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Spatial Effects on Current and Future Climate of *Ipomopsis aggregata* Populations in Colorado
Patterns of Precipitation and Maximum Temperature

Introduction

My dissertation research focuses on the evolutionary genetics and ecology of physiological variation in *Ipomopsis aggregata*, a wildflower native to the western United States. I specifically study populations of *I. aggregata* in Colorado, and am interested in local adaptation to climate and habitat variation. One component of my dissertation addresses phenotypic and population genetic variation among multiple populations spanning a range of elevations and habitats. Therefore, I am interested in how climate parameters vary across the Colorado landscape. Additionally, because *I. aggregata* occurs across a mountain range, it is an interesting system in which to start proposing questions about the variable effects of climate change on different populations.

For the current project, I am asking the following questions:

- 1) What are the effects of spatial location (i.e. latitude, longitude, and elevation) on climate parameters in *Ipomopsis aggregata* populations?
- 2) How will climate change vary with latitude, longitude and altitude?
- 3) What geographic areas of *I. aggregata* will experience the most extreme shifts in climate?

To address these questions, I am analyzing patterns of mean monthly precipitation and maximum temperature, using modeled estimates of current climate and predictions for 2080. For this project, I have limited analysis to six months spanning the four seasons: January (winter), April (spring), June, July and August (summer), and October (fall). The framework of analyses I completed include:

- 1) Creation of maps for current and predicted 2080 mean precipitation and maximum temperature
- 2) Calculation of climate change and creation of maps illustrating climate change
- 3) Summaries of current climate and change for known *I. aggregata* population locations
- 4) Statistical analysis of spatial effects on climate in these locations
- 5) Graphical illustration of latitudinal effects on climate in these locations
- 6) Identification of geographical areas and populations likely to experience more extreme climate change.

Data required

- 1) Known locations of *Ipomopsis aggregata* populations
- 2) Current climate parameters
- 3) Future climate predictions
- 4) Elevation (DEM)
- 5) Colorado outline

Data acquisition

In order to address questions about the climate of *Ipomopsis aggregata* populations, I needed specific coordinate locations for many known populations spanning a large geographical range. The Global Biodiversity Information Facility (GBIF, <http://www.gbif.org/>) is a resource for

species biodiversity information and collects data from multiple resources (e.g. herbaria and museum records). This data is freely available and easy to download. I was able to download coordinates for 234 *Ipomopsis aggregata* location records within the latitude and longitude bounds of the state of Colorado. This set of locations spanned the range of *I. aggregata* in Colorado (Figure 7).



Figure 1. Gathering population location data for *Ipomopsis aggregata* in Colorado from the GBIF website. The highlighted red square inside the United States encompasses the latitude and longitude lines defining Colorado.

For this project, I used climate data freely available from the WorldClim website (<http://worldclim.org>). This data is available in both grid and generic bil format, and was created by interpolating observed climate data over several years (minimum of 10) from 1950-2000. Current data is downloadable as 30 x 30 tiles, while future climate data is available as complete world files. Spatial resolution for the files I used is 30 arc-seconds (~1 km). WorldClim has predicted future climate data from multiple climate models and emission scenarios, all based on the IPCC's 3rd climate assessment. I used future data based on the CCCMA (Canadian Centre for Climate Modelling and Analysis) model of climate change and the a2a emission scenario, which is described as having a more drastic effect than another scenario, b2a. Worldclim also has DEMs in the same file formats.

I used a Colorado outline shapefile copied from one of the United States geography files available in the GEO327/386 class folder.

Data preprocessing

Because the climate and altitude files were in bil format and covered large geographical areas, they required preprocessing before I could use the data for spatial and statistical analysis. Additionally, I needed to use the current and future climate files to create 'change in climate' rasters. Lastly, once all my rasters were complete, I needed to join the data from each raster to the location point shapefile. Dr. Helper helped me figure out what steps I needed to do to preprocess my

DEM and climate files. Ephraim Taylor, the course TA, also helped me during this process. A fellow biology graduate student, Jesse Lasky, showed me a method for joining raster data to a point shapefile. I analyzed two climate parameters, for six months, for current and future climate, and altitude, for a total of 25 files that required preprocessing.

Preprocessing overview:

Climate and elevation

- 1) Define spatial reference
- 2) Convert bil format to grid format
- 3) Clip to Colorado outline
- 4) For temperature files, recreate true negative values
- 5) Create rasters for climate change
- 6) Create attribute table for 234 point locations and their associated altitude and climate parameters

Location points

- 7) Convert csv file of coordinates to shapefile.

Data for each climate variable was available for download as zip files containing all twelve months. The first preprocessing step was to define the spatial reference, which I did using the define spatial reference tool in ArcCatalog. The spatial reference for these files is WGS 1984. To convert the bil files to grid files, I used the export to different raster format function within ArcCatalog (Figure 2), and changed the file names to shorten them.

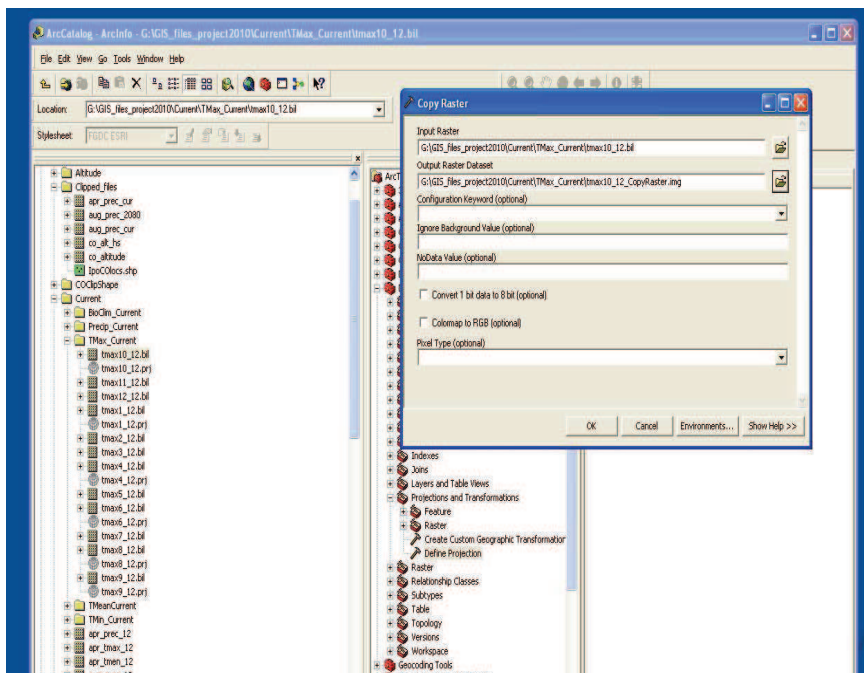


Figure 2. Data pre-processing steps 1 and 2 – defining projection and converting bil format to grid. These steps were completed in ArcCatalog.

After conversion to grid format, I opened the files in ArcGIS. The next step was to clip the files to my area of interest - Colorado. To do this, I set an analysis mask using the Colorado outline shapefile, then used the raster calculator tool to evaluate the data files within this mask (Figure 3). Once the 'calculation' was produced I made this data permanent to create new clipped raster files. The future climate data files were only available for the entire world, and were therefore very large. For this data, these steps took a considerable amount of time for the software to complete.

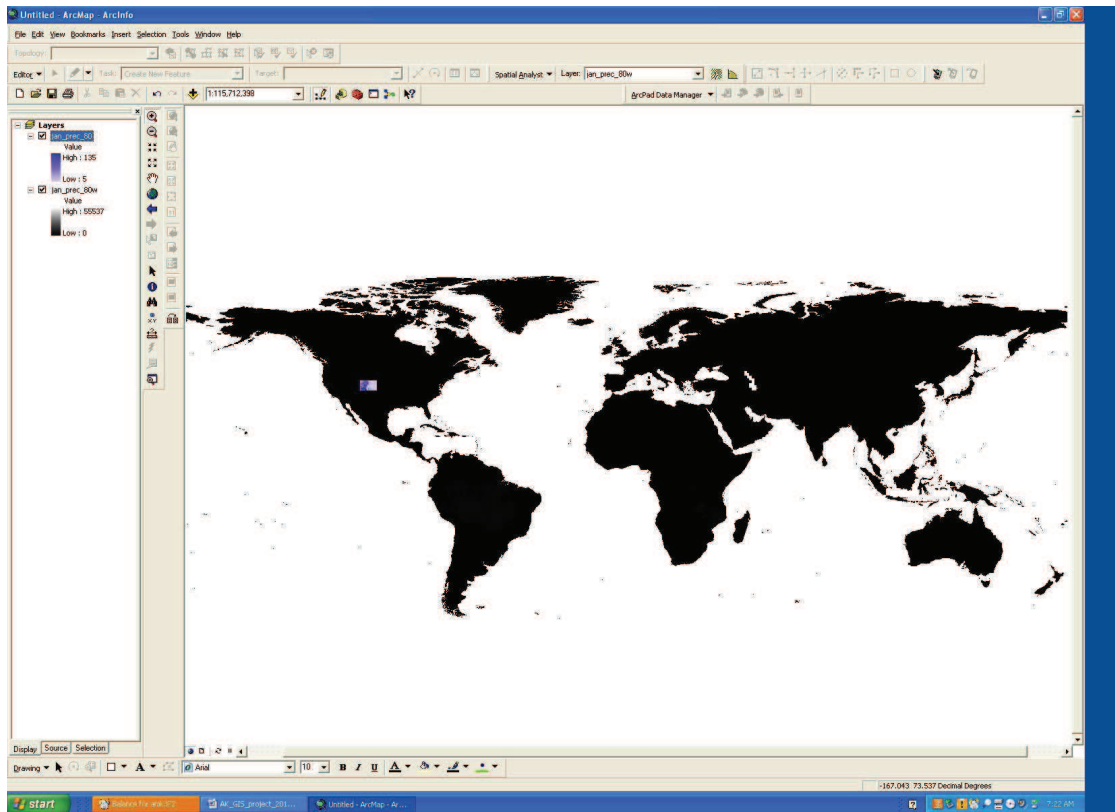


Figure 3. Data preprocessing step 3 – clipping files to a Colorado outline using raster calculator with an analysis mask. Clipped calculations were saved as new raster files. The blue square overlaying the United States shows the result of the clip.

At this stage, the precipitation data was ready for manipulation and analysis. However, the temperature data files required further processing. When converting bil files to grid files using Arc, negative values are automatically changed to $65536 - X$. For months with negative temperature values, the grid files needed to be fixed to recreate these true negative values. During conversion, negative values are changed, but positive values are maintained. Therefore, to recreate the original negative values but not change the correct positive values, I used the following conditional expression in the raster calculator tool: $\text{con}([\text{climate grid}] > \text{highest real positive value}, [\text{climate grid}] - 65536, [\text{climate grid}])$ (Figure 4). As an example, this means a false value of 65535 would be restored to its original true value of -1. Small positive values would be maintained as is. I made the resulting calculations permanent to save the corrected data as a new rasters.

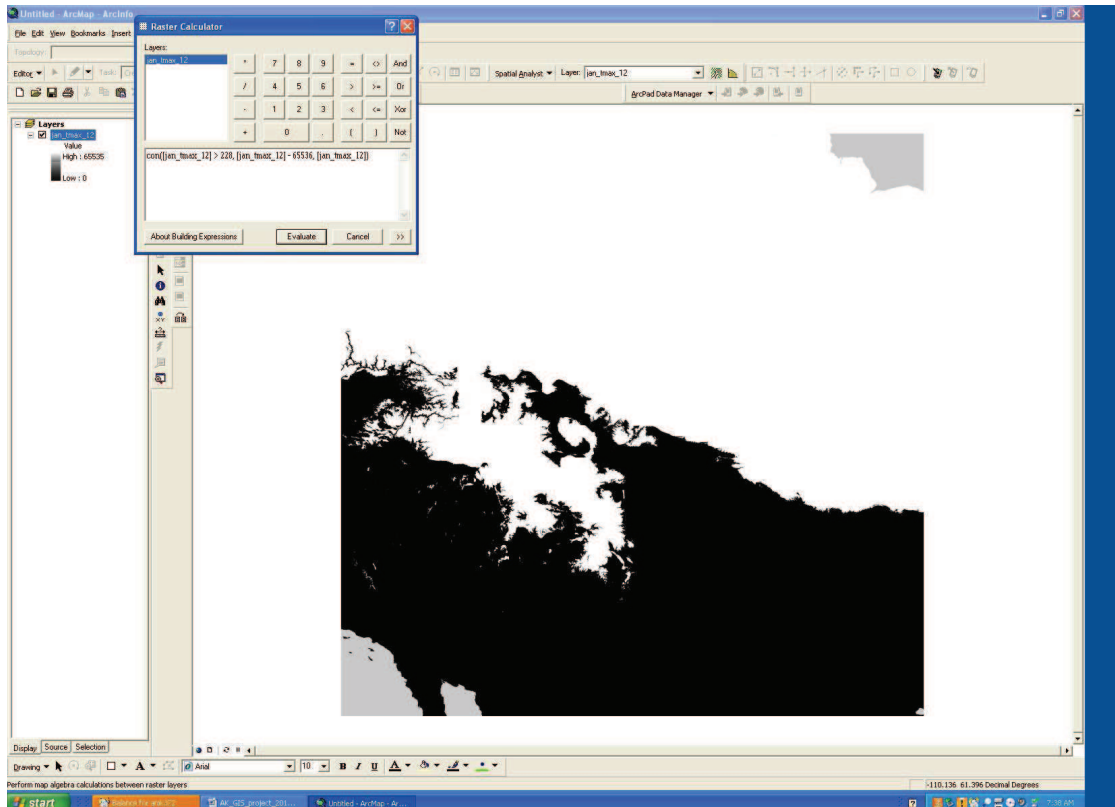


Figure 4. Data preprocessing step 4 – using raster calculator to recreate original negative temperature values after conversion of temperature bil files to grid files. The white space in the displayed data is from the large false values after conversion of bil files to grid files.

Once all the data was in the correct format, I needed to create raster files representing the amount of change in climate between current and 2080 predictions. To do this, I used the raster calculator tool and the following expression: $[\text{climate grid 2080}] - [\text{climate grid current}]$. This means that negative values in the new raster indicate a decrease in precipitation (or temperature), and positive values indicate an increase. I saved the resulting calculations as new climate change raster files (Figure 5). At this stage, the climate data was ready for manipulation, but I needed to create a shapefile containing *I. aggregata* location points.

