Research Paper

The Effect of Temperature Change on Snowy Owls, *Bubo scandiacus,* Non-Breeding Range.

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Introduction

Previous studies have linked anthropogenic climate change to widespread shifts in species' geographic distribution and migratory behaviour (La Sorte & Thompson, 2007. Brommer *et al., 2012).* Although response varies, among migratory bird species, climate change has widely resulted in latitudinal range shifts north (Brommer *et al.*, 2012). A study of 32 North American bird species found that all study species experienced northward shifts in mean breeding latitude, and northern leading range margins (Rushing et al., 2020). This field has implications for biodiversity management, particularly as changing climates push species beyond their historical ranges, complicating existing conservation frameworks (Tomas, 2010).

As migratory birds with an extensive range (Fink et al., 2022) Snowy Owls (Bubo scandiacus), could provide important insight into how variations in climate affect species habitat and survival. Much of the species' range is located in the Arctic, where the average temperature has risen nearly four times the global average (Rantanen et al., 2022). This makes Snowy Owls a powerful indicator species for climate change.

Key Uncertainty

Previous studies have focused on tracking this species' migratory behaviour and irruptive movements (Fuller et al., 2003). For example, lemmings are often considered a driver in Snowy Owl migration. In years when lemmings reach high densities, large numbers of young Snowy Owls migrate south during their first winter, called an irruption migration (Holt *et al.*, 2024). However, significant uncertainty regarding these movements in the context of climate change remains. The highly variable nature of Snowy Owl migration leaves gaps in our understanding of how changes in temperature influence this species. We lack clear data on how climate variability may influence long-term population dynamics and survival. This study addresses this gap by exploring the relationship between temperature fluctuations and the habitat range of the Snowy Owls. We raise the question: How do increasing temperatures in non-breeding ranges affect the geographic distribution of Snowy Owls in North America?

Hypothesis and Prediction

This study tests the hypothesis that species' geographical ranges are determined by their organismal responses to temperature. This study predicts that increasing temperatures will shift the geographic range of snowy owls' wintering, non-breeding ranges northward as the species track their preferred climate zone poleward. For example, from 2000 to 2023, we expect snowy owl abundance to decrease in lower latitude grids and increase in higher latitude grids in response to anthropogenic warming. We expect range shifts to vary with the amount of warming and therefore to differ across longitudes, which experience different amounts of warming.

Methods

Our analysis utilized two data sets: (1) An eBird data set consisting of snowy owl observations across Canada and the United States of America, and all the checklists in for those areas(Fink *et al.*, 2023), and (2) Berkeley's Gridded land and ocean temperature set (Berkeley Earth, 2023). To assess our data, we split the snowy owls' wintering range into 12 distinct latitudinal-longitudinal observation zones (Figure 1). This technique was inspired by Kerlinger et al. (1986), who assessed the migratory range of snowy owls. The longitude ranges for the grids were chosen to correspond with major physiographic boundaries and named to correspond with their relative geographic position, as seen in Table 1.

Temperature data was sourced from the University of California, Berkeley's Gridded land and ocean temperature data set. The data includes temperature anomalies from 1850 to the present based on a baseline period from 1950 to 1981. To use the data, we extracted the latitude, longitude, temperature anomalies, and climatology data for our specified grid (Table 1). We then calculated the absolute temperature for our grid regions from 2000 to 2023.

NW (55°N to 60°N; 140°W to 110°W)	NC (55°N to 60°N; 110°W to 80°W)	NE (55°N to 60°N; 80°W to 50°W)
UCW (50°N to 55°N; 140°W to 110°W)	UCC (50°N to 55°N; 110°W to 80°W)	UCE (50°N to 55°N; 80°W to 50°W
LCW (45°N to 50°N; 140°W to 110°W	LCC (45°N to 50°N; 110°W to 80°W)	LCE (45°N to 50°N; 80°W to 50°W)
SW (40°N to 45°N; 140°W to 110°W)	SC (40°N to 45°N; 110°W to 80°W)	SE (40°N to 45°N; 80°W to 50°W)

Table 1. Latitudinal- Longitudinal grid ranges used for the study (November to April) NW (North West), NC (North Centre), NE (North East), UCW (Upper central West), UCC (Upper central centre), UCE (Upper central east), LCW (Lower central west), LCC (Lower Central centre), LCE (Lower central east), SW (South West), SC (South centre), SE (South East).

