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Spatial and Temporal Patterns in Irruptive Fringillid Movements

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Abstract

Historic Christmas Bird Count and eBird data indicates that during winter invasions, North American irruptive fringillid species occur in relatively even numbers across latitudes east of the Rocky Mountains. Most boreal breeding species show large southward invasions every other winter, with this pattern typically being strongest across the northern and mid United States. eBird data confirms that many northern fringillids irrupt synchronously, and both datasets also show positive correlations between the winter movements of southern breeding species in many areas. Winter abundance records show negative correlations between northern breeding species and southern breeding species in nearly all monitored areas of North America.

Introduction

Seasonal migration has been observed in around 19% of all known bird species (La Sorte et al., 2016). All of these birds move between distinct areas or habitats in response to factors such as food availability, competition, and climate (e.g. Ramenofsky and Wingfield, 2007). Typically, migratory birds travel to the same breeding and nonbreeding grounds with similar timing each year (Wilson, 2009; Newton, 2011). On the other hand, some species are much less predictable in their movements. For these birds, the locations of adequate resources change year to year, driving great variation in the distance and timing of yearly migration events (Newton, 2012).

Many northern hemisphere seed-eating species exhibit variation in migratory behavior. Although these birds encompass a range of families, some of the most well-studied examples are finches in the family Fringillidae. These birds move in response to the synchronized masting cycles of key food-producing tree species, which cause the availability of sufficient wintertime food to change geographically from year to year (Smith, 1986). Many breed in the boreal and subarctic zones, and are capable of surviving the winter months in these northern latitudes when sufficient food remains available year-round. However, in winters when seed and fruit crop failures are widespread in boreal zones, entire populations can move great distances south from typical breeding areas, often irrupting into localities with sufficient food (Bock and Lepthein, 1976).

Although large-scale southern irruptions often seem to be isolated events, many studies have used historic records to identify regularity in fringillid movements. Extensive databases of citizen-reported data allow for investigation of these patterns. One such source is the Christmas Bird Count, an annual birding census dating back to 1900 overseen by the National Audubon Society. The purpose of the program is to observe changes in bird populations over time by collecting observations from the same areas throughout North America each year (National Audubon Society, 2016). A second important source, eBird, is a real-time online database on which birders can report sightings any day of the year and from any geographic area (eBird, 2016). eBird represents a rich resource for future research.

Most studies have used these and other sources to investigate the winter movements of one or only a few species (Bock and Lepthein, 1976; Kennard, 1977; Troy, 1983; Prescott, 1991; Hochachka et al., 1999; LeBaron, 1999; Wilson, 1999; Wilson, 2006; Wilson, 2008; Wilson and Brown, 2012). However, in this project, I analyze historic data for thirteen North American fringillid species with large enough distributions in the continental US and Canada to allow comparisons in abundance patterns among states and territories: the Evening Grosbeak (*Hespiriphoa vespertina*), Pine Grosbeak (*Pinicola enucleator*), Gray-crowned Rosy-Finch (*Leucosticte tephrocotis*), Cassin's Finch (*Haemorhous cassinii*), Purple Finch (*Haemorhous purpureus*), House Finch (*Haemorhous mexicanus*), Hoary Redpoll (*Acanthis hornemanni*), Common Redpoll (*Acanthis flammea*), Red Crossbill (*Loxia curvirostra*), White-winged Crossbill (*Loxia leucoptera*), American Goldfinch (*Spinus tristis*), Lesser Goldfinch (*Spinus psaltria*), and Pine Siskin (*Spinus pinus*). These related species all exhibit at least somewhat irregular southward movements from northern breeding areas, representing a broad range of ecological niches and feeding habits.

The Pine Grosbeak is a primarily frugivorous species that breeds in the subarctic and boreal forests. It tends to winter further north and irrupt less frequently than other finches (Adkisson, 1999). Common and Hoary Redpolls also breed in the far northern reaches of the continent, feeding primarily on small seeds. The two species often associate together during irruptions into the northern United States (Knox et al., 2000). In comparison, the Evening Grosbeak typically breeds farther south in the mixed conifer forests of central Canada, and feeds on a variety of seed types during the winter. Due to shared food preferences and similar breeding ranges, irruptive Evening Grosbeaks often travel in mixed flocks with Purple Finches, Pine Siskins, and both crossbill species (Gillihan, 2001). The White-winged and Red Crossbills are the most specialized and irregular North American finches, continually traveling throughout the boreal forest in search of bumper pine cone crops (Adkisson, 1996; Benkman, 2012). Not all North American fringillids breed across the northern latitudes of the continent. For instance the Cassin's Finch and the Gray-crowned Rosy-Finch are two high-altitude breeding species restricted to the Rocky Mountain regions of western North America. In addition to moving south in winter months, these species often travel to lower elevations as well (Hahn, 1996; Macdougall-Shackleton et al., 2000). Finally, the House Finch, American Goldfinch, and the Lesser Goldfinch in the southwest, are familiar year-round residents in more southern latitudes and lower elevations. However, all three species are known to make variable southward movements during the winter.

Scientists have already examined the wintertime time movements of all these species, with the exception of the Lesser Goldfinch, and these projects have greatly improved our understanding of irruptive movements (Bock and Lepthein, 1976; Hochachka et al., 1999; Kennard, 1977; King and Wales, 1964; LeBaron, 1999; Prescott, 1991; Prescott and Middleton, 1990; Samson, 1976b; Troy,

1983; Wilson, 1999; Wilson, 2006; Wilson, 2008; Wilson and Brown, 2012). Previous analyses of historic data has identified distinct biennial patterns in the southward irruptions of many species, and has also found some similarities in the movements of different species due to shared food resources (Bock and Lepthien. 1976). However, most of these studies are limited in spatial or temporal scale. In this study, I use both Christmas Bird Count and eBird records to investigate the movement patterns of irruptive finches for the entire continental United States and southern Canada. For each species, I use the CBC database to compare patterns in yearly winter abundance between different areas, specifically comparing yearly numbers across latitudes and longitudes. Similarly, I use eBird to compare yearly invasion patterns in these areas on a daily scale. Finally, I use both datasets to compare the southward movements of different species with respect to location, size, and timing.

These comparisons are particularly meaningful for filling gaps in the understanding of irruptive movements on a large scale. Although multiple studies indicate that irruptive species tend to invade southwards in large numbers in alternate years, it is unclear how the strength of this biennial pattern varies between regions and between all thirteen species in my study. Additionally, while previous studies analyzing movements of individual birds using banding and reencounter records found irruptive fringillids move on a longitudinal basis with little east-west movements, it is uncertain how the timing and strength of southward irruptions vary across a latitude (Wilson and Brown, 2012).

My comprehensive approach analyzing information from throughout North America in separate citizen-science databases provides greater understanding of the movements of these 13 fringillid species in different regions. In this thesis, I identify patterns in irruptions across latitudinal and longitudinal tiers, as well as relationships between the movements of different species.

Materials and Methods

To examine latitudinal and longitudinal patterns in irruptions, I subdivided the North American continent into eight tiers:

- Latitudinal Tier 1 (Southern Canada): Prince Edward Island, Nova Scotia, New Brunswick, Newfoundland and Labrador, Quebec, Ontario, Manitoba, Saskatchewan, Alberta, British Columbia
- Latitudinal Tier 2 (Northern United States): Maine, New Hampshire, Vermont, New York, Ontario, Michigan, Wisconsin, Minnesota, North Dakota, Montana, Idaho, Washington
- Latitudinal Tier 3 (Mid United States): Rhode Island, Connecticut, New Jersey, Pennsylvania, Ohio, Indiana, Illinois, Iowa, Nebraska, Wyoming, Idaho, Oregon
- Latitudinal Tier 4 (Southern United States): North Carolina, Tennessee, Oklahoma, Arkansas, Texas, New Mexico, Arizona, California
- Longitudinal Tier 1 (East Coast): Newfoundland and Labrador, Nova Scotia, Prince Edward Island, New Brunswick, Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut, New Jersey, Maryland, Virginia, North Carolina, South Carolina, Georgia, Florida
- Longitudinal Tier 2 (Midwest): Manitoba, Minnesota, Iowa, Missouri, Arkansas, Louisiana
- Longitudinal Tier 3 (Rocky Mountains): Northwest Territories, Saskatchewan, Montana, Wyoming, Colorado, New Mexico, Texas
- Longitudinal Tier 4 (West Coast): Alaska, Yukon Territory, British Columbia, Washington, Oregon, California

Statistical Analysis:

All exploratory and statistical analysis was done with the programming language R, using the interactive development environment RStudio. Graphs were developed with the ggplot2 package, correlation plots were developed with the corrplot package, and maps were developed with the choroplethr package. Raw data were organized with the packages dplyr, tidyr, and lubridate.

Christmas Bird Count Data:

I acquired state and province-level CBC records from the public Christmas Bird Count online database. Although this program began in 1900, it had comparatively limited participation in the first half of the twentieth century. Therefore, I excluded all records before the year 1960 from my analyses. For each species, I compared yearly abundance patterns between states and provinces within the same latitudinal and longitudinal tiers. I also compared these trends for each species within all latitudinal and longitudinal tiers.

eBird data:

eBird was created much more recently than the Christmas Bird Count and lacks any efforts for standardization. However the fact that it accepts observations throughout the year allows for study of bird movements on a daily scale. The eBird database includes historic observations from well before the creation of the program in 2002. However, these records are infrequent, and I focused my analyses on observations from 2002 to August, 2015.

I began by grouping the observations for each species by date, and used these numbers to compare invasion patterns in the different states and provinces within the same latitudinal and longitudinal tiers. Then, grouping total observations by tier, I compared invasion patterns between years. Finally, I compared the invasion patterns of individual species within each tier.

Results

Evening Grosbeak

CBC Analyses

Christmas Bird Count data since 1960 show the highest numbers of Evening Grosbeaks across southern Canada and the northern United States, with higher numbers recorded in the east. Sizeable numbers have been recorded in states down the Appalachian and Rocky Mountain ranges (Fig. 1).

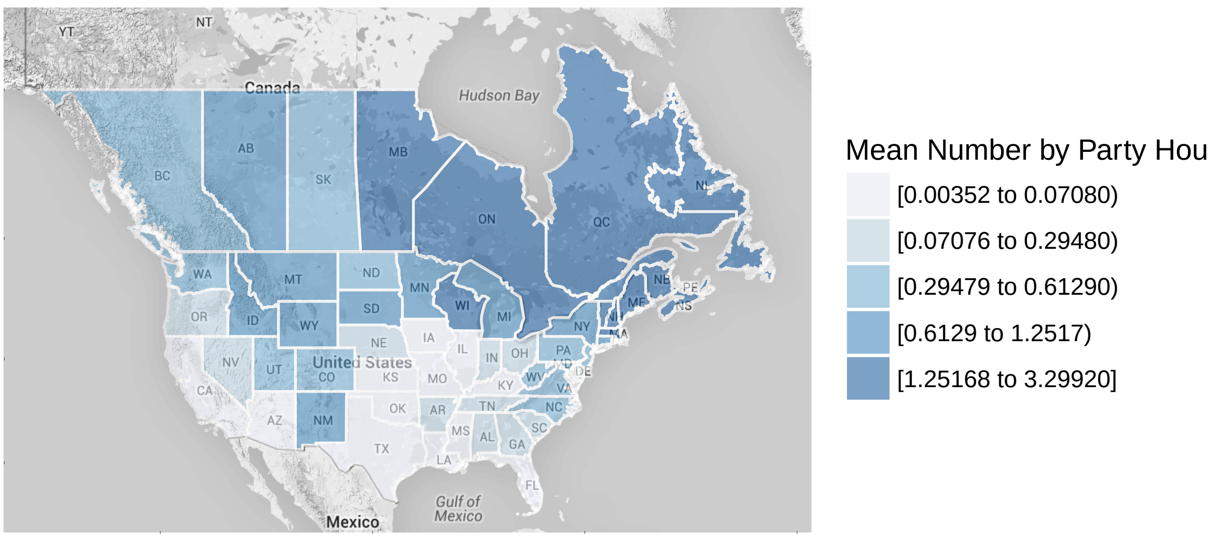


Figure 1: Evening Grosbeak abundance by area, CBC data.

Christmas Bird Count data since 1960 show the highest variation in Evening Grosbeak numbers occurs across the southern United States (Fig. 2).

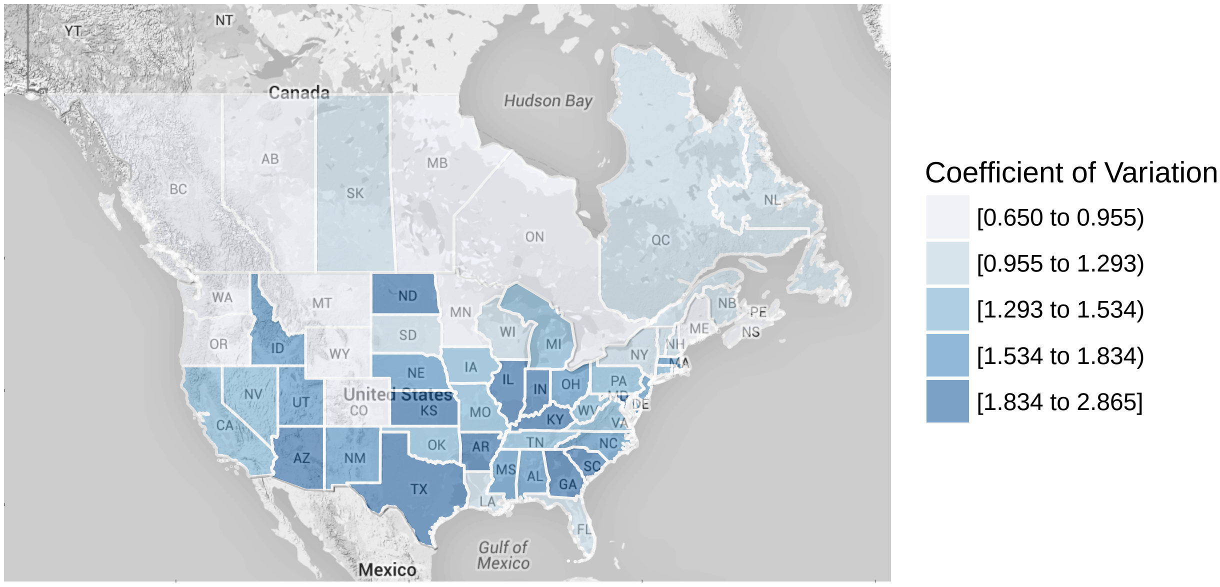


Figure 2: Coefficient of variation for Evening Grosbeak abundance by area, CBC data.

Along the northernmost latitudinal tier, Evening Grosbeak numbers recorded by the Christmas Bird Count are relatively similar between different provinces over time, with some shared rises and falls in abundance between areas. The strongest correlations in historic abundances are between neighboring provinces in the east. In the correlation matrix, p-values are given for all correlations that are not significant. All correlations that do not have a p-value listed are significant ($p<0.05$) (Fig. 3).

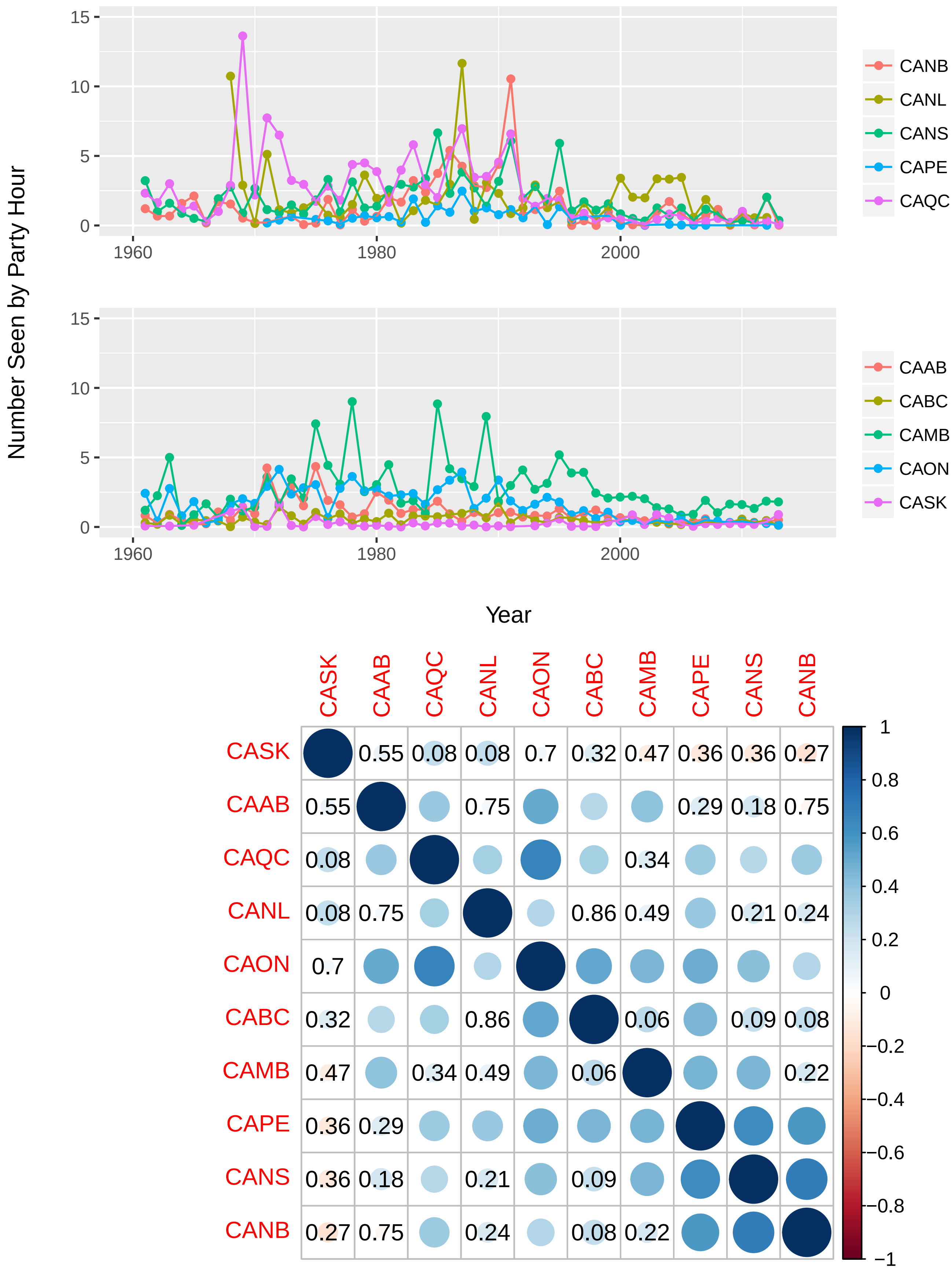


Figure 3: Evening Grosbeak abundance trends and area correlations across 1st (Canadian) latitudinal tier, CBC data.

Across the northern United States, Evening Grosbeak numbers are also similar between different areas, although there are a few alternating rises in abundance between states in the east and states in the midwest. The CBC recorded very few Evening Grosbeaks across this latitude after the mid 1990's. The strongest positive correlations in historic abudance are between states in the east (Fig. 4).

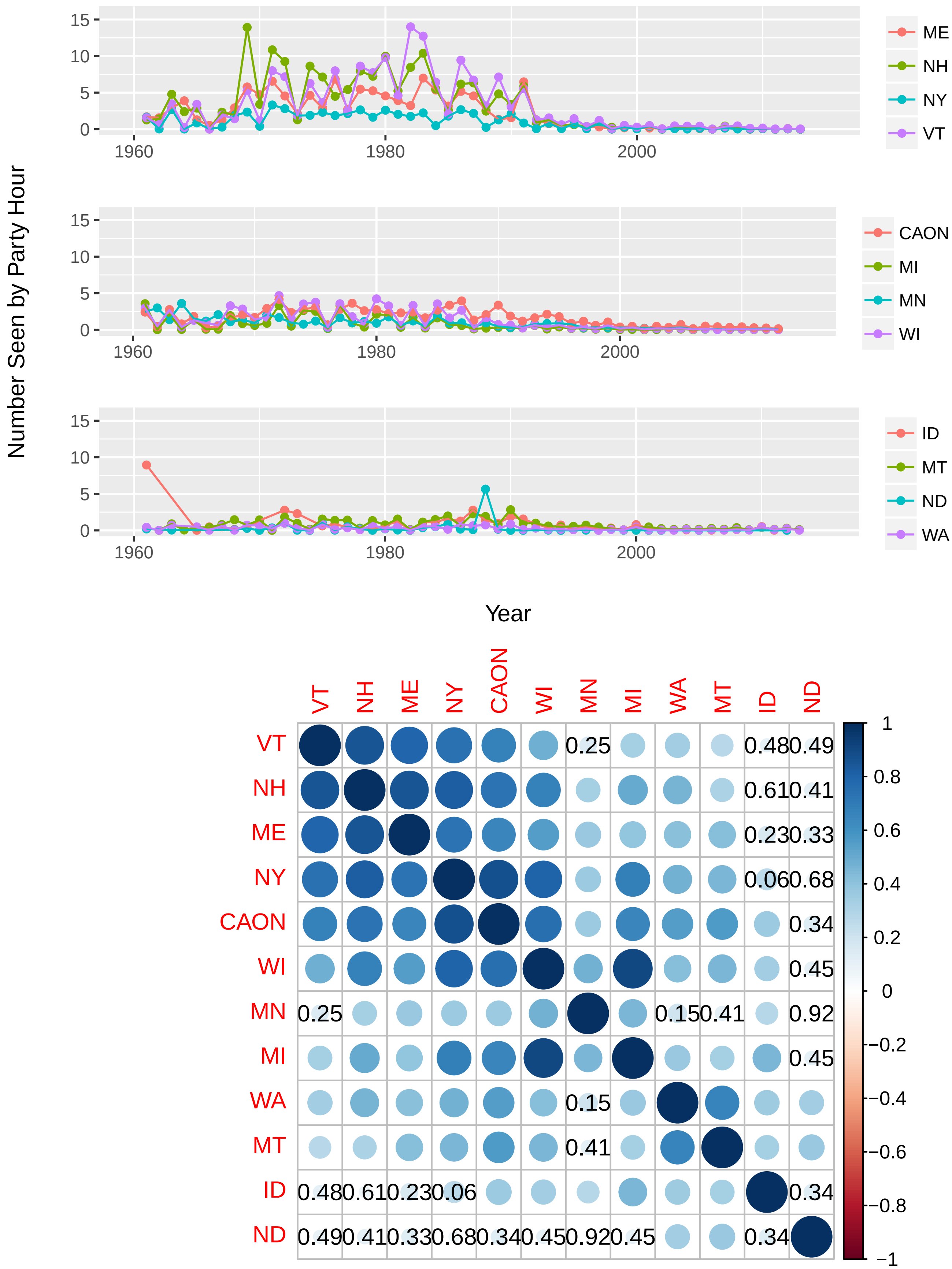


Figure 4: Evening Grosbeak abundance trends and area correlations across 2nd (northern US) latitudinal tier, CBC data.

States in the third latitudinal tier show similar timings in rises and falls in abundance. Similar to the second latitudinal tier, hardly any Evening Grosbeaks were recorded by the CBC in any of the states in this tier after the mid 1990's. The strongest correlations are between states in the east that show similar historic population trends, and between states in the midwest which have very few Evening Grosbeaks recorded (Fig. 5).