Location coordinates (latitude and longitude) were downloaded as a csv text file. Once I imported the text file in to ArcGIS, I exported the table as a shapefile to make the data usable. To create a data table containing population coordinates, altitude, and climate variables for analysis, I needed to combine the elevation and climate data to associated coordinates in the location point file. To do this, I used a freely available package designed for Arc called HawthTools (<http://www.spatial ecology.com/htools/tooldesc.php>). I used the intersection points tool to add climate and altitude values to the attribute table of the points shapefile (Figure 6). Once complete, I exported the table as a text file for statistical analysis.

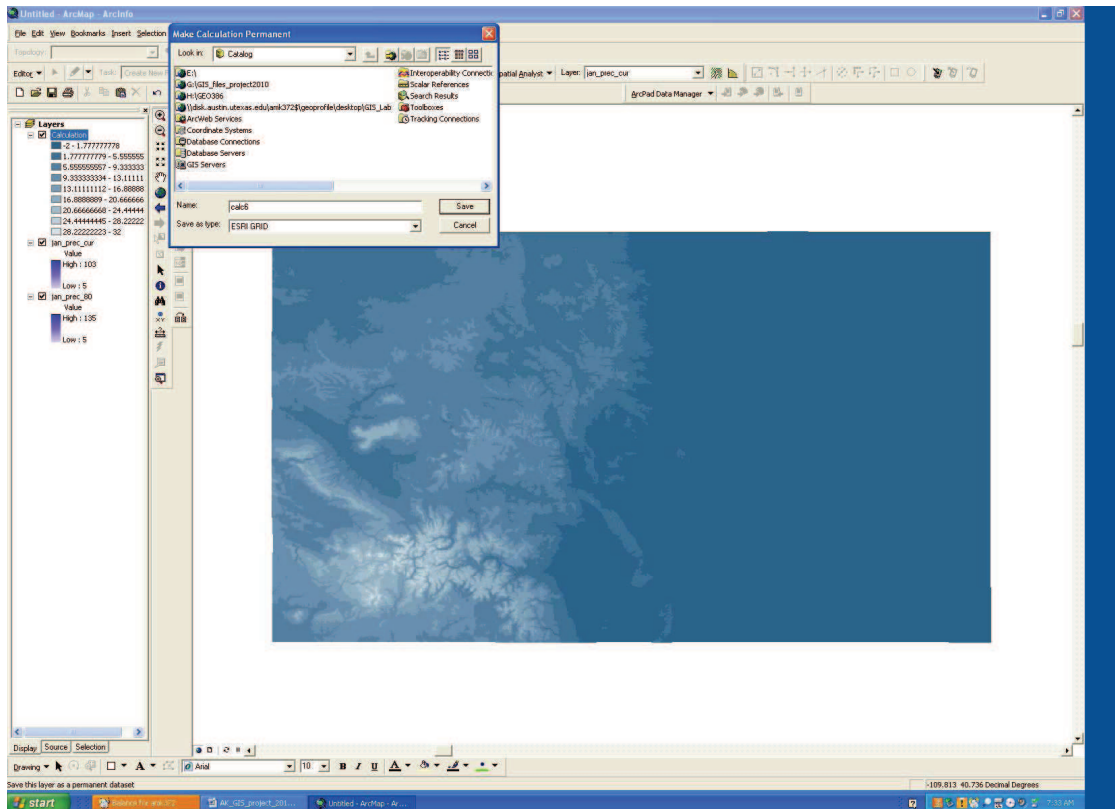


Figure 5. Data preprocessing step 5 – creating rasters for climate change by calculating the difference between current and 2080 climate values using raster calculator. A resulting calculation is shown here (with the current and 2080 raster datasets below it in the TOC).

Data analysis and Results

To quantify and summarize general patterns in current climate and climate change for *Ipomopsis aggregata* population locations, I generated means, standard deviations, and ranges for monthly mean precipitation and maximum temperature for the six months included in this study (Table 1). These summary data was produced using SAS. To visually compare spatial patterns of climate among seasons, I created current, future, and climate change maps for January (Figs. 14-19), April (Figs. 8-13), and August (Figs. 20-25), representing winter, spring, and summer, respectively.

Overall, the range of monthly precipitation is going to increase, with some locations receiving more precipitation and others receiving less. Mean precipitation across sites will increase for four out of six of the analyzed months (Table 1). Mean precipitation will decrease for June and August. The largest range of precipitation change will be seen in April (spring) and August (late summer), with June (early summer) showing the third largest range in change. August precipitation

will decrease for all sites. Mean monthly temperature is going to increase in all population sites for all six months analyzed (Table 1).

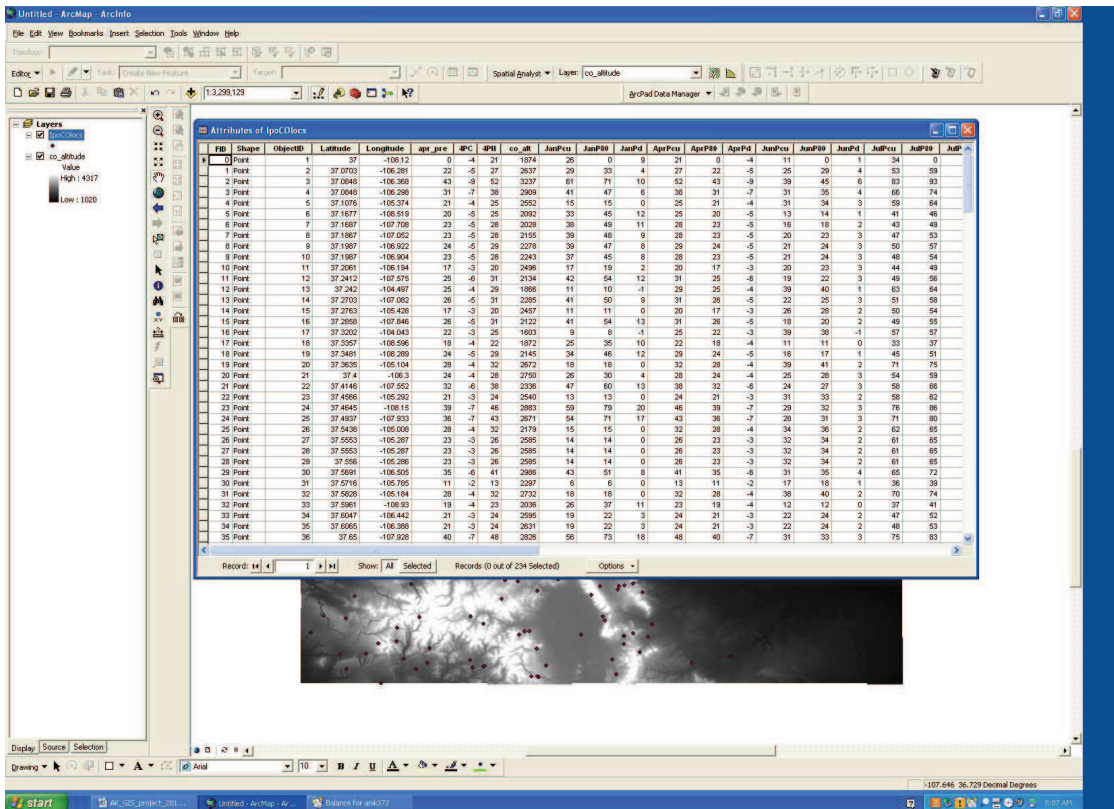


Figure 6. Data preprocessing step 6 – creating an attribute table of the 234 *Ipomopsis aggregata* locations and their associated altitude and climate values. Data from the other rasters was linked to the location points using the free package HawthTools. The resulting attribute table is shown.

Current and future mean precipitation are greater at higher altitudes (Figure 28), while current and future maximum temperature are lower at higher altitudes (Figure 30). Overall, precipitation is going to increase more often than decrease (Figure 29). Generally, increases in precipitation will be greater at higher altitudes (Figure 29). However, the relationship between precipitation change and altitude appears to vary by month/season. For January (winter), April (spring) and October (fall), precipitation will increase much more at higher altitudes. For June and July, the relationship is still positive but weaker. Interestingly, for August, the only month where precipitation will only decrease, decrease in precipitation will be greater at higher altitudes (Figure 29). This may result in higher elevation habitats being proportionately drier near the end of the blooming season, but proportionately wetter the rest of the year.

To determine statistical significance of spatial effects on climate, I performed multi-way analysis of variance for each climate factor-month combination (performed in SAS). Spatial location, including latitude, longitude, altitude, and their interactions are highly significant factors affecting current and future precipitation, and precipitation change (Table 2). Latitude and longitude, and their interaction significantly affect current, predicted 2080, and increase in

maximum temperature (Table 2). Altitude and its interactions with latitude and longitude significantly affect variation in current maximum temperature; however, altitude does not seem to be a strong driver of variation in future temperatures or temperature increase (Table 2, Figure 31). One exception is seen in a significant negative relationship between altitude and maximum temperature increase during April, suggesting that spring temperatures may increase less at higher altitudes (Figure 31).

General trends in current climate and climate change, due to latitude, longitude, and altitude are visually observable in the produced climate maps (Figures 8-25). Most interestingly, the relationship between climate change and geography seem to vary by season. For January, the greatest increase in precipitation will be in southwestern Colorado at higher altitudes, while the opposite is seen during April, which shows greater increases in precipitation in northeastern Colorado, and reduced precipitation at higher elevations in southwestern Colorado (Figure 10). In August, reduced precipitation will be greatest at higher elevations in southwestern Colorado and at lower elevations in eastern Colorado (Figure 10).

Seasonal differences are also seen in the relationship between geography and increase in maximum temperature. During the winter (January) maximum temperature will increase most at more extreme latitudes and longitudes (Figure 19). During spring and summer (April and August), maximum temperature will increase most in more eastern longitudes (Figure 13, 25). Additionally, spring increases in temperature appear to be greater at more northern latitudes, while in summer temperature will increase most in southeastern Colorado.

In addition to quantifying and describing spatial effects on climate change, I am interested in determining which geographic areas and populations may experience the most extreme changes. This is the first step in predicting what populations may be most adversely affected by climate change or experience altered selection pressures. To do this, I first identified which months show larger changes in precipitation and temperature. April, June and August show the largest decreases in precipitation and increases in maximum temperature (Table 1). Because spring and summer are the primary growing seasons, and summer is the blooming period for *I. aggregata*, decreases in precipitation combined with increases in maximum temperature during these times may significantly increase plant stress and reduce survival and/or reproduction.

Using the range of predicted changes, I identified a subset of locations that would experience both drier and hotter springs and summers. To do this, I wrote an expression in the select by attributes tool that selected locations with decreases in precipitation greater than -2.0 mm in either April or June and increases in maximum temperature greater than 4.6 C in April, June, and July (Figure 27). Seventy three of the 234 *I. aggregata* population locations met these criteria. These populations are located on the southern and eastern ends of the range of *I. aggregata* in Colorado (Figure 26). *I. aggregata* also grows south in to New Mexico, so it is likely that northern New Mexico populations will experience more extreme climate change as well. This may act to reduce connectivity and gene flow between Colorado and New Mexico populations if populations in this area were to decline. The eastern range of *Ipomopsis* in Colorado represents the most eastern range of *I. aggregata*. If populations in these areas were to decline it would act to significantly shift the range westward, and reduce the number of populations growing on prairies at lower altitudes.

Due to the spatial effects on how climate may change in the future, this project illustrates how populations in certain geographic areas will likely be affected differently than others. Often the relationship between climate and one spatial factor (e.g. altitude) depends on another spatial factor (e.g. longitude) therefore full spatial analyses will be necessary to predict how climate may change conditions experienced by populations in different areas. Additionally, the relationship between geography and climate may vary by season, demonstrating the importance of considering the phenology of a particular organism when predicting the biological effects of climate change.

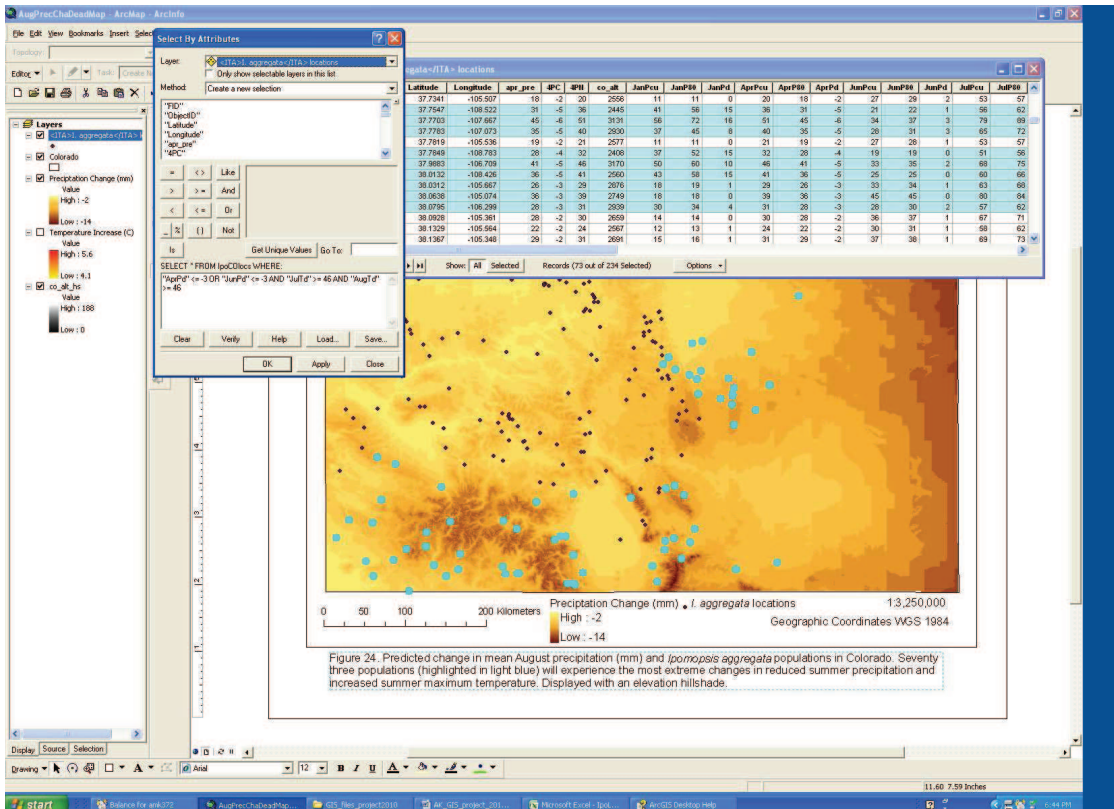


Figure 24. Predicted changes in mean August precipitation (mm) and *Ipomopsis aggregata* populations in Colorado. Seventy three populations (highlighted in light blue) will experience the most extreme changes in reduced summer precipitation and increased summer maximum temperature. Displayed with an elevation hillshade.