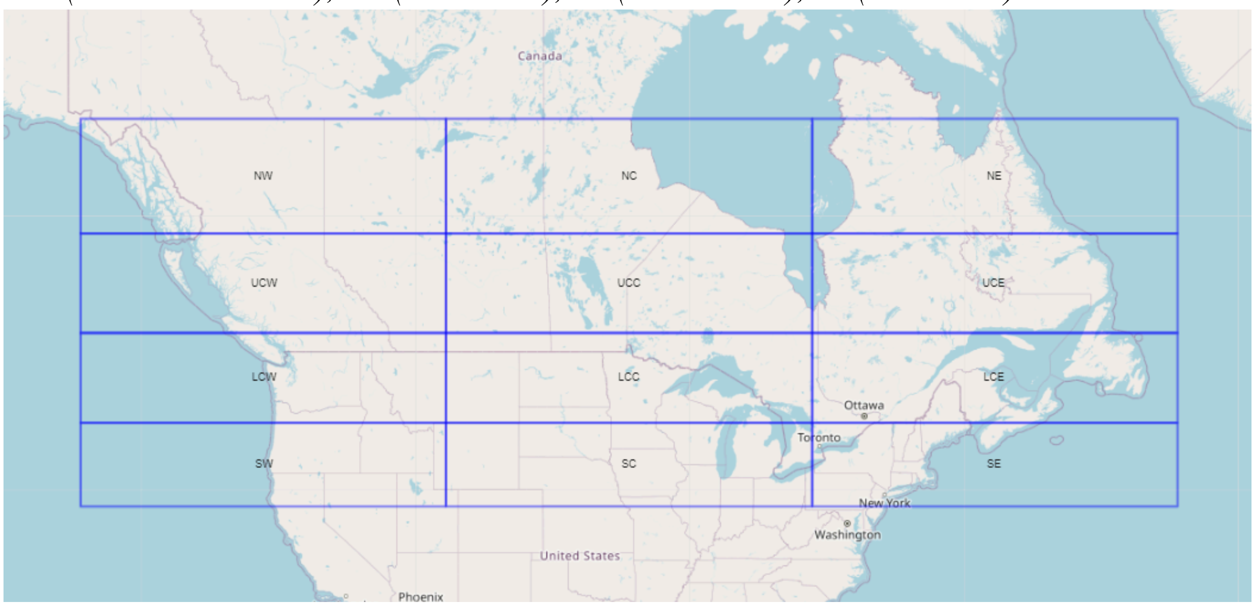

Figure 1. Latitudinal-longitudinal observation grids. Splits the snowy owl's winter range into a 4x3 grid for 12 distinct regions.

Filtering was likewise necessary for the eBird data set. We removed unwanted columns, duplicates, missing data, and outliers. Outliers were particularly common in eBird observation data pre-2007. This cleaned data was then organized into our grids (table 1). The data was then standardized by taking the total number of observations in a grid and dividing it by the total number of checklists in the same grid square.

The eBird and temperature data sets were then combined. To assess the effect of temperature from each grid square on the standardized count of snowy owls, we conducted a gamma linear model analysis. A gamma linear model was chosen as the values for the standardized count were right-skewed and near zero, making them a gamma distribution. 12 gamma linear models were conducted, one for each grid section. For each analysis, we used the standardized count from one grid square as our dependent variable and the temperatures from the four grid squares in the same column as the independent variables. For example, if we used the standardized count from the southwest as the dependent variable, we would use the temperature data from the southwest, lower central west, upper central west, and northwest to visualize the effect these temperatures have on snowy owl migration.

Results

Our analysis found no significance between temperature and snowy owl observations in any of our 12 models (Figure 3). We found no significant evidence to support our hypothesis that snowy owls' geographical ranges are determined by their organismal responses to temperature or our prediction that increasing temperatures will shift the geographic range of snowy owls' wintering, non-breeding ranges northward.

