The Shift in Geographical Range of Birds in Colombia

Women in Stem
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Introduction

Climate change threatens the future of our planet. Currently in the zone of certainty with increasing risk, climate change is one of the nine planetary boundaries that puts a limit on what Earth can handle while being able to provide for generations to come (Steffen et al., 2015). Without reform, greenhouse gasses from human emissions will continue to trap heat in the atmosphere for long periods of time resulting in increased global temperatures (Steffen et al., 2015). This scenario puts individuals, populations, and species at risk which leads to loss of biodiversity within ecosystems (Pettorelli et al., 2021). However, the biodiversity crisis and climate change are interdependent as biodiversity loss threatens valuable ecosystem services like carbon sequestration which results in even more carbon remaining in the atmosphere (Novasek & Cleland, 2001; Pettorelli et al., 2021).

Climate change increases primary productivity, the spread of invasive species, biotic attrition, sea levels, and the number of extreme events, like floods and wildfires (Colwell et al, 2008; Lipton et al., 2018). These climatic changes not only affect ecosystems, but also the ecology of each of the species found within. Species have to face the challenge of finding ways to adapt to these negative effects brought on by climate change or they risk going extinct. Examples of the way species have adapted are by changing their individual traits, the timing of important biological events, or their geographic ranges (Lipton et al., 2018). These three adaptations have been widely researched in birds which makes them an important indicator for climate change (Şekercioğlu et al., 2012). Some adaptations to increasing temperatures studied in bird species include smaller body size, but longer wingspans across North American migratory birds (Weeks et al., 2019), earlier breeding seasons in the black-throated blue warbler (*Setophaga caerulescens*) (Lany et al., 2015), and expansion in the range of lowland birds to higher elevations in southeastern Peru (Freeman et al., 2018). However, birds are not always able to overcome these challenges and adapt. It is predicted that if temperatures continue to increase at the rate that they are, 600–900 species of land birds will go extinct by the year 2100 (Şekercioğlu et al., 2012).

In particular, tropical birds have an even greater susceptibility to warming temperatures, as they exhibit narrower climatic niches since they only experience limited temperature variation throughout the year (Neate-Clegg et al., 2021; Şekercioğlu et al., 2012). Still, each bird species responds in a different way depending on their traits, such as body size, dispersal ability, and territoriality (Neate-Clegg et al., 2021). The factors that influence birds' responses to climate change are complex. Therefore, it is advisable to look at their adaptations from a regional standpoint to accurately predict a geographical shift among birds (Neate-Clegg et al., 2021). In this study, we chose to focus on bird species from Colombia.

Problem Statement

This study focuses on observing the geographical scope of bird species in Colombia. Through analyzing the bird species observations in Colombia, scientists can keep track of the locations and abundance of various birds as well as how they change over time. This can be seen through our process of finding the location of various bird species observations and correlating these results with the longitude and latitude coordinates; this focus can further our analysis on the effects of global warming and temperature change on the overall bird species we worked with. This application could further improve conservation efforts worldwide.

Related Works

Colwell, R. K., Brehm, G., Cardelús Catherine L., Gilman, A. C., & Longino, J. T. (2008). Global warming, elevational range shifts, and lowland biotic attrition in the Wet Tropics. Science, 322(5899), 258–261. https://doi.org/10.1126/science.1162547

Several studies indicate that global warming is driving species to higher elevations. This trend. Species in lowlands may be more likely to go in decline or simply go extinct with the inability to move or adapt to higher elevations. This is important to us in order to understand what sort of trends and movements we might see with different species of birds.

Freeman, B.G., Scholer, M.N., Ruiz-Gutierrez, V., Fitzpatrick, J.W. (2018). Climate change causes upslope shifts and mountaintop extirpations in a tropical bird community. Proceedings of the National Academy of Sciences, 115 (47) 11982-11987. https://doi.org/10.1073/pnas.1804224115

Species that already exist at high elevations are likely to be at high risk of extinction due to their inability to go any higher to escape the increasing temperatures caused by climate change. This demonstrates the importance of studying birds that already have a limited area that they can live in to see how climate change has impacted them.

