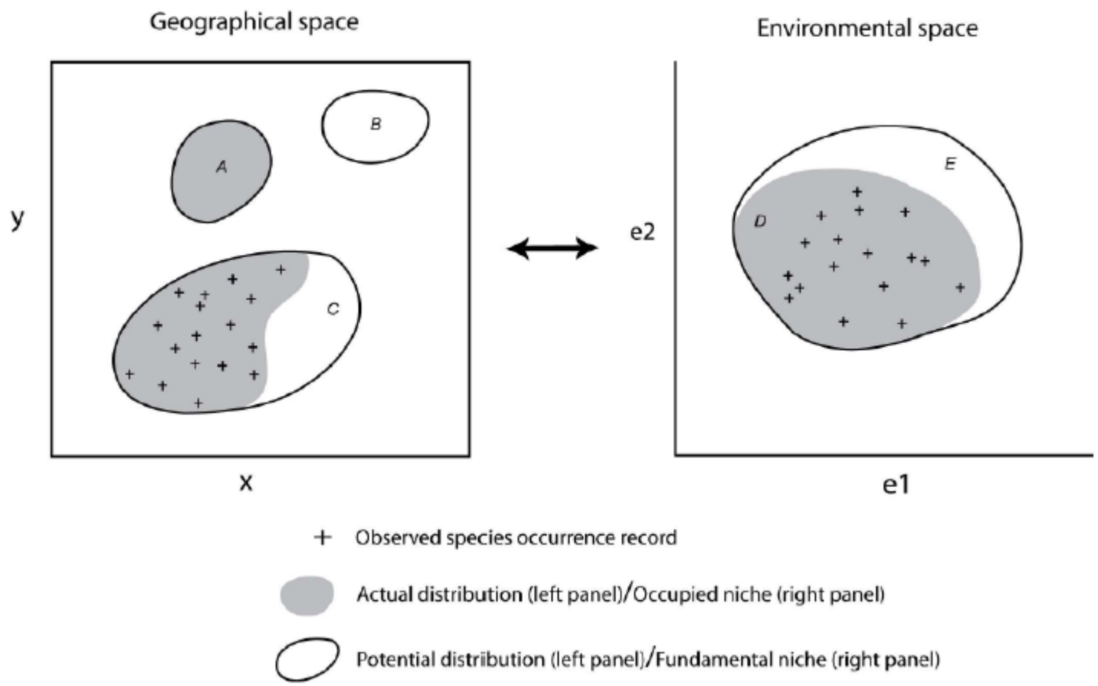


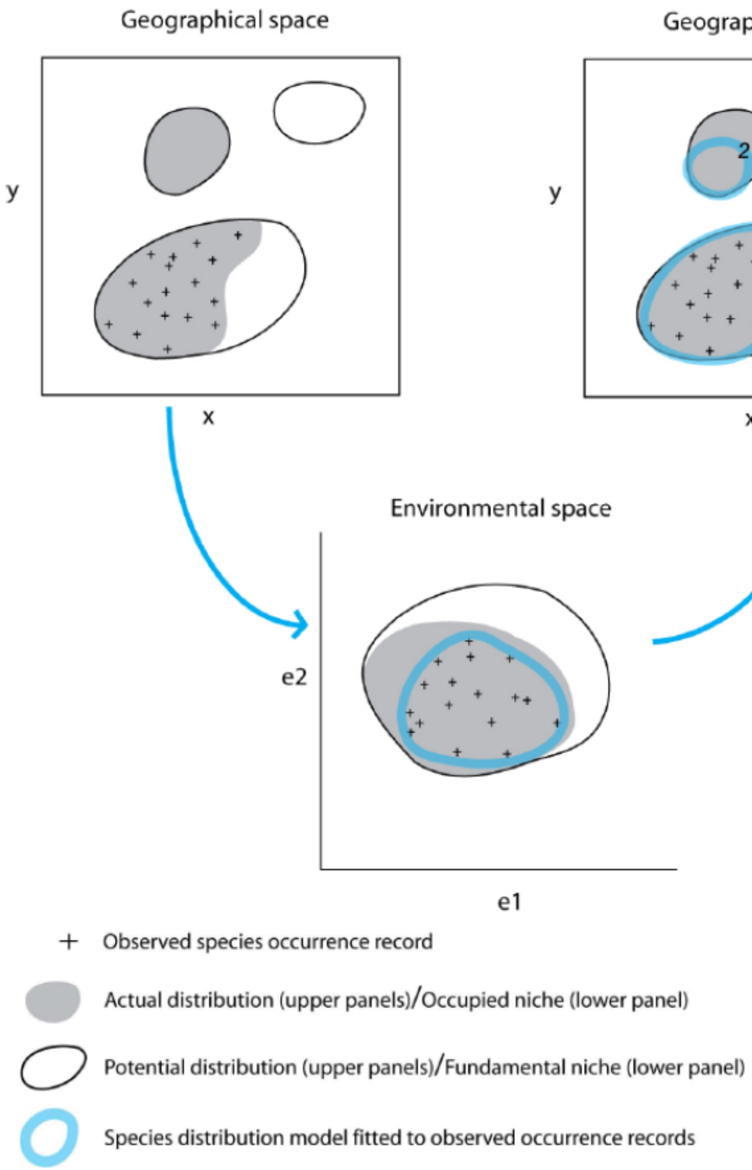
Figure 2. Illustration of the relationship between a hypothetical species' distribution in geographical space and environmental space. Geographical space refers to spatial location as commonly referenced using *x* and *y* coordinates. Environmental space refers to Hutchinson's *n*-dimensional niche, illustrated here for simplicity in only two dimensions (defined by two environmental factors, e_1 and e_2). Crosses represent observed species occurrence records. Grey shading in geographical space represents the species' *actual distribution* (i.e. those areas that are truly occupied by the species). Notice that some areas of actual distribution may be unknown (e.g. area *A* is occupied but the species has not been detected there). The grey area in environmental space represents that part of the niche that is occupied by the species: the *occupied niche*. Again, notice that the observed occurrence records may not identify the full extent of the occupied niche (e.g. the shaded area immediately around label *D* does not include any known localities). The solid line in environmental space depicts the species' *fundamental niche*, which represents the full range of abiotic conditions within which the species is viable. In geographical space, the solid lines depict areas with abiotic conditions that fall within the fundamental niche; this is the species' *potential distribution*. Some regions of the potential distribution may not be inhabited by the species due to biotic interactions or dispersal limitations. For example, area *B* is environmentally suitable for the species, but is not part of the actual distribution, perhaps because the species has been unable to disperse across unsuitable environments to reach this area. Similarly, the non-shaded area around label *C* is within the species' potential distribution, but is not inhabited, perhaps due to competition from another species. Thus, the non-shaded area around label *E* identifies those parts of the fundamental niche that are unoccupied, for example due to biotic interactions or geographical constraints on species dispersal.