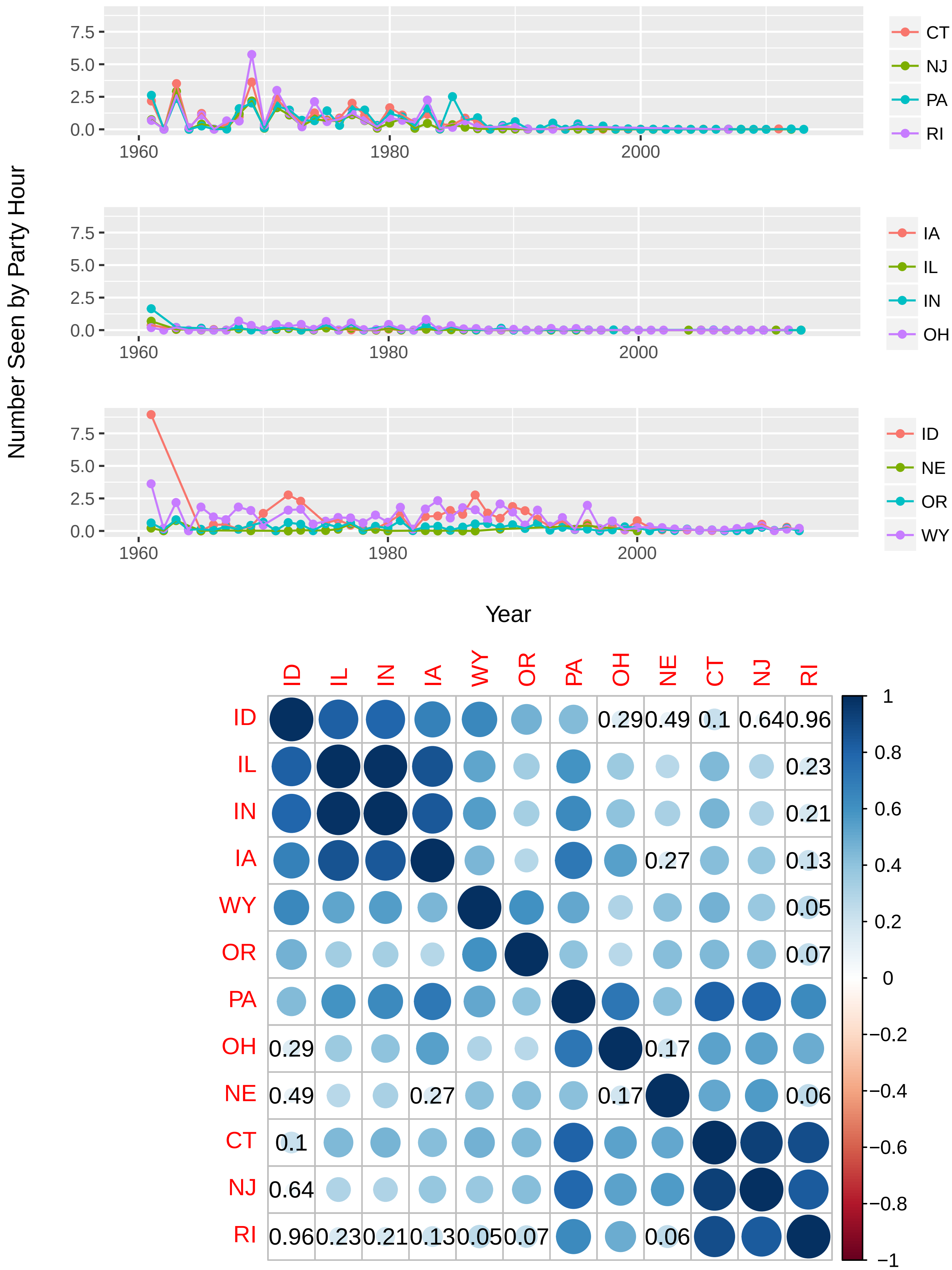


Figure 5: Evening Grosbeak abundance trends and area correlations across 3rd (mid US) latitudinal tier, CBC data.

In the southernmost latitudinal tier, CBC records show more different timings in rises and falls of Evening Grosbeak abundance between different states. The strongest correlations are between states that never had high abundances of Evening Grosbeaks during the study period, with a moderate positve correlation between the neighboring states of Tennessee and North Carolina (Fig. 6).

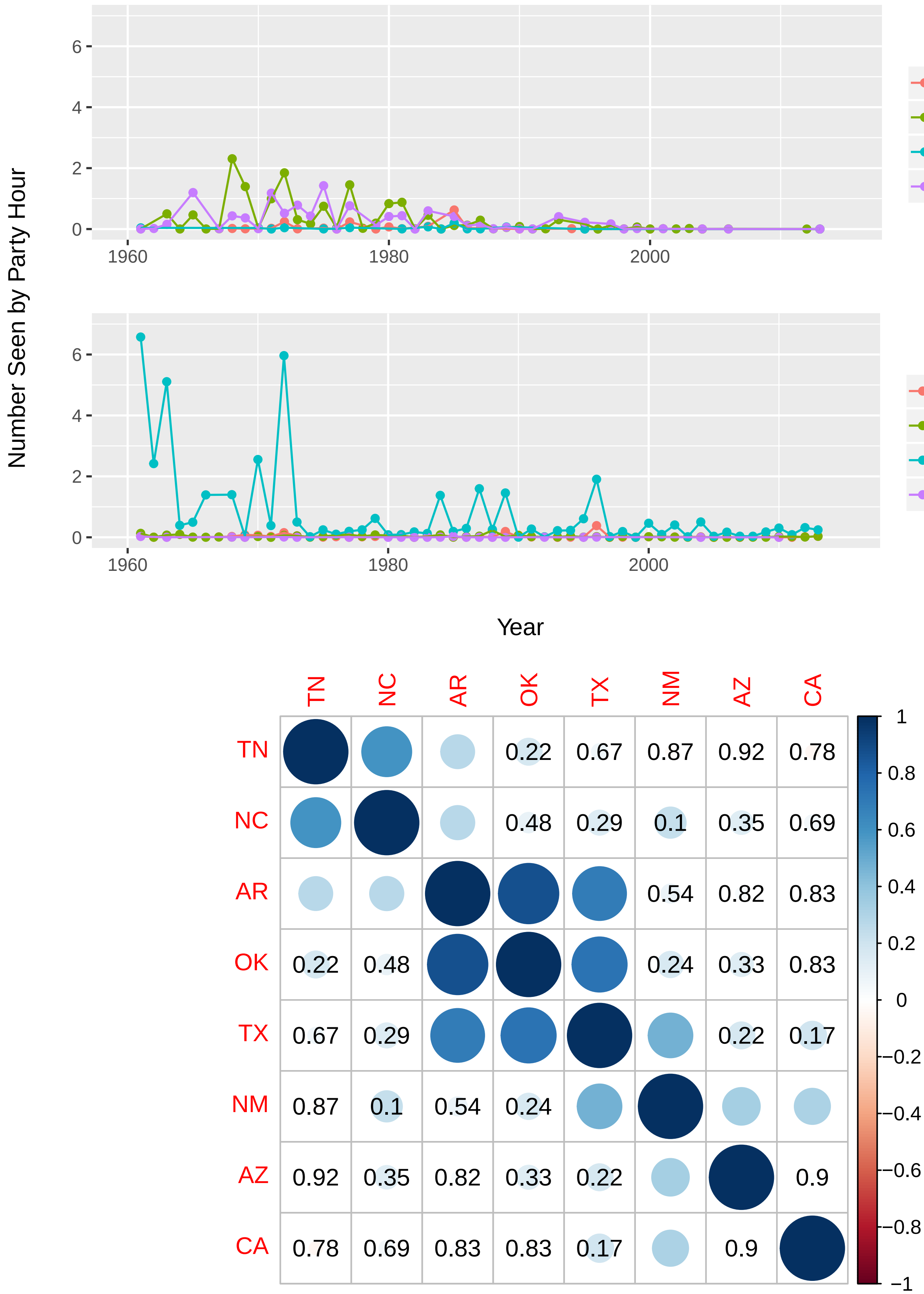


Figure 6: Evening Grosbeak abundance trends and area correlations across 4th (southern US) latitudinal tier, CBC data.

Along the easternmost longitudinal tier, there are somewhat similarly timed rises and falls in Evening Grosbeak abundance in northern states and provinces, and comparatively few records in the southern states. There are strong positive correlations between states in New England and the Mid-Atlantic coast, with the strongest correlations between states that are next to each other (Fig. 7).

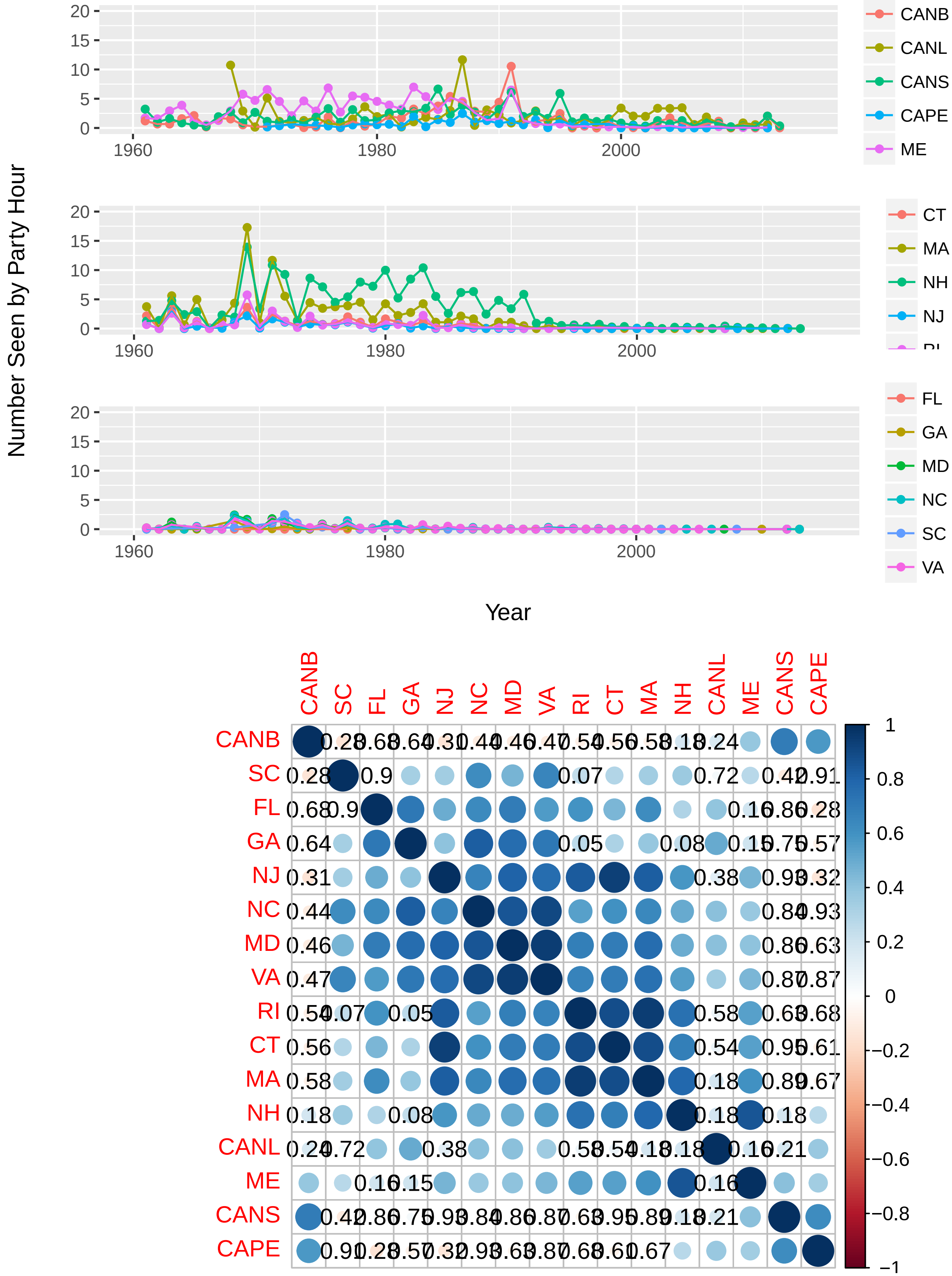


Figure 7: Evening Grosbeak abundance trends and area correlations across 1st (Atlantic) longitudinal tier, CBC data.

Across the second longitudinal tier, northernmost areas show the highest rises in abundance, with corresponding, smaller spikes in southern areas. The CBC never recorded high abundances of Evenening Grosbeak in the southernmost areas. CBC records in most areas show significant positive correlations with records from many other areas (Fig. 8).

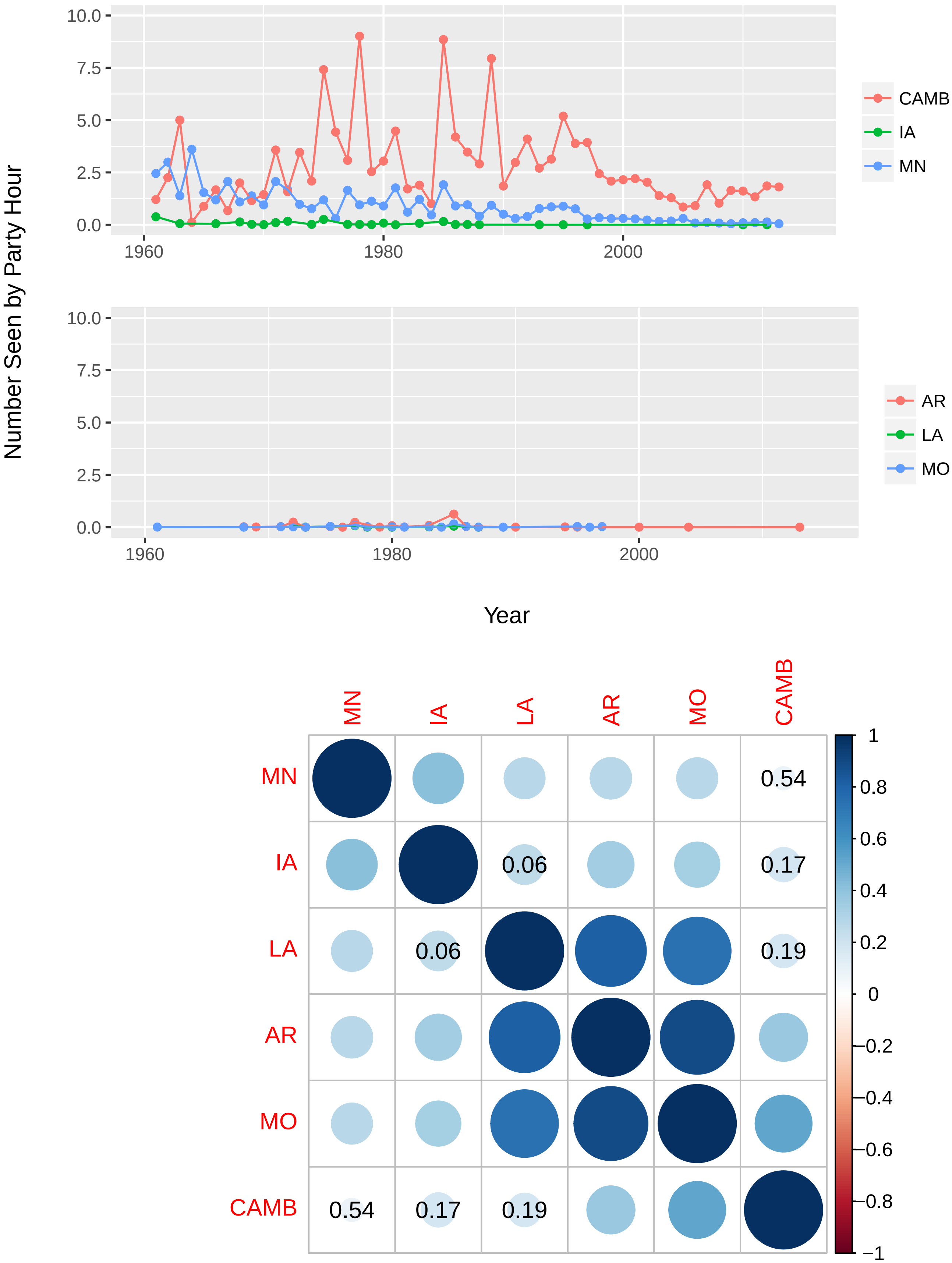


Figure 8: Evening Grosbeak abundance trends and area correlations across 2nd (midwest) longitudinal tier, CBC data.

In the third longitudinal tier, Evening Grosbeak abundance trends in Texas, Colorado, Wyoming, and New Mexico show significant positive correlations with each other. New Mexico and Wyomin show significant negative correlations with the northernmost areas in the tier, due to some alternations in abundance spikes (Fig. 9).

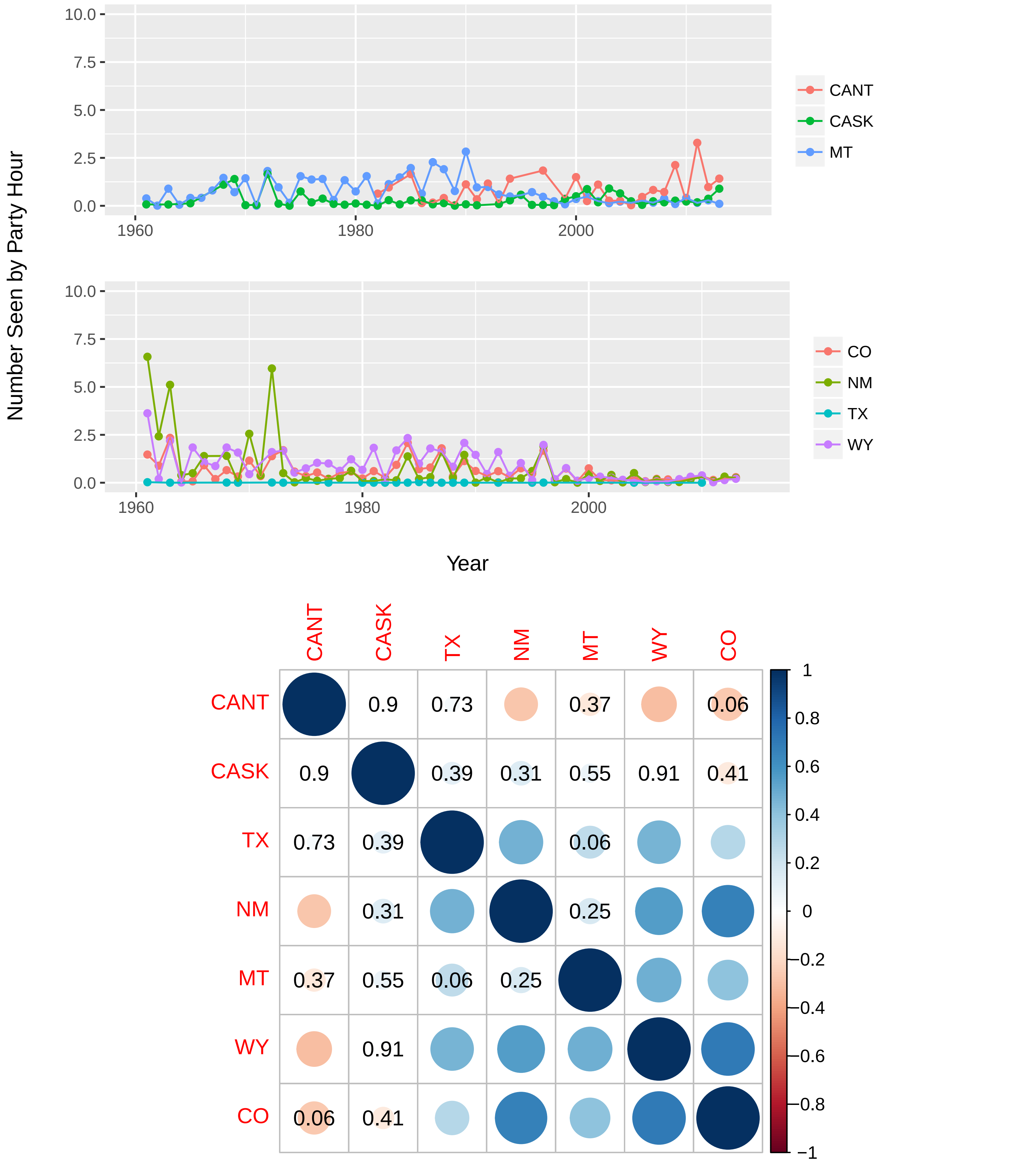


Figure 9: Evening Grosbeak abundance trends and area correlations across 3rd (Rocky Mountains) longitudinal tier, CBC data.

States and provinces in the fourth longitudinal tier show similarly timed rises and falls in abundance, with different areas alternating in size during high abundance years. The CBC records in all areas show strong positive correlations, all of which are statistically significant (Fig. 10).

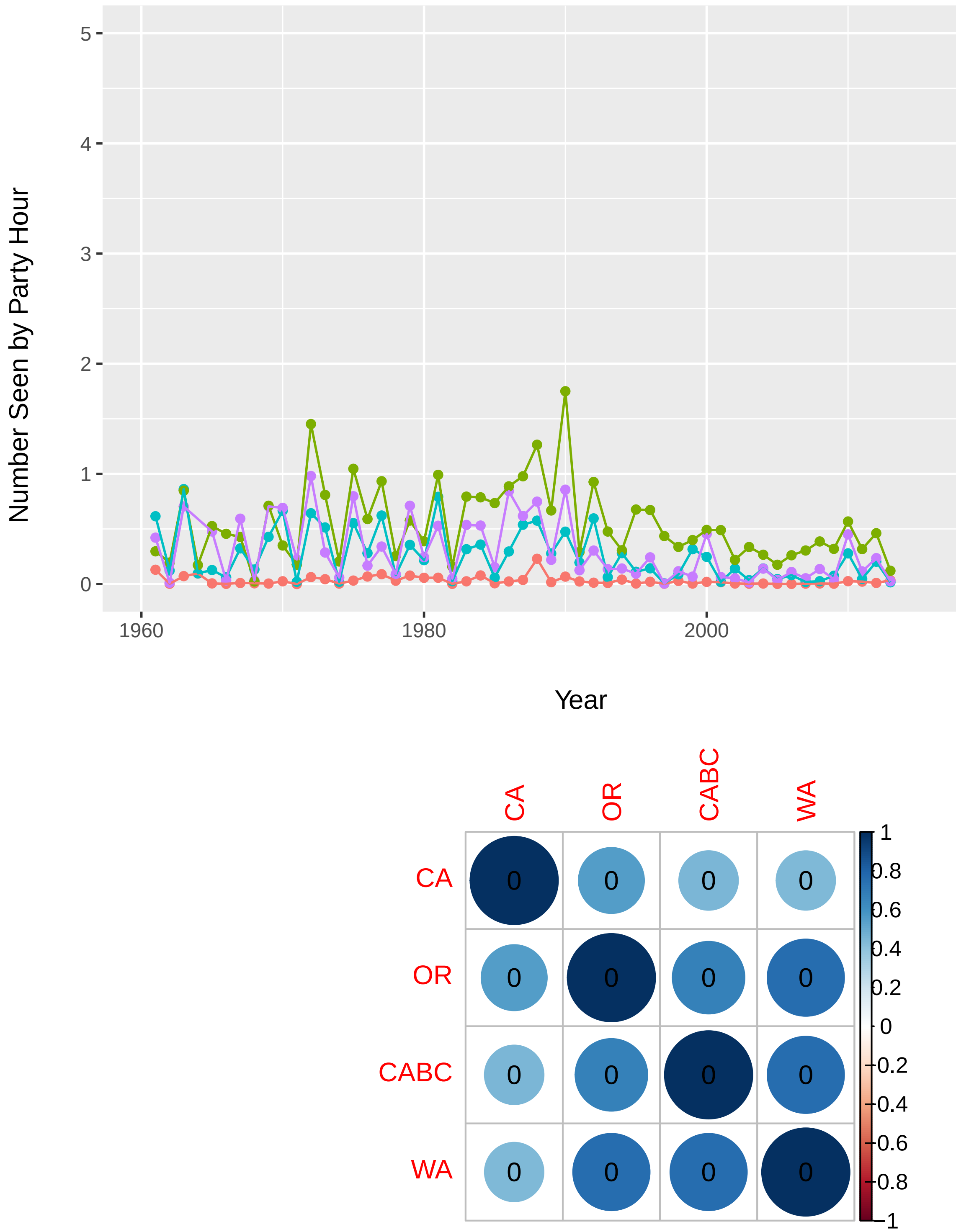


Figure 10: Evening Grosbeak abundance trends and area correlations across 4th (Pacific) longitudinal tier, CBC data.

eBird Analyses

In the northernmost latitudinal tier, there are no strong correlations in the daily abundance patterns for Evening Grosbeaks between diffferent provinces, with some weak positive correlations between nearby provinces. Daily abundance patterns across the latitude show moderate positive correlations between recent years (Fig. 11).