Lany, N. K., Ayres, M. P., Stange, E. E., Sillett, T. S., Rodenhouse, N. L., & Holmes, R. T. (2015). Breeding timed to maximize reproductive success for a migratory songbird: The importance of phenological asynchrony. Oikos, 125(5), 656–666. https://doi.org/10.1111/oik.02412

Similar to our project, the adaptations birds have made due to climate change has been widely studied. However, in this paper the author addresses a bird that resides in

temperate areas, the black-throated blue warbler. Scientists observed a shift to an earlier breeding season within this species.

Lipton, D., M.A. Rubenstein, S.R. Weiskopf, S. Carter, J. Peterson, L. Crozier, M. Fogarty, S. Gaichas, K.J.W. Hyde, T.L. Morelli, J. Morisette, H. Moustahfid, R. Muñoz, R. Poudel, M.D. Staudinger, C. Stock, L. Thompson, R. Waples, and J.F. Weltzin, (2018). Ecosystems, Ecosystem Services, and Biodiversity. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 268–321. https://doi.org/10.7930/NCA4.2018.CH7

This paper provides the background we need for our project. Climate change goes beyond just increasing temperatures. It is completely changing the abundance of species within various ecosystems. The authors then address the three ways species are having to adapt to these changes, one of which is the focus of our report (geographic ranges).

Neate-Clegg, M. H., Jones, S. E., Tobias, J. A., Newmark, W. D., & Şekercioğlu, Ç. H. (2021). Ecological correlates of elevational range shifts in tropical birds. Frontiers in Ecology and Evolution, 9. https://doi.org/10.3389/fevo.2021.621749

One of the ways that birds adapt to climate change is by shifting where they live based on elevation. The direction and speed at which a bird's elevational range changes varies based on species basis. This paper gives us a known trend in a response to climate that we can then utilize to look at our own findings to see if that appears to be true.

Novacek, M. J., & Cleland, E. E. (2001). The current biodiversity extinction event: Scenarios for mitigation and Recovery. Proceedings of the National Academy of Sciences, 98(10), 5466–5470. https://doi.org/10.1073/pnas.091093698

Many current efforts in order to rescue biodiversity often lack important information such as distribution and diversity of species. This article points out these problems and the importance of needing to come together to fix them. We aim to aid in this endeavor through determining how different birds of Colombia are affected.

Pettorelli, N., Graham, N. A., Seddon, N., Maria da Cunha Bustamante, M., Lowton, M. J., Sutherland, W. J., Koldewey, H. J., Prentice, H. C., & Barlow, J. (2021). Time to integrate Global Climate Change and biodiversity science‐policy agendas. Journal of Applied Ecology, 58(11), 2384–2393. https://doi.org/10.1111/1365-2664.13985

These authors address the importance of making change now. With climate change threatening biodiversity, lower levels of biodiversity actually threaten to make climate change even worse. This cycle has the ability to never end unless we start doing something to make a difference. Our project sees these effects as the birds are moving geographic ranges which leads to abiotic attrition for the species that remain.

Şekercioğlu, Ç. H., Primack, R. B., & Wormworth, J. (2012). The effects of climate change on tropical birds. Biological Conservation, 148(1), 1–18. https://doi.org/10.1016/j.biocon.2011.10.019

Tropical birds have been found to be extremely vulnerable to climate change. Coupled with habitat loss this greatly increases bird extinction. This demonstrates the importance of investigating birds in tropical regions and seeing how they are being directly impacted.

Steffen, W., Richardson, K., Rockström, J., Cornell, S. E., Fetzer, I., Bennett, E. M., Biggs, R., Carpenter, S. R., de Vries, W., de Wit, C. A., Folke, C., Gerten, D., Heinke, J., Mace, G. M., Persson, L. M., Ramanathan, V., Reyers, B., & Sörlin, S. (2015). Planetary boundaries: Guiding human development on a changing planet. Science, 347(6223). https://doi.org/10.1126/science.1259855

Scientists have come together to inform the world that there are 9 planetary boundaries that our Earth cannot handle if we exceed. If these do not get lowered, there will not be a planet for our future generations. Multiple of these boundaries have already been exceeded which in part has turned to climate change. This provides the big picture of our project, and where the root of the issue started.