Concepts

- fundamental niche
- realized nice
- conversion from maps (of species locations, e1, and e2) to niche defined by e1, e2

Pearson, 2007

Prof. J. Hicke

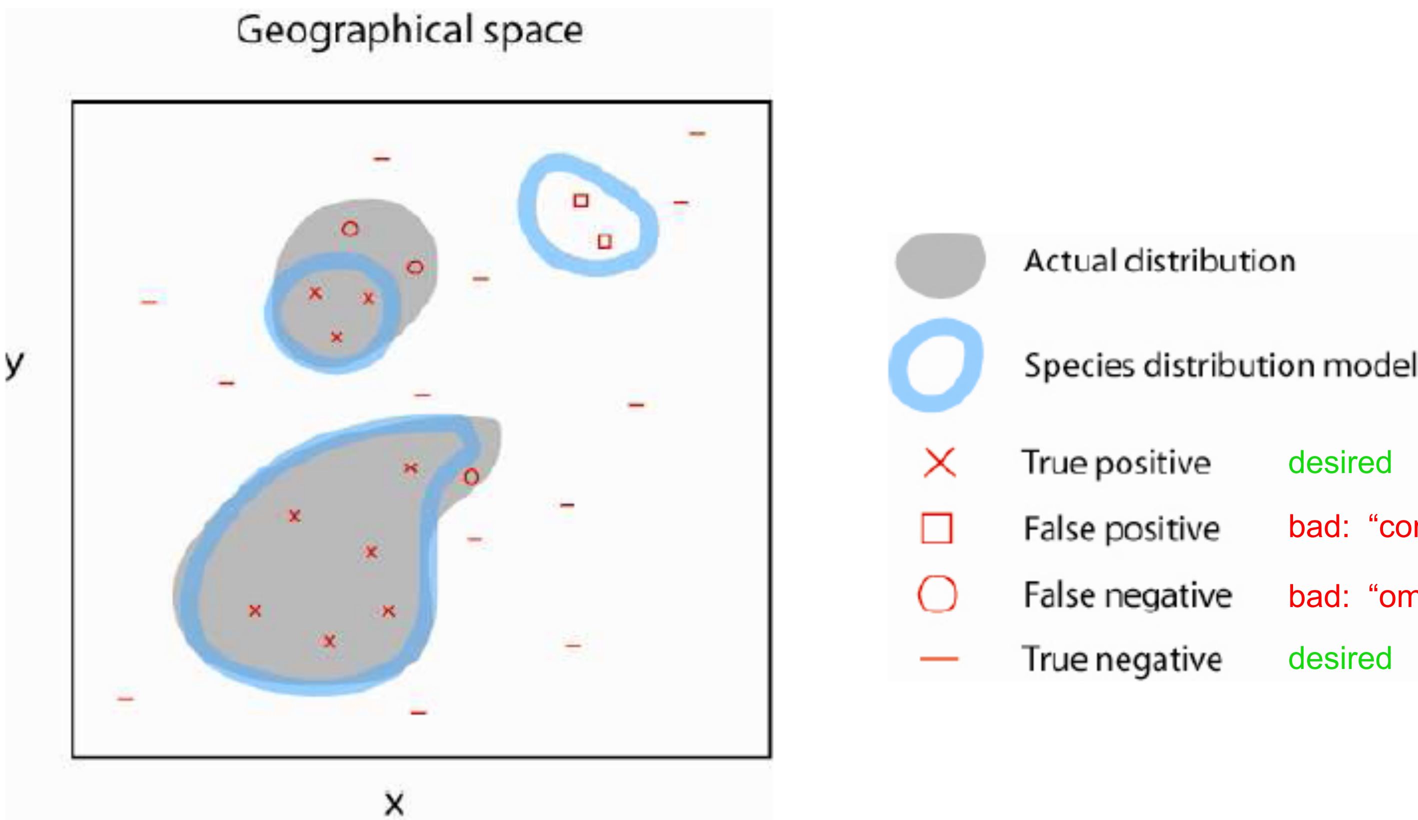


Species distribution modeling of geographic and niche space

Pearson, 2007

Figure 3. Diagram illustrating how a hypothetical species' distribution model may be fitted to observed species occurrence records (using the same hypothetical case as in Fig. 2). A modelling technique (e.g. GARP, Maxent) is used to characterize the species' niche in environmental space by relating observed occurrence localities to a suite of environmental variables. Notice that, in environmental space, the model may not identify either the species' occupied niche or fundamental niche; rather, the model identifies only that part of the niche defined by the observed records. When projected back into geographical space, the model will identify parts of the actual distribution and potential distribution. For example, the model projection labeled *1* identifies the known distributional area. Projected area *2* identifies part of the actual distribution that is currently unknown; however, a portion of the actual distribution is not predicted because the observed occurrence records do not identify the full extent of the occupied niche (i.e. there is incomplete sampling; see area *D* in Fig. 2). Similarly, modeled area *3* identifies an area of potential distribution that is not inhabited (the full extent of the potential distribution is not identified because the observed occurrence records do not identify the full extent of the fundamental niche due to, for example, incomplete sampling, biotic interactions, or constraints on species dispersal; see areas *D* and *E* in Fig. 2).

Evaluating models



- True positive: desired
- False positive: bad: "commission" (why?)
- False negative: bad: "omission" (why?)
- True negative: desired

Figure 4. Diagram illustrating the four types of outcomes that are possible when assessing the predictive performance of a species distribution model: true positive, false positive, false negative and true negative. The diagram uses the same hypothetical actual and modeled distributions as in Figure 3. Each instance of a symbol (x, □, ○, -) on the map depicts a site that has been surveyed and presence or absence of the species recorded (it is assumed here that if a site falls within the actual distribution then the species will be detected). These survey records constitute the test data. Frequencies of each type of outcome are commonly entered into a confusion matrix (see main text).