Figure 27. Identification of population locations with the most extreme climate change using the select by attributes tool. Note selected and non selected records in the visible section of the location attribute table.

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Table 1. Summary of current, predicted 2080, and change in monthly mean precipitation (mm) and maximum temperature (°C) for 234 *Ipomopsis aggregata* population locations.

	January			April			June			October		
	Mean	Std Dev	Range	Mean	Std Dev	Range	Mean	Std Dev	Range	Mean	Std Dev	Range
Precipitation (mm)												
Current	28.04	14.71	6 to 65	37.98	10.15	13 to 66	35.15	11.82	11 to 61			
2080	32.87	18.69	6 to 83	40.35	14.28	11 to 81	33.49	10.80	11 to 55			
Change	4.97	4.55	-1 to 20	2.44	5.50	-9 to 18	-1.60	2.62	-7 to 6			
	July			August			October					
Current	52.12	14.14	19 to 86	53.13	13.97	17 to 94	35.14	9.70	17 to 72			
2080	54.86	15.37	19 to 93	47.85	13.14	14 to 85	40.66	13.83	15 to 87			
Change	2.93	2.06	-1 to 10	-5.11	1.36	-9 to -3	5.73	4.41	-2 to 16			
Maximum Temperature (°C)												
	January			April			June					
Current	0.90	2.77	-3.7 to 8.6	11.18	3.38	2.9 to 19.6	22.65	3.33	14.5 to 30.8			
2080	4.57	2.69	-0.1 to 12.7	17.50	3.55	9.1 to 26.2	27.79	3.76	19.7 to 36.5			
Change	3.70	0.31	3.2 to 4.8	6.41	0.57	5 to 7.8	5.28	0.37	4.6 to 6.3			
	July			August			October					
Current	25.81	3.43	17.8 to 33.9	24.44	3.35	16.6 to 32.4	14.67	2.78	7.9 to 21.5			
2080	30.10	3.93	22.1 to 38.1	28.72	3.85	20.8 to 36.6	19.76	3.05	13.0 to 27.1			
Change	4.44	0.28	4 to 5.4	4.42	0.21	4.1 to 5.2	5.19	0.17	4.8 to 5.6			

Table 2. Analysis of variance of spatial effects on current, predicted 2080, and change in monthly mean precipitation (mm) and maximum temperature (°C) for 234 *Ipomopsis aggregata* population locations. Values are F ratios from Anovas performed in SAS. Numbers in bold indicate statistically significant effects of spatial factors on climate. ***<0.0001 **<0.001 * ≤0.05

Climate Variable/ Spatial Factor	Latitude	Longitude	Altitude	Altitude* Latitude	Altitude* Longitude	Latitude* Longitude
Precipitation (mm)						
Current						
January	34.92***	29.24***	32.94***	1.94	35.60***	37.10***
April	25.65***	16.88***	15.93***	0.14	22.67***	24.80***
June	12.82**	4.00*	7.89*	4.16*	17.11***	10.86*
July	18.11***	10.17*	0.73	11.57**	7.18*	17.27***
August	13.77**	9.03*	0.35	12.86**	1.38	13.48**
October	40.29***	34.19***	6.21*	9.54*	18.92***	39.47***
2080						
January	41.38***	32.77***	47.66***	0.24	59.16***	43.20***
April	25.94***	17.26***	15.96***	0.96	17.07***	24.91***
June	11.62**	3.08	4.28*	13.53**	16.80***	9.44*
July	19.07***	10.62*	0.25	20.66***	8.03*	17.68***
August	9.77*	5.72*	0.73	16.18***	1.19	9.12*
October	33.52***	26.96***	10.95*	14.21**	31.28***	32.05***
Change						
January	165.83***	133.43***	187.59***	0.39	249.15***	173.65***
April	12.84**	12.59**	1.97	58.85***	3.99*	13.20**
June	0.45	0.00	39.59***	55.48***	11.79**	0.40
July	102.24***	101.34***	9.51**	33.49***	0.27	103.83***
August	0.06	0.47	3.92*	18.03***	18.16***	0.00
October	105.88***	99.07***	83.74***	3.45	127.42***	109.08***
Maximum Temperature (°C)						
Current						
January	2.43	0.61	26.16***	0.67	25.49***	3.15
April	67.47***	44.92***	12.82**	3.27	43.69***	59.92***
June	26.11***	10.72*	8.25*	8.39*	39.30***	21.22***
July	28.26***	16.77***	0.01	4.01*	7.78*	25.81***
August	19.81***	10.39*	0.35	8.49*	6.50*	17.43***
October	1.38	0.73	1.31	0.00	0.02	0.63
2080						
January	0	0.73	25.13***	0.06	27.34***	0.00
April	12.80**	14.34**	0.66	5.92*	0.02	14.22**
June	8.44*	9.14*	0.24	5.00*	0.07	9.43*
July	7.89*	9.22*	0.00	5.74*	0.85	9.11*
August	8.54*	9.98*	0.02	5.33*	0.98	9.89*
October	5.41*	7.11*	0.07	7.02*	1.57	6.25*
Change						
January	35.35***	27.72***	1.10	12.00**	0.20	34.38***
April	1.93	22.91***	0.12	9.43*	1.00	6.13*
June	202.62***	213.52***	6.83*	1.92	12.48**	194.27***
July	200.09***	222.72***	0.47	2.17	0.00	191.33***
August	273.87***	294.90***	0.75	0.04	0.57	284.39***
October	338.15***	385.82***	0.00	0.63	0.19	354.59***

Ipomopsis aggregata Population Locations in Colorado

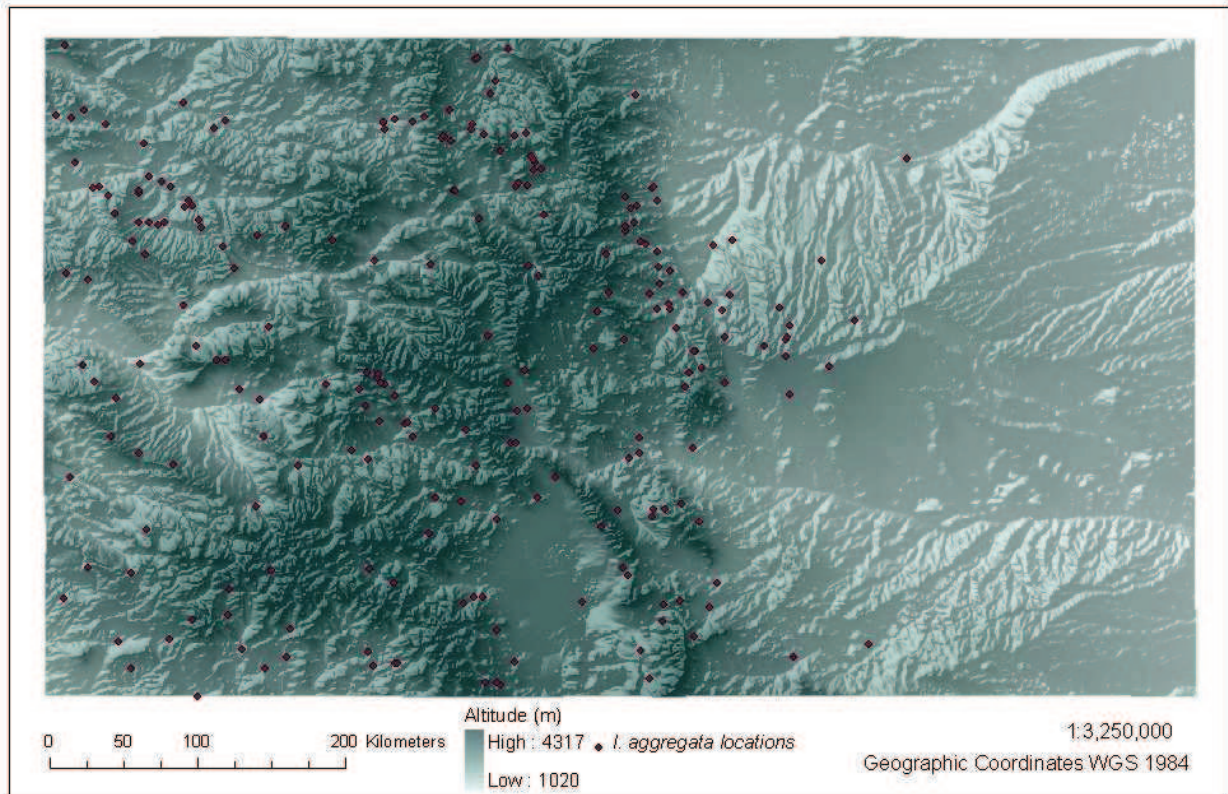


Figure 7: Locations of 234 *Ipomopsis aggregata* populations in Colorado overlaid on altitude and with an altitude hillshade. The elevation hillshade was created using the surface analysis tool in the spatial analyst toolbar.

Current April precipitation and *Ipomopsis aggregata* population locations

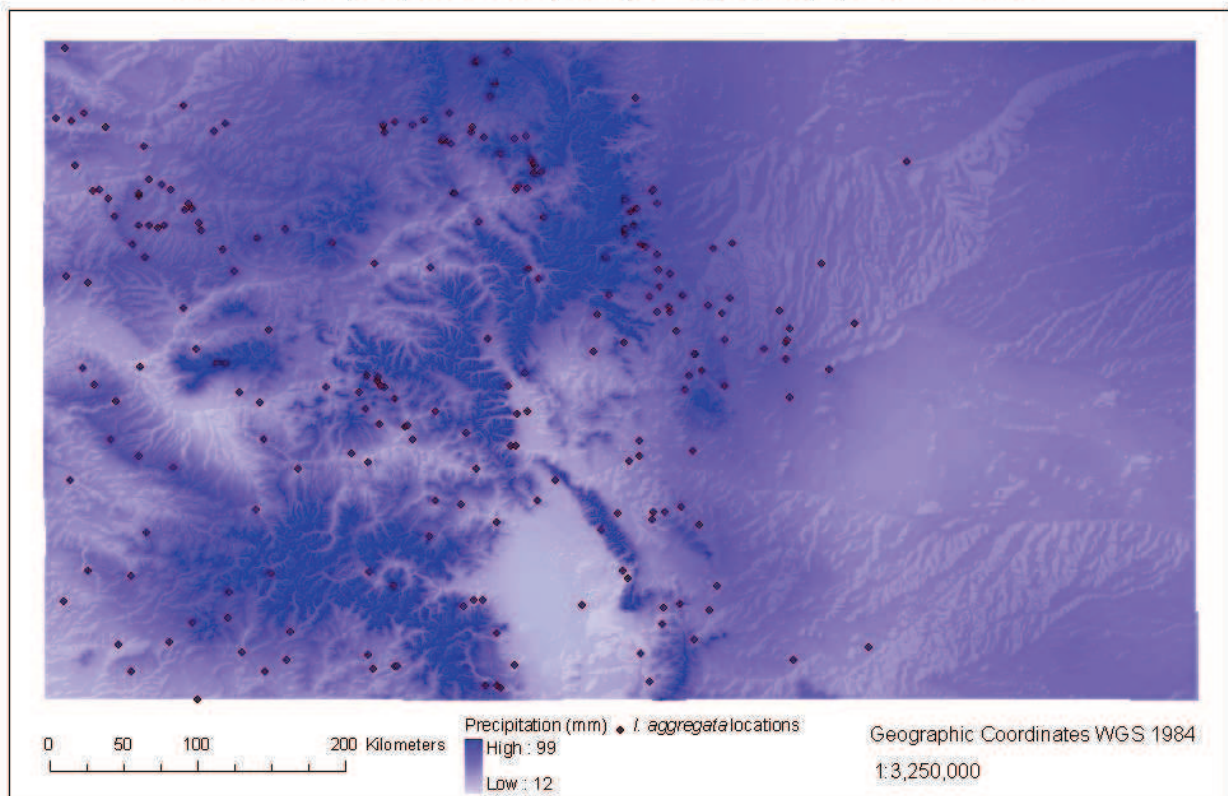


Figure 8: Current April mean precipitation (mm) and *Ipomopsis aggregata* populations in Colorado. Displayed with an elevation hillshade.

Predicted 2080 April precipitation and *Ipomopsis aggregata* population locations

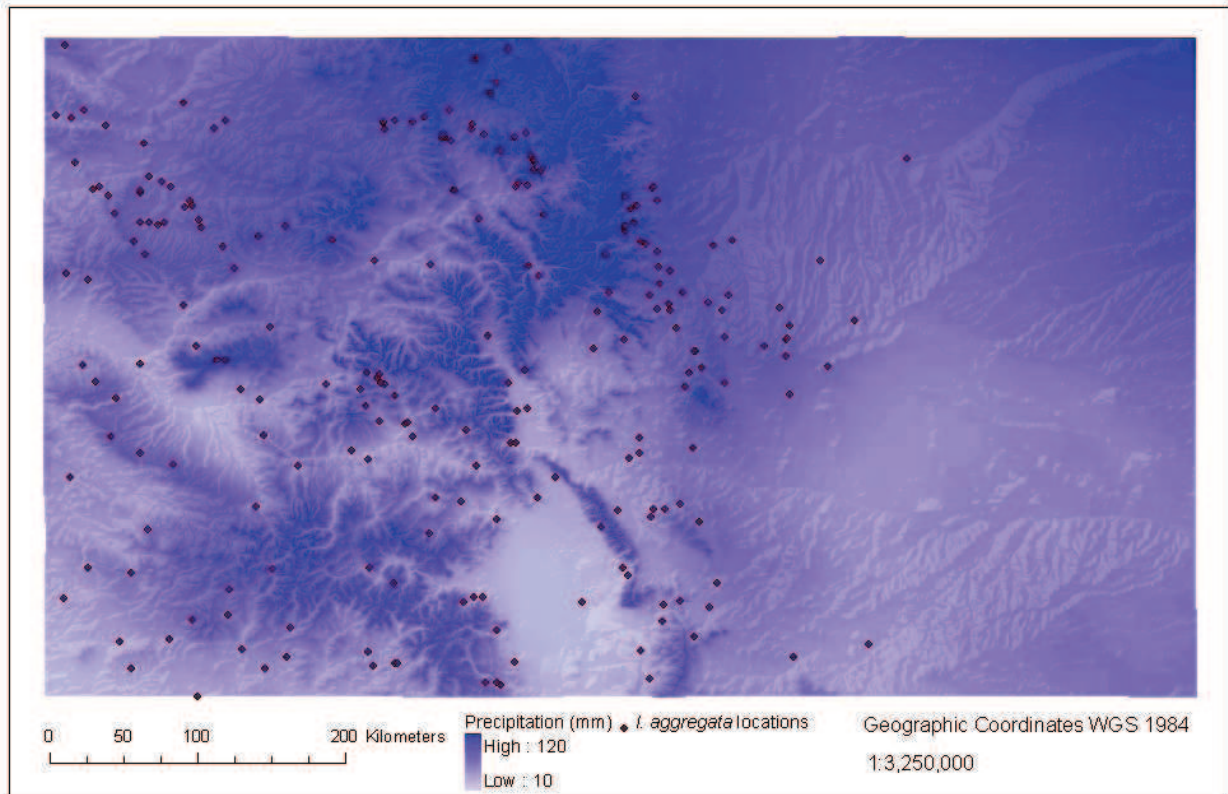


Figure 9. Predicted 2080 April mean precipitation (mm) and *Ipomopsis aggregata* populations in Colorado. Displayed with an elevation hillshade.