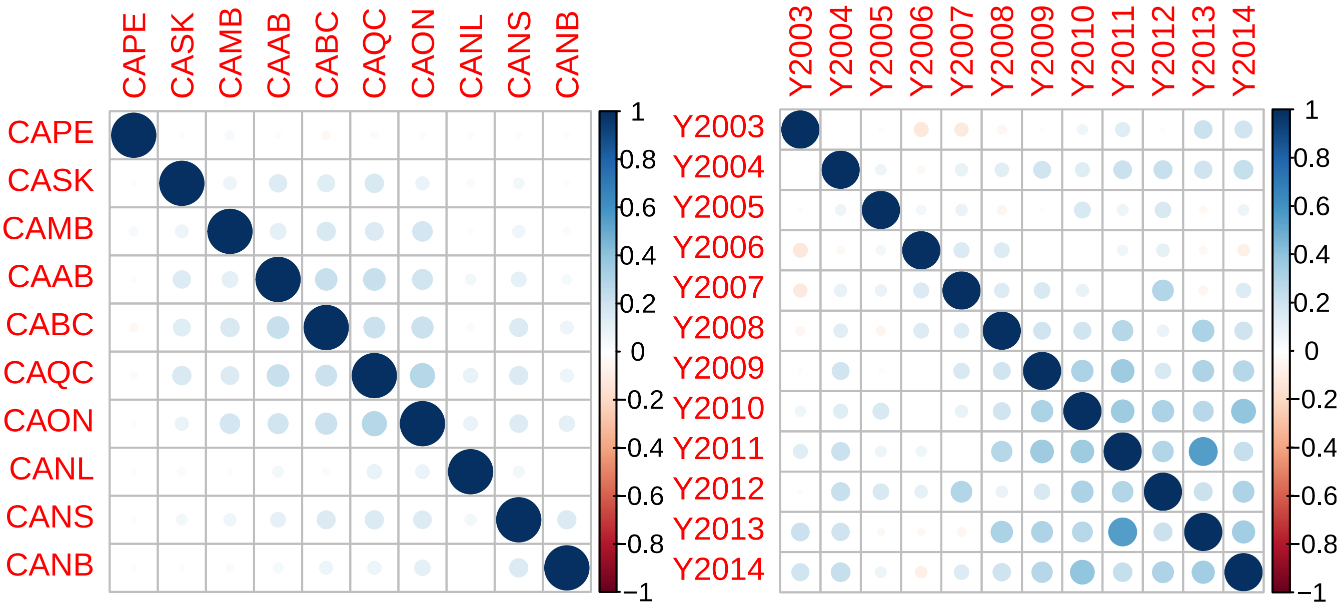


Figure 11: Correlations of Evening Grosbeak invasion pattern between individual areas and between years for the 1st (Canadian) latitudinal tier, eBird data.

In the second latitudinal tier, there are no strong correlations in the daily abundance patterns for Evening Grosbeaks between diffferent areas, with some weak positive correlations between nearby states and provinces. Daily abundance patterns across the latitude show moderate positive correlations between some years (Fig. 12).

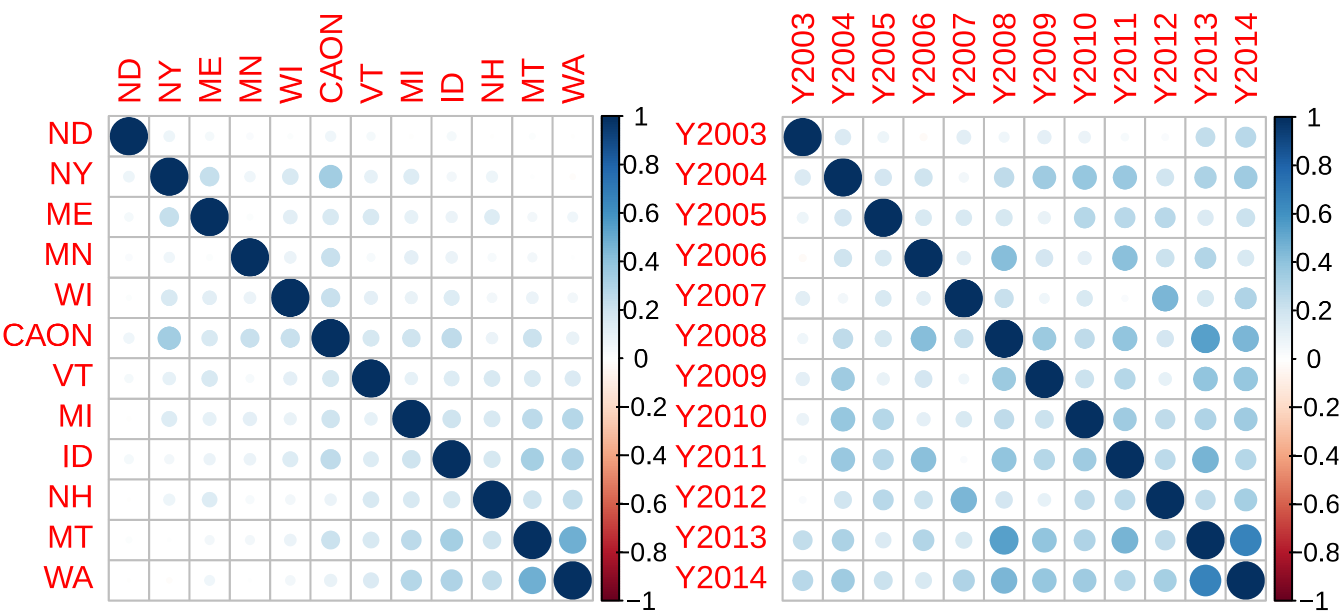


Figure 12: Correlations of Evening Grosbeak invasion pattern between individual areas and between years for the 2nd (northern US) latitudinal tier, eBird data.

In the third latitudinal tier, daily eBird records show few strong positive correlations between areas, with some weak positive correlations between nearby states. Daily abundance patterns across the latitude show moderate to strong positive correlations between some years (Fig. 13).

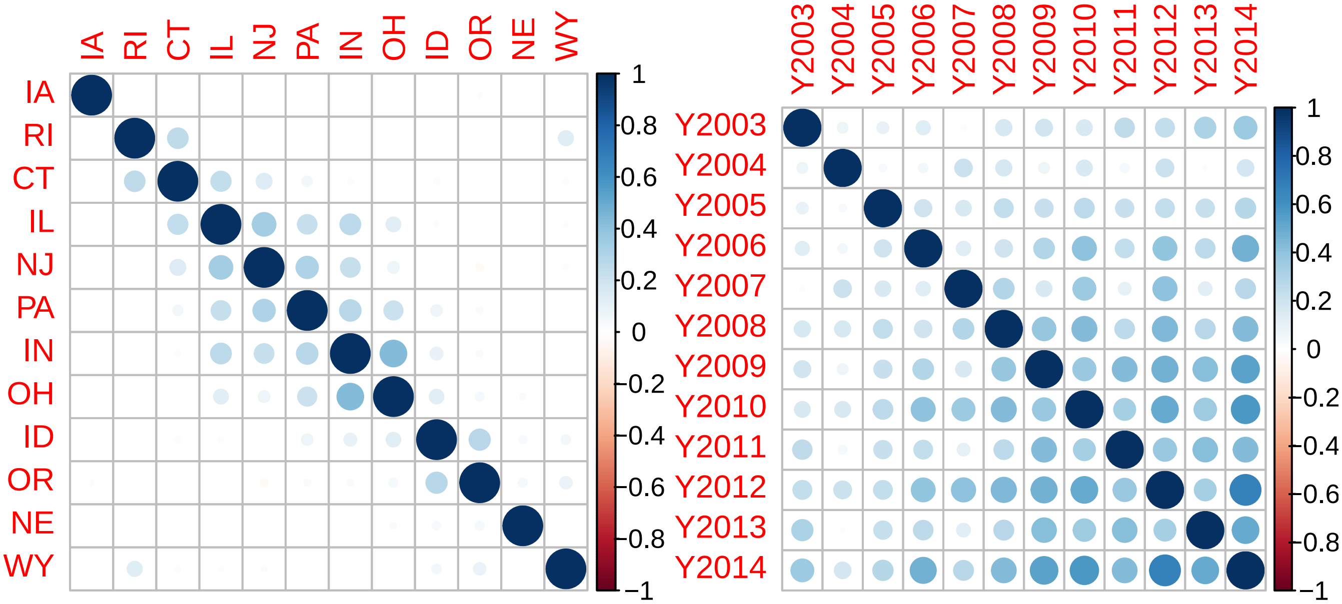


Figure 13: Correlations of Evening Grosbeak invasion pattern between individual areas and between years for the 3rd (mid US) latitudinal tier, eBird data.

In the fourth latitudinal tier, daily eBird records show almost no correlations between areas, and hardly any correlations between years (Fig. 14).

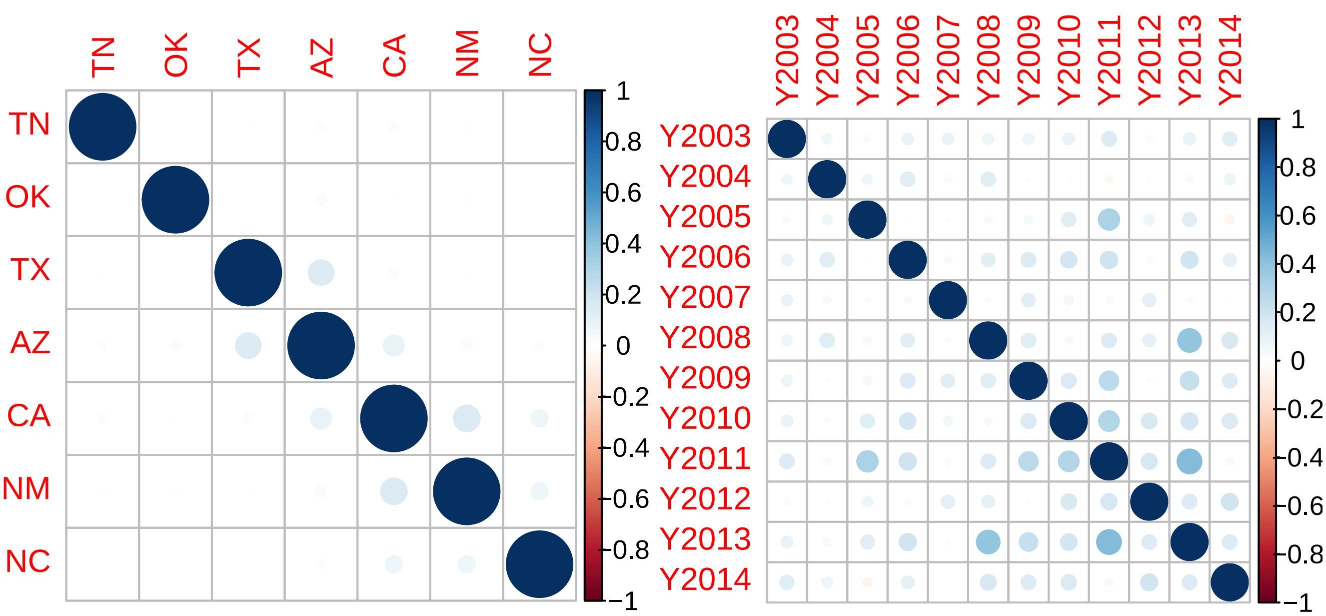


Figure 14: Correlations of Evening Grosbeak invasion pattern between individual areas and between years for the 4th (southern US) latitudinal tier, eBird data.

Down the easternmost longitudinal tier, daily eBird records show few correlations between areas, with some extremely weak positive correlations between nearby states. Daily abundance patterns across the latitude show weak positive correlations between every other year (Fig. 15).

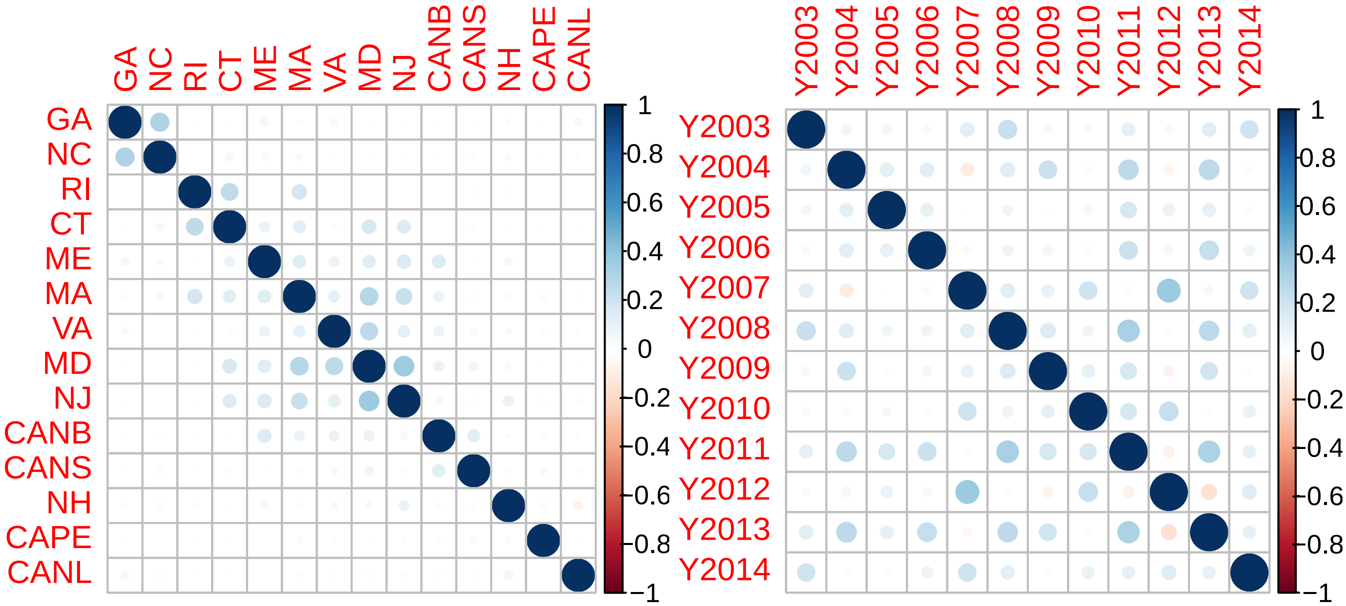


Figure 15: Correlations of Evening Grosbeak invasion pattern between individual areas and between years for the 1st (Atlantic) longitudinal tier, eBird data.

Down the second longitudinal tier, eBird records show no correlation between areas, and few weak positive correlations between years (Fig. 16).

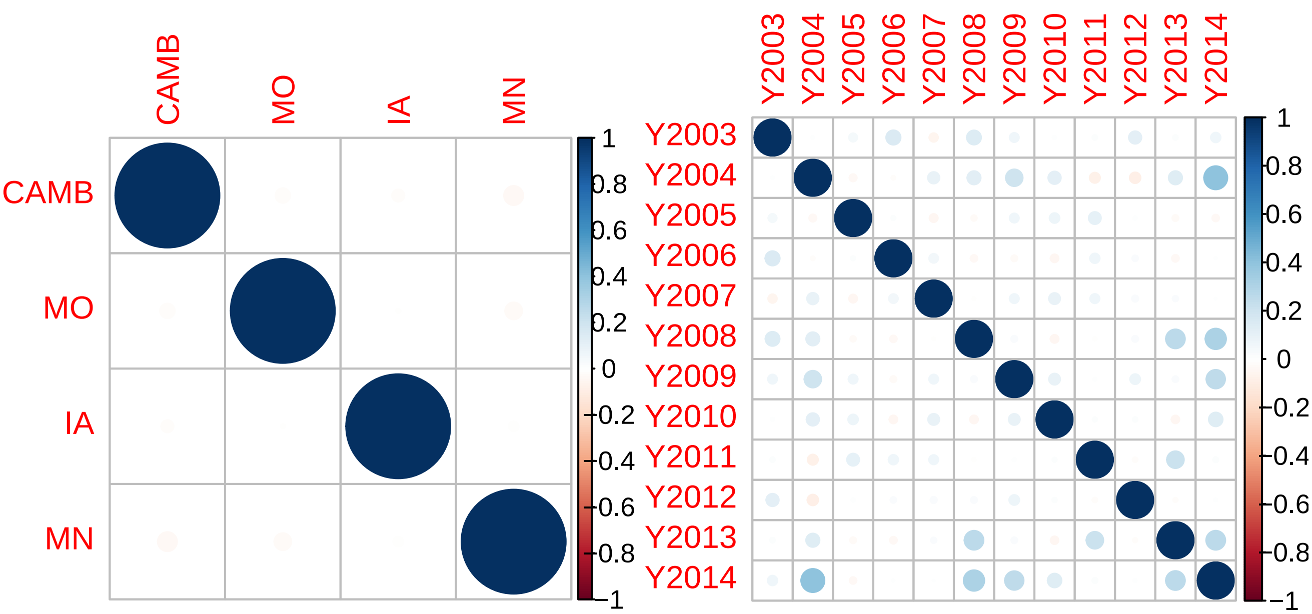


Figure 16: Correlations of Evening Grosbeak invasion pattern between individual areas and between years for the 2nd (midwest) longitudinal tier, eBird data.

Down the third longitudinal tier, eBird records show few correlations between areas, with the some weak positive correlations between neighboring areas, and weak to moderate positive correlations between years (Fig. 17).

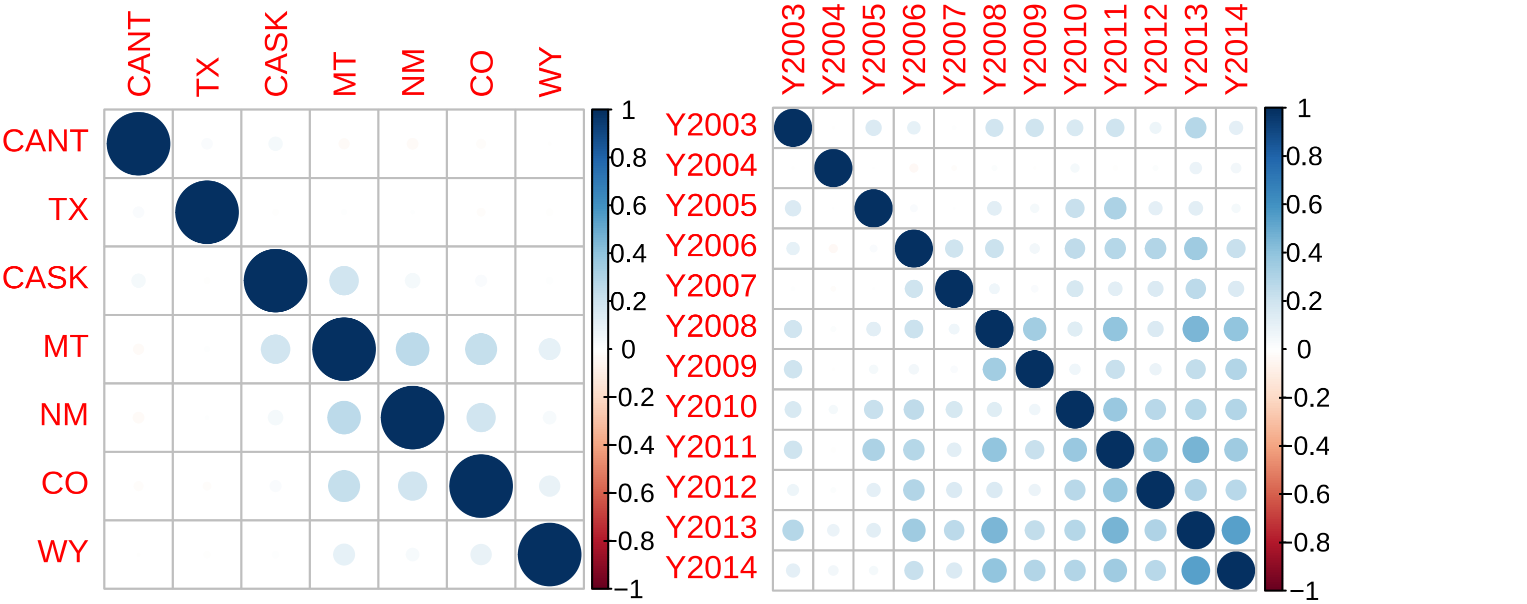


Figure 17: Correlations of Evening Grosbeak invasion pattern between individual areas and between years for the 3rd (Rocky Mountains) longitudinal tier, eBird data.

Down the westernmost longitudinal tier, daily eBird records show strong positive correlations between areas, with the strongest correlations between Oregon and Washington, and between recent years (Fig. 18).

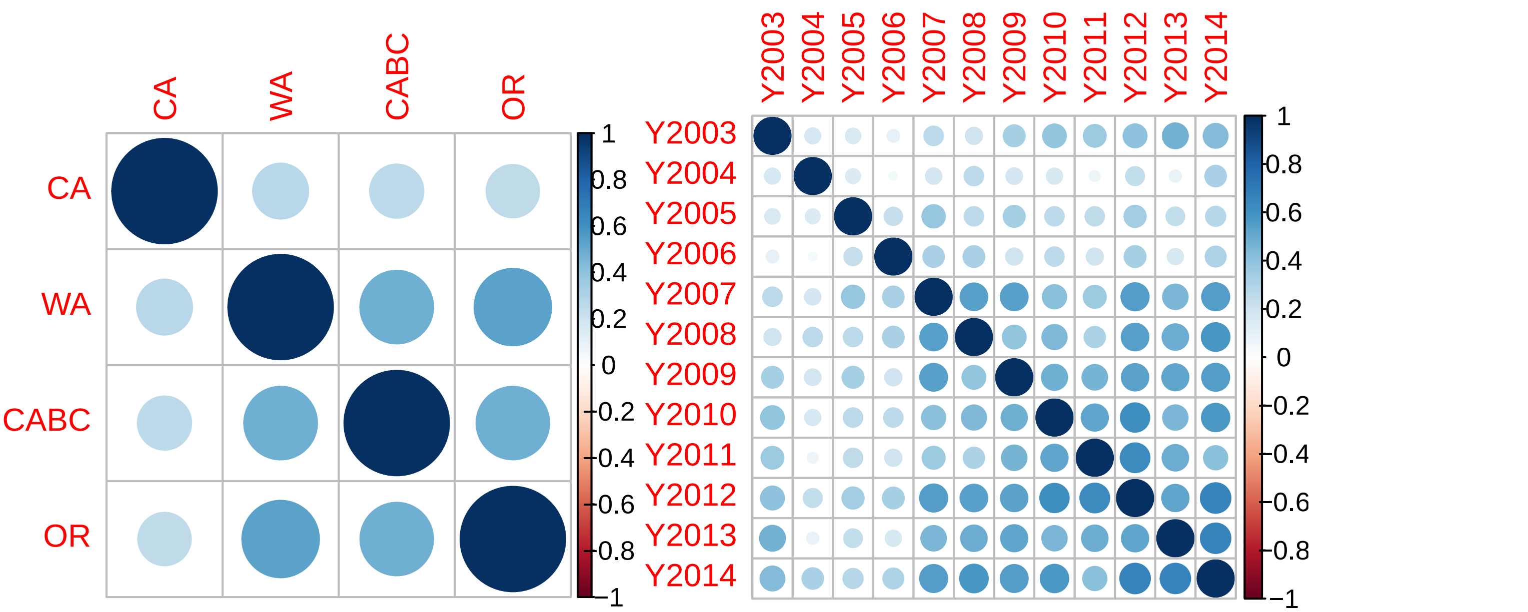


Figure 18: Correlations of Evening Grosbeak invasion pattern between individual areas and between years for the 4th (Pacific) longitudinal tier, eBird data.