Weeks, B. C., Willard, D. E., Zimova, M., Ellis, A. A., Witynski, M. L., Hennen, M., & Winger, B. M. (2019). Shared morphological consequences of global warming in North American Migratory Birds. Ecology Letters, 23(2), 316–325. https://doi.org/10.1111/ele.13434

Another paper that addresses the adaptations of birds, this one focuses on the change of individual traits of North American migratory birds. Over time, these birds have developed smaller body sizes and longer wingspans. This is in contrast to the birds of the tropics who have to quickly adapt to the rising heat.

Data Model

We retrieved data from eBird database concerning bird observations in the country of Colombia from the years 1970 to 2017. This data contains a variety of information about the bird species, such as, scientific name, species' subspecies, observation count, breeding code, location, date of observation, and more.

The data model we used is a document based dataset. This is because a document stores information about a single object and any of its related metadata. In our case this would be our "Global Unique Identifier" field which represents a single sighting report with its metadata explaining what the sighting entails. The document database provides flexibility in utilizing queries on the database.

After researching the advantages of working with document databases, using a document database is an intuitive data model for quick and easy use. The flexible schema will be applicable for any changes we need to make upon working on our project. Working with MongoDB and our document based dataset, document store data in field-value pairs, meaning, we are able to work with a variety of types and structures: strings, numbers, dates, arrays, or objects. We will also have the option of storing documents in JSON, BSON, and XML formats.

The parser that we created connected to the specified MongoDB cluster and database. It then looks at the specific document collection to read the files into. In our case it was the "Colombia" collection. The parser indicates the headers that are within the data file and proceeds to read in the data row by row. As it reads in each row, it inserts it as one document into the database.

With the parser, it took approximately 3 days, 72 hours, to load the data into the database. To actually load and look at the data in the database, it takes approximately 5 to 10 minutes. Our dataset included a total of 2,326,338 documents with around 34 elements per document. The physical storage size was 4.42 GB and we created six compound indexes to store the data in MongoDB. We had created 6 total compound indexes which were loosely related to Species, Breeding/Behavior, Location, Observations, Sampling, and eBIRD Approval information respectively. By creating these compound indexes, it meant that we were able to support several different queries. For example, we could use the Species Information compound index to query on just "COMMON NAME" or on both "COMMON NAME" and "EXOTIC CODE".

Algorithm and Methods

First we retrieved the data we are focusing on: common name, latitude, longitude, observation date. We used the pymongo package to query our database in MongoDB to get the required data. We are getting data species by species. Then, we transformed the output from dict form to a csv file for each bird species.

We utilized mrjob, a MapReduce package in Python, to find counts based on observation date, latitude, and longitude. We ran it for each bird species, which allowed us to easily extract data tracking the location and date for each bird observation.

Using the data we extracted from the MapReduce function, we generated a geographical scatterplot for each species and statistics on which species location changes the most over the years. To do this, we used plotly and geopandas, both geographical based Python packages, to create the scatterplots. The scatterplots include a map as the background, and different colors represent different years, to more easily see the distribution of any given bird species over time. For the scatterplots that showed the most changes, we then went on to generate statistics explaining how drastically the bird population has changed over time.

We have implemented optimization techniques with focusing on species by species rather than the entire big data set. Another way we are optimizing is by narrowing the fields in which we are focusing on to common species names, observation date, and longitude/latitude coordinates. When working with the common species names items and the corresponding observation dates, longitude/latitude coordinates of observations we are optimizing our runtime, accuracy, and implementations of the various algorithms we are working with.

Results

Before diving into results, we do have to consider that the overall number of observations has grown across the board, with more people reporting to eBird each year. Thus, we cannot assume that any bird species is increasing in population due to there being more reported observations. We may also need to take into consideration human population location and how they correlate to where birds are sighted, especially as time goes on. As there has been an increase in bird observations, we are only assuming this could be related to an increase in user input on eBird, but nonetheless, we are able to analyze the locations of the bird species over time.