	Estimate	Std. error	T value	P value
Intercept	0.4366600	0.3760279	1.161	0.2725
NW	0.0135949	0.0065627	2.072	0.0651
UCW	-0.0360274	0.0168698	-2.136	0.0585
LCW	0.0318249	0.0165676	1.921	0.0837
SW	-0.0140623	0.0073345	-1.917	0.0842
Year	-0.0002091	0.0001872	-1.117	0.2902

Table 2. Summary of South West gamma linear model. Includes the variables: temperatures from 4 regions—NW (North West), UCW (Upper Central West), LCW (Lower Central West), SW (South West), and year. The table shows the estimated coefficient, standard error, T-value, and p-value for each variable.

The South West gamma linear model results (Table 2.) were closest to significance. For the region, the coefficient for NW (Estimate = 0.0136, p = 0.0651) was positive and approached significance at the 0.05 level, suggesting a potential positive association between temperature in the NW and standardized owl count in the SW. UCW had a negative coefficient (Estimate = -0.0360, p = 0.0585) and also approached significance. This suggests that an increase in UCW is associated with a decrease in the response variable (standardized owl count). The coefficient for LCW was positive (Estimate = 0.0318, p = 0.0837), and the SW region (Estimate = -0.0141, p = 0.0842) had a negative coefficient, but neither reached statistical significance. While none of the coefficients reached conventional levels of statistical significance ($p < 0.05$), the variables show trends that may warrant further investigation with more data or refined modelling.

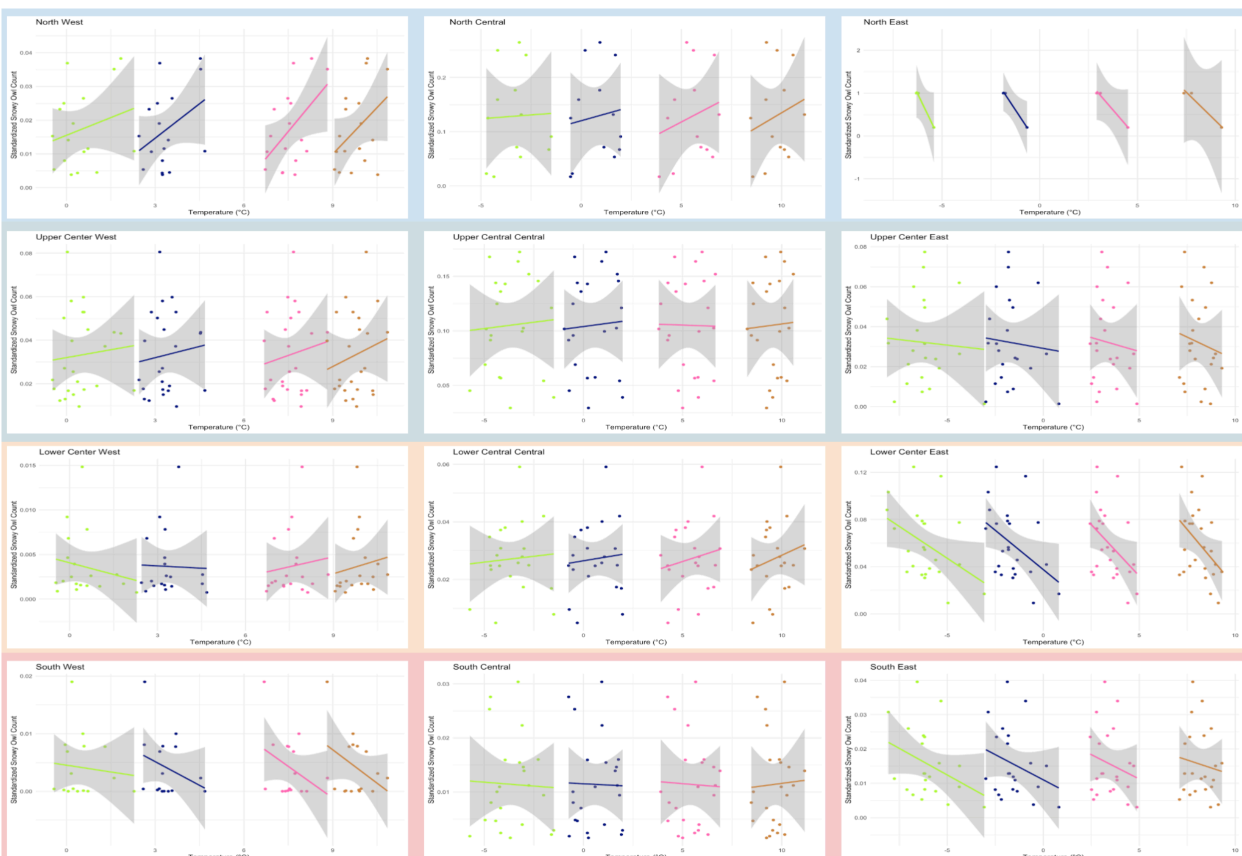

Figure 3. Gamma Linear Regression of the temperature and snowy owl abundance in each of the grid sections. From right to left: NW, NC, NE, UCW, UCC, UCE, LCW, LCC, LCE, SW, SC, SE.