Predicted Change in April Precipitation and *Ipomopsis aggregata* population locations

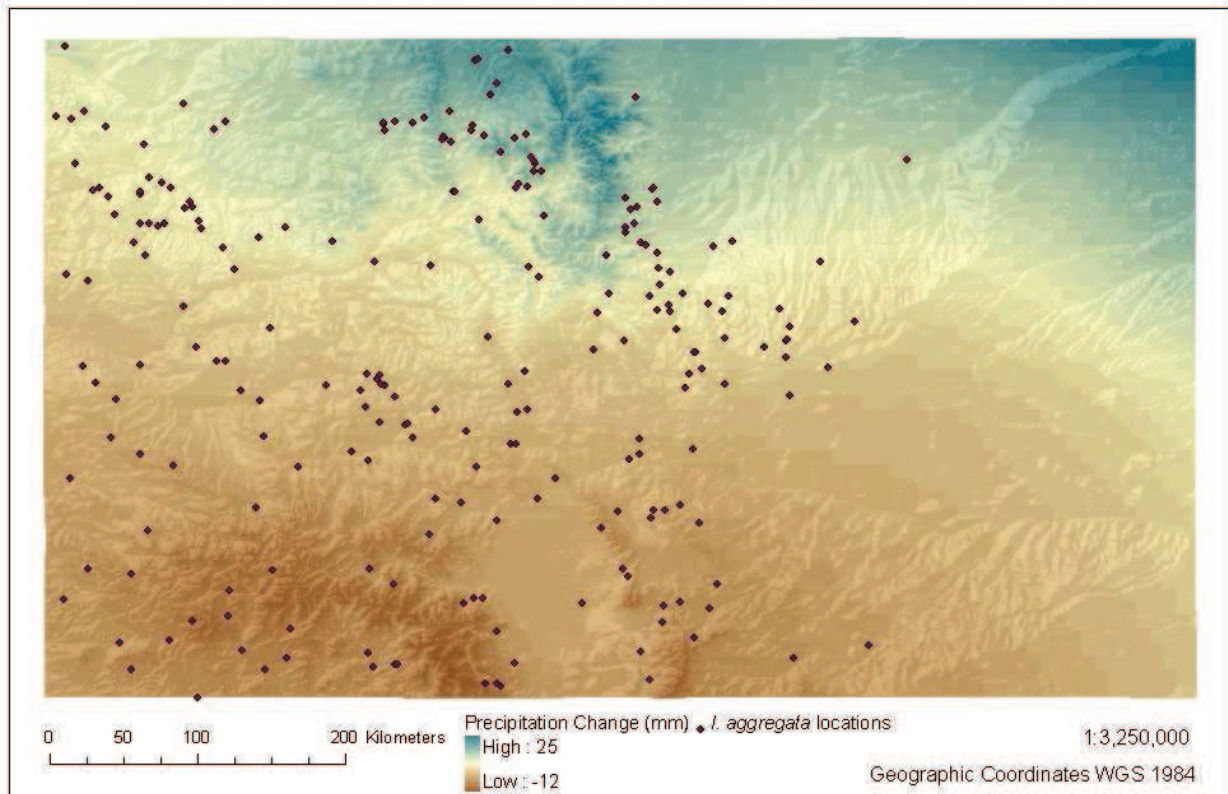


Figure 10. Predicted change in mean April precipitation (mm) and *Ipomopsis aggregata* populations in Colorado. Displayed with an elevation hillshade.

Current Maximum April Temperature and *Ipomopsis aggregata* population locations

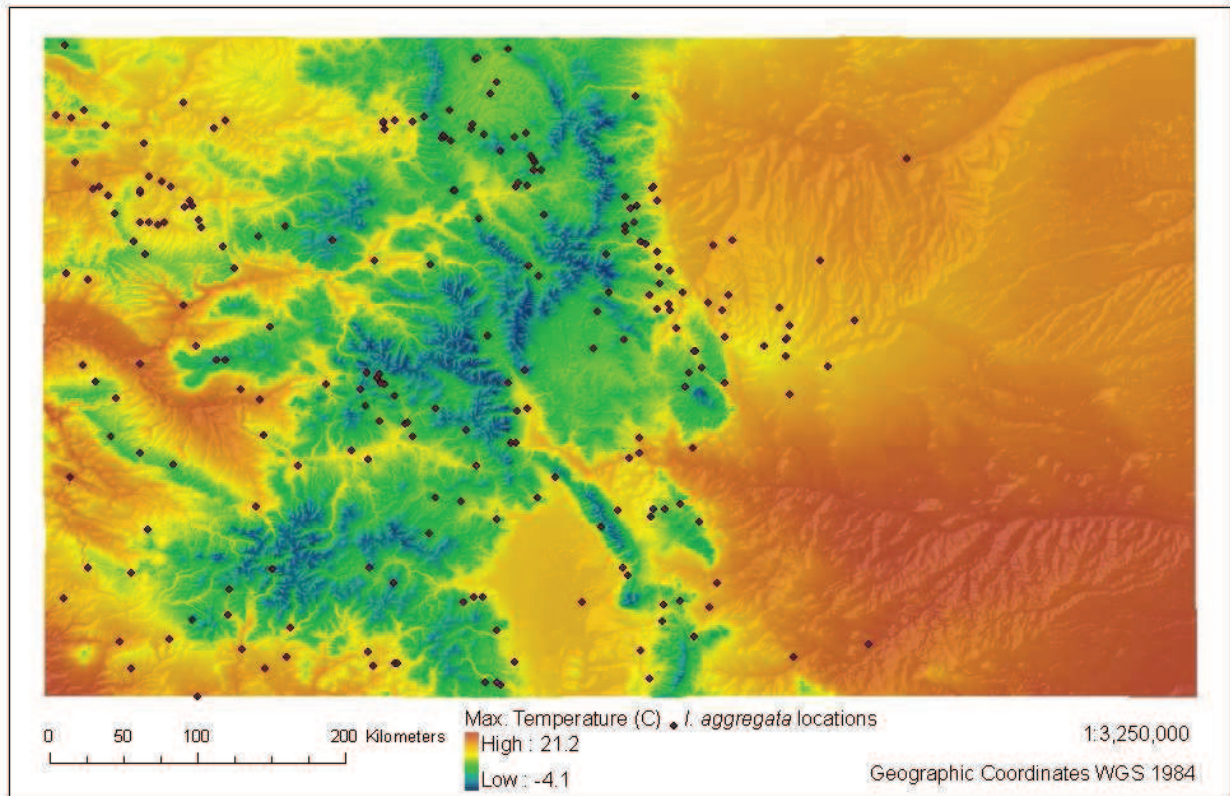


Figure 11. Current mean maximum April temperature (C) and *Ipomopsis aggregata* populations in Colorado. Displayed with an elevation hillshade.

Predicted 2080 Maximum April Temperature and *Ipomopsis aggregata* population locations

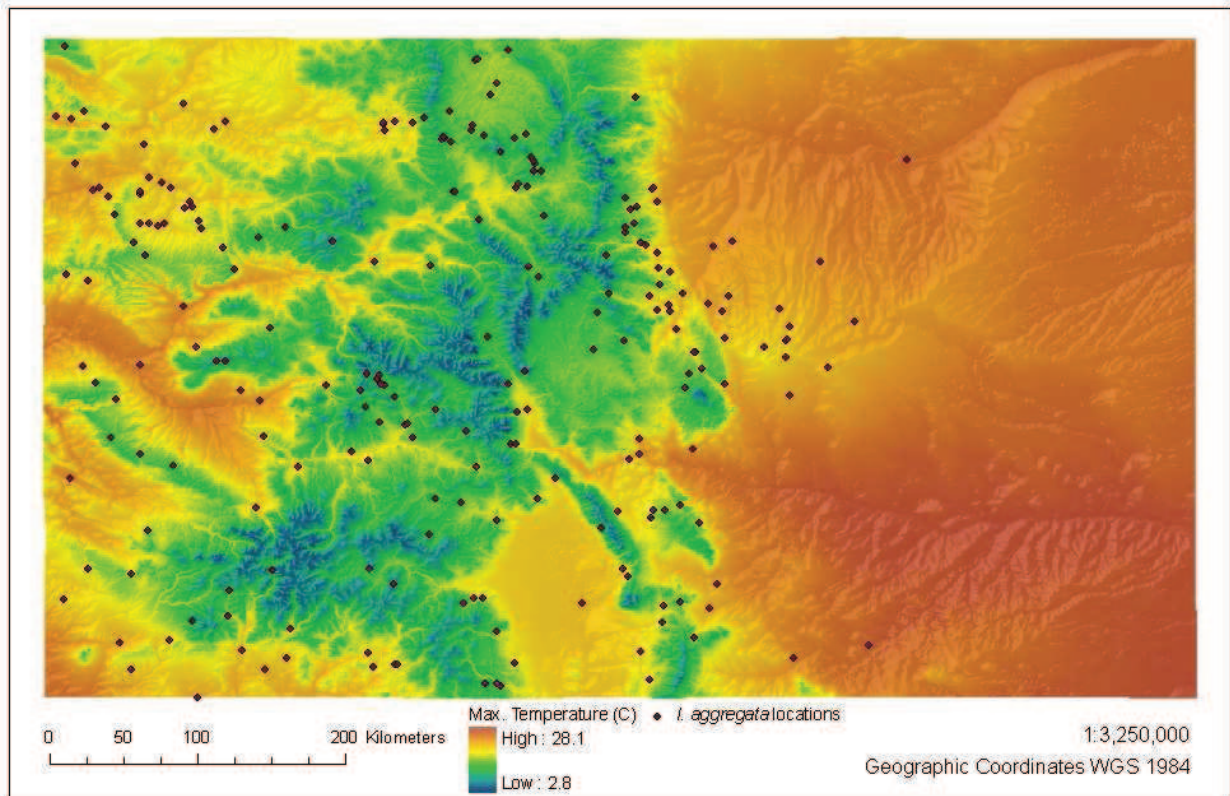


Figure 12. Predicted 2080 mean maximum April temperature (C) and *Ipomopsis aggregata* populations in Colorado. Displayed with an elevation hillshade.

Predicted 2080 Increase in Maximum April Temperature
and *Ipomopsis aggregata* Population Locations

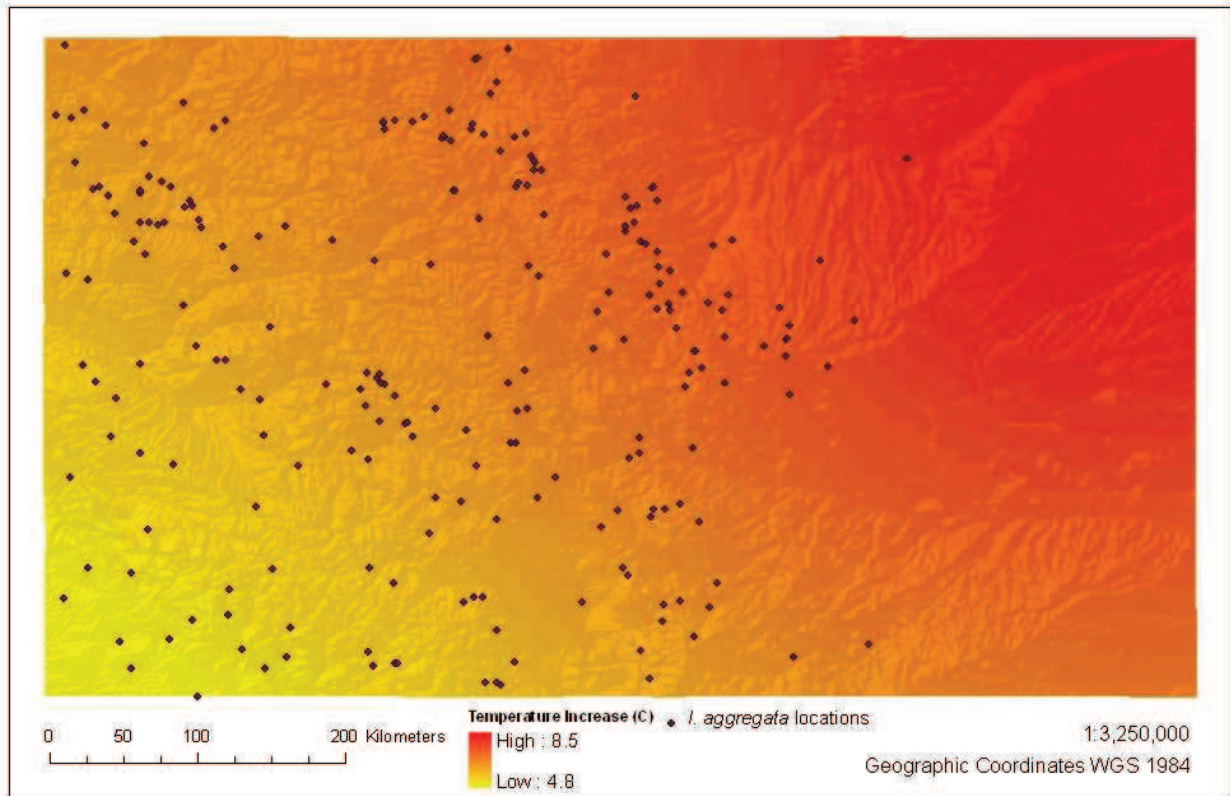


Figure 13. Predicted 2080 increase in mean maximum April temperature (C) and *Ipomopsis aggregata* population locations. Displayed with an elevation hillshade.

