Michael Anderson EES 391 Final Report
Climate Change Species Impacts

OVERVIEW

Last semester, I took an environmental law class which thoroughly broke down the Endangered Species Act and looked into how laws could be used in the future as a means to assist in the relocation of species driven out of their habitats by global warming. This piqued my interest, so I chose the topic of "climate change species impacts" in order to gain a better understanding of how certain vulnerable species could be affected by a rapidly shifting global climate. Climate change from greenhouse gas emission is likely to make the planet warmer than any time within the past 10 million years, and at an unnaturally high rate, shifting the ranges of many species [1]. As temperatures increase, some species will either have to migrate or adapt within very short time frames in order to survive. The species most likely to be disturbed by climate change are those that occupy delicate, specific habitats and niches, such that even minor changes to their surrounding environments are highly impactful to survival and distribution [2]. Going into my study, I looked for an example species that seemed to be highly vulnerable to temperature shifts, and quickly found the American Pika.

Pikas are small mammals of the rabbit family that mostly inhabitat cold and rocky mountainous regions. Of the 30+ species on pika worldwide, most live in central Asia - North America is home to only two species, the American Pika and the Collared Pika [3]. With habitat ranging thousands of miles across the mountains of the Western United States and Canada, the American Pika is currently listed as a "least concern" species by the IUCN Red List of Threatened Species. This category is reflective of high and relatively stable populations across a species' given range [4]. While the pika is unlikely to become threatened with extinction in the near future, its physiology and habitat make it an ideal example species when examining temperature-species interactions.

Pikas are well adapted to living in freezing, snowy alpine conditions, having developed traits such as high metabolism and thick fur in order to cope with frigid conditions . Resulting from their cold-weather adaptations, pikas are vulnerable to hyperthermia in the summer [5]. Exposure to 78° F for 6 hours can result in death, while exposure to 82° F can result in death within just 2 hours [6]. Pikas avoid hyperthermia by resting in cool and shaded talus (rock) piles, which protect them from heat, but limit how much they can forage for food. Since pikas don't hibernate, instead feeding on their hay stocks during the winter, ample foraging is vital for pika survival [5]. For these reasons, summer temperatures are a major limiting factor in pika distribution.

Summer temperatures are one of three “limiting hypotheses” referenced frequently in studies involving the American Pika, the others being the “winter snowpack hypothesis” and the “forage availability hypothesis.” The winter snowpack hypothesis says that loss of snowpack limits pika range by damaging food stores and leading to overexposure to the cold and predation. Again, lack of hibernation introduces more variables into pika survival. Pikas need to remain active, feeding on their hay piles throughout the winter, but extreme cold can be damaging to both pikas and their food stocks without an insulative blanket of snow for protection. Lastly, the food availability hypothesis says that pikas are limited by how much food can grow in their habitats. Various studies have tested these hypotheses, and while some have challenged the snowpack hypothesis and the food availability hypothesis, the high impact of summer temperatures on pika survival has been frequently upheld.

One particular study (Yandow et al 2015)[7] tested the winter snowpack hypothesis using data from the winter of 2014/2015 in the Sierra Nevada mountains. During the season, the Sierra Nevada only received 3-17% of its usual snowfall on average, with some areas receiving no measurable snowfall at all. April snow water content levels were at just 5% of the historic average, making the winter 2014/2015 the driest on record. To reiterate the magnitude of this low point, the previous April record was 25% of the historic average. To test how this absurd lack of snow impacted Sierra Nevada pikas, the team compared summer 2014 and summer 2015 occupancy, with another follow up comparison in the summer of 2016. Occupancy was tested by looking for green hay piles at specific sites - meaning that a pika is actively collecting for its warm season harvest. Direct sightings and audible calls were also used as evidence for occupancy.

In the end, no evidence was found for snowfall increasing pika mortality, even in the most extreme case possible. In 2015, hay piles were found at 89.2% (33/37) of the baseline sites from 2014. Additionally, pikas were seen or heard at 78% (29/37) of summer 2014 sites and 91% (30/37) of summer 2015 sites. Overall, pika presence was found at 36/37 sites - the 2014 and 2015 results were almost identical. A follow up in 2016 looked at 33 of the sites, where 29 were found to have green hay piles.