As we were trying to determine how climate change affects the birds in Colombia, this was a primarily exploratory investigation. It involved having to create graphs and find trends over the years and also determine what was a trend and what was just due to increasing popularity of eBird. This is why we could not do any results purely based on observation count as we determined that it did not make sense. However, when we noticed other trends we investigated several bird species as well as looking at certain species of birds over the years to ensure the trends were what we were seeing. There is also an importance in studying the location trend of bird species observations as we can connect these data points to common trends with climate change, high elevation levels, and biodiversity hot spots. Below we dive into the main results of our findings.

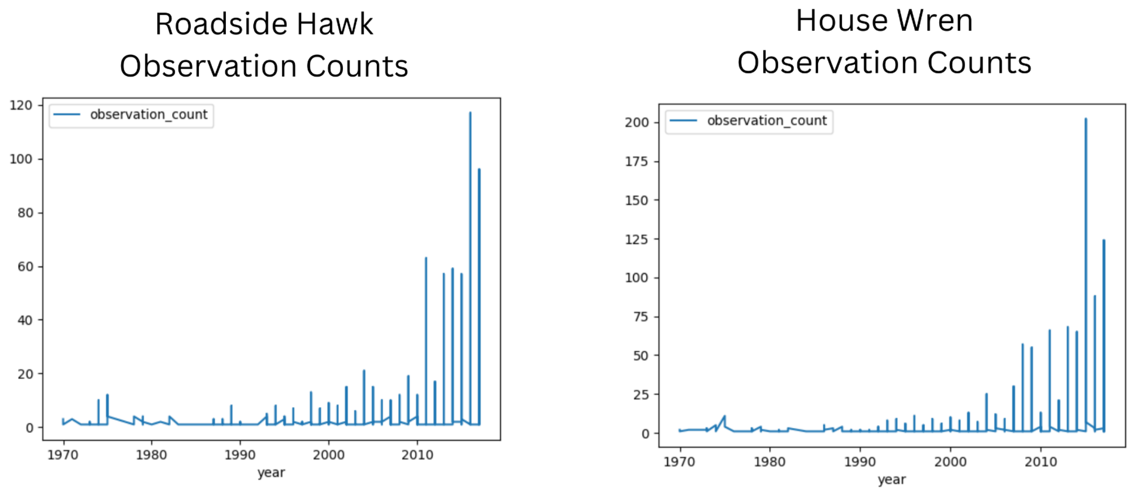
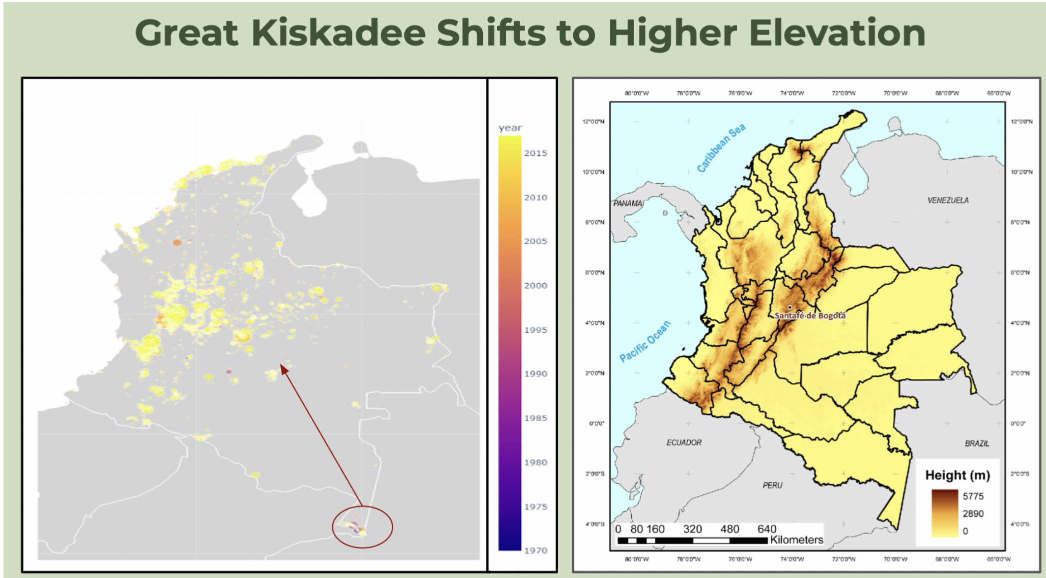


Fig 1. Observation Counts From 1970 to 2017.