Current January Precipitation and *Ipomopsis aggregata* population locations

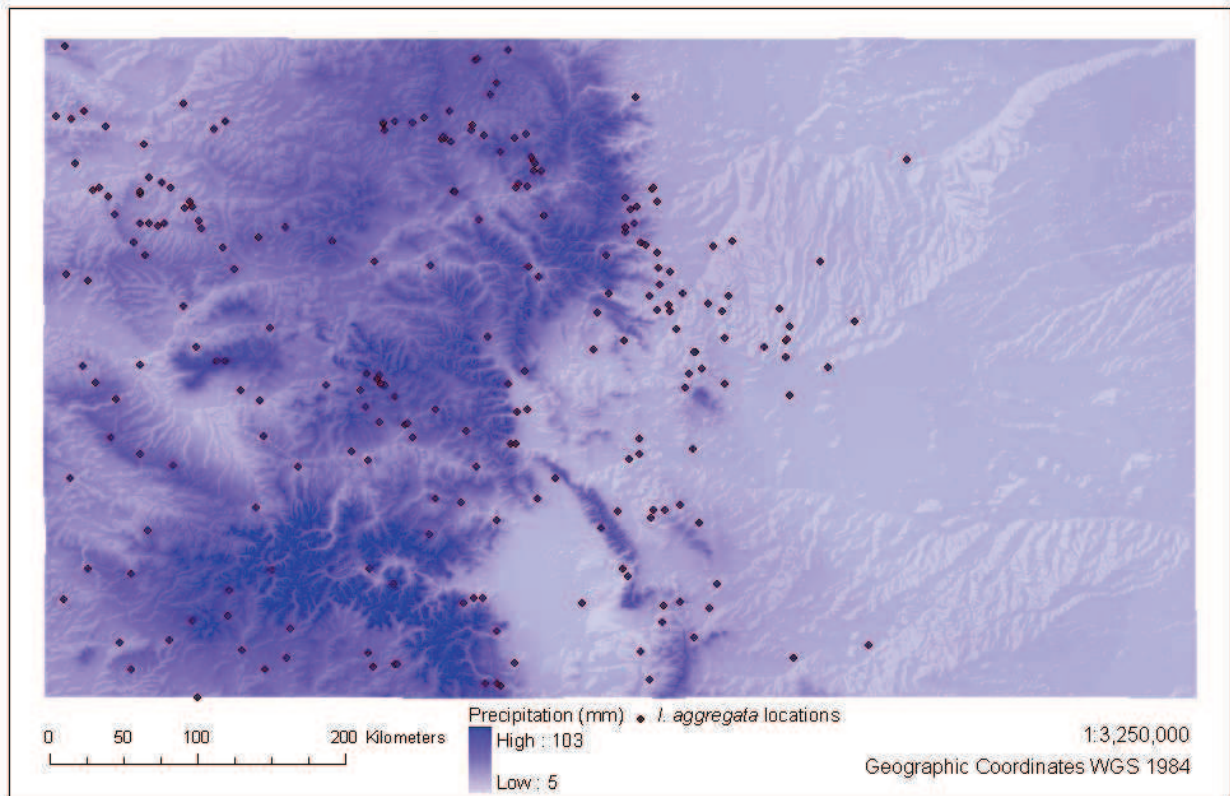


Figure 14. Current mean January precipitation (mm) and *Ipomopsis aggregata* population locations. Displayed with an elevation hillshade.

Predicted 2080 January Precipitation and *Ipomopsis aggregata* Population Locations

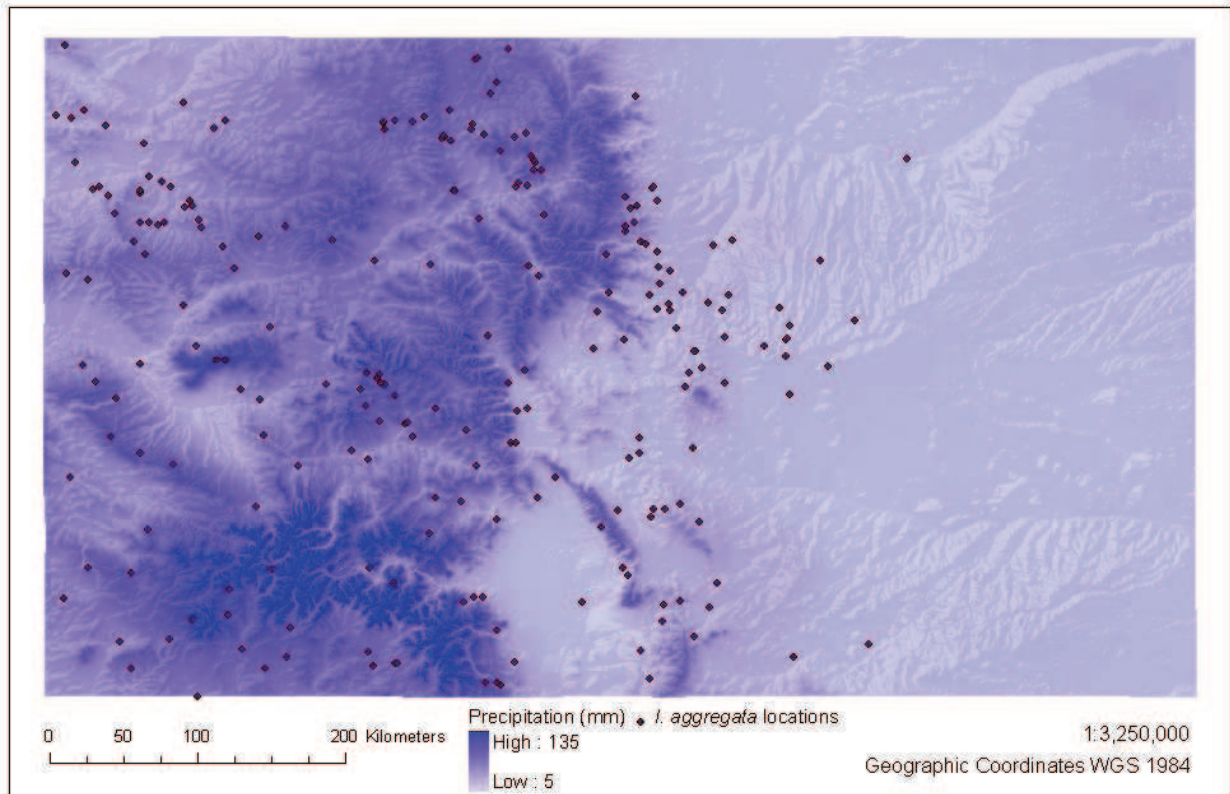


Figure 15. Predicted 2080 mean January precipitation (mm) and *Ipomopsis aggregata* population locations. Displayed with an elevation hillshade.

Predicted Change in January Precipitation and *Ipomopsis aggregata* population locations

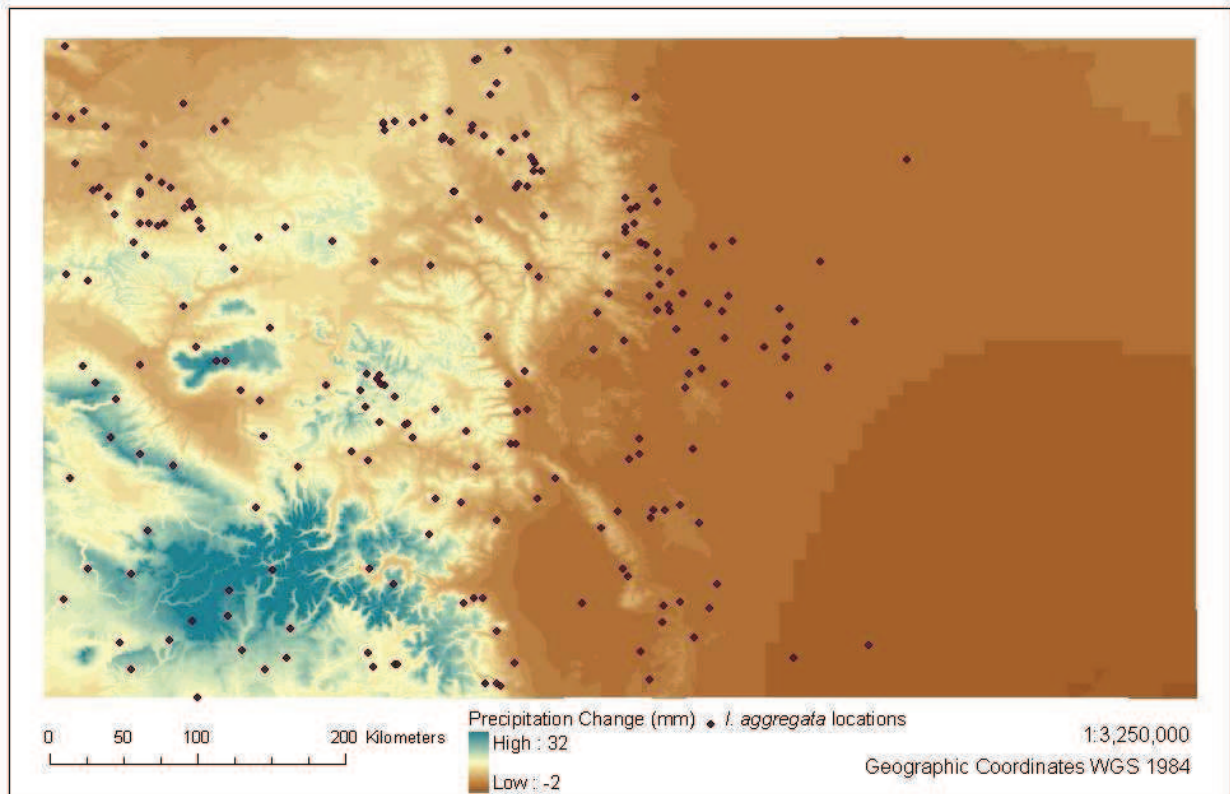


Figure 16. Predicted change in mean January precipitation (mm) and *Ipomopsis aggregata* population locations. Displayed with an elevation hillshade.

Current Maximum January Temperature
and *Ipomopsis aggregata* Population Locations

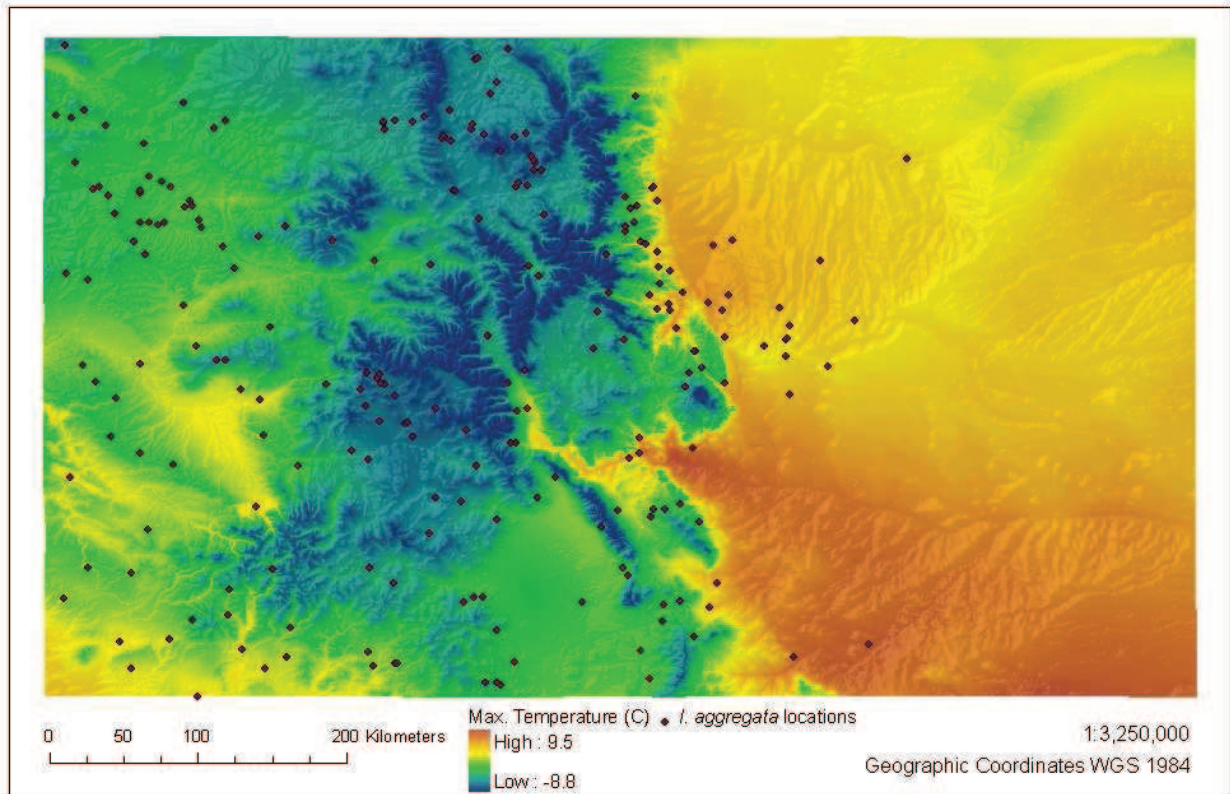


Figure 17. Current mean maximum January temperature (C) and *Ipomopsis aggregata* population locations. Displayed with an elevation hillshade.