Pine Grosbeak

CBC Analyses

Christmas Bird Count data since 1960 show the highest numbers of Pine Grosbeaks are recorded across southern Canada and the northern United States, with sizeable numbers recorded in states down the Rocky Mountains (Fig. 19).

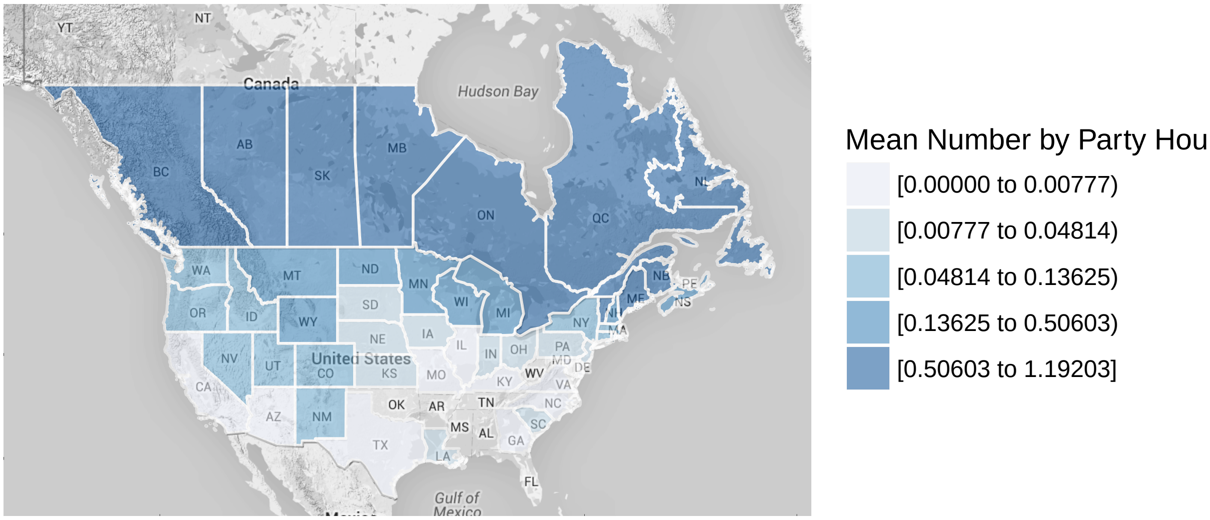


Figure 19: Pine Grosbeak abundance by area, CBC data.

Christmas Bird Count data since 1960 show the highest variation in Pine Grosbeak numbers occurs across the northern United States, down the Pacific coast, and the southwest United states (Fig. 20).

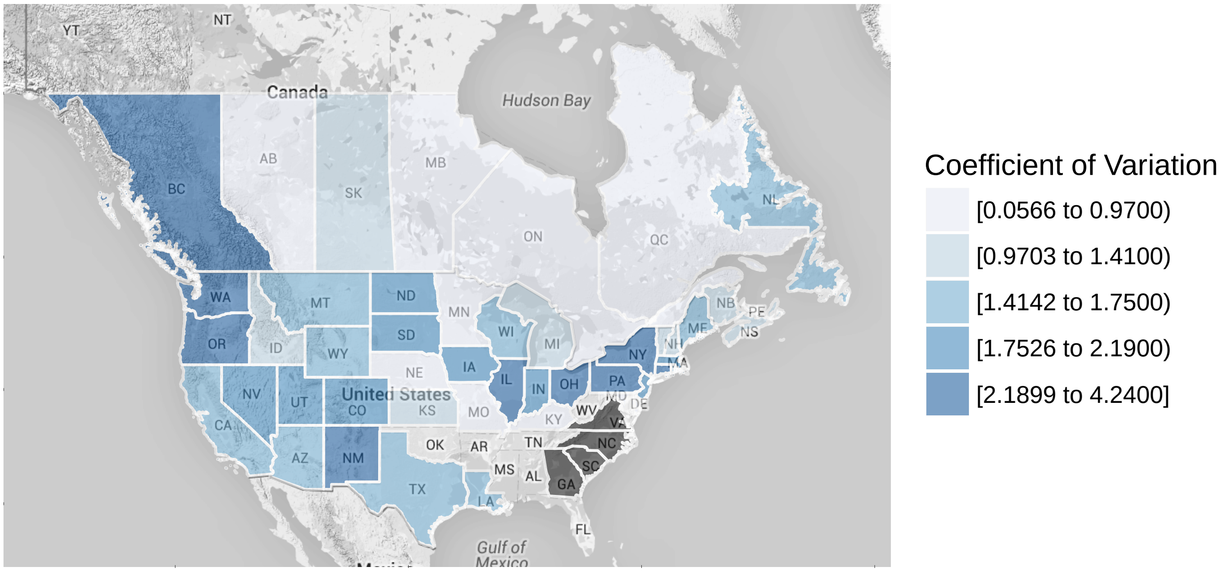


Figure 20: Coefficient of variation for Pine Grosbeak abundance by area, CBC data.

CBC data show rises and falls in Pine Grosbeak winter abundance across the northernmost latitude over time, with some spikes similarly timed between different areas. There are strong positive correlations between some provinces in the east (Fig. 21).

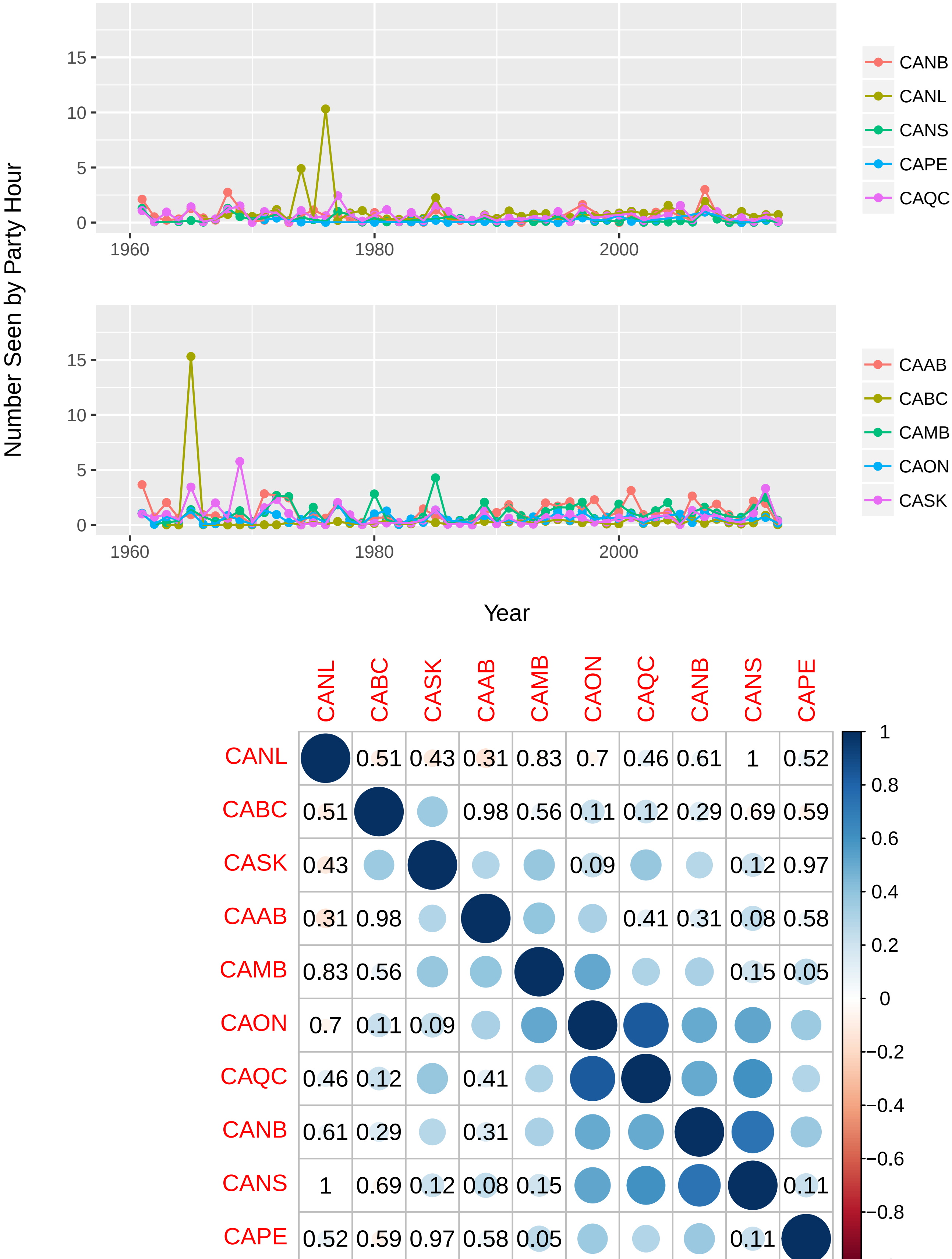


Figure 21: Pine Grosbeak abundance trends and area correlations across 1st (Canadian) latitudinal tier, CBC data.

In the 2nd latitudinal tier, rises and falls in Pine Grosbeak abundance tend to be more similarly timed between different areas, although there are some examples of alternation. There are strong correlations in abundance trends over time between areas across the tier, with states in the west with low numbers of Pine Grosbeaks over the study period being less strongly correlated to the other areas (Fig. 22).

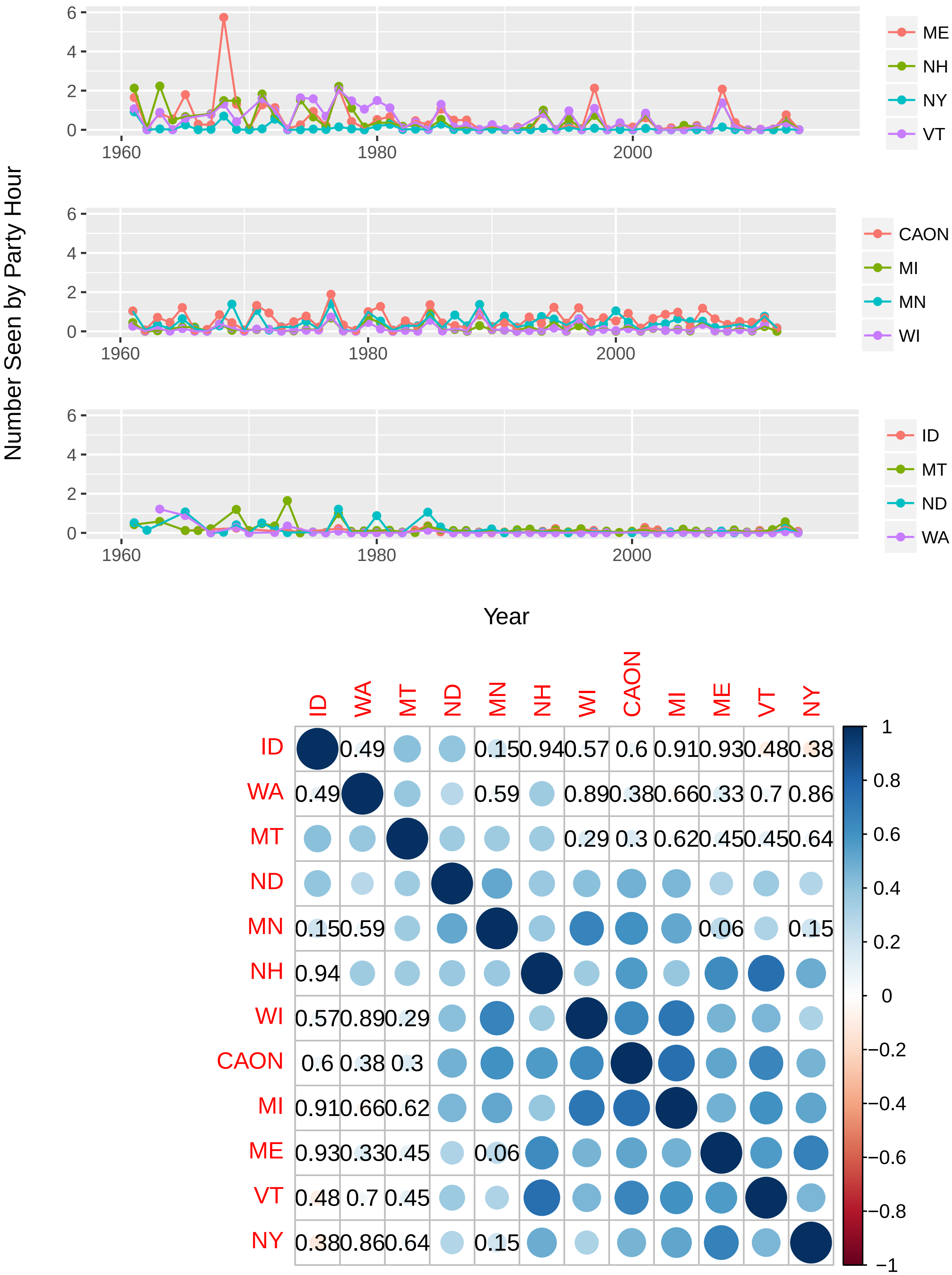


Figure 22: Pine Grosbeak abundance trends and area correlations across 2nd (northern US) latitudinal tier, CBC data.

Only a few states in the third latitudinal tier have significant CBC records for Pine Grosbeaks over the study period, and they mostly do not show similar timing in rises and falls in abundance. There are strong positive correlations between states that never record high abundances of these species (Fig. 23).

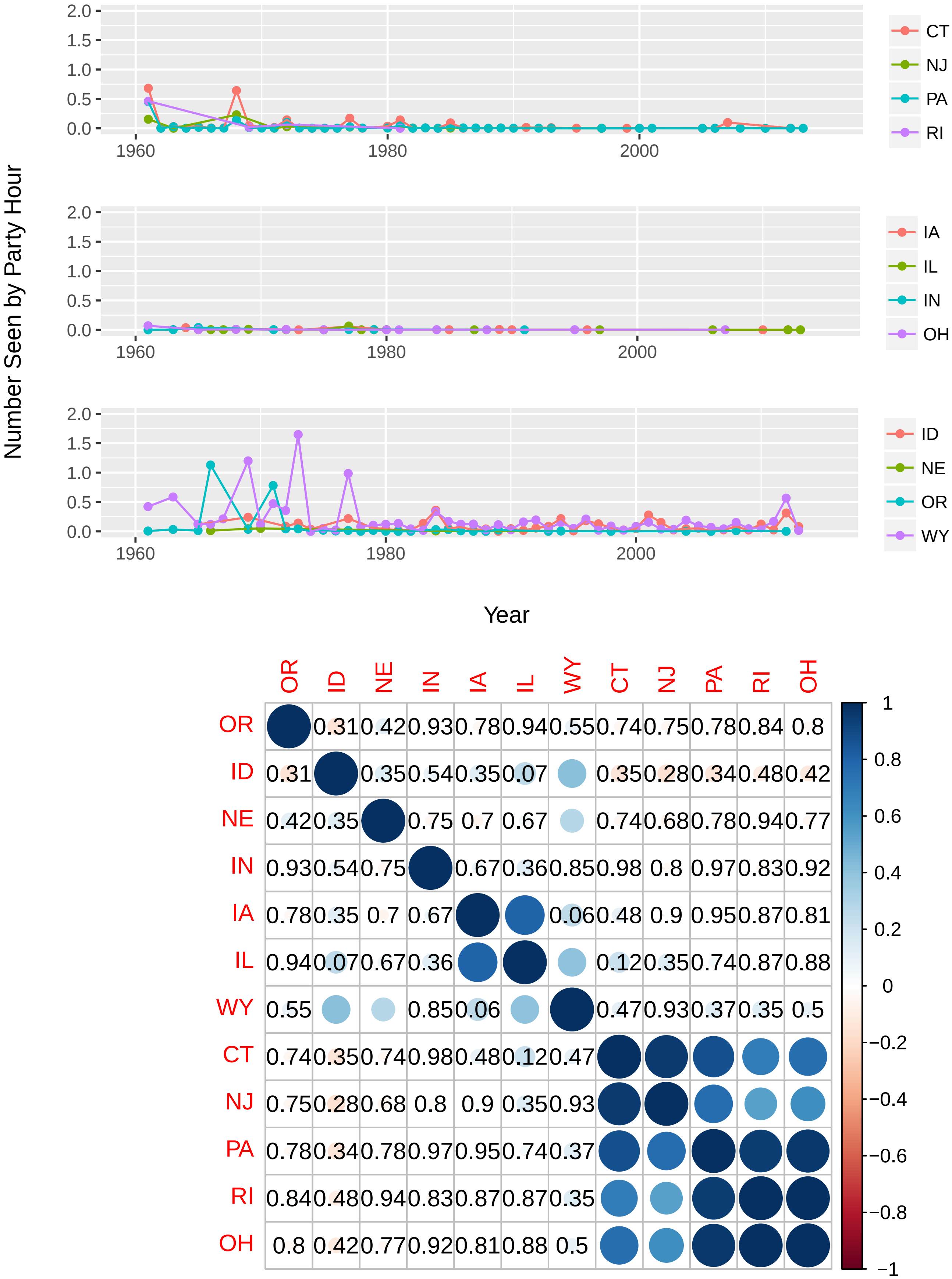


Figure 23: Pine Grosbeak abundance trends and area correlations across 3rd (mid US) latitudinal tier, CBC data.

The CBC has recorded very few Pine Grosbeaks in states in the southernmost latitudinal tier, and these areas do not have enough data to compare abundance trends over time. Down the first longitudinal tier, different areas mostly show similarly timed spikes in abundance, although the sizes of these spikes vary between areas during high abundance years. States in the northern Unites States show the strongest positive correlations (Fig. 24).

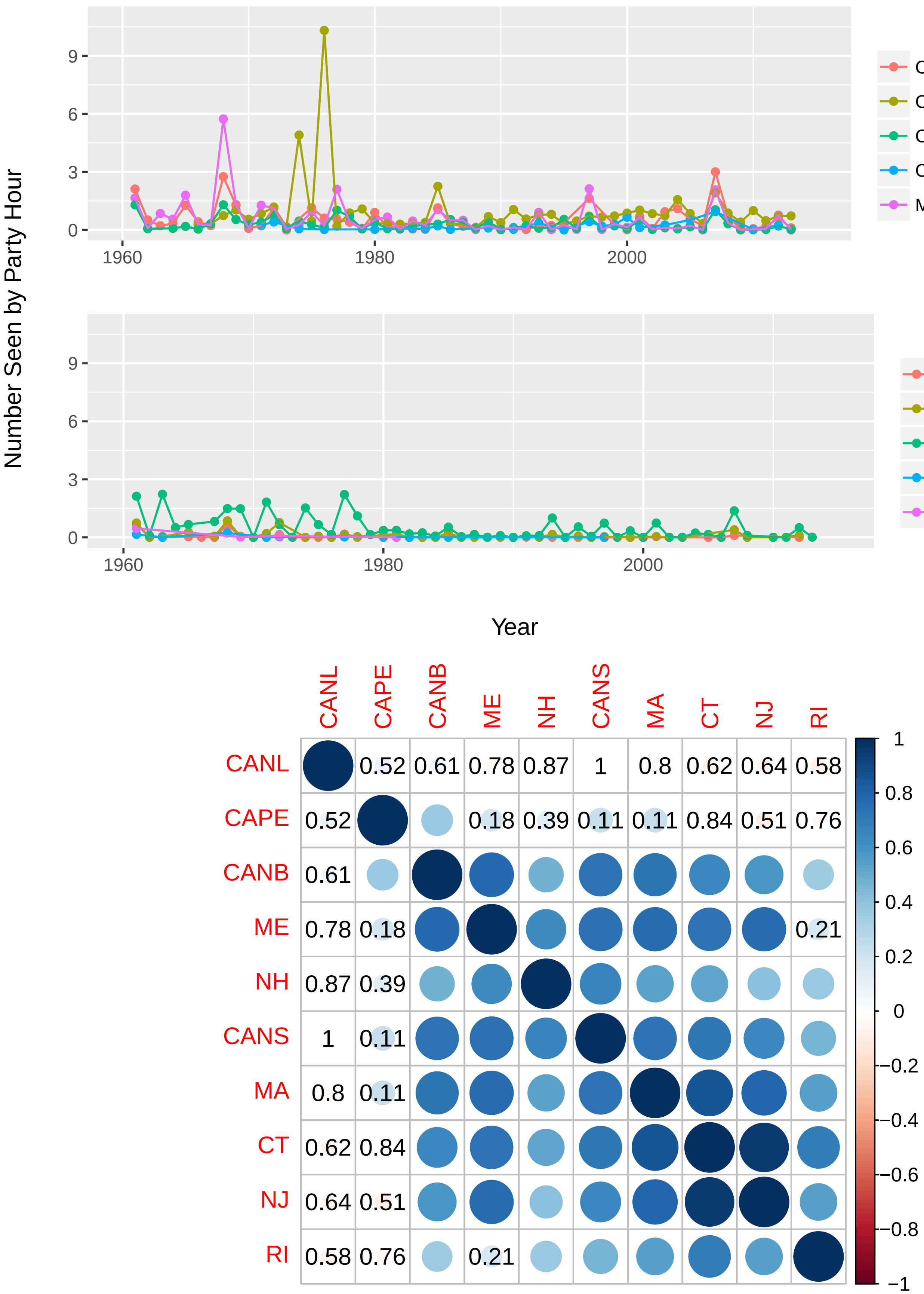
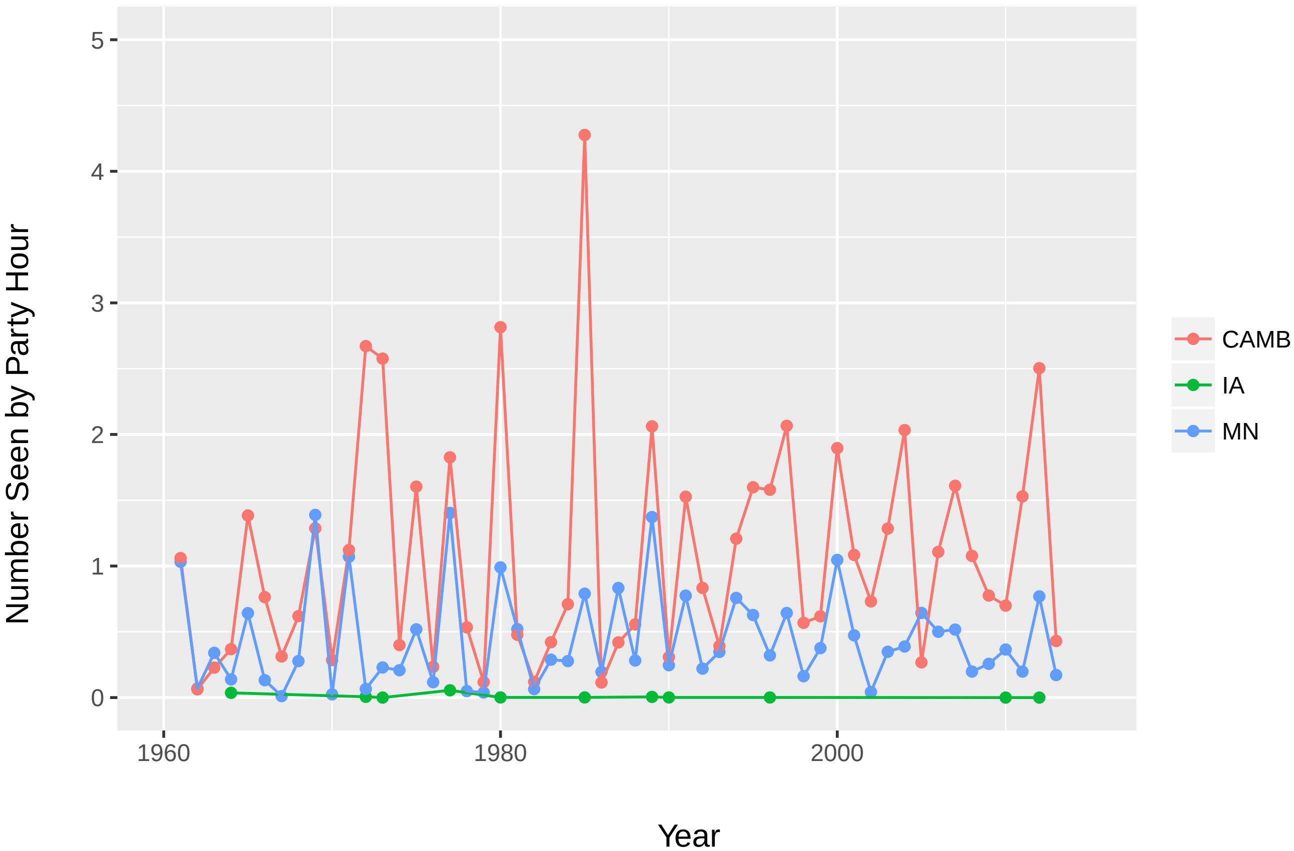


Figure 24: Pine Grosbeak abundance trends and area correlations across 1st (Atlantic) longitudinal tier, CBC data.