The graph above displays the number of observations of the Roadside Hawk and House Wren species for each year. These graphs demonstrate a trend of observation count spiking after 2010. Similar graphs of other bird species show this same trend. Since these bird species are known to exist in this area, we can assume that the increase in observations is only due to an increased use of eBird. However, assuming that the rate of eBird usage does not significantly differ in different areas of Colombia in the same year, we can still look at how the location of bird observations changes over the years to get a general idea of how bird populations have moved. Observation count was a big factor in our analysis as their observation points are very telling to their longitude and latitude points, further helping our analysis in determining patterns and trends within their observation locations. The increase in observation count from the above figure is very telling when pairing this information with longitude and latitude coordinates. Below we plot the observation counts on a map of Columbia and discuss the results of our findings.



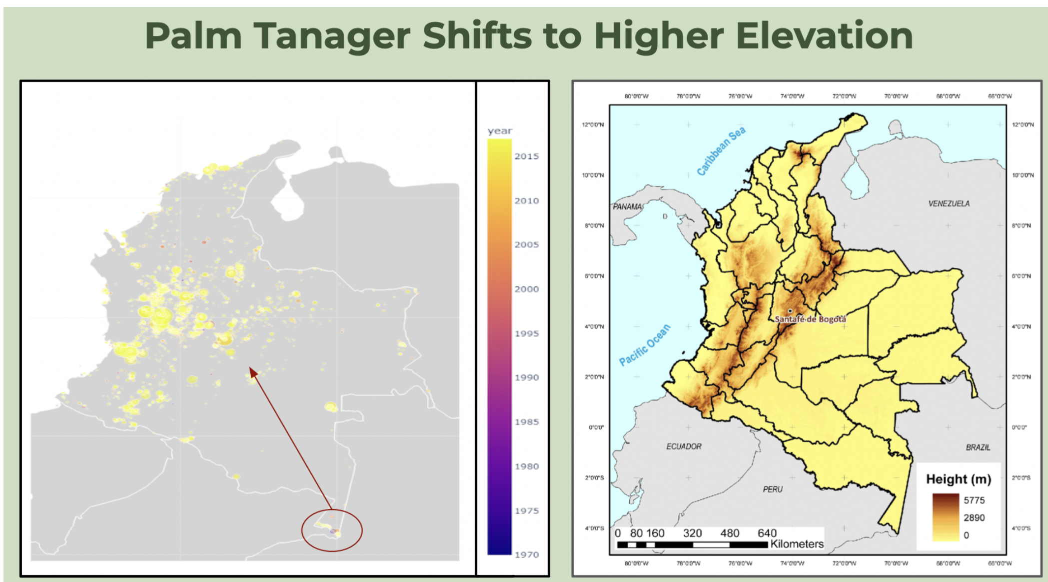


Fig 2 and 3. Trend of Birds Moving to Higher Elevations.

Here we focus on the bird species, the Great Kiskadee and the Palm Tanager. These scatterplot maps were made by our program we implemented. We can see the darker plots on the southwest tail end of Colombia. The darker plots displayed on both graphs show the historical bird species observations from the earlier years, 1970-2000s. For both of these birds, we see a shift from the southern corner of Colombia to a more central location in more recent years. This shift is displayed by the increase in lighter yellow plots, which are the bird species observations in the more recent years of 2005-2015+. As you can see the birds are shifting to the more central area of Columbia. When comparing these graphs to the map of the Andes Mountains in Columbia (map displayed on the right), we can see both birds are shifting towards the Andes Mountains. It becomes more clear that the birds are moving towards higher elevations as the temperature throughout Columbia and around the Andes Mountains are increasing over time.