Predicted 2080 Maximum January Temperature
and *Ipomopsis aggregata* Population Locations

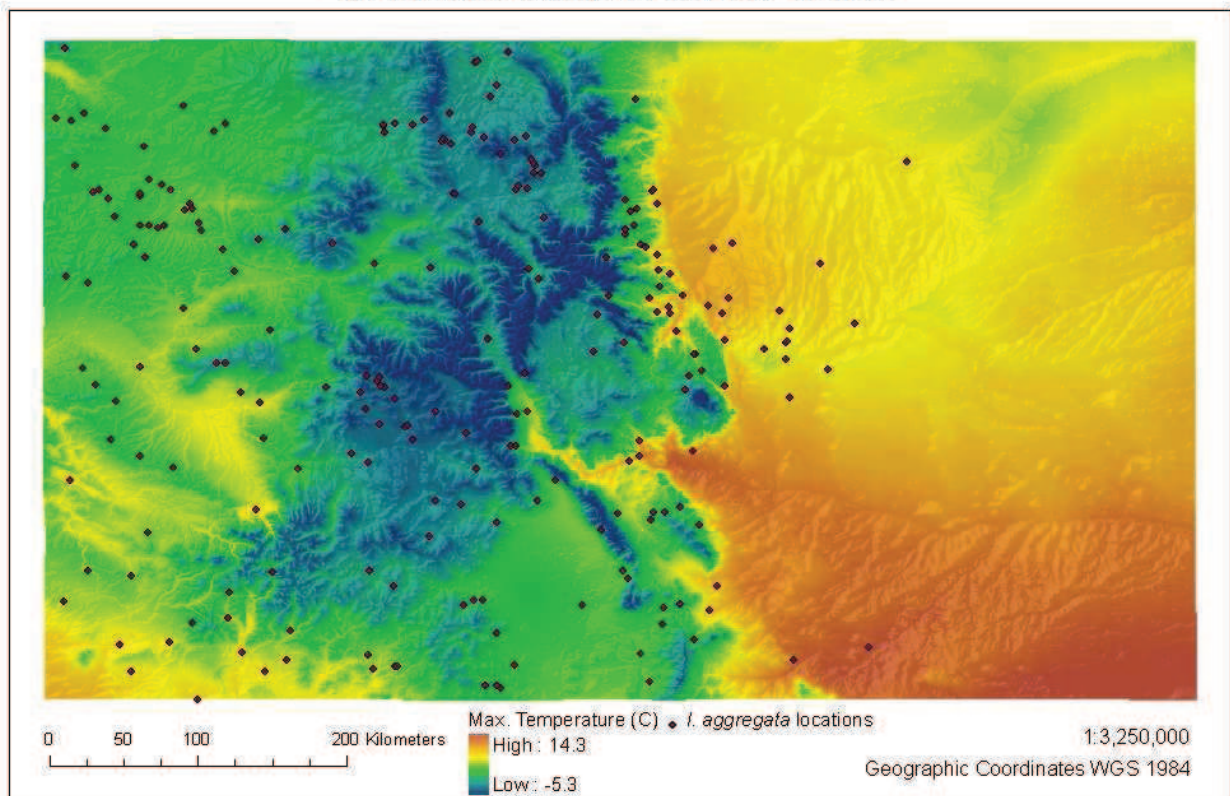


Figure 18. Predicted 2080 mean maximum January temperature (C) and *Ipomopsis aggregata* population locations. Displayed with an elevation hillshade.

Predicted 2080 Increase in Maximum January Temperature and *Ipomopsis aggregata* population locations

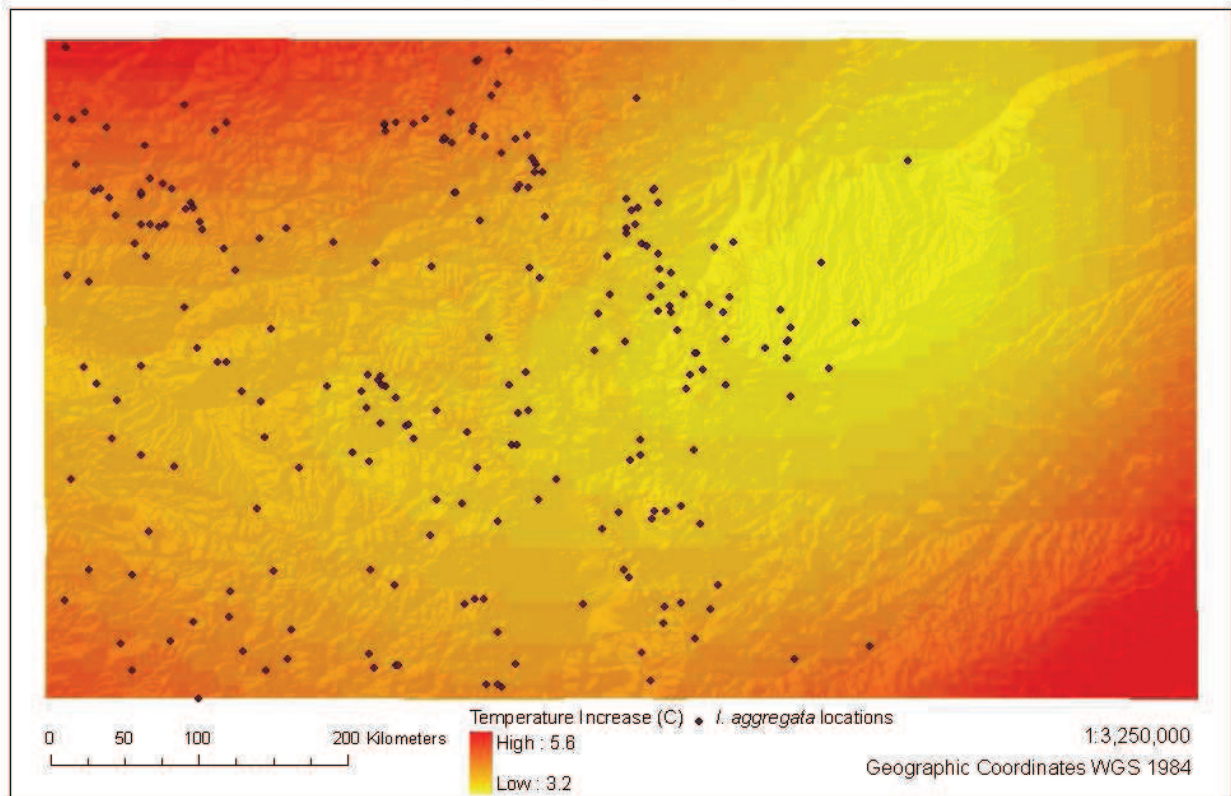


Figure 19. Predicted 2080 increase in mean maximum January temperature (C) and *Ipomopsis aggregata* population locations. Displayed with an elevation hillshade.

Current August Precipitation and *Ipomopsis aggregata* Population Locations

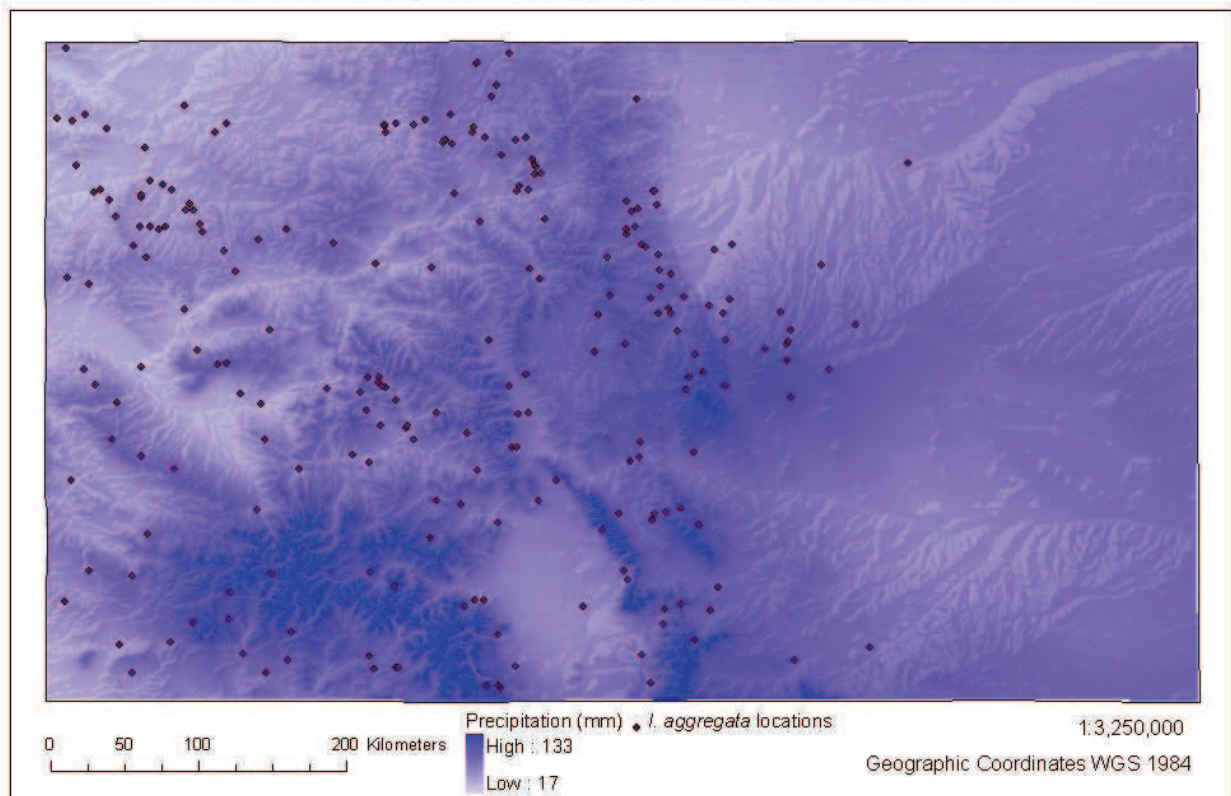


Figure 20. Current August mean precipitation (mm) and *Ipomopsis aggregata* populations in Colorado. Displayed with an elevation hillshade.

Predicted 2080 August Precipitation and *Ipomopsis aggregata* Population Locations

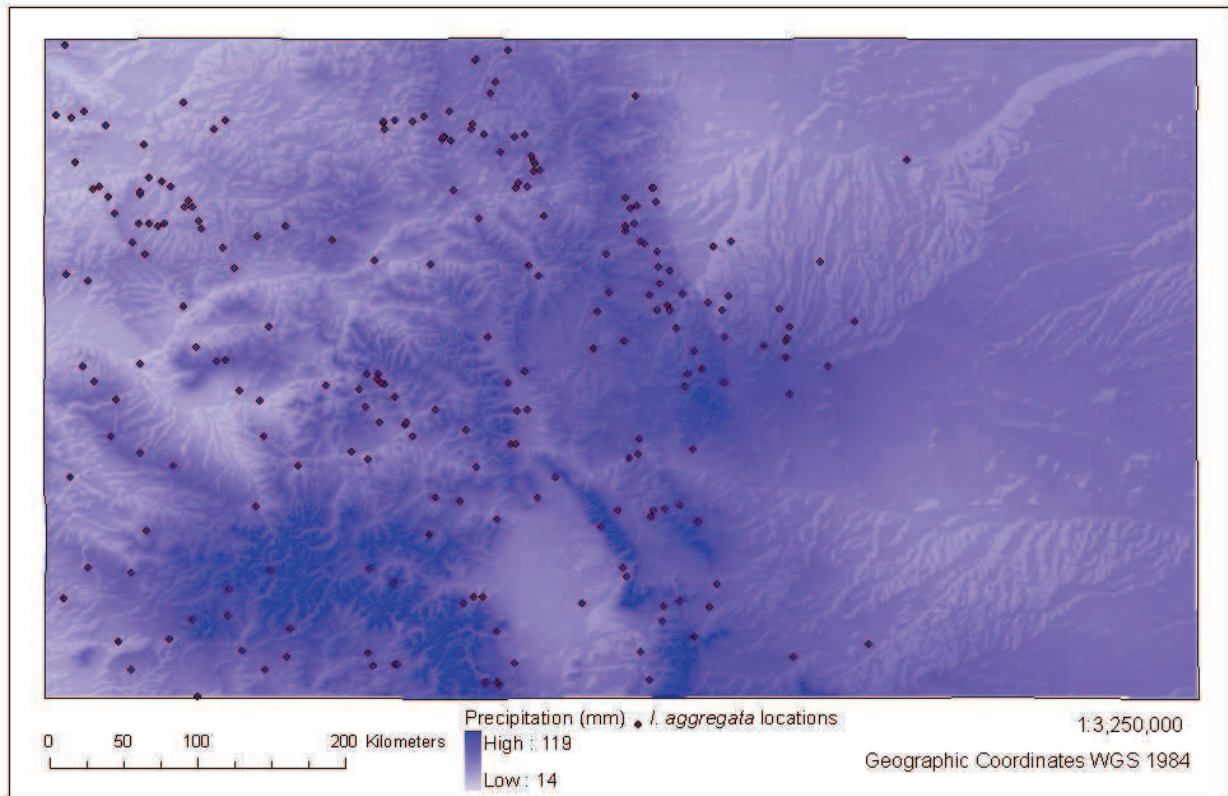


Figure 21. Predicted 2080 August mean precipitation (mm) and *Ipomopsis aggregata* populations in Colorado. Displayed with an elevation hillshade.

Predicted Change in August Precipitation and *Ipomopsis aggregata* Population Locations

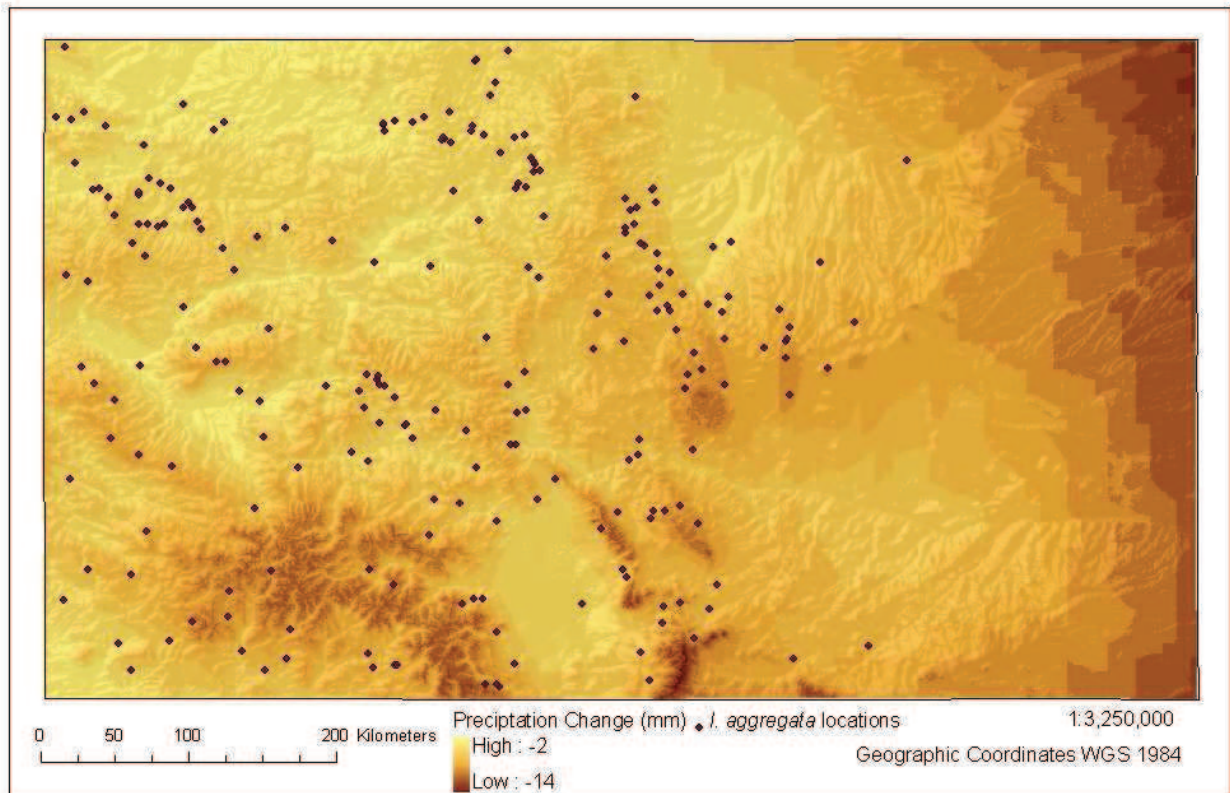


Figure 22. Predicted increase in mean maximum August temperature (C) and *Ipomopsis aggregata* populations in Colorado. Displayed with an elevation hillshade.