In the 2nd longitudinal tier, Manitoba and Minnesota show similarly timed, but differently sized spikes in abundance. There is a moderately strong positive correlation between Manitoba and Minnesota, and a weaker positive correlation between Minnesota and Iowa (Fig. 25).



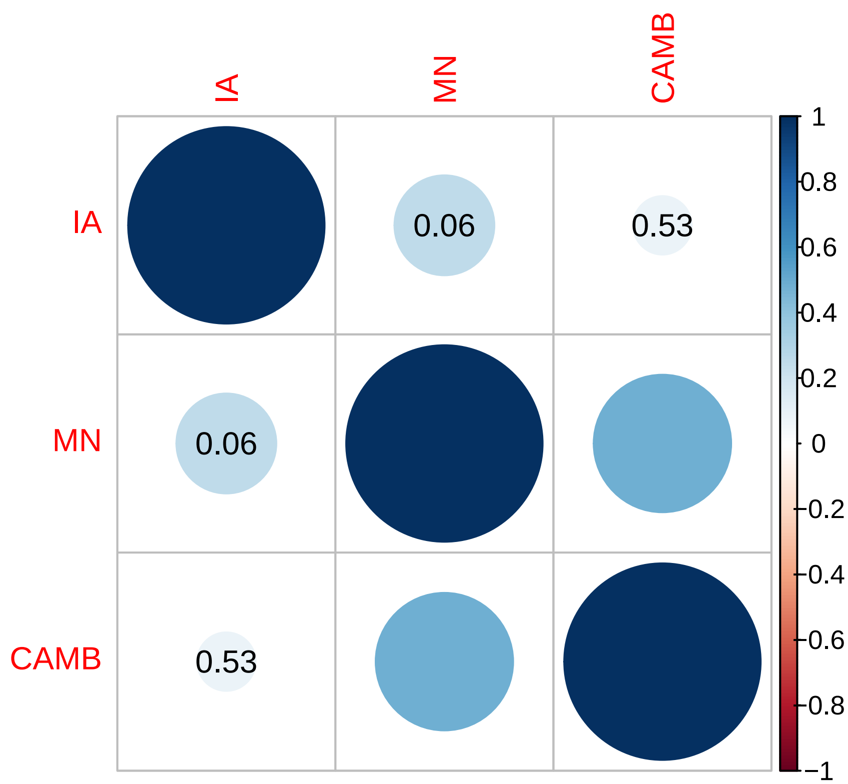


Figure 25: Pine Grosbeak abundance trends and area correlations across 2nd (midwest) longitudinal tier, CBC data.

Down the third latitudinal tier, there are similarly timed but differently sized rises and falls in abundance in different areas, with some areas alternating with others in having high abundances of Pine Grosbeaks. Colorado and the Northwest Territories show weak negative correlations with all other areas, and Saskatchewan, New Mexico, Montana, and Wyoming all show moderate to strong positive correlations with each other (Fig. 26).

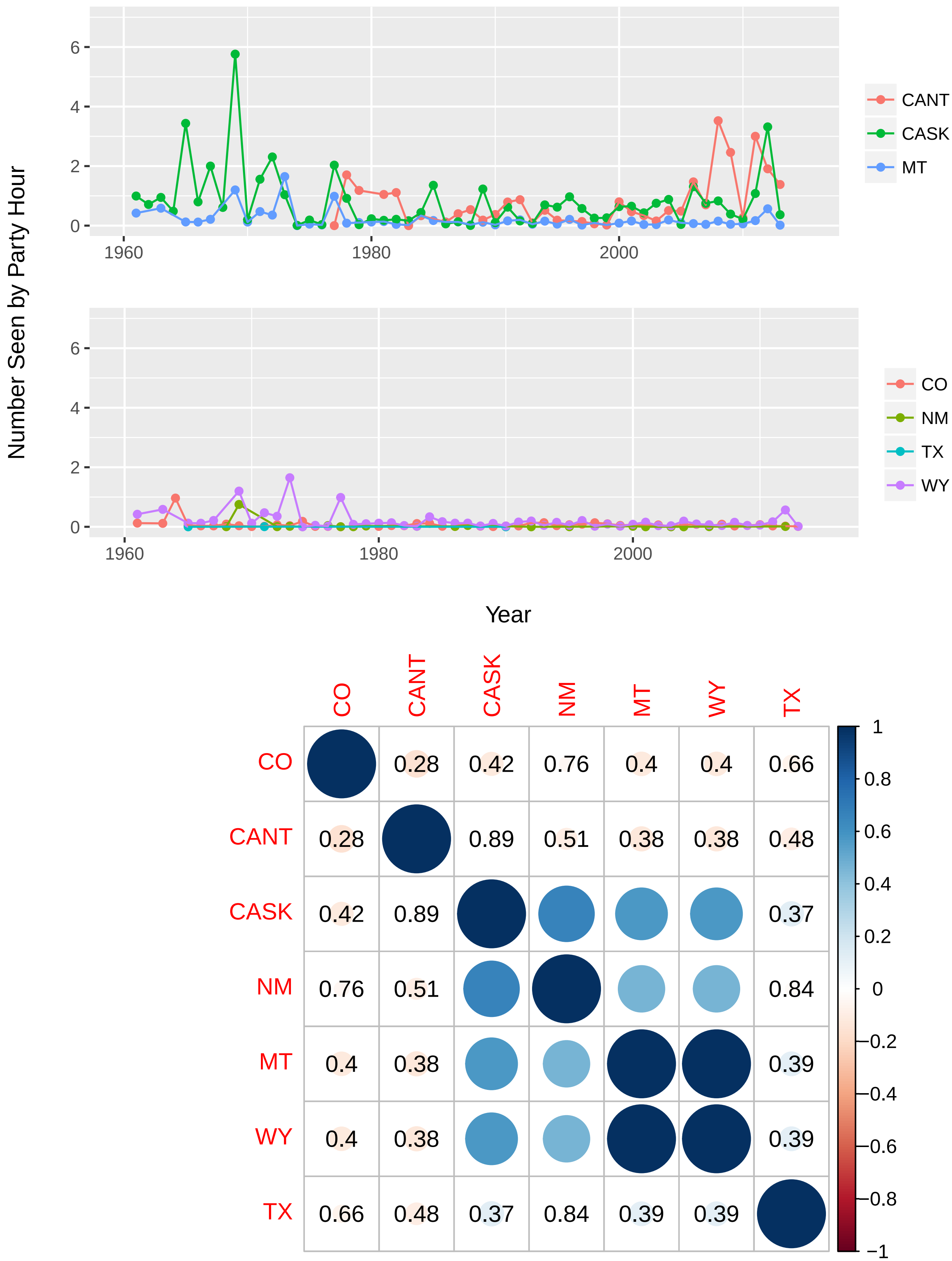


Figure 26: Pine Grosbeak abundance trends and area correlations across 3rd (Rocky Mountains) longitudinal tier, CBC data.

In the fourth longitudinal tier, only Alaska, the Yukon Territory, and British Colubia show large abundances of Pine Grosbeaks during the study period, and they show alternations in having high numbers of Pine Grosbeaks over time. These ares show weak to moderate negative correlations with the southern areas that have few records of Pine Grosbeaks, and Washington shows a strong positive correlation with British Columbia and California shows a strong positive correlation with Oregon (Fig. 27).

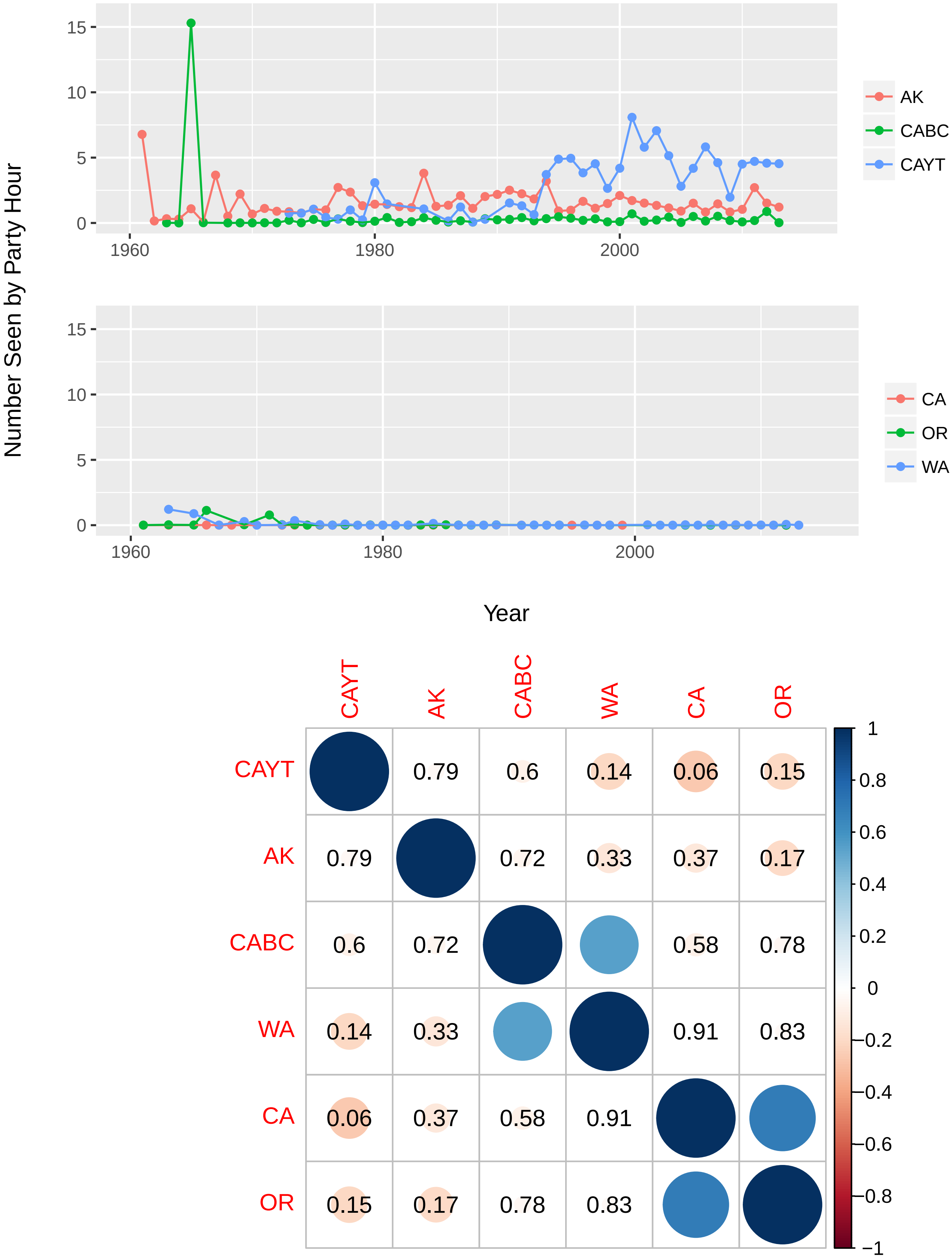


Figure 27: Pine Grosbeak abundance trends and area correlations across 4th (Pacific) longitudinal tier, CBC data.

eBird Analyses

Across the northermost latitudinal tier, daily eBird records show weak to moderate correlations between central provinces, and weak to strong positive correlations between different years (Fig. 28).

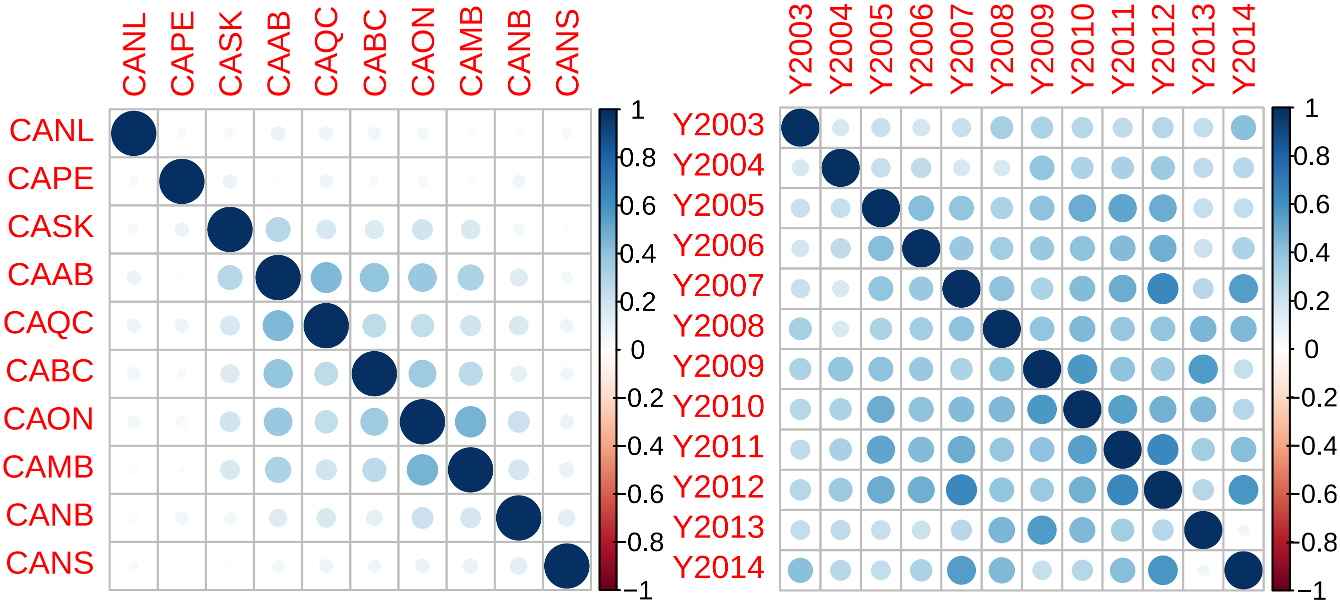


Figure 28: Correlations of Pine Grosbeak invasion pattern between individual areas and between years for the 1st (Canadian) latitudinal tier, eBird data.

Across the second latitudinal tier, daily eBird records show the strongest correations between eastern States, with weak to strong positive correlations between all years of the study. More recent years sometimes show alternating positive correlations (Fig. 29).

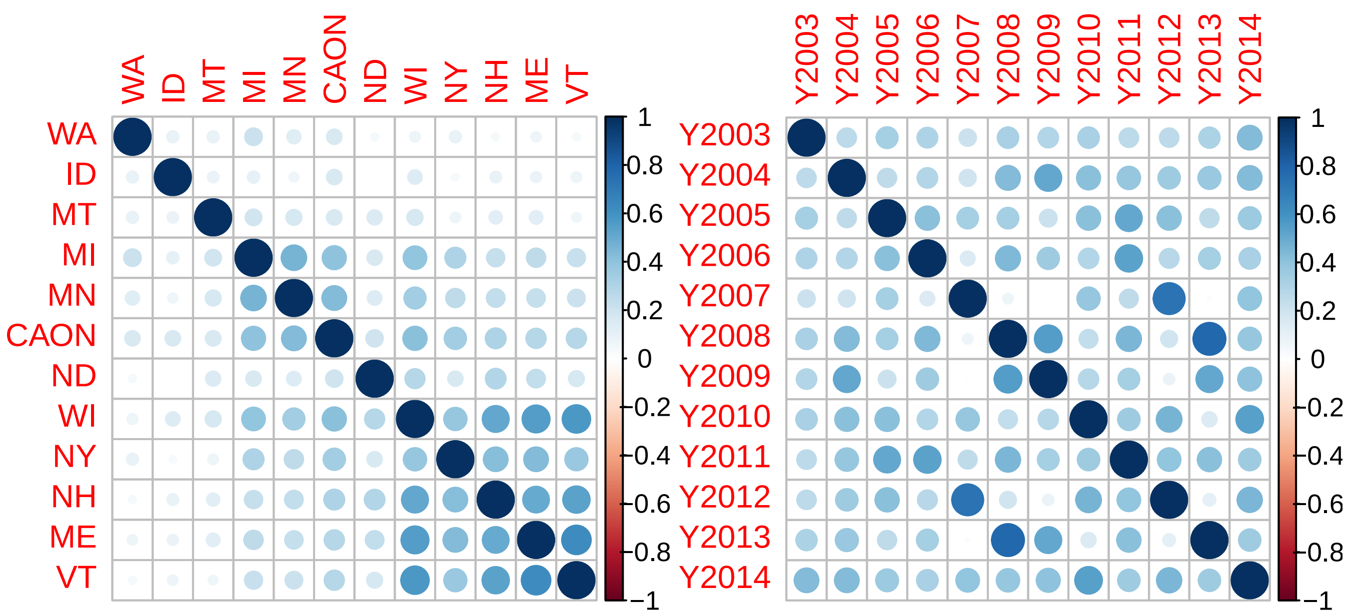


Figure 29: Correlations of Pine Grosbeak invasion pattern between individual areas and between years for the 2nd (northern US) latitudinal tier, eBird data.

Across the third latitudinal tier, daily eBird records show few correlations between areas, and few correlations between years (Fig. 30).

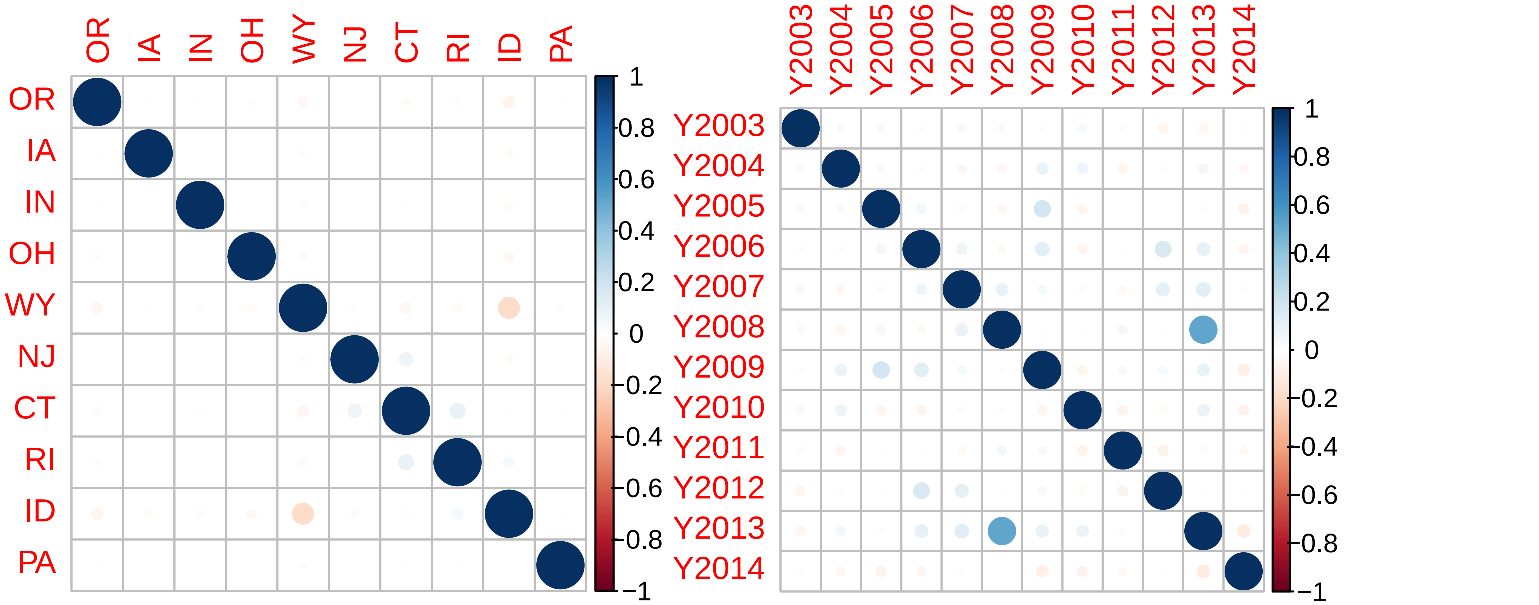


Figure 30: Correlations of Pine Grosbeak invasion pattern between individual areas and between years for the 3rd (mid US) latitudinal tier, eBird data.

Due to the paucity of eBird reports of Pine Grosbeak in areas in the southermost latitudinal tier, I excluded these areas from my analysis. In the easternmost longitudinal tier, daily eBird records show some weak to moderate positive correlations between neighboring states and provinces, and few correlations between years. Some years only show positive correlations with other years that are two or three time-steps away. Due to paucity of reports, I excluded Maryland, Virginia, North Carolina, South Carolina, Georgia, and Florida from analyses (Fig. 31).

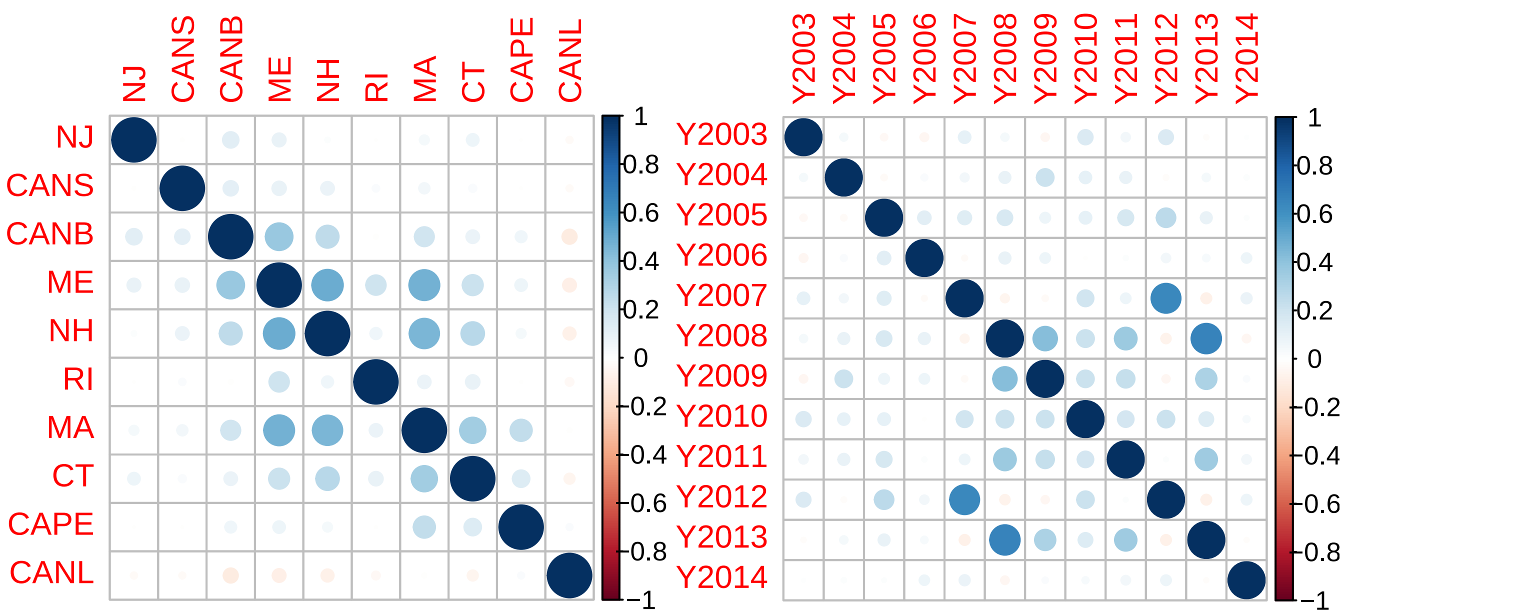


Figure 31: Correlations of Pine Grosbeak invasion pattern between individual areas and between years for the 1st (Atlantic) longitudinal tier, eBird data.