Summer temperature, on the other hand, was a constant in the various pika studies that I looked into. One 2015 study involved 12 years of pika data collection in the Sierra-Nevada. Of 16 variables tested, summer temperature with talus area was the best performing model in regards to its relationship with pika extirpation [5]. This makes sense given pika physiology, and their use of rock piles to avoid heat exhaustion.

DATA

With this in mind, I decided to look into how pika range could shift due to increasing summer temperatures, and chose the Sierra-Nevada as a starting point, as it was the setting for many studies. The idea at first was to use the Sierra-Nevada to figure out how to deal with the data and what to analyze, then to apply those methods to potentially the entire pika range. I obtained some very accurate pika habitat data from the USGS, and also managed to find a set of rasters containing predicted summer temperatures to 2100 from Esri. Specifically, this consisted of eight global temperature rasters containing predicted 20 year averages (i.e. 2020-2039 summer temperatures). These rasters were further categorized under two different climate scenarios, giving me four rasters from each respective climate scenario.

The IPCC (Intergovernmental Panel on Climate Change) has developed several different climate scenarios that are frequently referenced in predictive studies. These scenarios account for many different variables that will impact climate into the future, such as population growth and industrial development. The four main global "storylines" for future climate change developed by the IPCC are the A1, A2, B1, and B2 scenarios. The A1 and B1 scenarios involve an evolving world where technology, the global economy, and cultural integration experience rapid growth. Both see a population peak by 2050 which then declines slowly. The B1 scenario is more environmentally focused - centered on clean technology, global sustainability solutions, and growth towards a low-emissions information economy. The A2 and B2 scenarios involve a slowly evolving world where progress is stunted and population steadily increases. The world is still divided, and global environmental cooperation is low. Like before, the B2 scenario is more environmentally friendly. Tech progress is slow, but is focused on sustainability, and countries handle environmental issues locally [8]. Generally, B1 is the best case scenario while A2 is the worst case, so I chose mean summer temperature data from these two scenarios. In summary, my data consisted of eight rasters, split into four 20 year periods (2020-2039, 2040-2059, 2060-2079, and 2080-2099) holding mean summer temperatures modeled on the A2 and B1 climate scenarios.

ANALYSIS

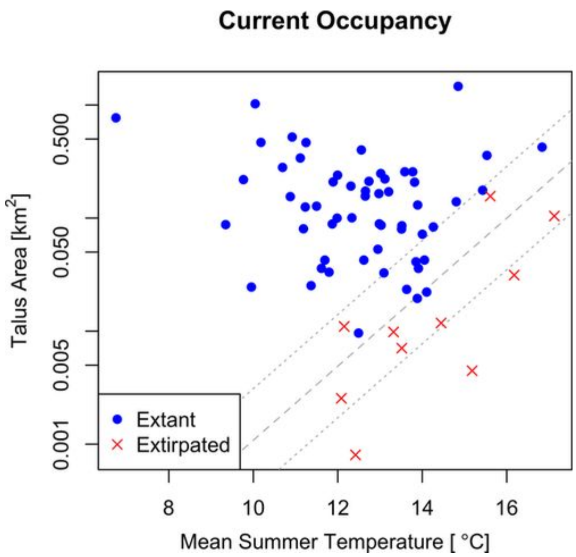
After obtaining the necessary data, a lot of work went into cleaning it up and making it usable. One of the first problems that I ran into was that many ArcGIS geoprocessing tools involving rasters were unable to process float value rasters. At the time, I didn't have access to Esri's Spatial Analyst License, which would have made smooth conversion easy, so I had to use some more roundabout methods to get the data into a usable format. Thanks to the RasterToNumPyArray and NumPyArrayToRaster functions built into ArcPy, I was able to to the conversions with a few lines of Python:

```
myRaster = RasterToNumPyArray("rasterfilename")
myRaster.astype(int)
NumPyArrayToRaster(myRaster, Point corner, sizex, sizey)
```

This allowed for me to convert the eight summer temperature rasters from float value to int so that they could be changed into shapefiles. This allowed for easier selections and data comparisons, specifically for joining the data spatially with my pika habitat layer. Originally, I had turned my pika range raster data into a polygon shapefile to better associate the data, since more comparisons can be done with shapefiles. I wanted to do a spatial join between my temperature shapefiles and range shapefiles - but I eventually realized that since the pika range data had basically no values in its attribute table, the join would not be accurate. This is because without any unique values, the pika range raster cells were large and globby when transformed into polygons, and not the same size as the original raster cells.