Discussions

Interpretation of Findings

Our results were not statistically significant. However, the overall trend in our data suggests a potential pattern. In the Southern Regions (SW, SC, SE), the relationship between temperature and Snowy Owl observations is the most pronounced, with clear negative trends across all areas. As temperatures rise, there is a sharp decrease in Snowy Owl observations. This indicates that snowy owls are less likely to inhabit or be observed in these regions when temperatures increase, in line with our prediction that snowy owls' abundance would decrease in lower latitudes as temperature increases. Lower-Central Regions (LCW, LCC, LCE) are less cohesive. Lower Central-East shows a noticeable negative trend, where Snowy Owl observations drop as temperatures rise. Lower Central Central and Lower West Central conversely show a slight positive trend. Upper-Central Regions (UCW, UCC, UCE) are likewise variable. Upper Central-East maintains the east grid's pattern, with a slight negative trend, suggesting snowy owls leave this region when temperature increases. Upper Central West displays a slight positive trend suggesting increasing snowy owls could increase with increasing temperature, while Upper Central Central is mostly neutral. Snowy Owl observations appear less responsive to temperature changes in these areas, indicating that temperature may not be the primary driver of migration or presence in this intermediate latitude.

The northern regions display a stronger positive trend between temperature and Snowy Owl observations. The North East does have a negative trend; however, the data in this region is the most limited and is therefore flawed. In the North Central, there is a weak positive trend, implying that Snowy Owls may maintain or slightly increase their activity in warmer conditions, possibly due to increased prey availability in this particular geographic zone. In the North west, this positive trend becomes most apparent, suggesting that Snowy Owl observations slightly increase with rising temperatures. This could indicate that in this region, warmer temperatures do not impact owl behaviour or migration patterns as strongly as in more southern areas. It could also be assumed that when temperatures are warm in the northern regions, they are warmer in the southern regions, which could mean they are limited in where else they can go. While not conclusive, our findings could indicate the early stages of a broader movement driven by environmental changes. Lack of statistical significance could be attributed to limitations in our dataset, such as the sample size or temporal coverage. This suggests that further data collection is necessary

Comparison with Previous Research

Little research has analyzed a potential relationship between anthropogenically increasing temperatures and snowy owl migration ranges. One study that challenged our results was by Curk et al., 2009, which found that snowy owls time their migration to occur before snowmelt, which was theorized to be driven by specific temperatures, wind conditions, and day lengths. Beyond snowmelt, snowy owl migration research predominantly focused on how variances in lemming populations and distribution alter snowy owl migration patterns (Holt et al., 2024). Many studies have found a relationship between changing temperatures and sparrows and warblers's migration timing and range changes (Abraham et al., 2008) (Visser et al., 2009). Clairbaux et al., 2019, analyzed how anthropogenic-driven temperature changes drive many arctic seabirds to stop migrating south and remain further north year-round. So although the research on snowy owls is sparse, the trends we found are in line with previous studies of migratory birds.

Potential Drivers Beyond Temperature

Lemmings, the main prey for snowy owls, could provide another possible driver for change outside of temperature: snowfall. Snowy owl populations have been observed to fluctuate with lemming populations (Holt et al., 2024), and lemming abundance is highly reliant on the amount of snowfall in any given year (Bilodeau et al., 2013). A typical lemming home consists of tunnels being built underneath the surface of deep snow. This protects them from the cold Arctic air and gives them shelter from predators. It was found that most avian predators leave the Arctic if the snowfall is too deep; snowy owls have a higher tolerance for these snowfall conditions and are therefore the main winter predators (Bilodeau et al., 2013). However, a particularly poor snowfall year, with insufficient snow cover, can reduce lemming populations, which in turn leads to lower snowy owl populations due to a lack of food resources.