Across the second longitudinal tier, daily eBird records show a weak correlation between Manitoba and Minnesota, and a few, seemingly irregular, weak positive correlations between years. Due to paucity of reports, I excluded Missouri, Arkansas, and Louisiana from analyses (Fig. 32).

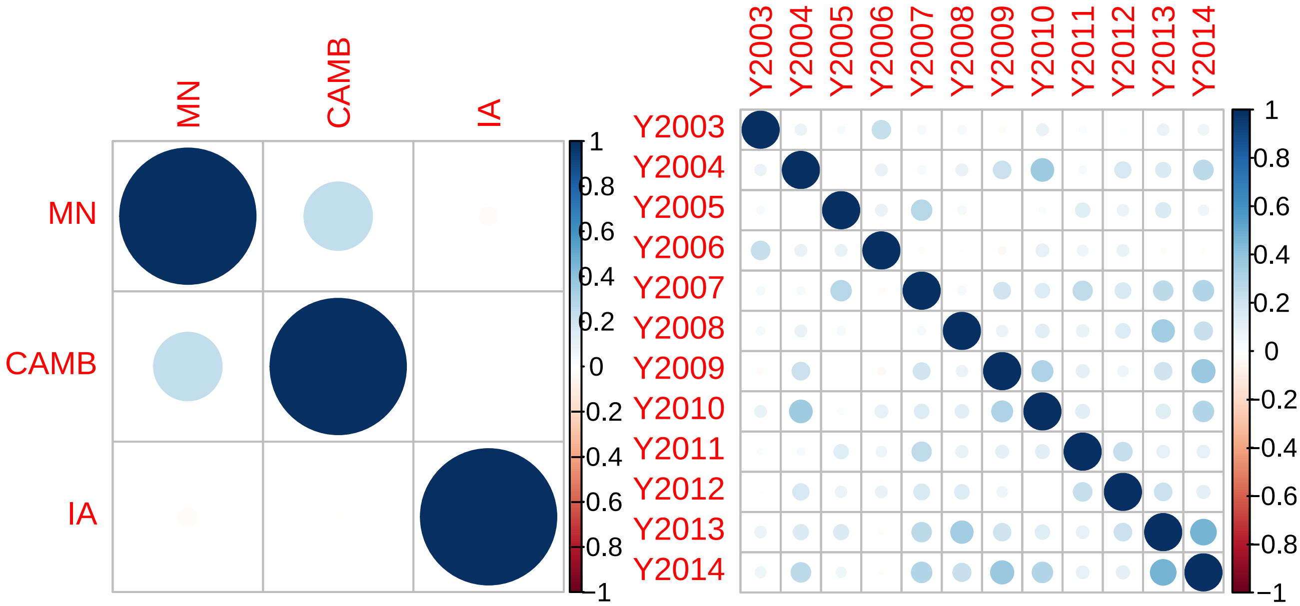


Figure 32: Correlations of Pine Grosbeak invasion pattern between individual areas and between years for the 2nd (midwest) longitudinal tier, eBird data.

In the third longitudinal tier, daily eBird records show few correlations between different areas, and few correlations between different years (Fig. 33).

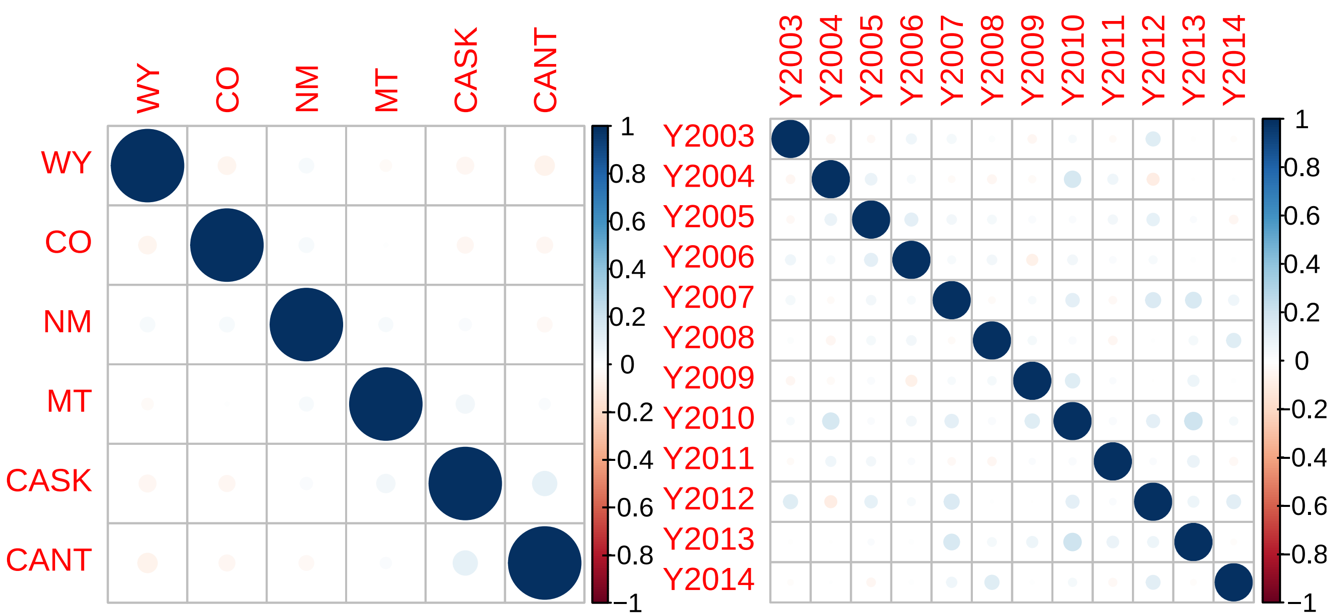


Figure 33: Correlations of Pine Grosbeak invasion pattern between individual areas and between years for the 3rd (Rocky Mountains) longitudinal tier, eBird data.

In the westernmost longitudinal tier, daily eBird records show few correlations between areas, and several weak positive correlations between years, with some years alternating in showing positive correlations (Fig. 34).

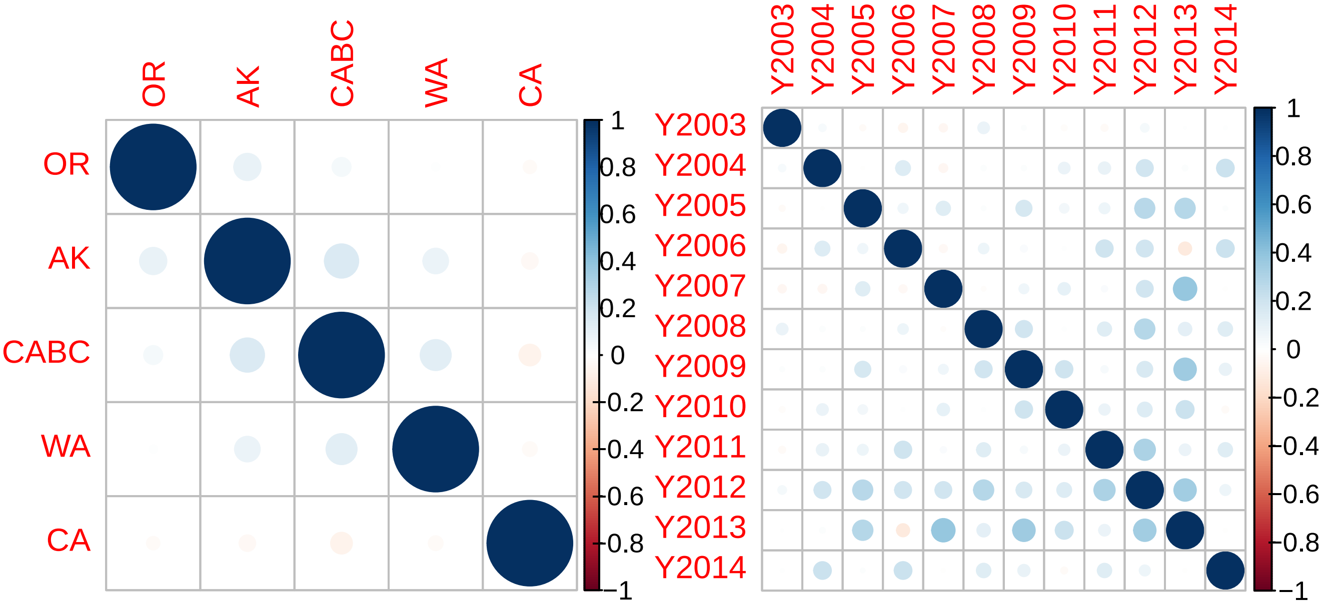


Figure 34: Correlations of Pine Grosbeak invasion pattern between individual areas and between years for the 4th (Pacific) longitudinal tier, eBird data.

Gray-crowned Rosy-Finch

CBC Analyses

Christmas Bird Count data since 1960 show the highest numbers of Gray-crowned Rosy-Finches in the Rocky Mountain states and North Dakota (Fig. 35).

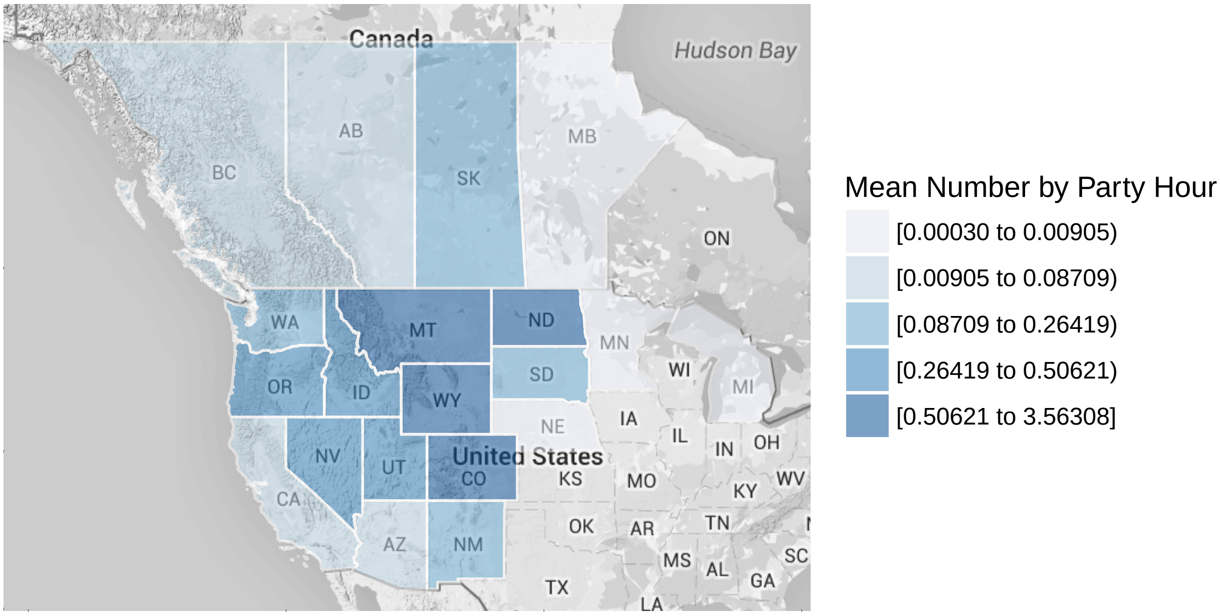


Figure 35: Gray-crowned Rosy-Finch abundance by area, CBC data.

Christmas Bird Count data since 1960 show the highest variation in Gray-crowned Rosy-Finch numbers occurs in southern Canada, the Pacific coast, and North and South Dakota (Fig. 36).

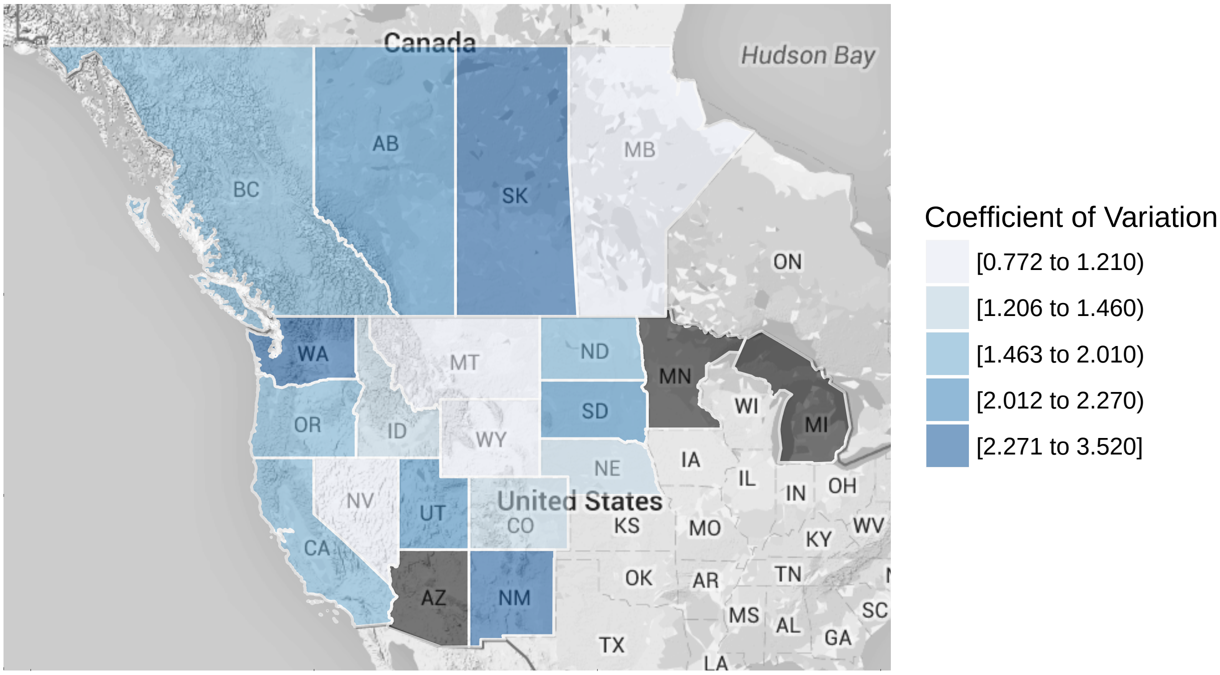


Figure 36: Coefficient of variation for Gray-crowned Rosy-Finch abundance by area, CBC data.

Across the northernmost latitudinal tier, provinces show differently timed and differently sized rises and falls in abundnace. Manitoba shows a weak positive correlation with British Columbia, and Saskatchewan shows a strong positive correlation with ALberta (Fig. 37).

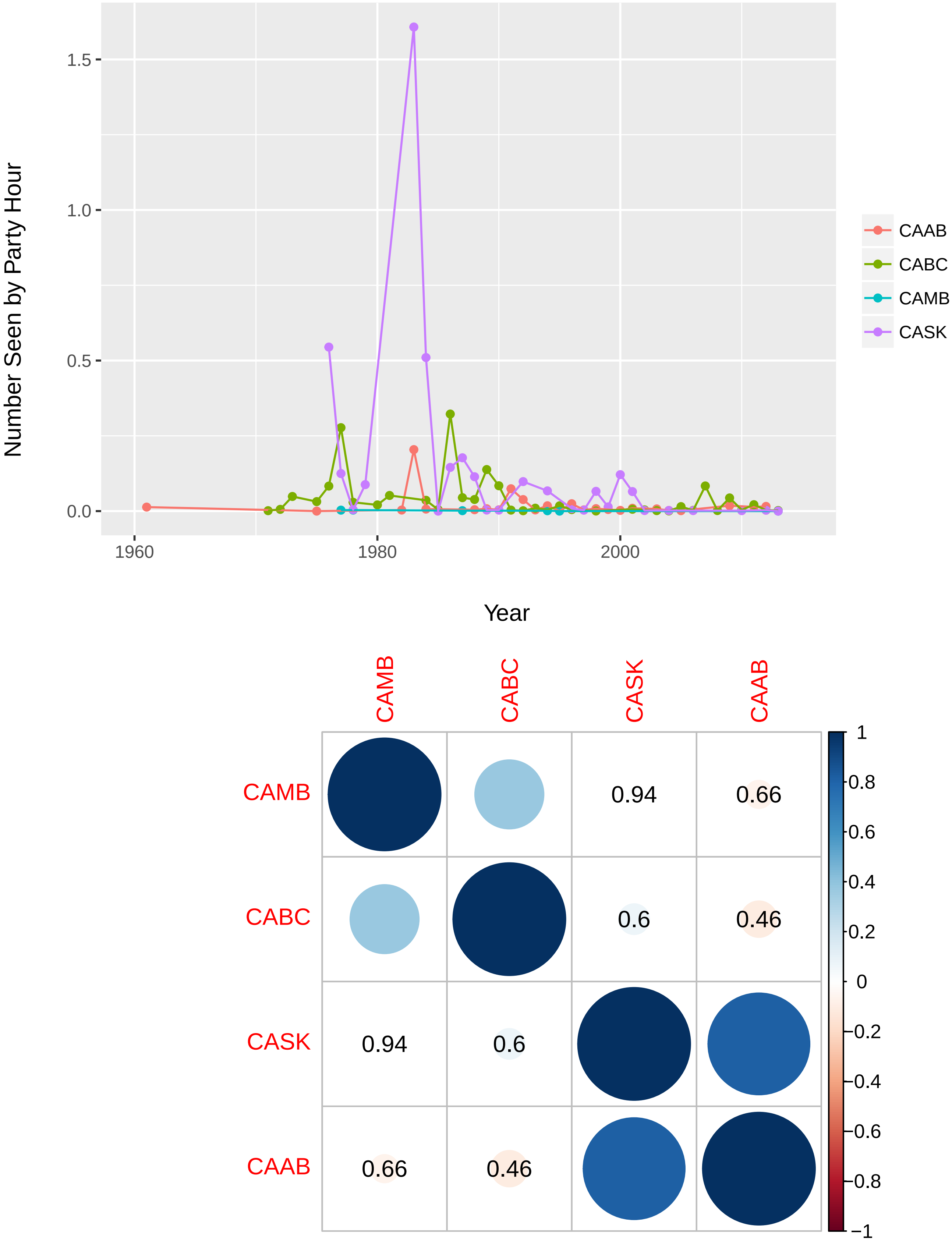
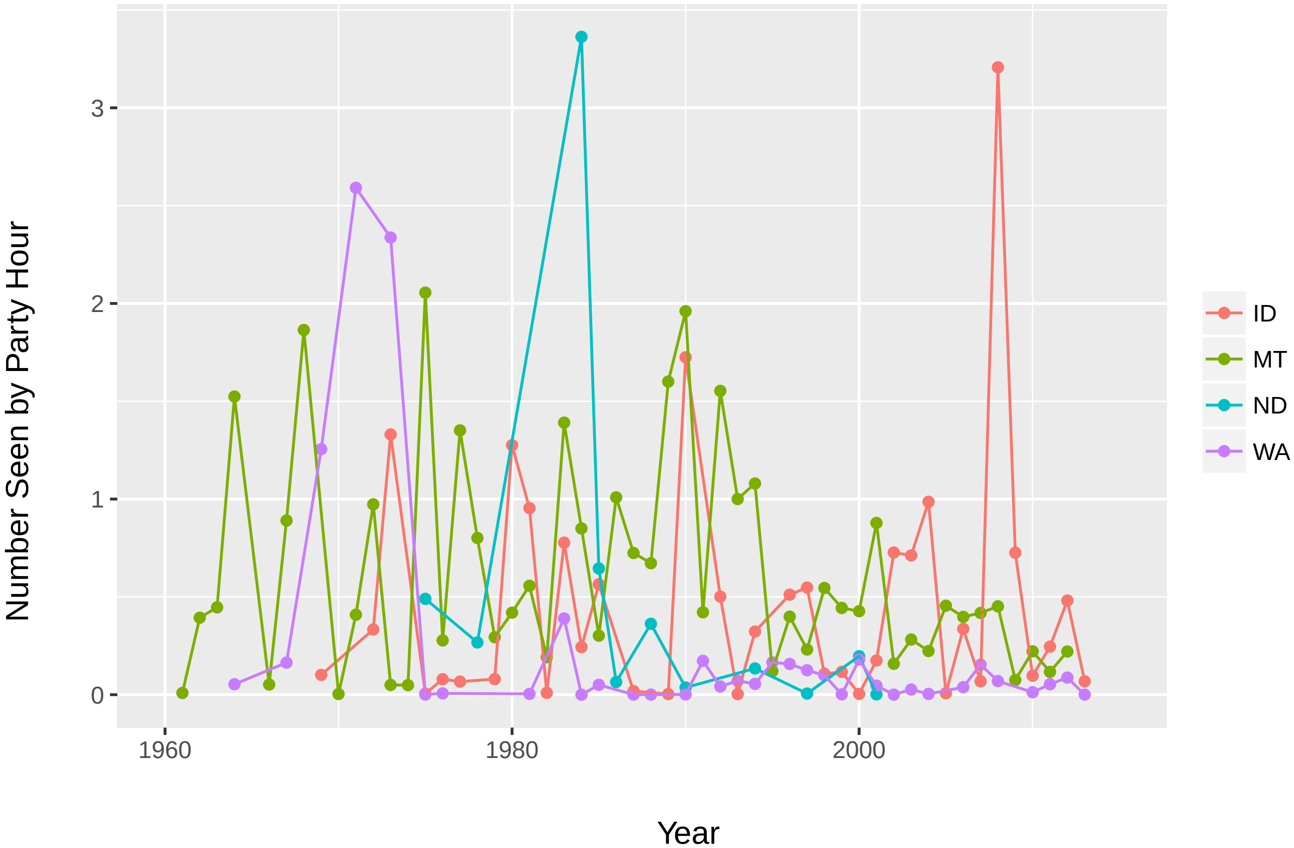


Figure 37: Gray-crowned Rosy-Finch abundance trends and area correlations across 1st (Canadian) latitudinal tier, CBC data.

Across the second latitudinal tier, CBC data show asynchronous abundance spikes of different magnitudes in different states. States do not show strong correlations with each other (Fig. 38).