To counter this, I decided that I would build an attribute table for the pika range of unique values - there turned out to be nearly 10 million - and turn the raster cells into points that I could then associate with the underlying temperature. Once I had my points, I successfully tied them to one of my temperature shapefiles using the intersect tool, which seemed to operate as a more user-friendly implementation of spatial join. It took a long time, since there were 10 million points, but it eventually worked.

Once I had the pika habitat data as points, so that they could be selected individually (instead of as very globby shapefiles), I had to incorporate the temperature data. Based on studies I've read, I went with less than or equal to 16 degrees Celsius for cut off for suitable pika habitat. The primary study I based my choice off of was Perrine et al's 2015 study on summer temperatures and pika extirpation in the Sierra Nevada. This study found a strong relationship between talus area, summer temperature, and pika extirpation, as shown below.

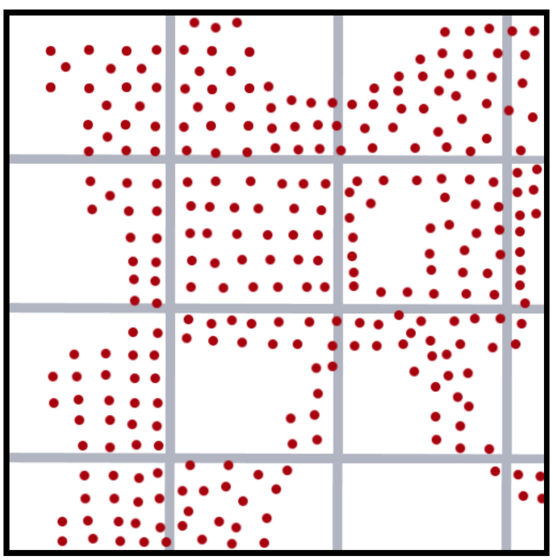


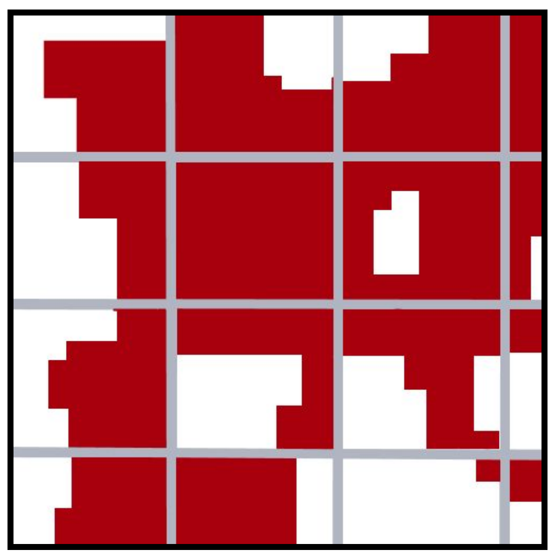
It’s important to note that 16 degrees C is a pretty ambitious cutoff, and 14 degrees might have been a better, more general choice looking back on things. Also, survival rates at different temperatures are influenced by talus area, which I couldn’t find data for. Having it would’ve allowed for choices to be made based on the temperature-talus relationship instead of just choosing some arbitrary temperature that seemed like a decent cutoff. It's possible that given high enough resolution maps, I could have made some rough guesses based on average colors, slope gradient, or even roughness, but this would have to be automated to be viable across the entire Sierra-Nevada range. At first, I thought the Sierra-Nevada was a small enough starting point to refine some sort of process, but this turned out to be a bit of an overshoot.