Pearson, 2007

How to develop a species distribution model

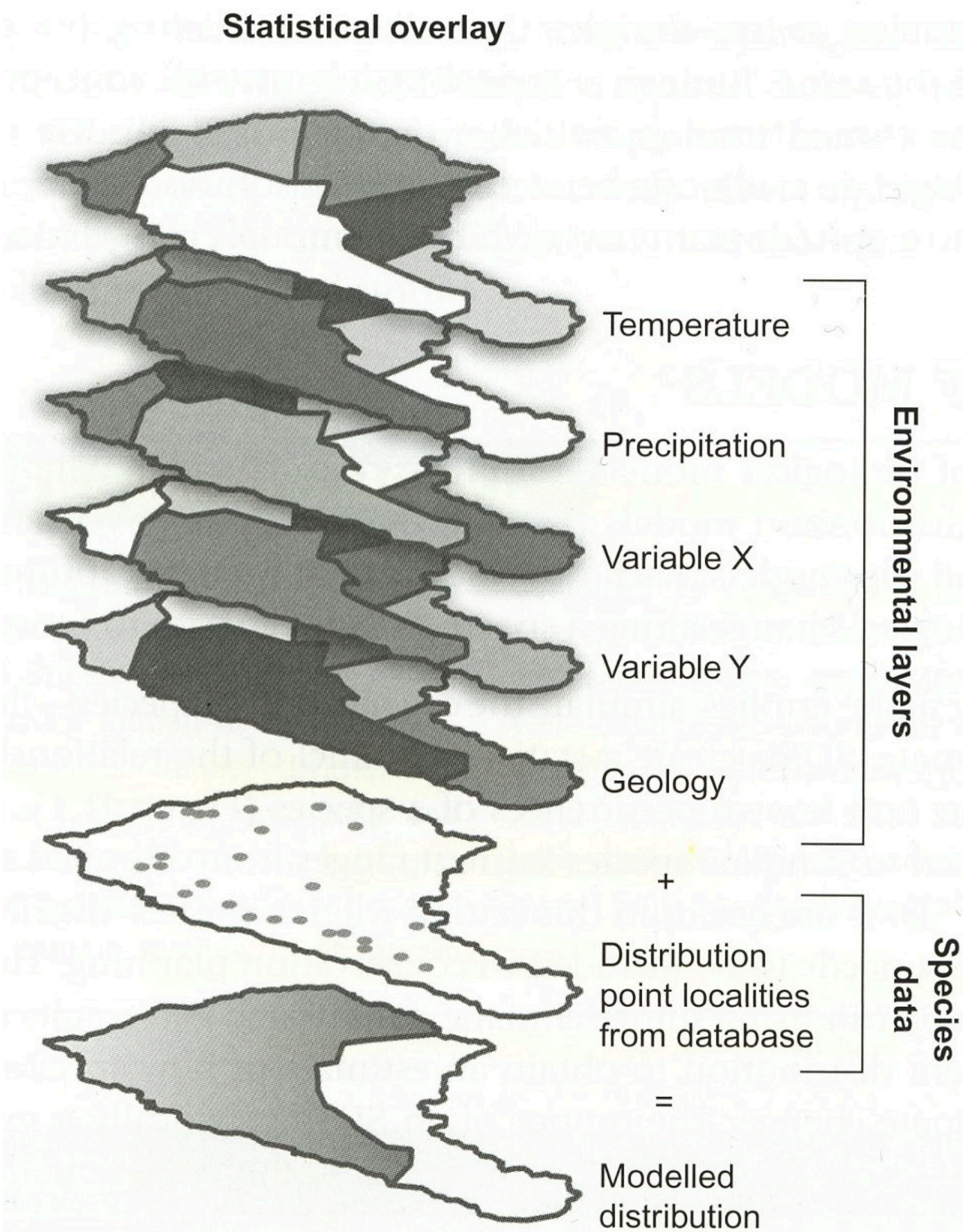


FIGURE 11.1 Schematic of an SDM.
Species distribution modeling begins with selection of a study area (left). The study area is usually selected to be large enough to include the complete ranges of species of interest to ensure that data sampling the entire climate space the species can tolerate are included. Climate variables and other factors constraining species distribution (shaded layers on right) are then correlated with known occurrences of the species of interest (layer with points). This statistical relationship can be projected geographically to simulate the species' range (bottom shaded area). Repeating this process using GCM-generated future climate variables allows simulation of range shifts in response to climate change.