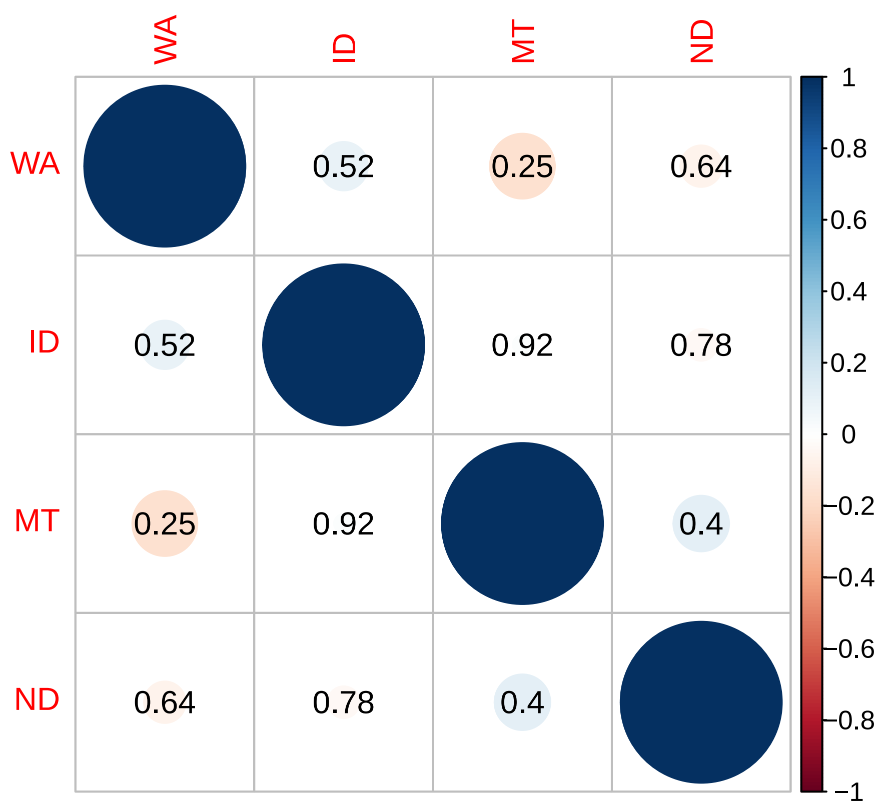
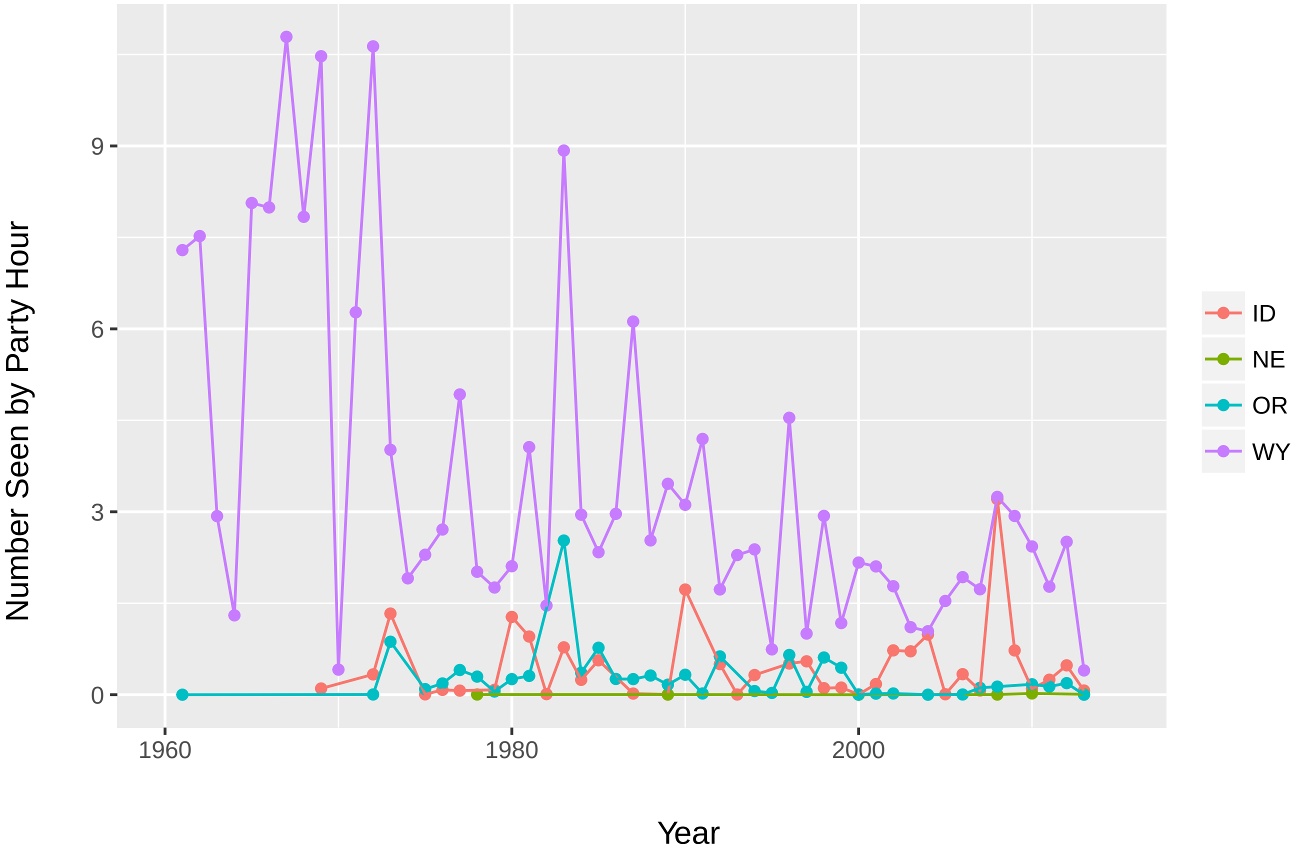


Figure 38: Gray-crowned Rosy-Finch abundance trends and area correlations across 2nd (northern US) latitudinal tier, CBC data.

In the third latitudinal tier, different states show somewhat similar timing in rises and falls in abundance, with occasional alternations in high abundances. Wyoming consistently having the highest records. There are few correlations between these states (Fig. 39).



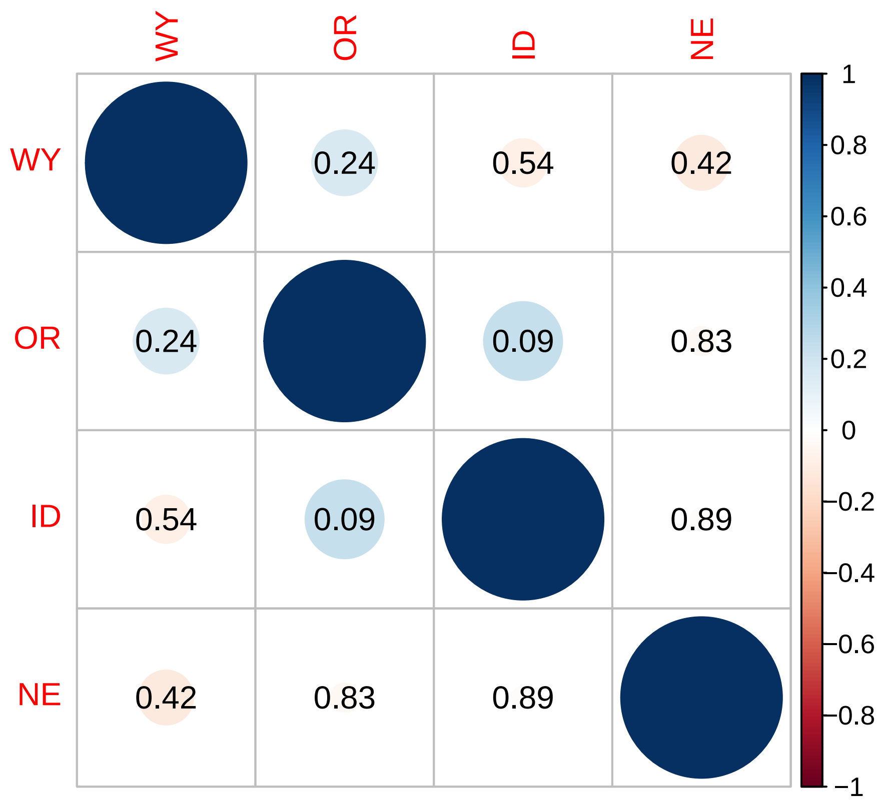
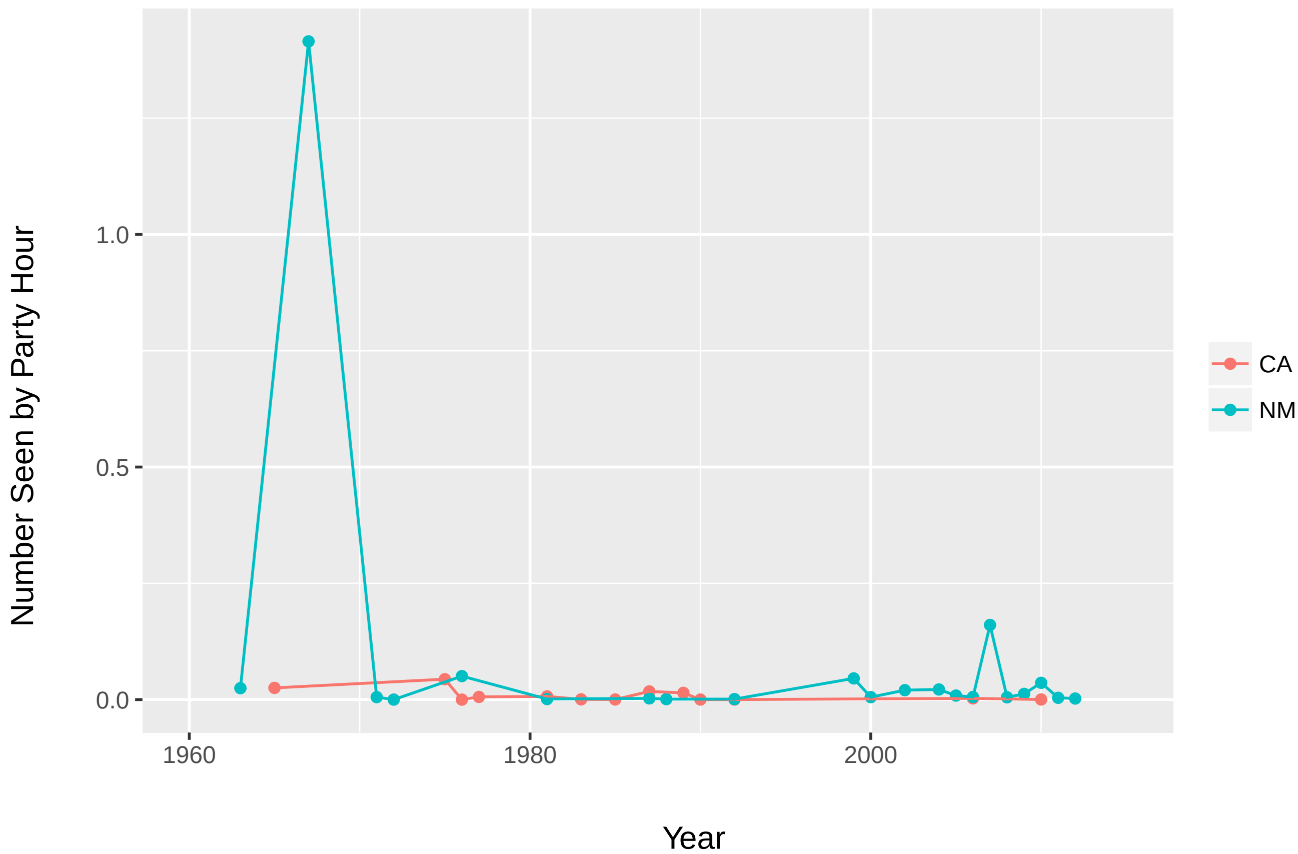


Figure 39: Gray-crowned Rosy-Finch abundance trends and area correlations across 3rd (mid US) latitudinal tier, CBC data.

Both states in the southernmost latitudinal tier show few Christmas Birdcount Records of Gray-crowned Rosy-Finches, and the records in the two states do not show a significant correlation with each other (Fig. 40).



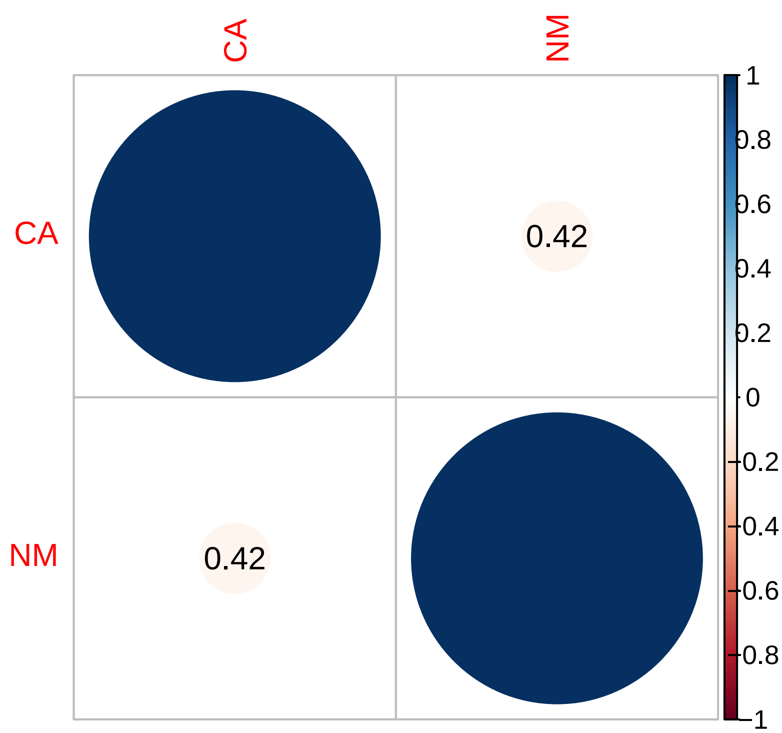


Figure 40: Gray-crowned Rosy-Finch abundance trends and area correlations across 4th (southern US) latitudinal tier, CBC data.

Due to lack of data, I excluded the first and second longitudinal tiers from analyses. Along the third longitudinal tier, different areas show synchronous rises and falls in abundance, with Wyoming consistently having the highest numbers. The records in a few areas show significant positive correlations with the records in other areas (Fig. 41).

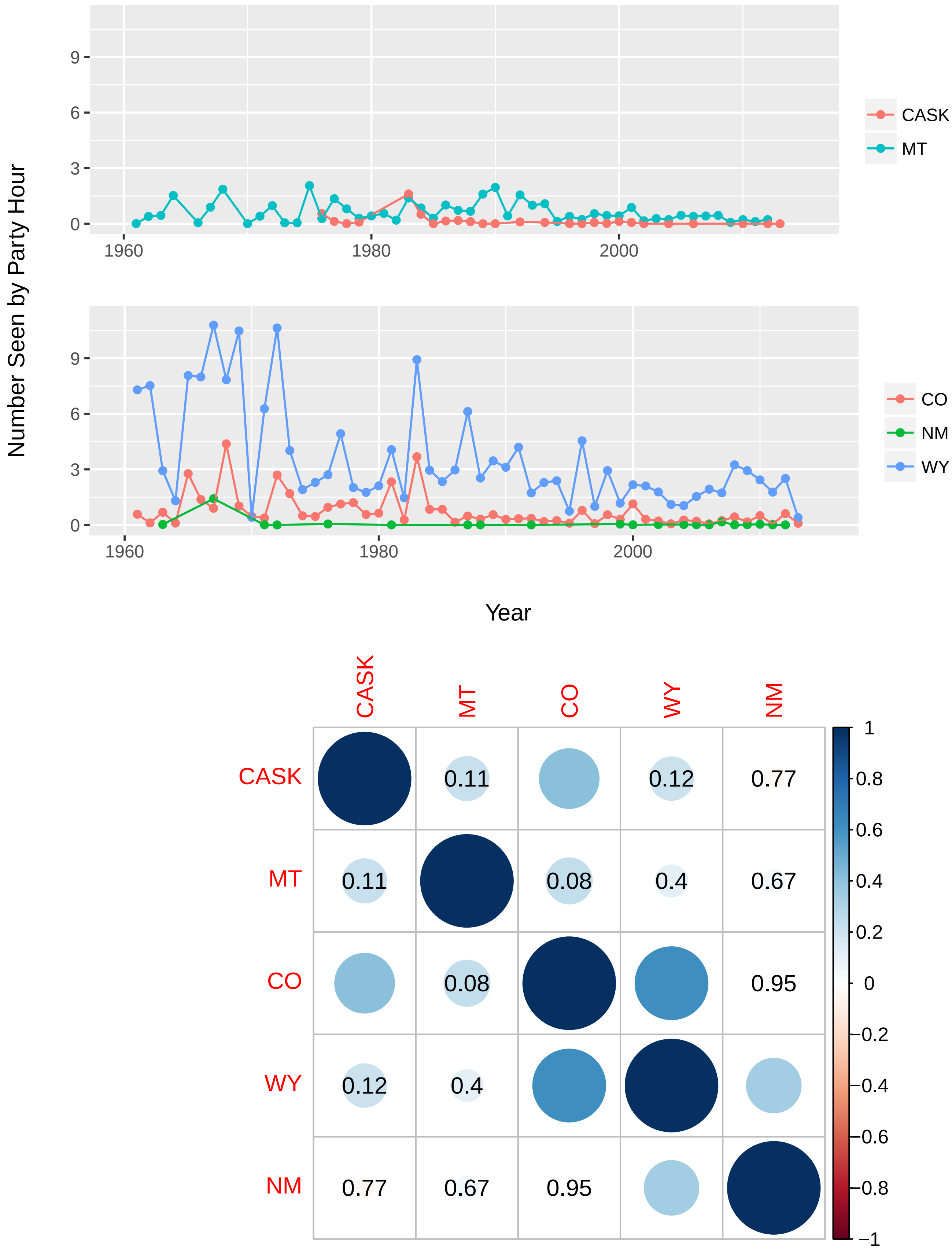


Figure 41: Gray-crowned Rosy-Finch abundance trends and area correlations across 3rd (Rocky Mountains) longitudinal tier, CBC data.

In the fourth longitudinal tier, there are few relationships between abundance trends of Gray-crowned Rosy-Finches in different areas, with Alaska showing a negative correlation in rises and falls in abundance with Oregon (Fig. 42).

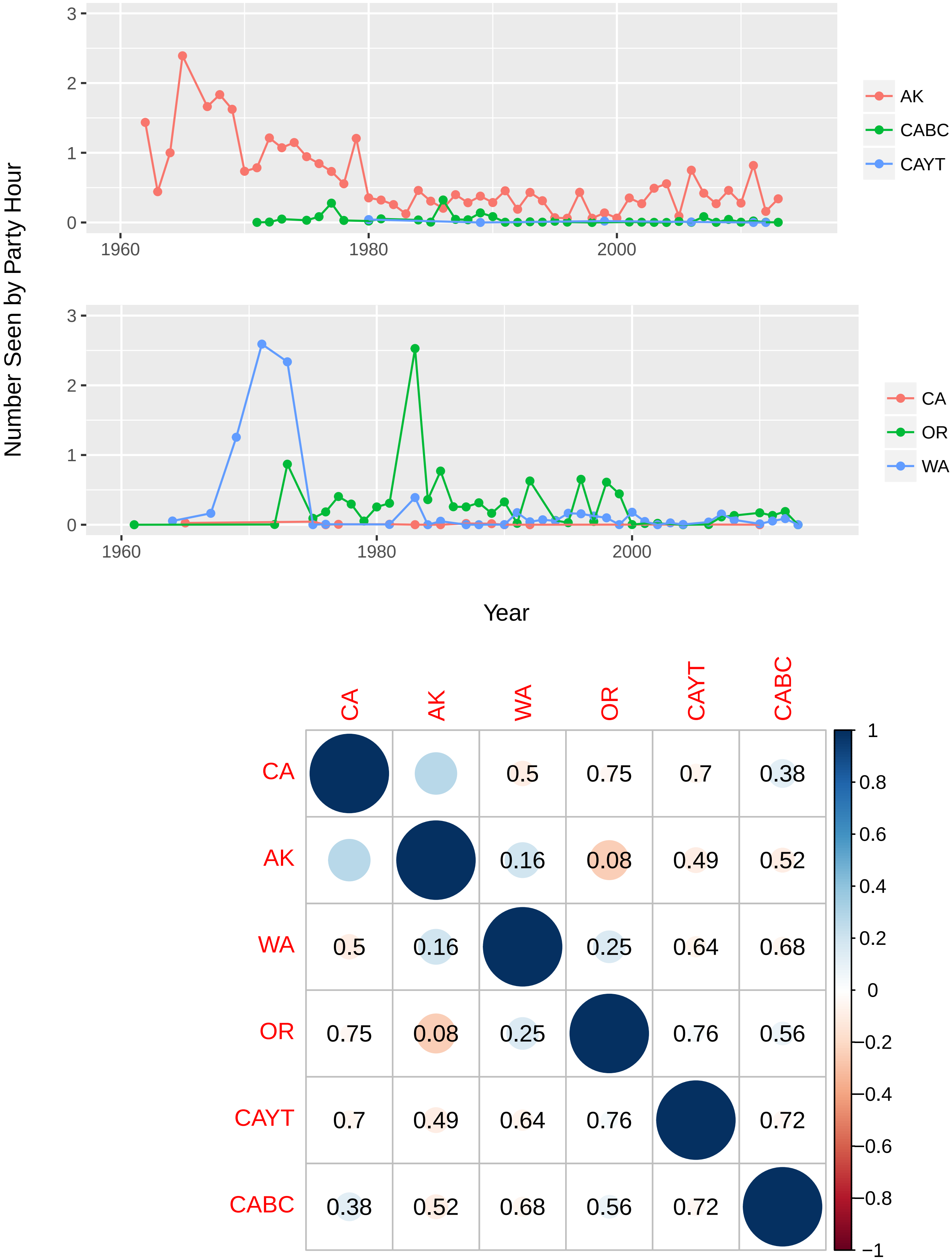


Figure 42: Gray-crowned Rosy-Finch abundance trends and area correlations across 4th (Pacific) longitudinal tier, CBC data.

eBird Analyses

Across the first latitudinal tier, daily eBird records show few correlations between different provinces and between different years (Fig. 43).

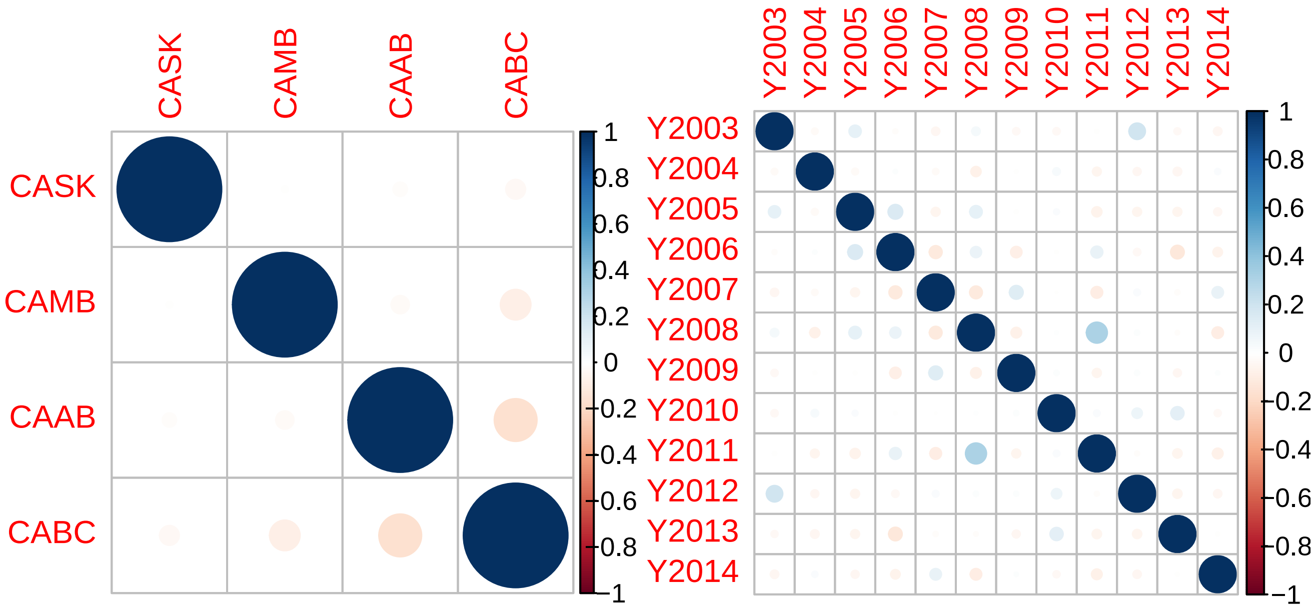


Figure 43: Correlations of Gray-crowned Rosy-Finch invasion pattern between individual areas and between years for the 1st (Canadian) latitudinal tier, eBird data.