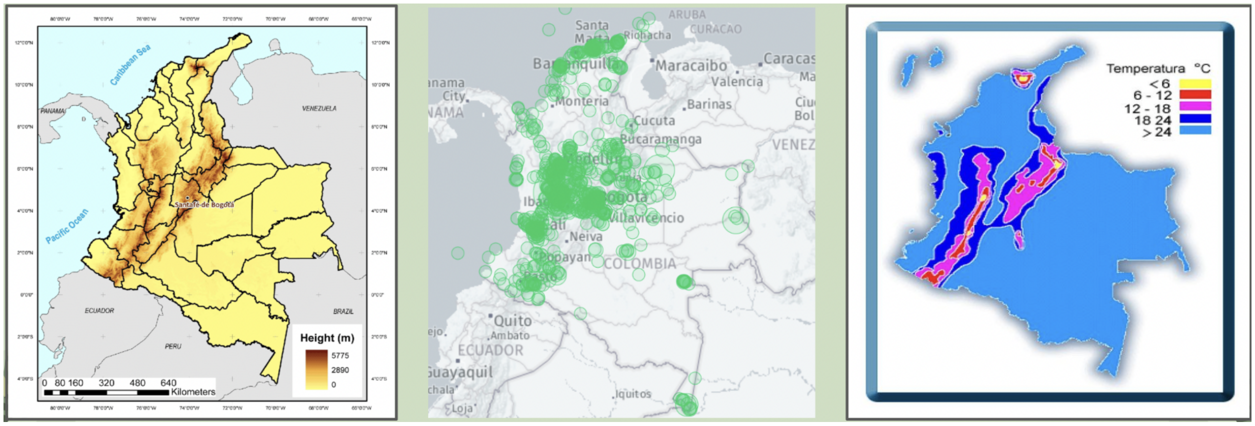


Fig 4. Biodiversity Hotspots Correlate with Higher Elevation and Lower Temperatures

To see if this trend continues with more than just the Great Kiskadee and the Palm Tanager, we mapped observations of all the species in Colombia with the resource, MongoDB. Once again we can see that most birds are grouping in higher elevated areas. To further understand why these birds are moving to higher elevations, we also compared these observations with a temperature map which demonstrates that the birds are keeping to where it is cooler which just so happens to overlap with higher elevations. This further demonstrates that birds are shifting to where it is cooler which happens to be higher in elevation.

Overall, plotting our data of all the bird species observations, we can see a huge grouping of species in the central area of Columbia. Most bird species observations are trending in similar ways. On the left, we have the Andes Mountains map and high elevation levels, the middle is our scatterplot map displaying overall bird species observations, and on the right we have a temperature map throughout the years of Columbia. When understanding these three maps have a strong correlation we have found out a lot about our dataset and the effect of climate change to the location of bird species observations. The birds are showing to shift towards the Andes Mountains, therefore higher elevation levels and when looking at the temperature map, we can see the temperature in the Andes Mountains are holding lower temperatures as elevation increases. This is the reasoning behind the shift in location per bird species observation can be seen to have a direct relationship with the increase in temperature due to global warming.

Discussion

Based on our results, we determined that the birds of Colombia are shifting to higher elevation areas to adapt to rising temperatures from global warming. Previously, these birds were observed to be more spread out, however in recent years they have been found to be more tightly clustered in areas of higher elevation. It was found that these areas of higher elevation are also areas of lower temperatures thus demonstrating that these birds are clustering in areas where they are able to tolerate the temperature. In other words, as time goes on, the bird species observations have shown to shift towards higher elevation areas in Columbia due to the temperatures of surrounding areas beginning to increase due to global warming. The Andes Mountains are displayed to be a natural hub spot for the overall bird species we have analyzed.

These results have aided in being able to identify areas with a high number of species which are called biodiversity hotspots. By investigating these hotspots closely, it can aid in conservation of biodiversity. When identifying biodiversity hotspots, these are areas in which biodiversity, in this case bird species in Columbia, are heavily threatened by human activity, in this case the increase of global warming. In turn, identifying biodiversity hotspots can help locate the bird species that are essentially in danger due to increasing temperatures. After the first step of analyzing the locations of the common biodiversity hotspots, we can then analyze the factors that are contributing to the increasing size/locations of hotspots. Once we can determine the direct factors, such as, climate change and global warming, we are a few steps closer in analyzing the entire issue as a whole and determining calls to action that can potentially result in positive changes.