Uncertainties and Limitations

Our study relied heavily on eBird observation data. However, this reliance introduces several limitations, eBird data is primarily collected by the public, meaning the quantity and quality of data depend on the activity, experience, and accessibility of observers. For the snowy owl, a significant portion of its range lies in remote and sparsely populated regions, such as the Arctic tundra and northern boreal forests. These areas lack widespread human presence and reliable connectivity, leading to sparse and inconsistent data collection. The uneven geographic distribution of observations introduces spatial bias, with higher reporting rates in more populated and accessible areas. This disparity may overrepresent sightings in urban and suburban locations while underrepresenting the true extent of the snowy owl's range, particularly in its core breeding habitats. Furthermore, the data is subject to observer bias, as less experienced birders may misidentify species or fail to record sightings accurately (Callaghan & Gawlik, 2015).

Suggestions for Further Study

Future studies should focus on other potential factors that may be driving changes in snowy owl migration ranges, including snowfall and melt, lemmings, irruptions, and food shortages. Irruption is a sporadic phenomenon where birds suddenly migrate south of their wintering grounds (Holt et al., 2024). However, the specific causes of irruption are still debated, so research is recommended for further understanding. Snowfall and melt are also key factors that could affect the migration ranges of snowy owls. While they are more tolerant of snowfall conditions, there is significant individual variation in migration after snowfall, which should be further researched (Curk et al., 2020). Lemmings already play a significant role in snowy owls' diet and migration habits, driving some irruptive behaviour, fitness, and breeding success (Holt et al., 2024). Given that anthropogenically driven changing snowmelt patterns affect lemmings' seasonal abundance, further research should be done to understand how those changes in abundance affect snowy owls (Bilodeau et al., 2013) (Holt et al., 2024).

Future studies of the relationship between temperature and snowy owl migration could benefit from the use of satellite transmitters rather than observation data (Liel et al., 2019). Lei et al. 2019 used satellite-tracking technology to determine that only 15% of migratory birds' stopover locations in East Asia are protected under the authority of the World Database of Protected Areas. Klaassen et al., 2013, also integrated satellite tracking to determine when and where raptor bird populations were experiencing the highest rates of mortality. Both these studies used satellite tracking to better understand where migratory birds are experiencing the greatest mortality and what areas require greater conservation efforts (Klaassen et al., 2013) (Lei et al., 2019). Using satellite tracking, the migration paths of snowy owls can be better understood.

Ecological and Conservation Implications

While temperature was not statistically significant in our study, the visual pattern showing a decrease in snowy owl count in lower latitudinal grids indicates that temperature may still have an impact. A 2020 study by Curk et al. found a statistically significant relationship between snowmelt and snowy owl migration, so perhaps a greater timespan and a tracking-based dataset will produce more accurate significant results. Decreases in rain and snowmelt and changes in lemming and vole latitudinal ranges and pesticides are all possible avenues for greater research about changes in snowy owl migration (Gauthier et al., 2024). There are problems with building and vehicular collisions due to their white colour, leading to relocation and mitigation efforts to put them further from northern airports (McCabe, 2022). So when considering conservation, we must expand protection to newly suitable habitats while ensuring the continued protection of traditional ones. It might also be necessary to revise current conservation strategies to focus on more dynamic, anthropogenic-resilient landscapes rather than static, historically significant regions. Conservation may also wish to focus on maintaining lemming populations as a way to support snowy owls. Ultimately, more research is needed to understand where conservation resources would be best applied.

Conclusion

In summary, while our analysis did not find statistically significant results linking temperature changes to Snowy Owl non-breeding range shifts, the trends observed suggest potential patterns worth exploring further. Continued monitoring and long-term ecological studies will be essential for understanding the broader implications of climate change on owls and their ecosystems.