Hannah, 2011

Evaluating species distribution models with historical observations

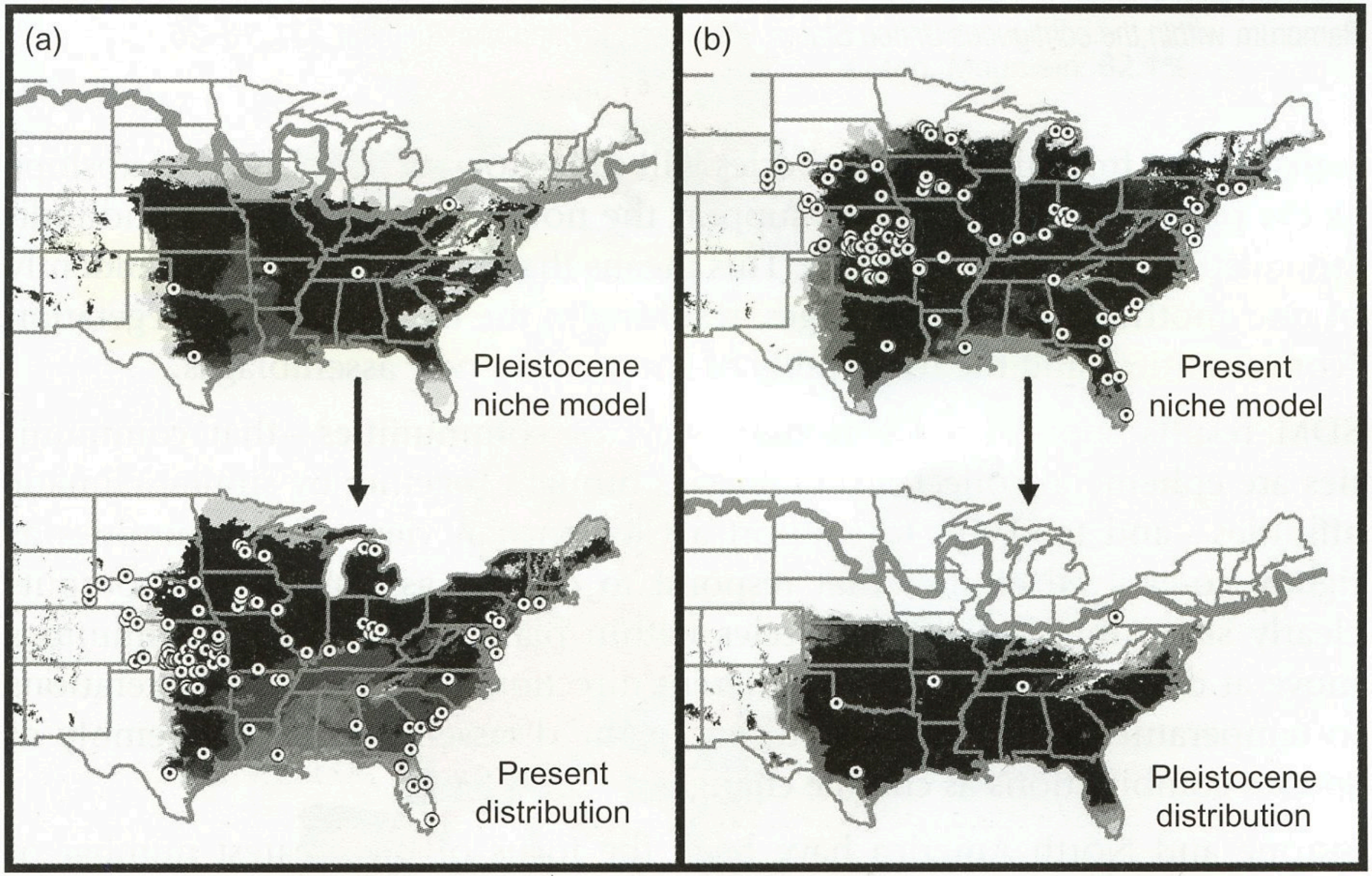


FIGURE 11.9 **Backwards and Forwards Modeling of Eastern Mole (*Scalopus aquaticus*).** (A) SDM created from known Pleistocene occurrences predicts present distribution. (B) SDM created from known current distribution predicts known fossil occurrences. *From Martinez-Meyer, E., et al. 2004. Ecological niches as stable distributional constraints on mammal species, with implications for Pleistocene extinctions and climate change projections for biodiversity.* Global Ecology and Biogeography *13, 305–314.*