Current Maximum August Temperature and *Ipomopsis aggregata* Population Locations

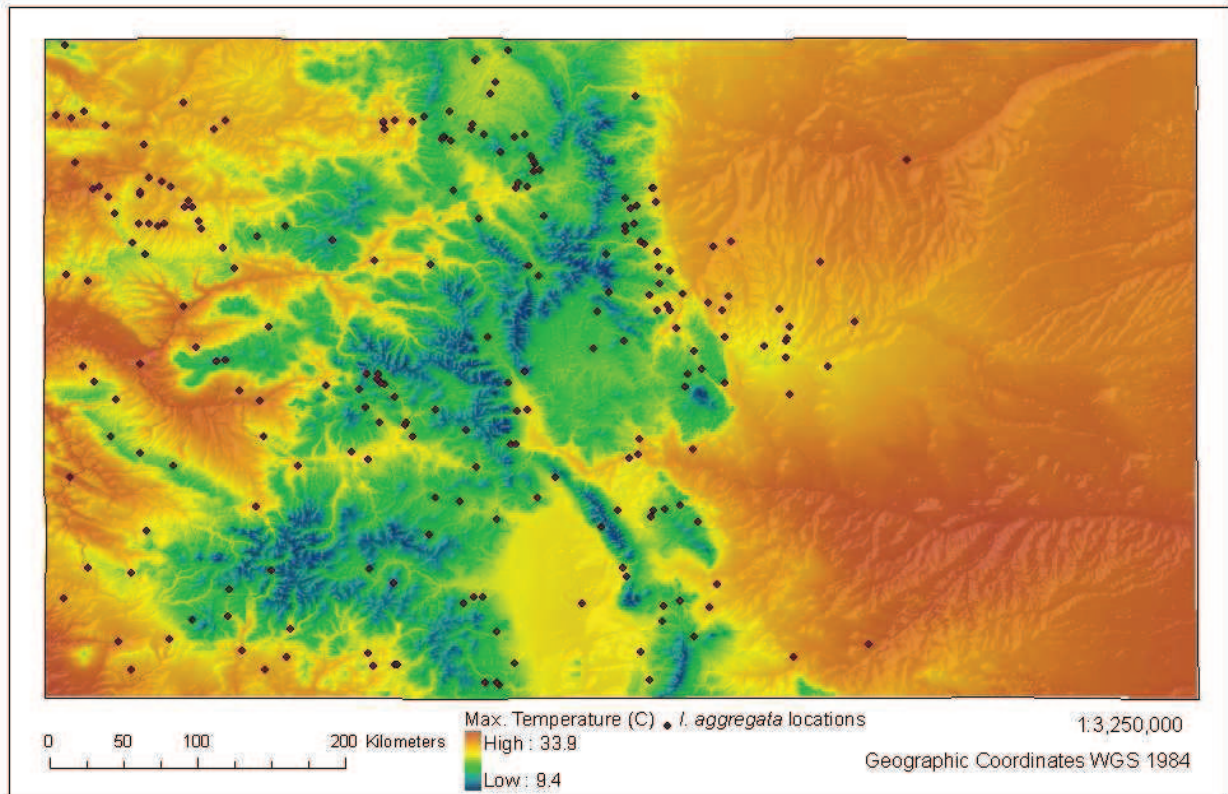


Figure 23. Current mean maximum August temperature (C) and *Ipomopsis aggregata* populations in Colorado. Displayed with an elevation hillshade.

Predicted 2080 Maximum August Temperature and *Ipomopsis aggregata* Population Locations

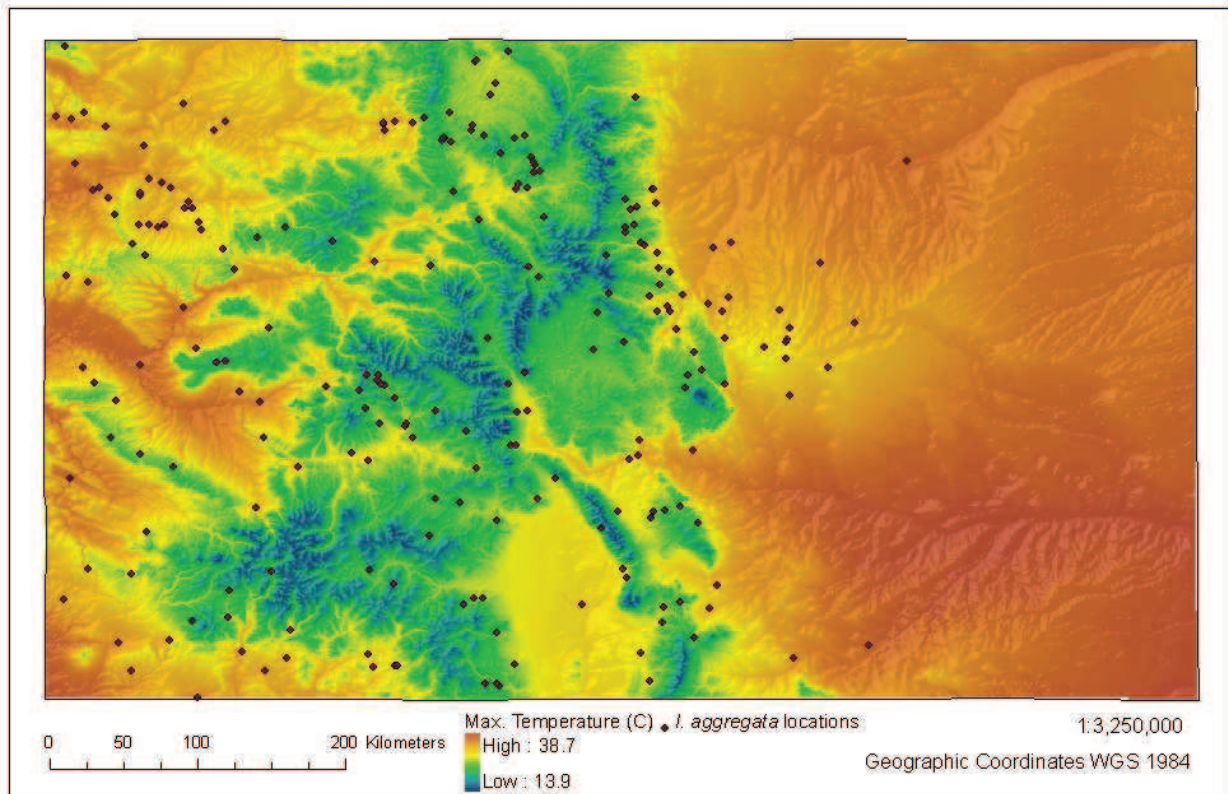


Figure 24. Predicted 2080 Mean Maximum August Temperature (C) and *Ipomopsis aggregata* populations in Colorado. Displayed with an elevation hillshade.

Predicted Increase in August Maximum Temperature and
Ipomopsis aggregata Population Locations

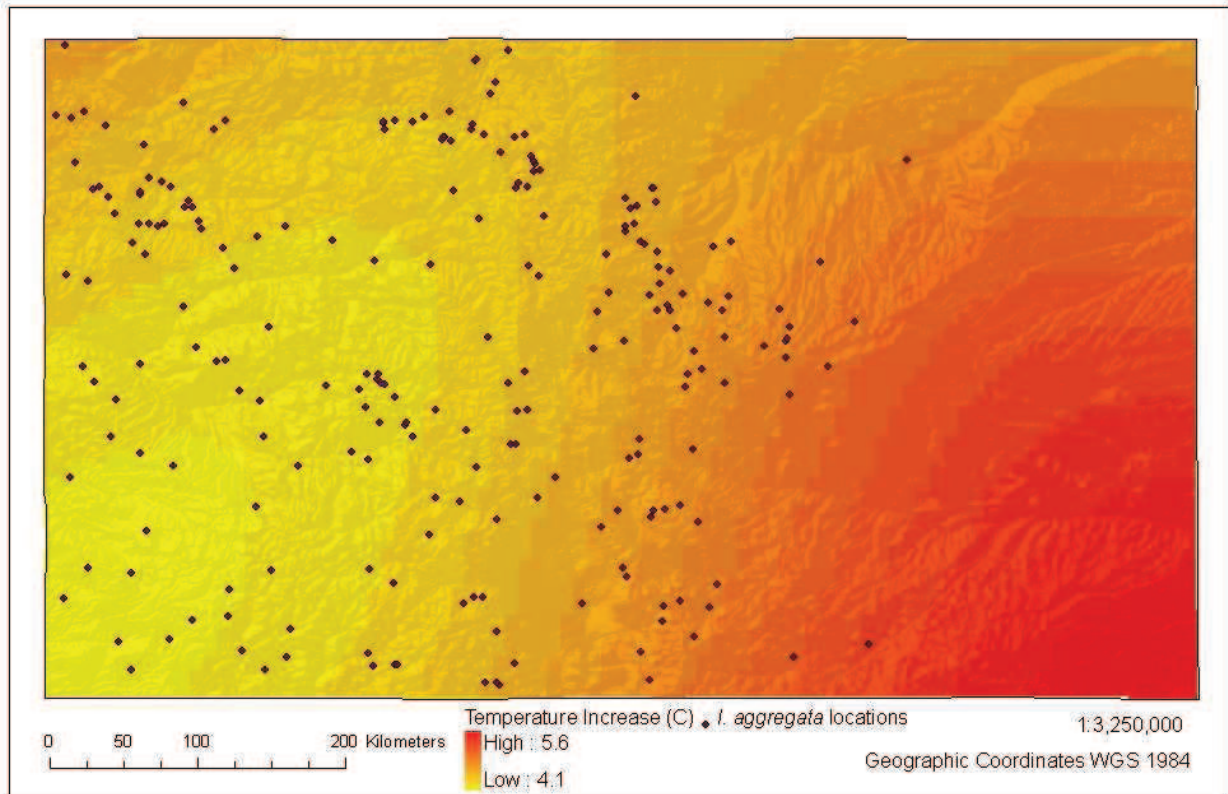


Figure 25. Predicted increase in mean maximum August temperature (C) and *Ipomopsis aggregata* populations in Colorado. Displayed with an elevation hillshade.

Ipomopsis aggregata Populations with Extreme Predicted Climate Change
Overlaid on Predicted Change in August Precipitation

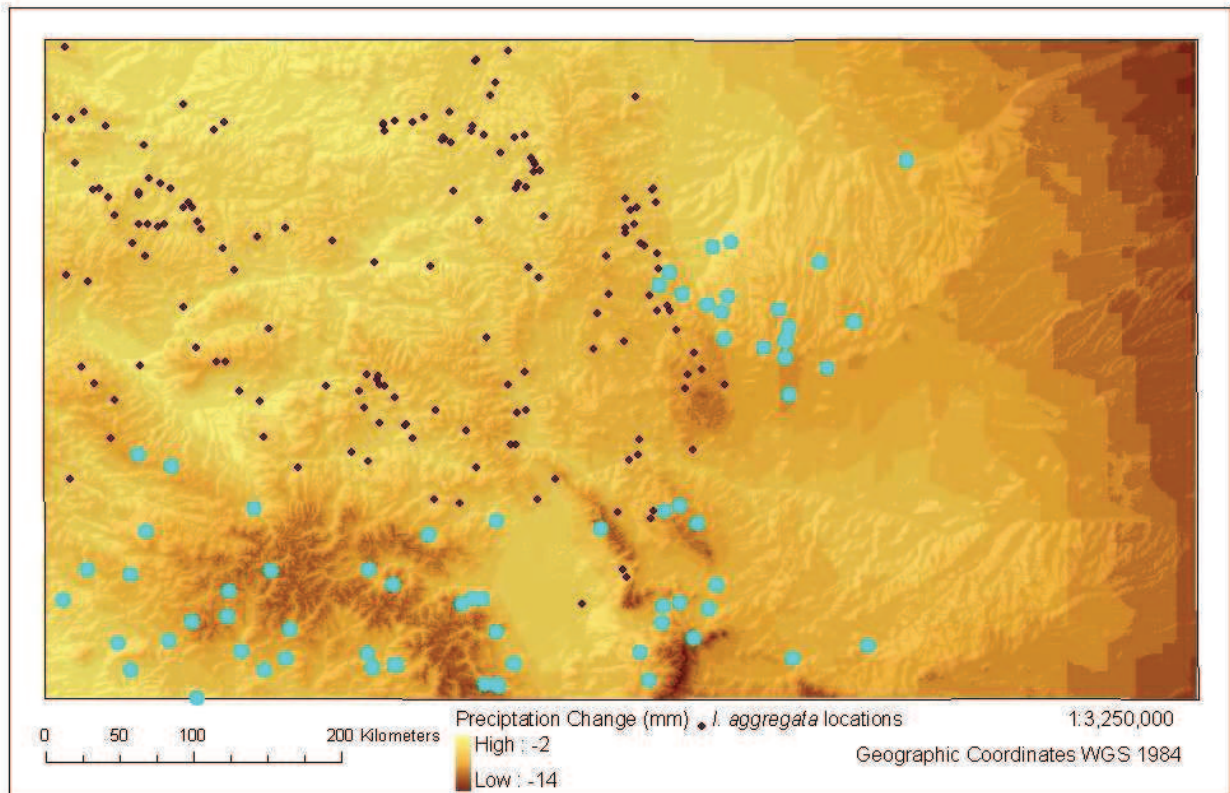


Figure 25. Predicted change in mean August precipitation (mm) and *Ipomopsis aggregata* populations in Colorado. Seventy three populations (highlighted in light blue) will experience the most extreme changes in reduced summer precipitation and increased summer maximum temperature. Displayed with an elevation hillshade.