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Appendix

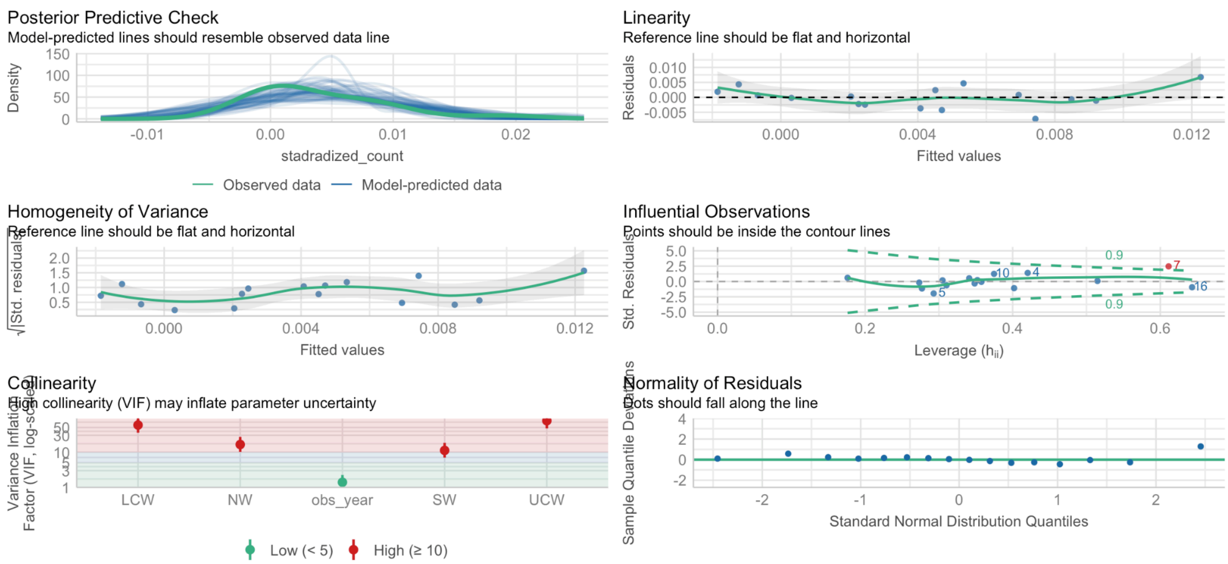

Figure 4. Model assumptions. South West Model assumptions tested using the R package "performance". Note the high collinearity in the different temperature variables.

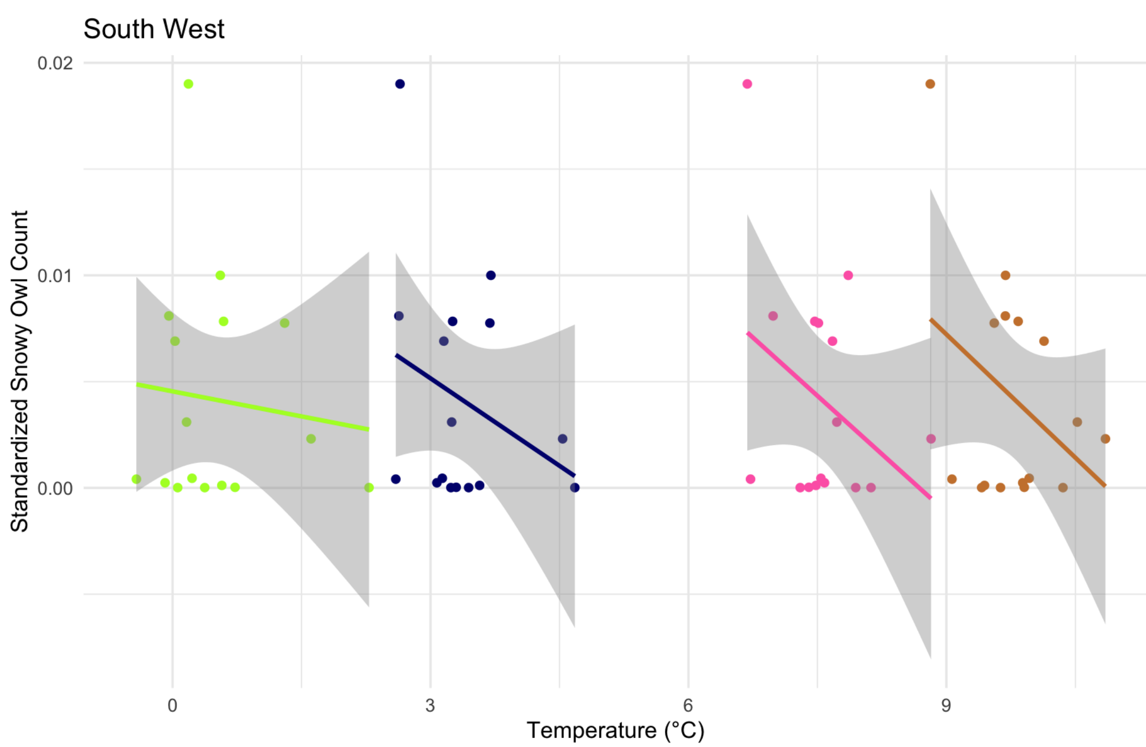

Figure 5. A gamma linear model of the south west region. Lines on the graph represent