Hannah, 2011

Example application of species distribution model

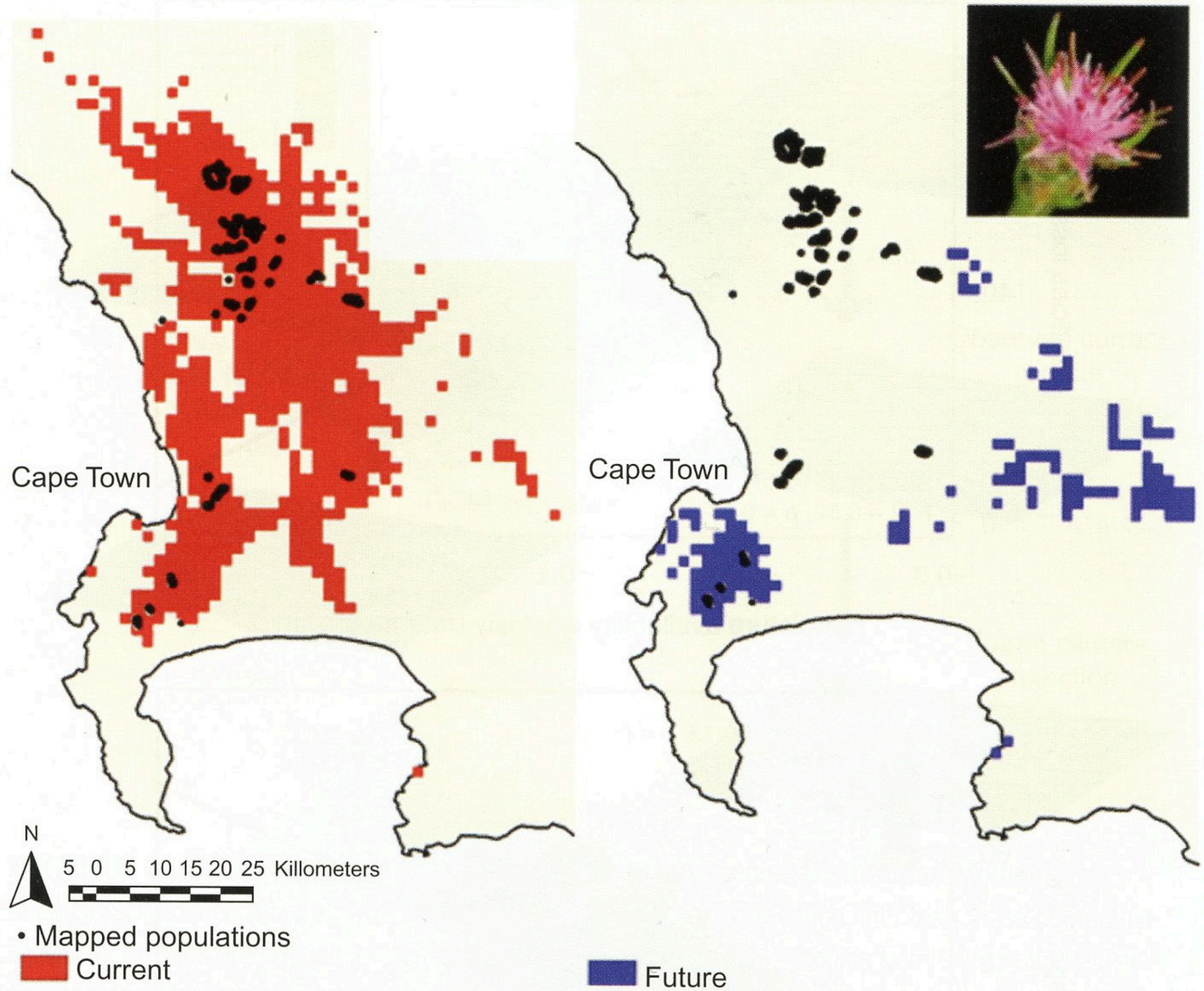


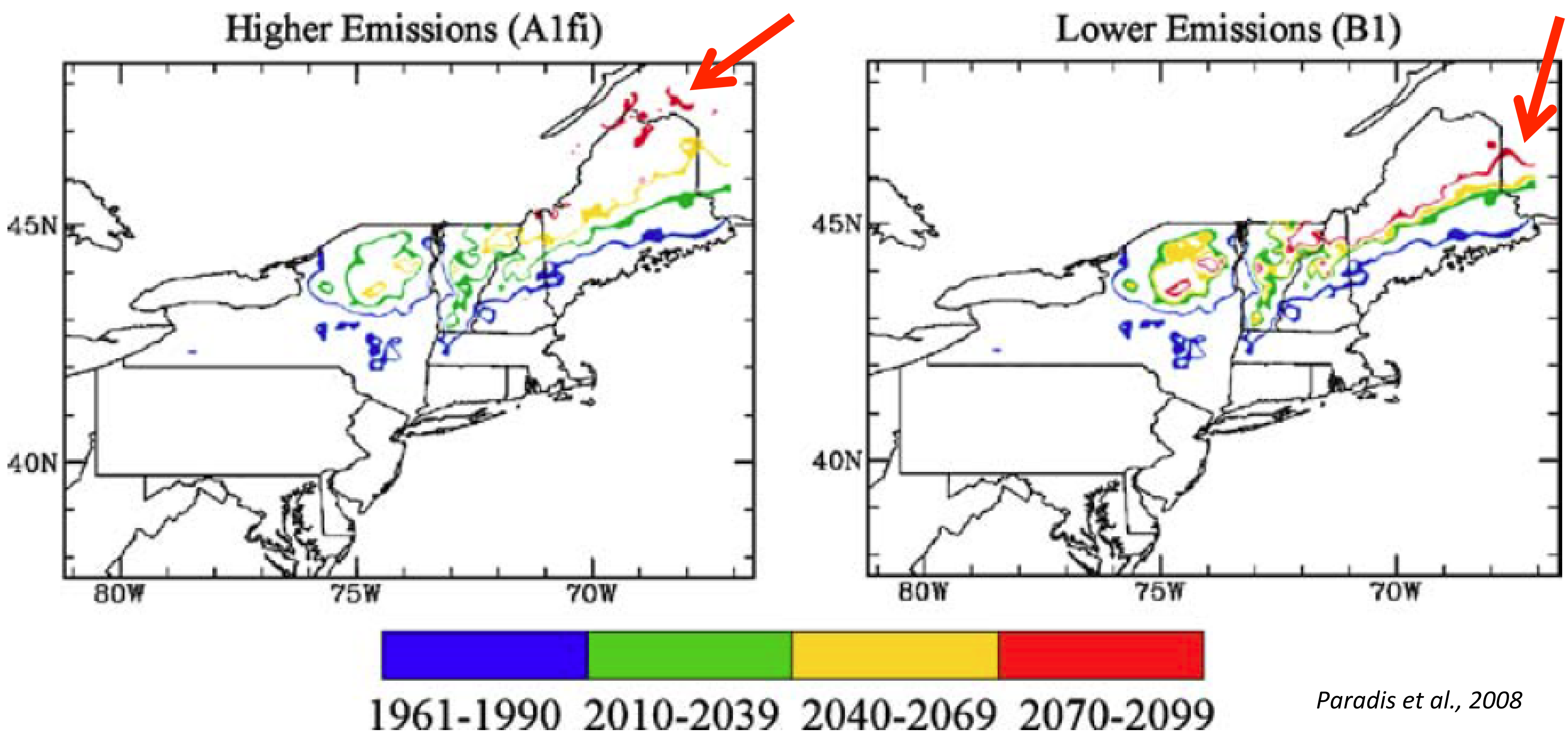
FIGURE 11.8 Example of SDM Output.
SDM output for a protea (pictured) from the Cape Floristic Region of South Africa. Current modeled range is shown in red, and future modeled range is shown in blue. Known occurrence points for the species are indicated by black circles. *Figure courtesy Guy Midgley.*

Hannah, 2011

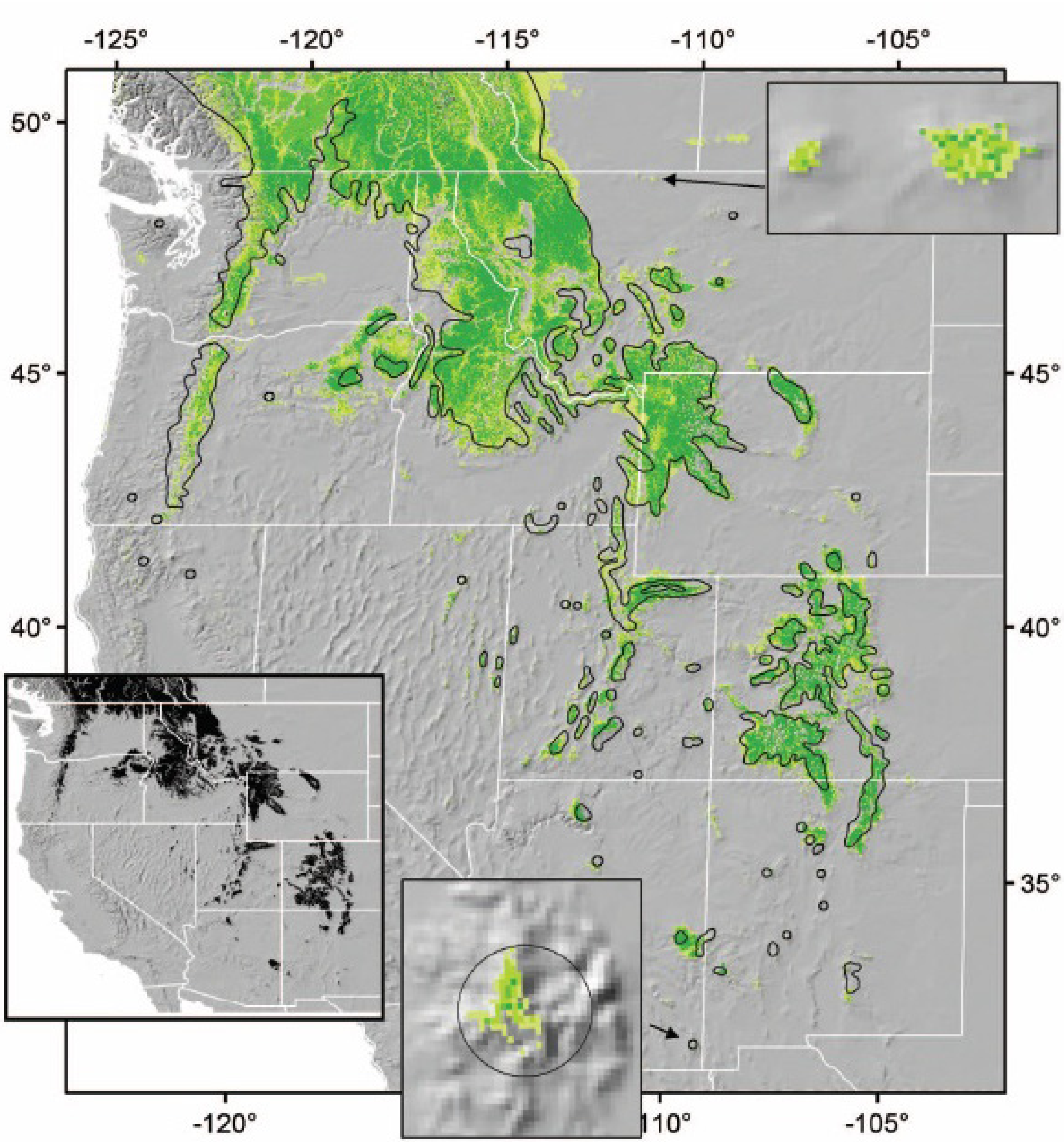
Insect outbreaks: Projections given future climate change

Change in range of invasive hemlock woolly adelgid

Evaluate sensitivity to uncertain future conditions



Paradis et al., 2008



Rehfeldt et al., 2006

Fig. 8 Modeled bioclimate profile of *Picea engelmannii* (see fig. 7).

