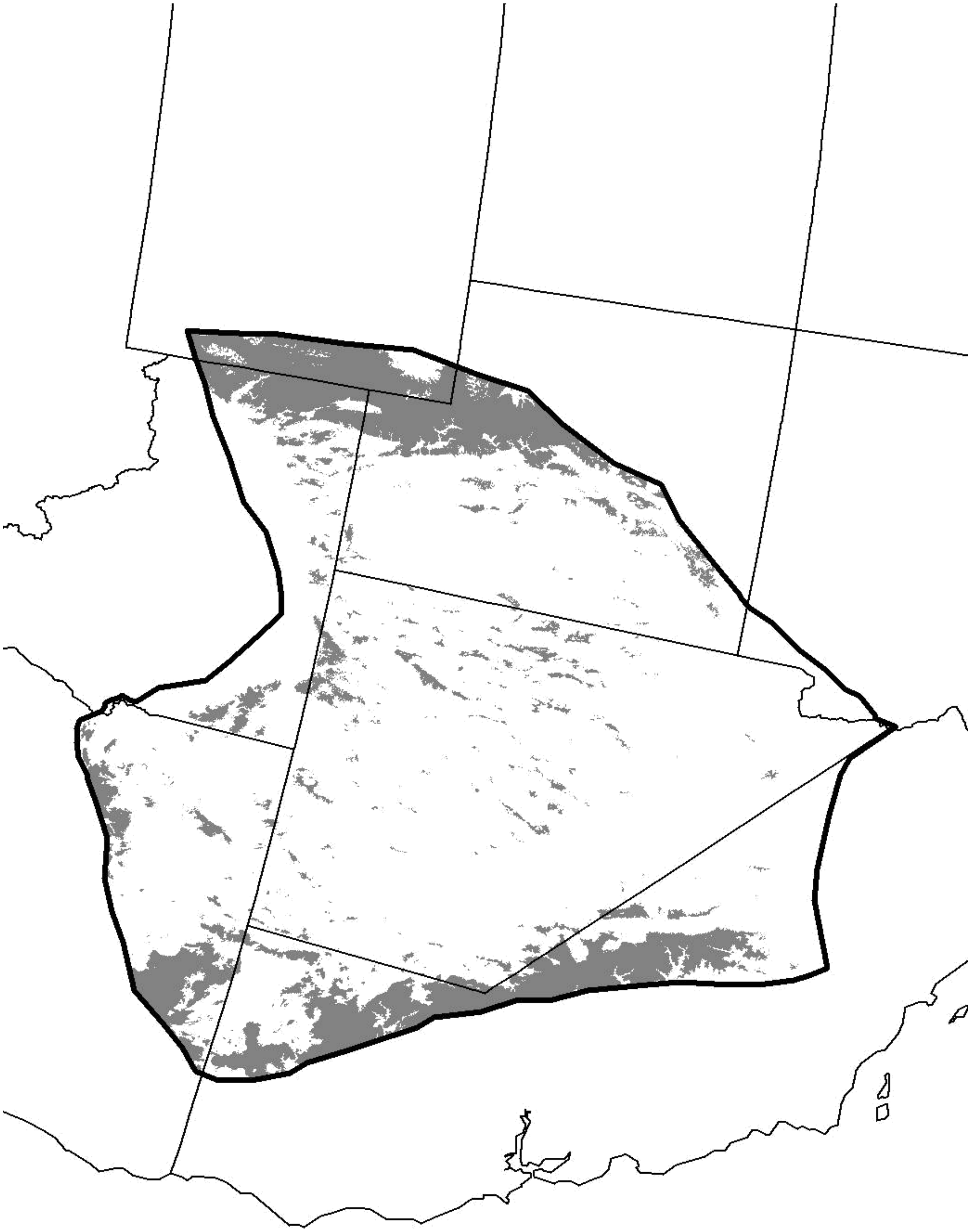


Figure 13. A) Distribution of the Western jumping mouse (*Zapus princeps*) in the Great Basin predicted by Maxent for historical conditions. B) Distribution of the Western jumping mouse in the Great Basin predicted by Maxent for minimum emission scenario (b2a, CCCma). C) Distribution of the Western jumping mouse in the Great Basin predicted by Maxent for maximum emission scenario (a2a, CCCma). Shaded areas indicate the predicted distribution of the species.