We do acknowledge that our largest limiting factor in this was the fact that the eBird data has continued to increase in popularity which has resulted in more bird observations being recorded. This limitation made it difficult to be able to track whether the amount of a species of bird has changed in size or if the trend of where they are being sighted is truly significant. In the future, we should cross reference other databases or see if other regions of the world have similar observation count trends. For the future directions of this project, we plan on trying to incorporate Hadoop into our data processing to allow our MapReduce algorithm to be even more scalable. We also plan on incorporating weather datasets with machine learning to be able to find trends that we may have missed as well as back up our findings. Overall, we believe that we did demonstrate that climate change has impacted the birds of Colombia. Now we need to dig deeper to truly understand exactly when and why these trends began.

Project Contribution

Team Member	Tasks Completed	Contribution (0-100%)
Anna McDonald	• Provided the data • eBird expert • Wrote the introduction and provided the related works • Interpreted the results in a real world context • Investigated other methods from previous studies on birds • Designed the final presentation slides	25%

Bayley McDonald	- Setup the server on MongoDB to store the data on - Wrote the main code for algorithms - Setup team meetings - Expert on the code and algorithms	25%
Janani Thoguluva	- Contributed to each milestone report, wrote about our analyses and plans for algorithms - Helped research documentation for MapReduce, Plotly, and Geopandas code - Contributed to and practiced final presentation - Helped write the final report, explained some methods and analysis	25%
Rhea Toves	- Contributed to each milestone report in putting our analysis results and future goal findings into words. - Worked with others in researching the best fit programs and data mining tools that worked well with our data. - Finalized the project presentation slides and report. - Helped write our finalized results into a cohesive presentation and report.	25%
All Members	- Discussed problem statement - Determined how to answer it - Wrote milestones, presentation, and final report - Edited writing - Researched Data Mining Tools - Compiled useful background information - Practiced Presentation - Found and interpreted results	100%

Works Cited

Colwell, R. K., Brehm, G., Cardelús Catherine L., Gilman, A. C., & Longino, J. T. (2008). Global warming, elevational range shifts, and lowland biotic attrition in the Wet Tropics. Science, 322(5899), 258–261. https://doi.org/10.1126/science.1162547

Freeman, B.G., Scholer, M.N., Ruiz-Gutierrez, V., Fitzpatrick, J.W. (2018). Climate change causes upslope shifts and mountaintop extirpations in a tropical bird community. Proceedings of the National Academy of Sciences, 115 (47) 11982-11987. https://doi.org/10.1073/pnas.1804224115

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Neate-Clegg, M. H., Jones, S. E., Tobias, J. A., Newmark, W. D., & Şekercioğlu, Ç. H. (2021). Ecological correlates of elevational range shifts in tropical birds. Frontiers in Ecology and Evolution, 9. https://doi.org/10.3389/fevo.2021.621749

Novacek, M. J., & Cleland, E. E. (2001). The current biodiversity extinction event: Scenarios for mitigation and Recovery. Proceedings of the National Academy of Sciences, 98(10), 5466–5470. https://doi.org/10.1073/pnas.091093698

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Şekercioğlu, Ç. H., Primack, R. B., & Wormworth, J. (2012). The effects of climate change on tropical birds. Biological Conservation, 148(1), 1–18. https://doi.org/10.1016/j.biocon.2011.10.019

Steffen, W., Richardson, K., Rockström, J., Cornell, S. E., Fetzer, I., Bennett, E. M., Biggs, R., Carpenter, S. R., de Vries, W., de Wit, C. A., Folke, C., Gerten, D., Heinke, J., Mace, G.

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Weeks, B. C., Willard, D. E., Zimova, M., Ellis, A. A., Witynski, M. L., Hennen, M., & Winger, B. M. (2019). Shared morphological consequences of global warming in North American Migratory Birds. Ecology Letters, 23(2), 316–325. https://doi.org/10.1111/ele.13434