- sensitivity of model predictions represented by voting (yellow=fewer votes; green=more votes
- evaluation against ancillary data set (Little range map)

Prof. J. Hicke

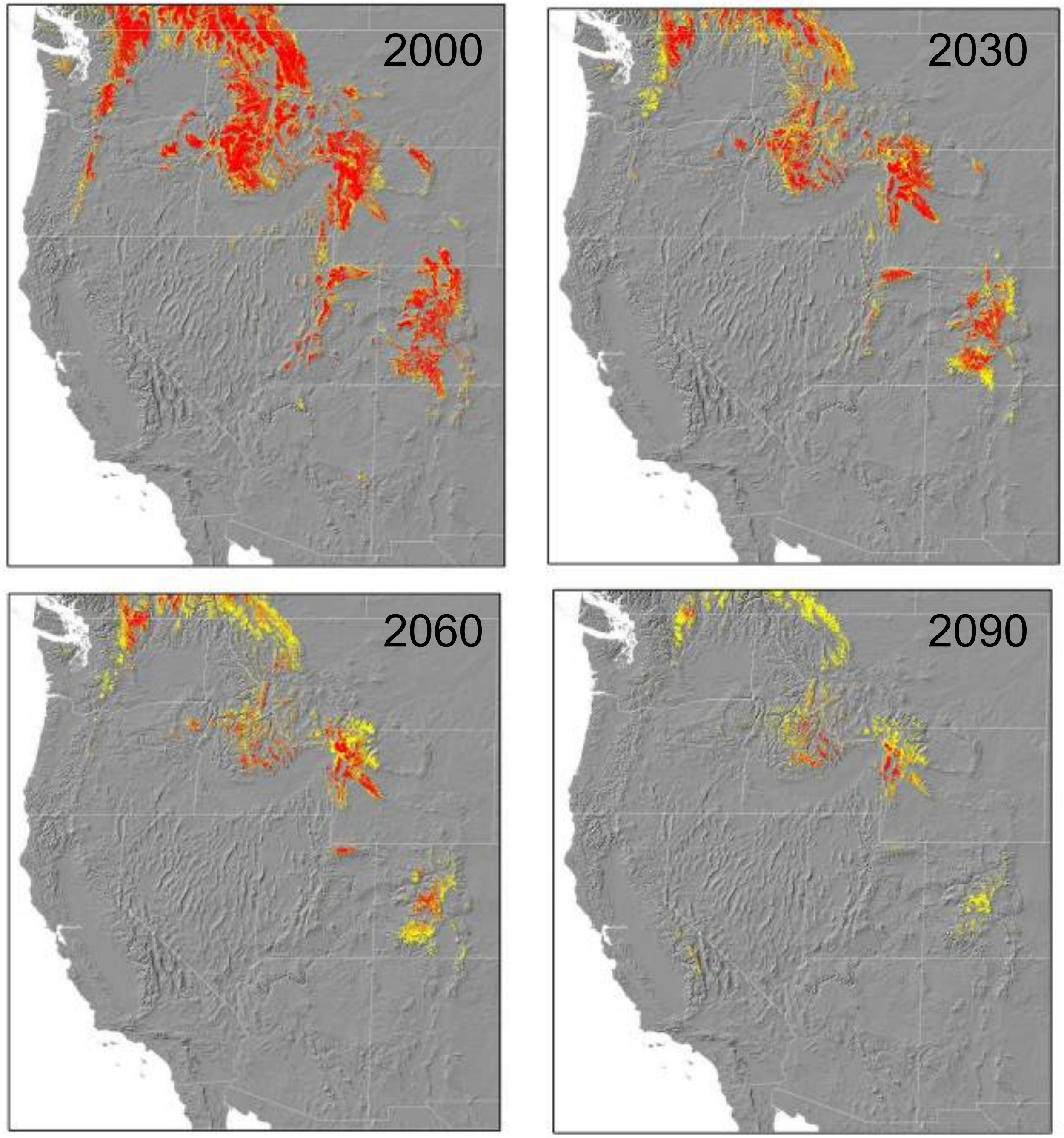
Application of model using climate change projections