temperatures from different grid squares from left to right NW (North West), UCW (upper central West), LCW (lower central West), SW (South West). Not the results of this model are similar to the results in our south west grid.

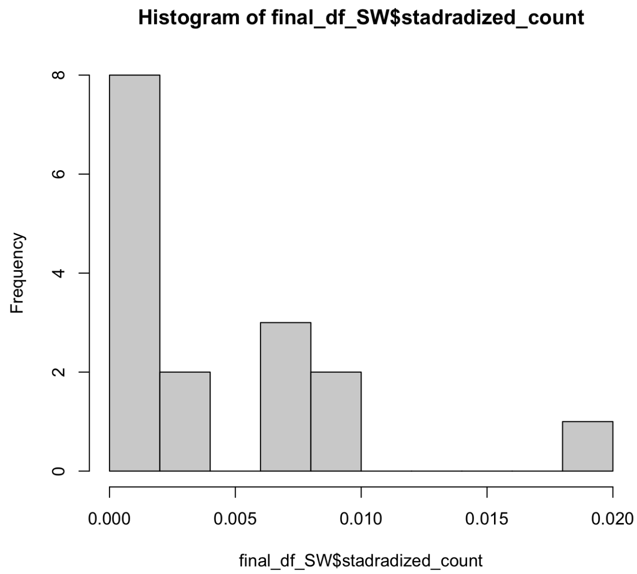

Figure 6. A histogram showing the right skewed distribution of the standardized count of snowy owls in the south west grid square. This distribution allowed us to use a gamma-linear model.

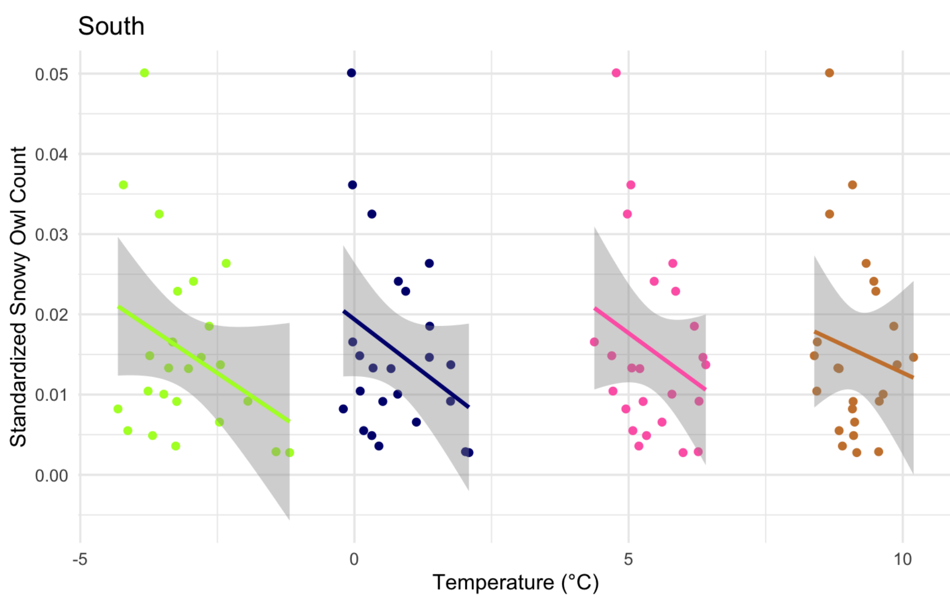

Figure 7. A gamma linear model of the south. This model shows the results of a different approach we chose not to take in our data analysis. This approach combines the grid squares longitudinally to form 4 latitude bands. This model shows the results of the standardized count of snowy owls in the south and the temperature from the 4 other latitude bands.