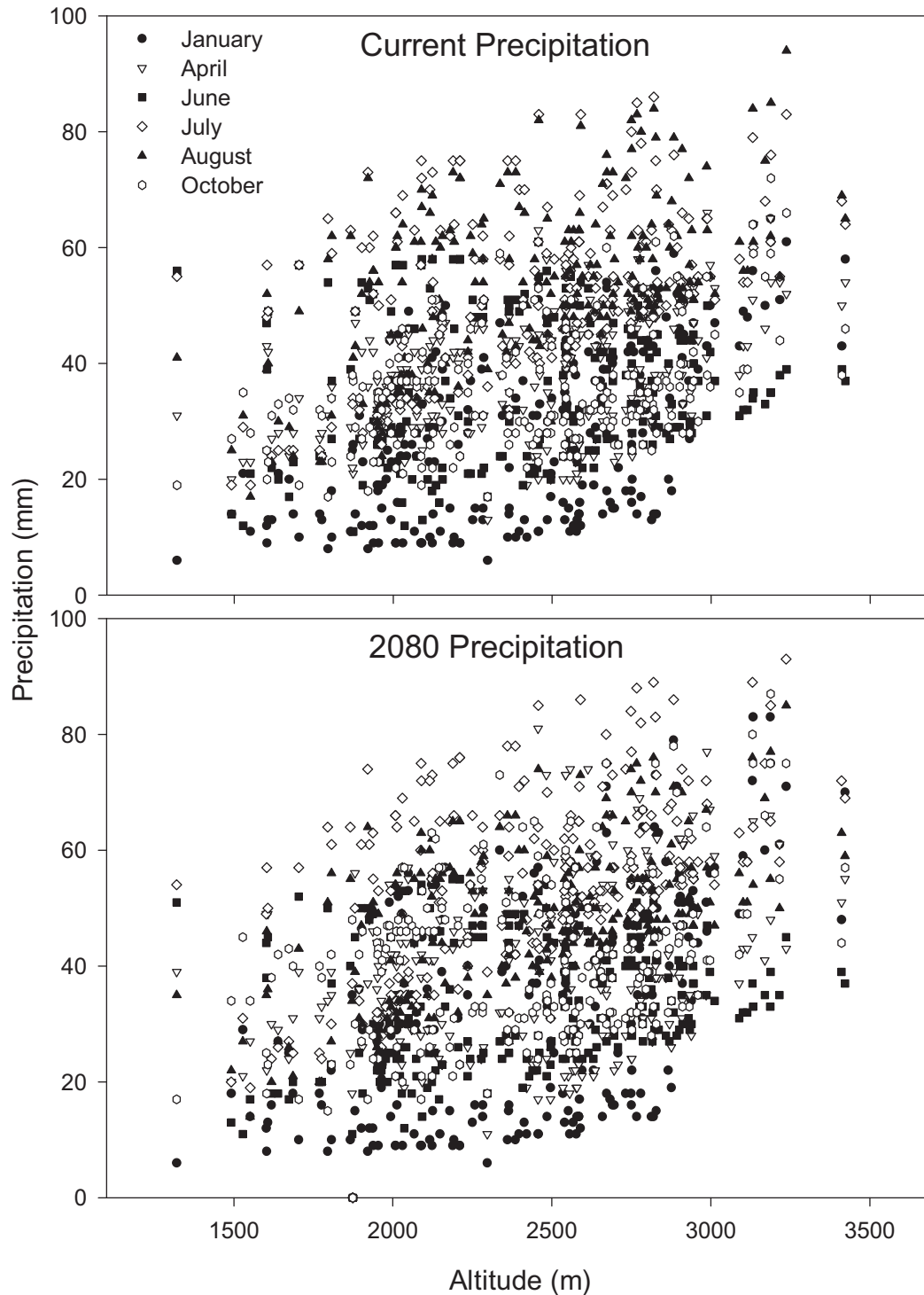


Figure 28. Current and predicted 2080 mean monthly precipitation (mm) vs altitude (m) for 234 *Ipomopsis aggregata* population locations. All slopes significantly different from zero at $p < 0.001$. Partial regression coefficients for current precipitation: January = 0.02290; April = 0.01158; June = 0.00302; July = 0.01350; August = 0.01509; October = 0.00990. Partial regression coefficients for 2080: January = 0.02716; April = 0.01254; June = 0.00422; July = 0.01656; August = 0.01491; October = 0.01347.

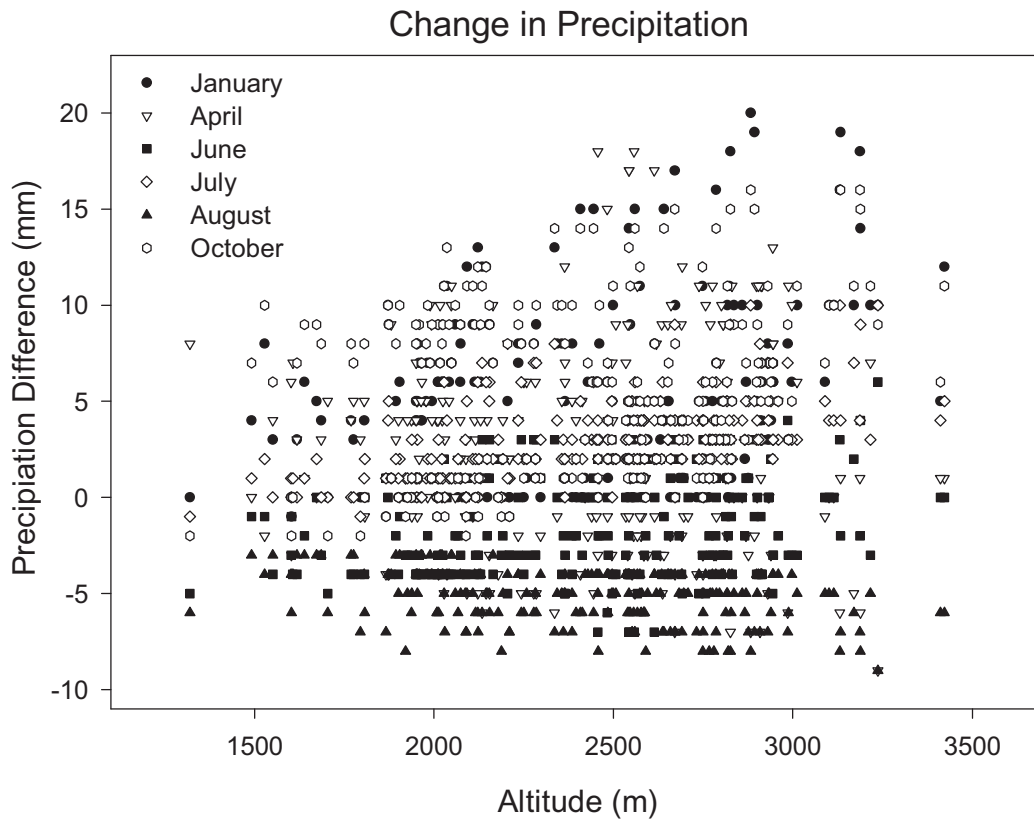


Figure 29. Predicted change in monthly precipitation (mm) vs. altitude (m) for 234 *Ipomopsis aggregata* population locations. All slopes significantly different from zero at $p < 0.05$. Partial regression coefficients: January = 0.00372; April = 0.000698; June = 0.00104; July = 0.00153; August = -0.000722; October = 0.00288.

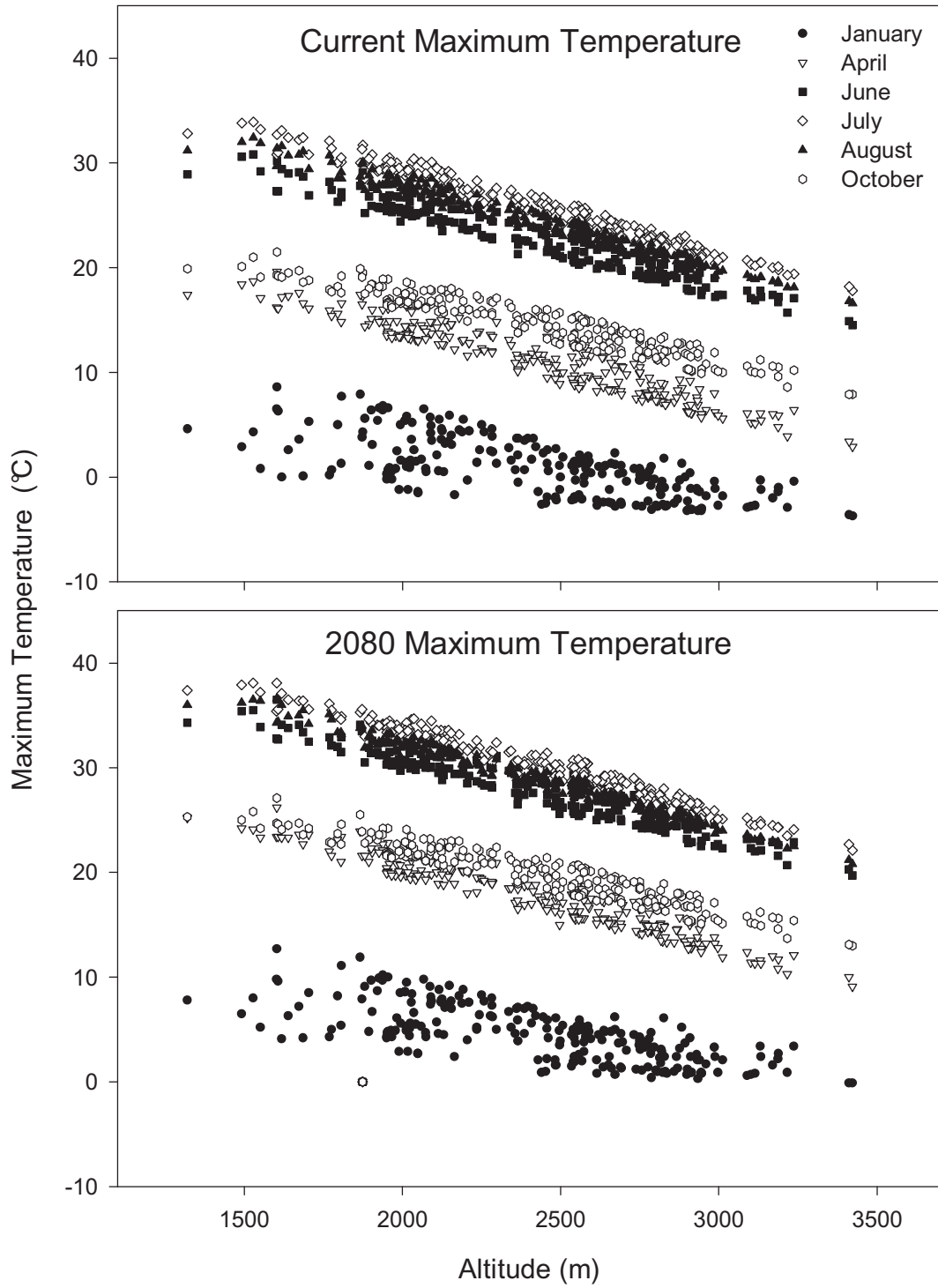


Figure 30. Current and predicted 2080 monthly maximum temperature vs altitude for 234 *Ipomopsis aggregata* population locations. All slopes significantly different from zero at $p < 0.0001$.

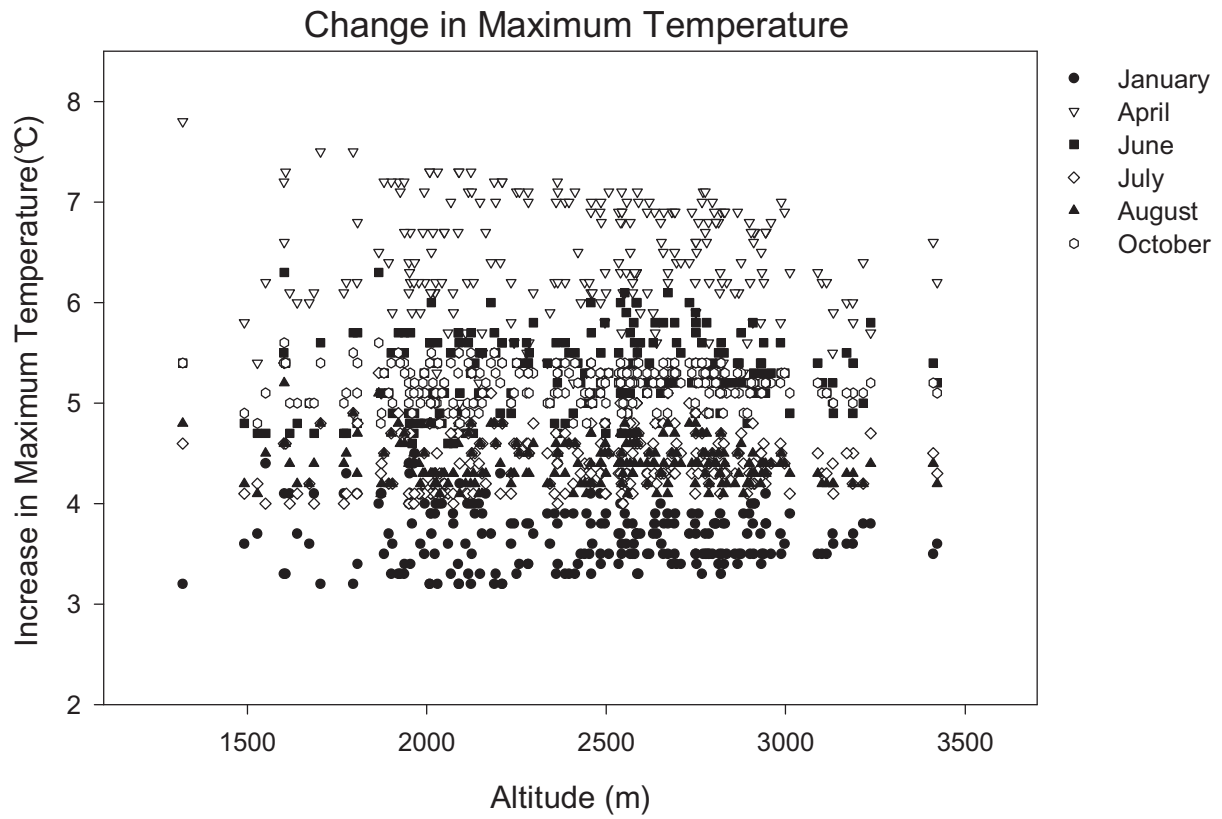


Figure 31. Predicted change in mean monthly maximum temperature vs. altitude for 234 *Ipomopsis aggregata* population locations. All slopes not significantly different from zero, except June, which had the overall highest temperature increase. June partial regression coefficient = -0.0005713 at $p < 0001$.