Subalpine Fir

Climate Model Probability

50-75 %

75-100 %



Rehfeldt et al., 2006

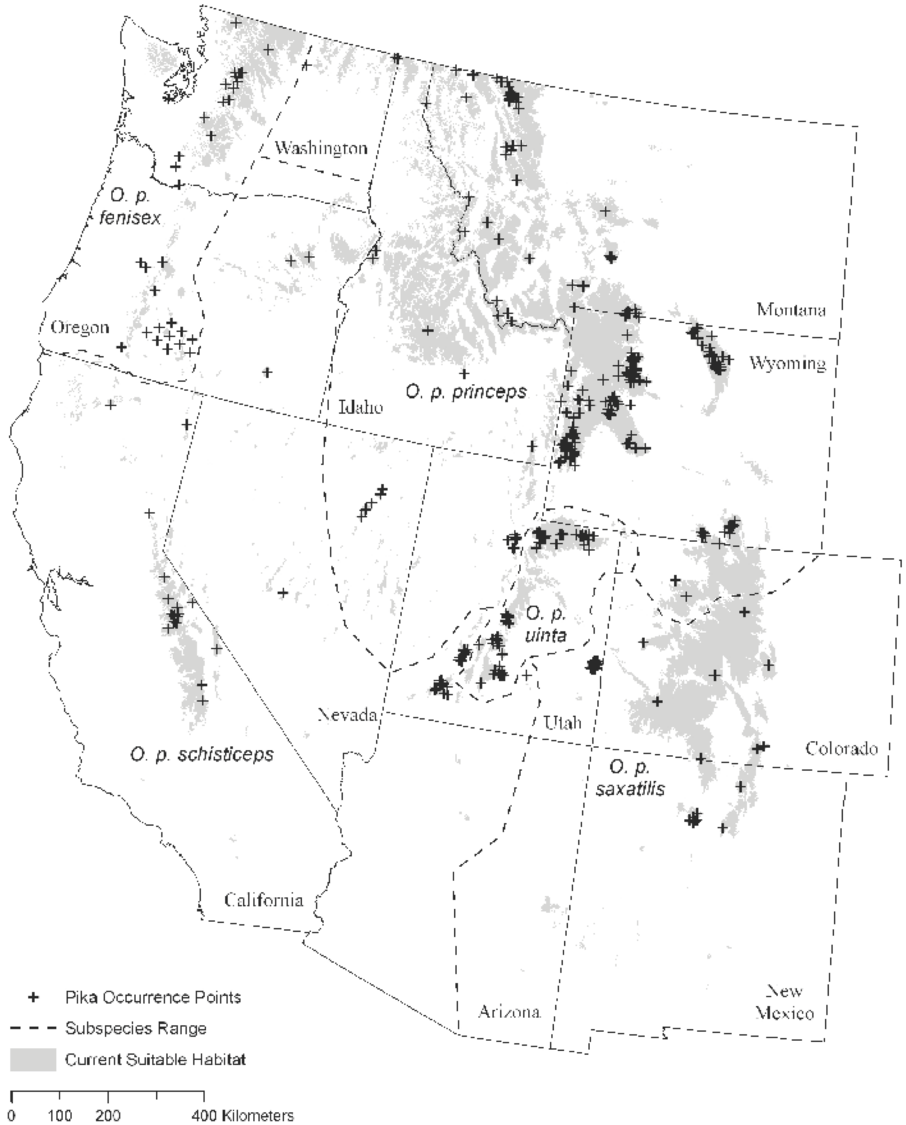
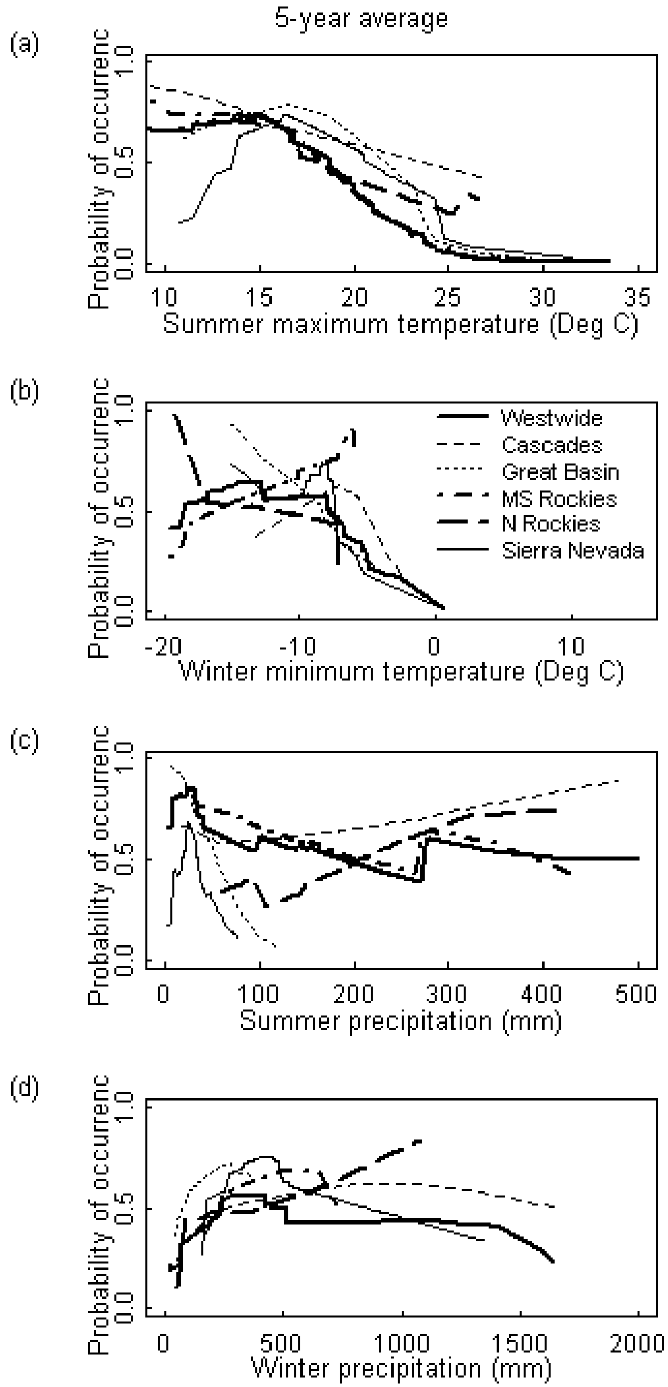


Figure 1. Observed pika occurrence points (plusses), pika subspecies (dashed lines), and modeled suitable habitat for current climate (gray).

Species distribution model of pika

Trook, Buotte, Hicke, unpublished



Probability of occurrence (response variable)

versus

climate variables (explanatory variables)