Using Sierra-Nevada pika habitat left me with 10 million data points, which made things very slow going. At first, I tried selecting based on the point’s attributes - I had integrated the temperature of each point in each scenario at each time frame in order to make this easy to do. The selection seemed to work, but the new layer was output unchanged from the original. Eventually, I figured out that my dataset was just too large and had to be split into smaller chunks. Using 8 cookie cutter layers (my temperature shapefiles for <=16 ° C blocks), I split each cookie cutter into 2 halves, then selected points that were intersecting with the layer. This lead to having 16 sets of points, all of which represented pika habitat with <=16 ° C summer temperature.

Using the software ImageMagick, I then used screenshots of my data sets to make gif animations for the A2 and B1 scenarios to show the habitat progression over time. I initially wanted to make heatmaps of my data sets, which would have looked much better in gif form, but something about the symbology made ArcGIS Pro freeze and crash.

A lot of the issues I had with crashes and slow data processing had to do with the millions of points I was working with. Using points meant that I could take a temperature layer and use it to select for underlying habitat accurately, but unfortunately was very inefficient. An ideal scenario would involve turning the points into a grid of polygon shapefiles that match the grid of temperature data spatially. This way, I could still use the temperature layer to accurately select habitat within the range while only having dozens of elements instead of millions. This could be done manually for a small area, but wouldn't be viable otherwise. Below, I made a rough example to illustrate: hundreds of points in the temperature grid vs 16 polygons.





RESULTS

Scenario/Year	baseline	b1_2020	b1_2040	b1_2060	b1_2080
Data Points	9,038,098.00	8,649,606.00	8,545,052.00	8,179,376.00	8,122,585.00
Percentage	100%	95.70%	94.54%	90.50%	89.87%
Elevation	2,682 m	-	-	-	2,812 m

Scenario/Year	baseline	a2_2020	a2_2040	a2_2060	a2_2080
Data Points	9,038,098.00	8,656,499.00	8,245,200.00	7,681,668.00	6,311,271.00
Percentage	100%	95.78%	91.23%	84.99%	69.83%
Elevation	2,682 m	-	-	-	2,865 m

Selecting habitat where summer mean temperatures stayed at or below 16 degrees Celsius, the B1 scenario led to just a ~10% loss in habitat while the A2 scenario led to a ~30% loss by 2099. Habitat increased in elevation by 130 meters for B1 and by 183 meters for A2. If mean summer temperature is the only thing impacting pika range, the species has nothing to worry about. In reality, however, there are probably dozens or even hundreds of contributing factors to how the American pika will react to global warming. Temperature may be considered the most important, but talus area, weather, moisture, vegetation growth, and countless other variables will ultimately combine to decide the pika’s fate. If anything, my results show the importance of collectively reaching a better climate scenario. Steps need to be taken in order to make sure that the worst case doesn’t happen, and our current pace is not good enough. In the coming decades, the pika’s habitat will gradually increase in elevation as it naturally avoids rising temperatures. Extirpation from warmer areas will continue to become more likely as climate change worsens, and if temperatures never level off, at some point pikas will simply run out of space.

Citations

[1] Climate sensitivity, sea level and atmospheric carbon dioxide - Hansen et al. 2013 - https://royalsocietypublishing.org/doi/full/10.1098/rsta.2012.0294

[2] Global warming and extinctions of endemic species from biodiversity hotspots. Malcolm et al. 2006 - https://www.ncbi.nlm.nih.gov/pubmed/16903114

[3] Ochotona - Pikas - Animal Diversity Web - https://animaldiversity.org/accounts/Ochotona/classification/

[4] The IUCN Red List of Threatened Species - https://www.iucnredlist.org/

[5] Summer temperature and habitat area predict pika extirpations in California - Perrine et al. 2015 - https://onlinelibrary.wiley.com/doi/full/10.1111/jbi.12466

[6] Physiology of thermoregulation in the pika, Ochotona princeps - MacArthur and Wang 1973 - https://www.nrcresearchpress.com/doi/abs/10.1139/z73-002

[7] Climate Tolerances and Habitat Requirements Jointly Shape the Elevational Distribution of the American Pika - Yandow et al. 2015 - https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0131082#pone-0131082-g003

[8] IPCC Emissions Scenario Report 2000 - https://www.ipcc.ch/site/assets/uploads/2018/03/emissions_scenarios-1.pdf