A



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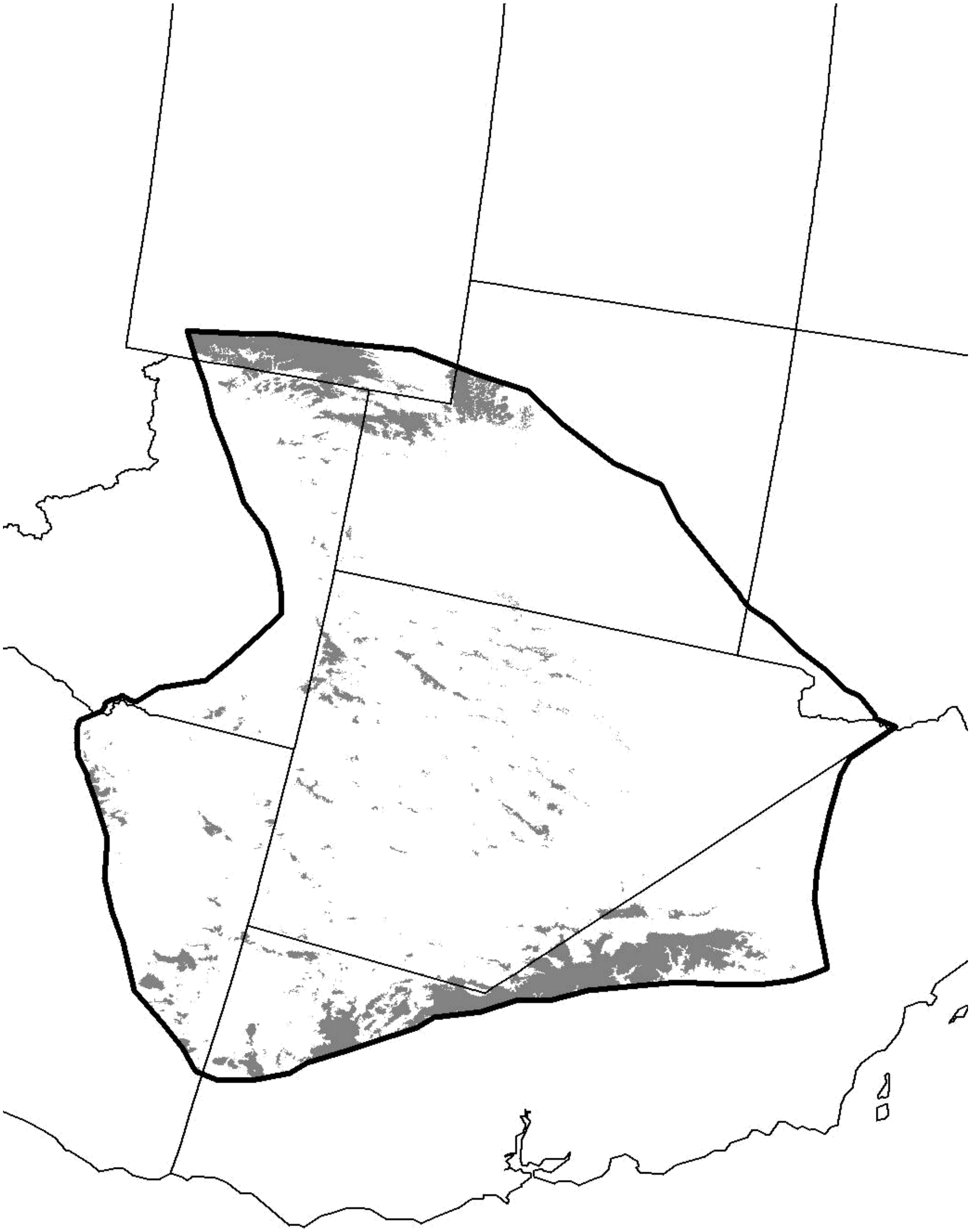

C