Trook, Buotte, Hicke, unpublished

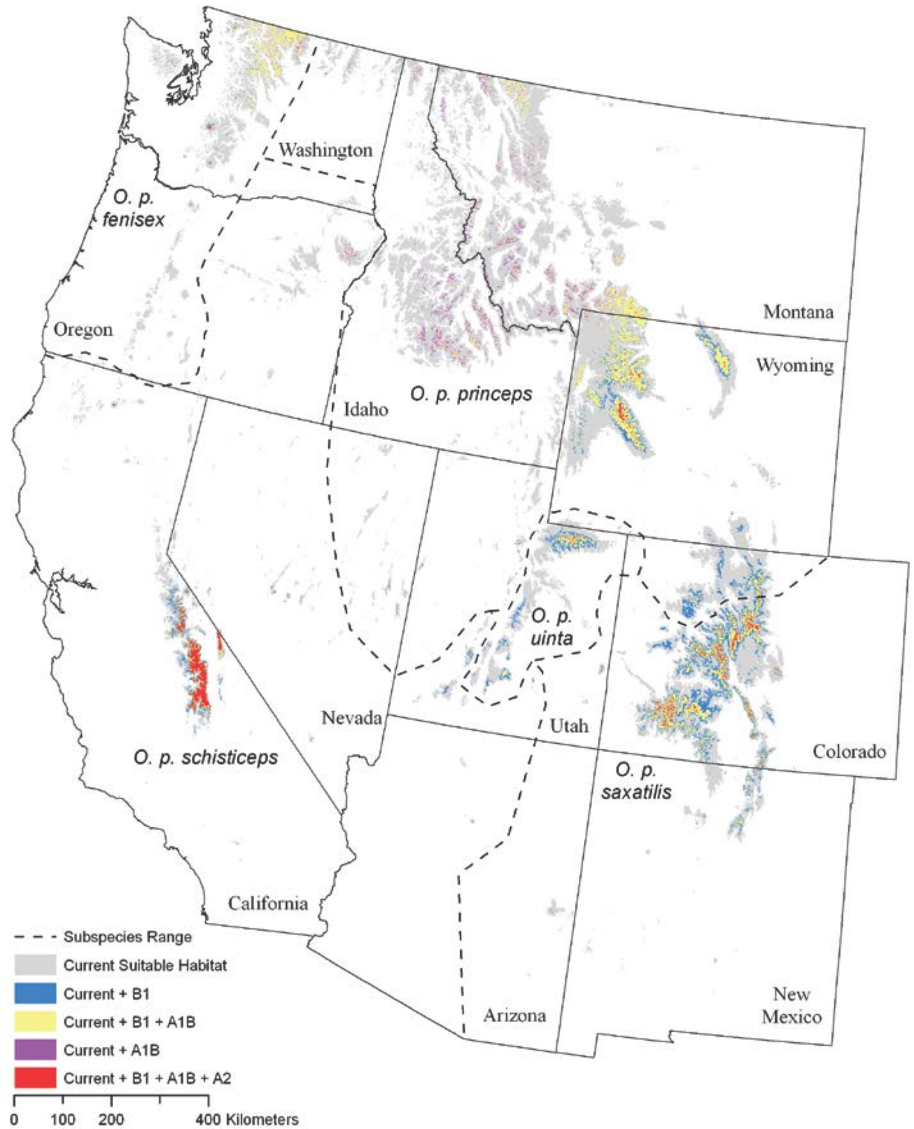


Figure 2. Modeled suitable habitat for American pika for current climate and for climate emission/model projections GFDLCM21/B1, CGCM3/A1B, and GFDLCM21/A2. For the majority of future habitat, more warming leads to a contraction in habitat area upslope (or disappearance). In the small amount of purple area in the northern Rocky Mountains, the GFDLCM21/B1 projection was warmer in the warmest month than the CGCM3/A1B projection.

Projections of future potential habitat based on climate change projections

Trook, Buotte, Hicke, unpublished

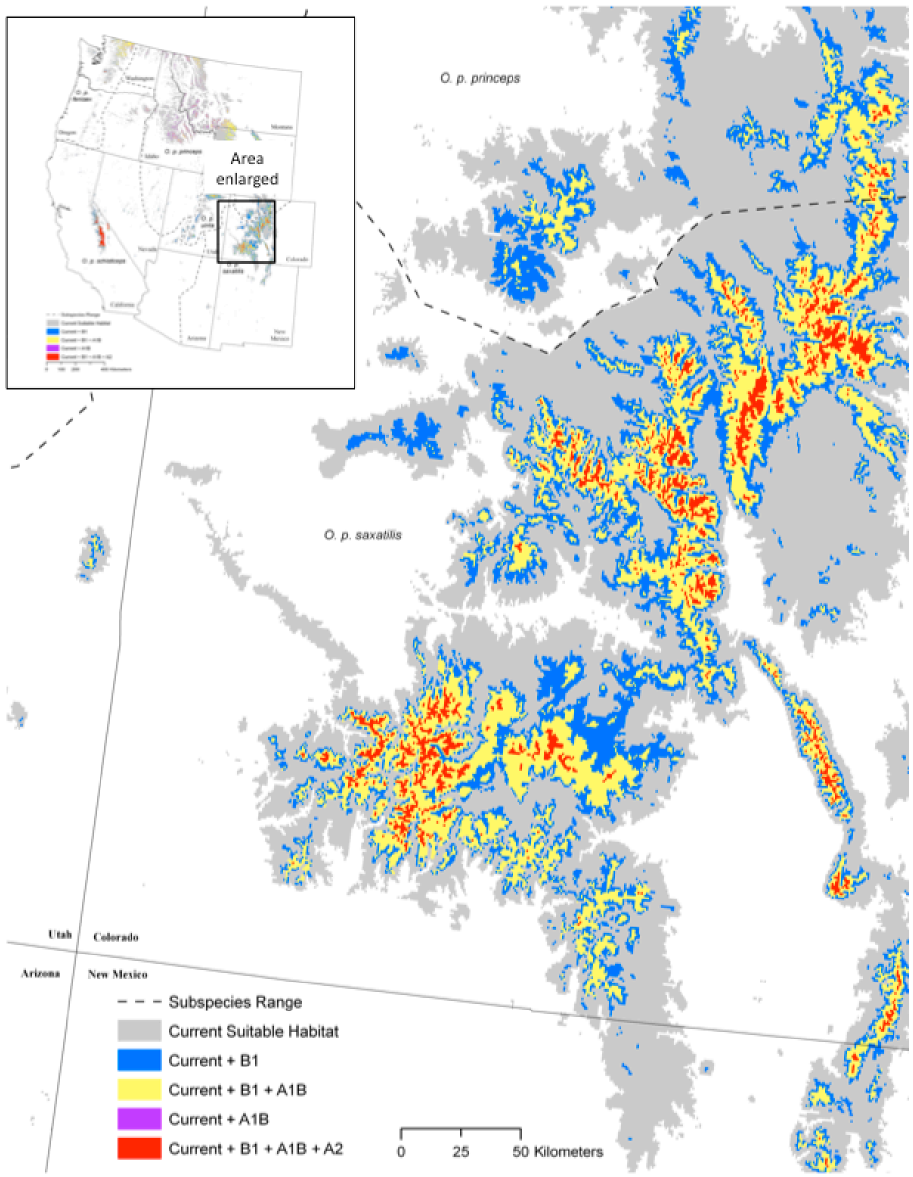


Figure 3. Same as Figure 2 but for an area in southwestern Colorado illustrating increased fragmentation of pika habitat as a result of warming.

Fine spatial resolution projections allowed visualization of habitat fragmentation

Trook, Buotte, Hicke, unpublished

We couldn't get this work published…why?

- lack of inclusion of necessary habitat
  - talus maps of uncertain quality
- lack of inclusion of known important variables
  - presence of subtalus snow or water
  - no data available
- uncertainty about importance of other factors
  - snow cover as insulation
  - cold-air drainage through talus slopes
- uncertainty about pika's ability to persist in hot, dry places
  - behavioral change

Trook, Buotte, Hicke, unpublished