Across the second latitudinal tier, daily eBird records show few correlations between different areas and between different years (Fig. 44).

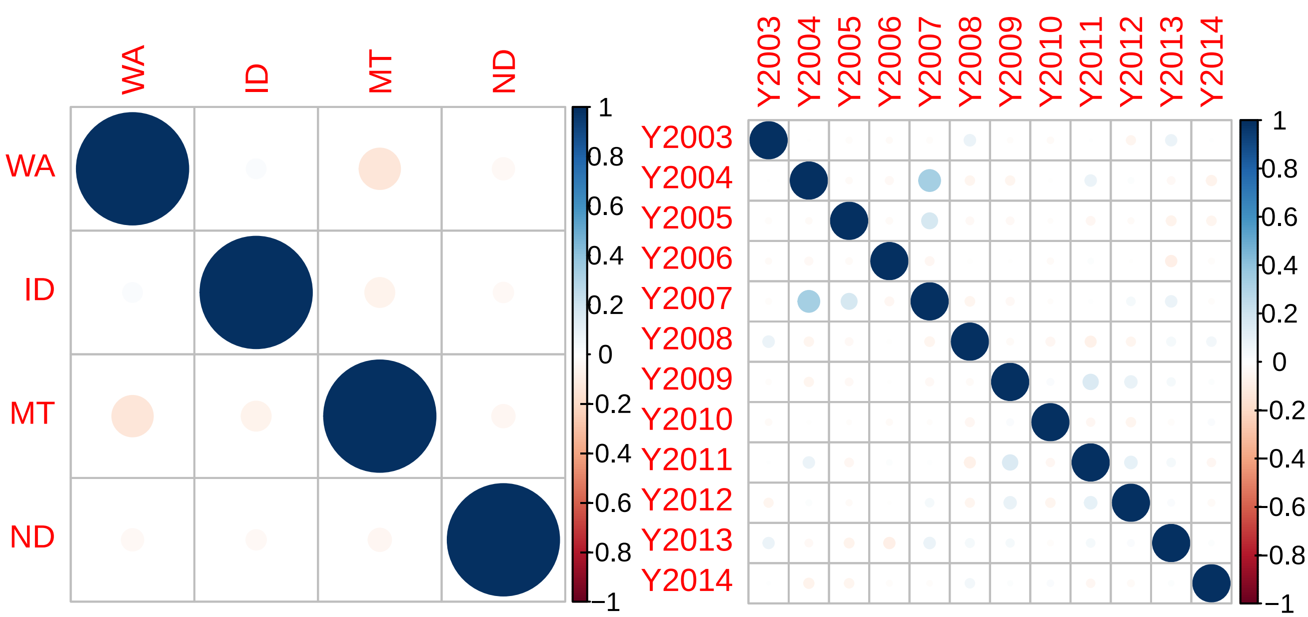


Figure 44: Correlations of Gray-crowned Rosy-Finch invasion pattern between individual areas and between years for the 2nd (northern US) latitudinal tier, eBird data.

Across the third latitudinal tier, daily eBird records show a moderately strong positive correlation between Wyoming and Nebraska, and few correlations between different years (Fig. 45).

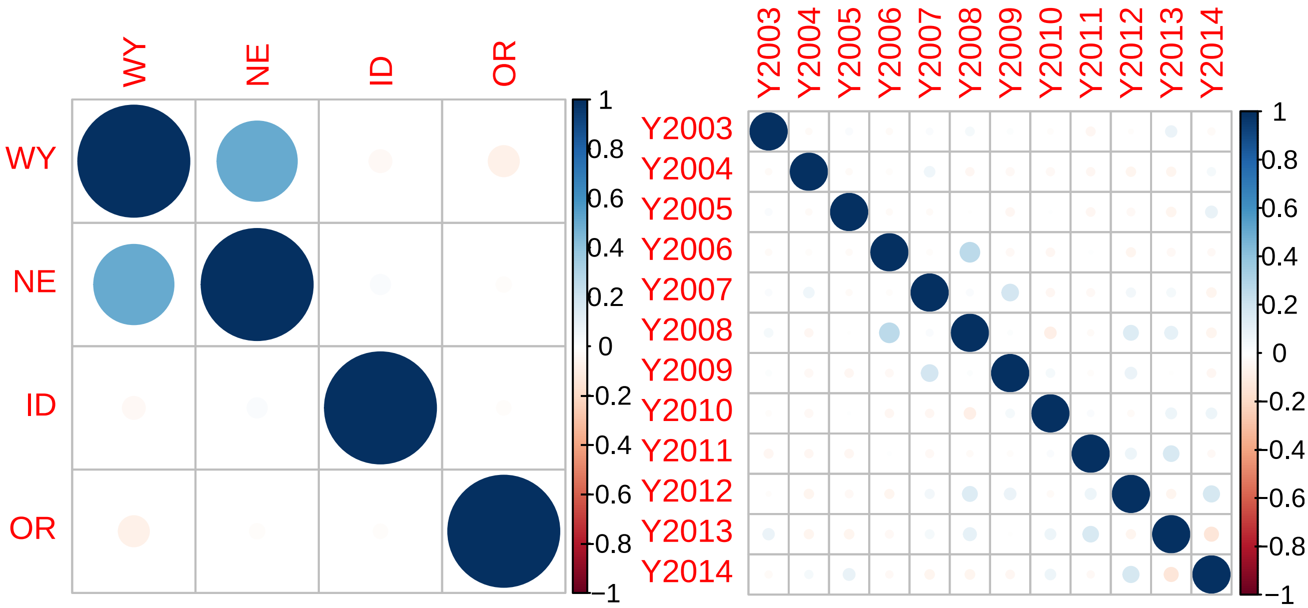


Figure 45: Correlations of Gray-crowned Rosy-Finch invasion pattern between individual areas and between years for the 3rd (mid US) latitudinal tier, eBird data.

Across the fourth latitudinal tier, daily eBird records show a weak negative correlation between the two included states, and few correlations between different years (Fig. 46).

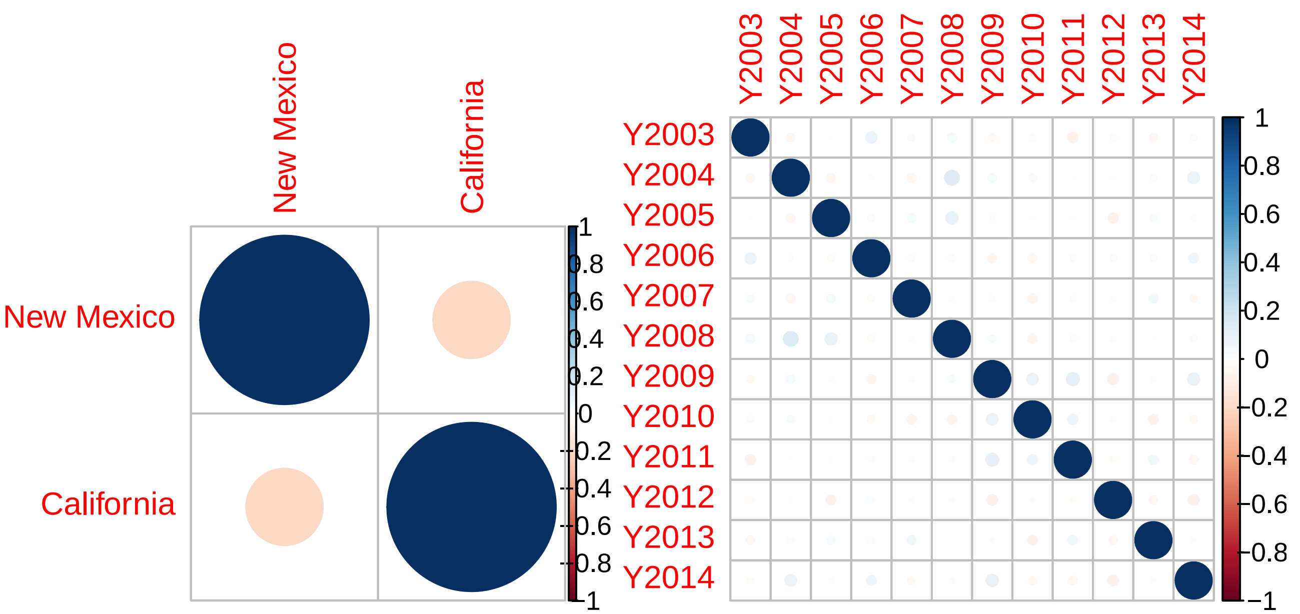


Figure 46: Correlations of Gray-crowned Rosy-Finch invasion pattern between individual areas and between years for the 4th (southern US) latitudinal tier, eBird data.

Across the third longitudinal tier, daily eBird records show few correlations between different areas and between different years (Fig. 47).

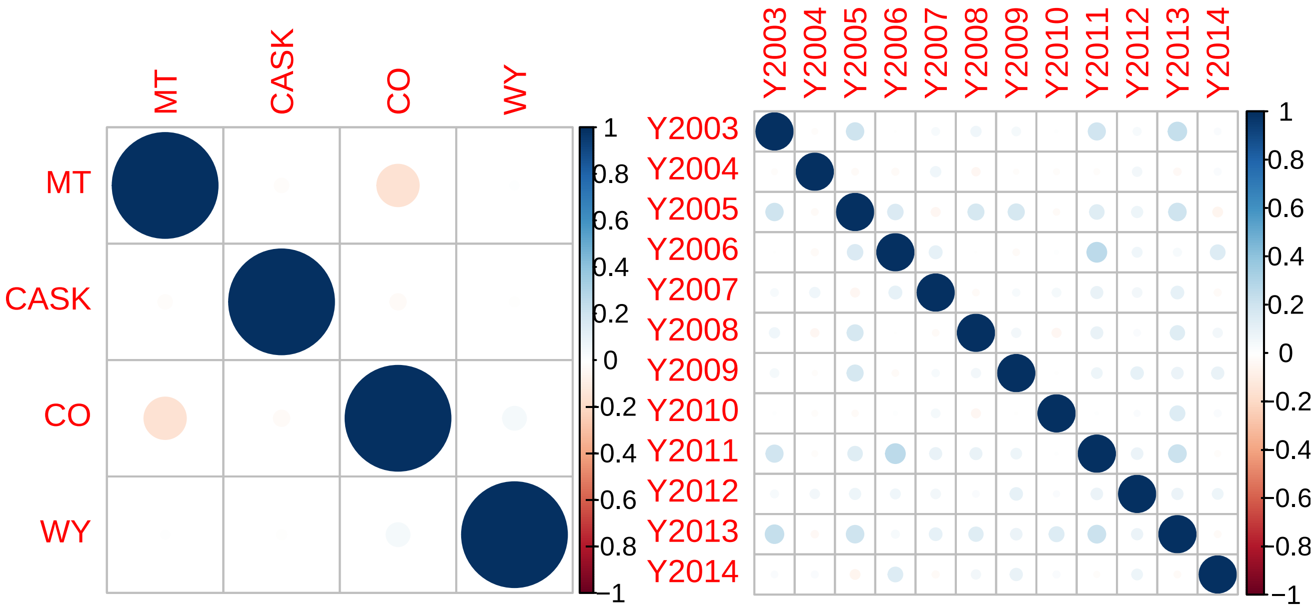


Figure 46: Correlations of Gray-crowned Rosy-Finch invasion pattern between individual areas and between years for the 4th (southern US) latitudinal tier, eBird data.

Across the fourth longitudinal tier, daily eBird records show few correlations between different areas, with several weak positive correlations between recent years (Fig. 48).

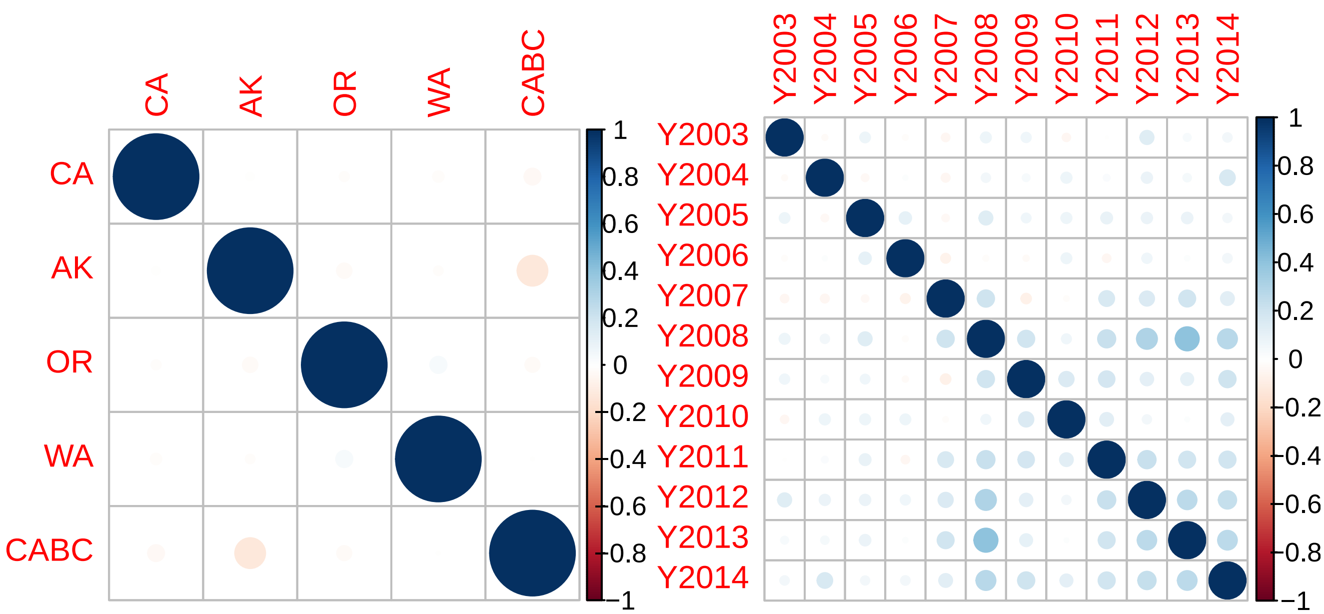


Figure 48: Correlations of Gray-crowned Rosy-Finch invasion pattern between individual areas and between years for the 4th (Pacific) longitudinal tier, eBird data.

Cassin’s Finch

CBC Analyses

Christmas Bird Count data since 1960 show the highest numbers of Cassin’s Finches in areas that contain the Rocky Mountains (Fig. 49).

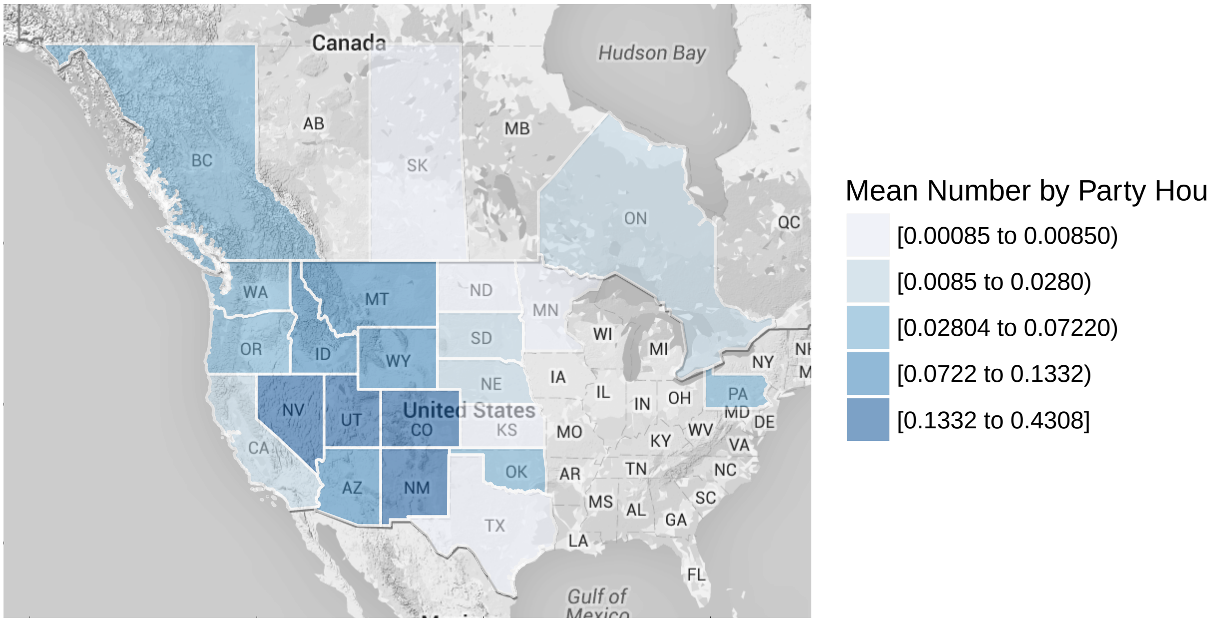


Figure 49: Cassin’s Finch abundance by area, CBC data.

Christmas Bird Count data since 1960 show the highest variation in Cassin's Finch numbers occurs in the southeast and northwest parts of the species' winter range (Fig. 50).

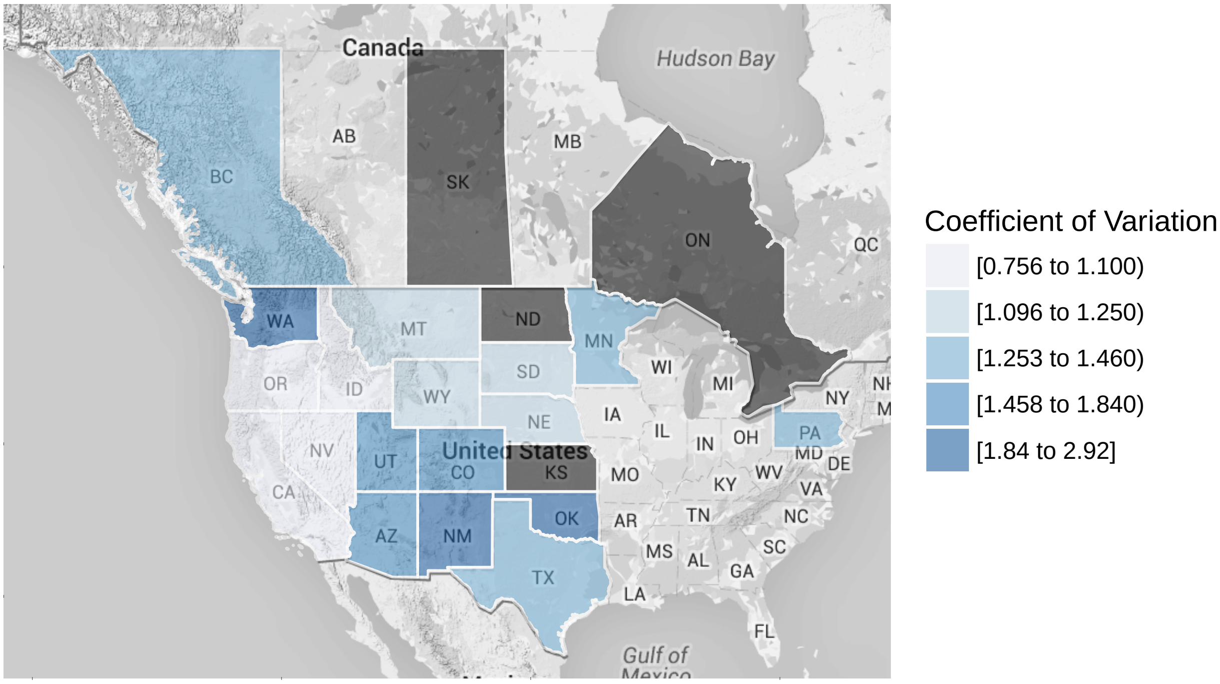


Figure 50: Coefficient of variation for Cassin's Finch abundance by area, CBC data.

In the first latitudinal tier, British Columbia is the only province with consistent CBC records of Cassin's Finches during the study period (Fig. 51).

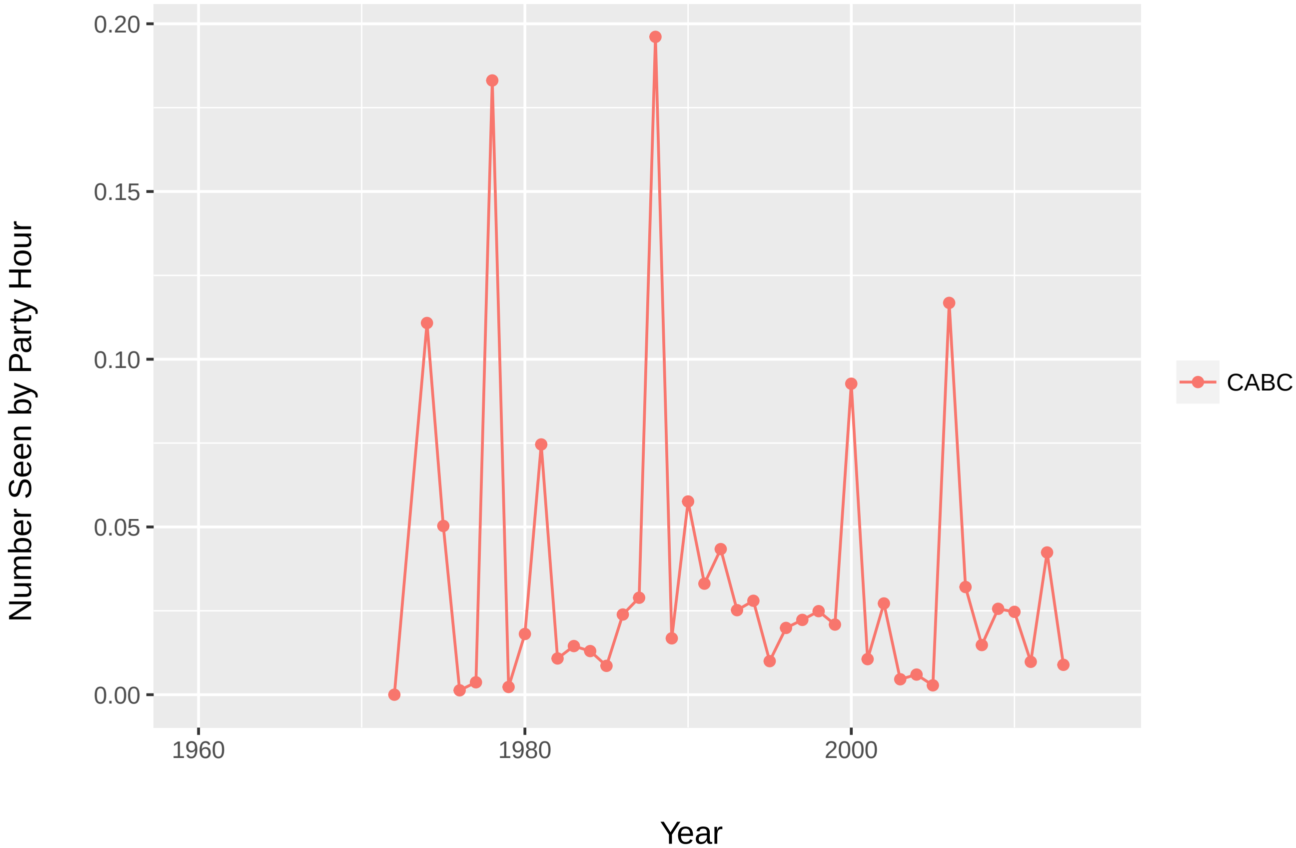
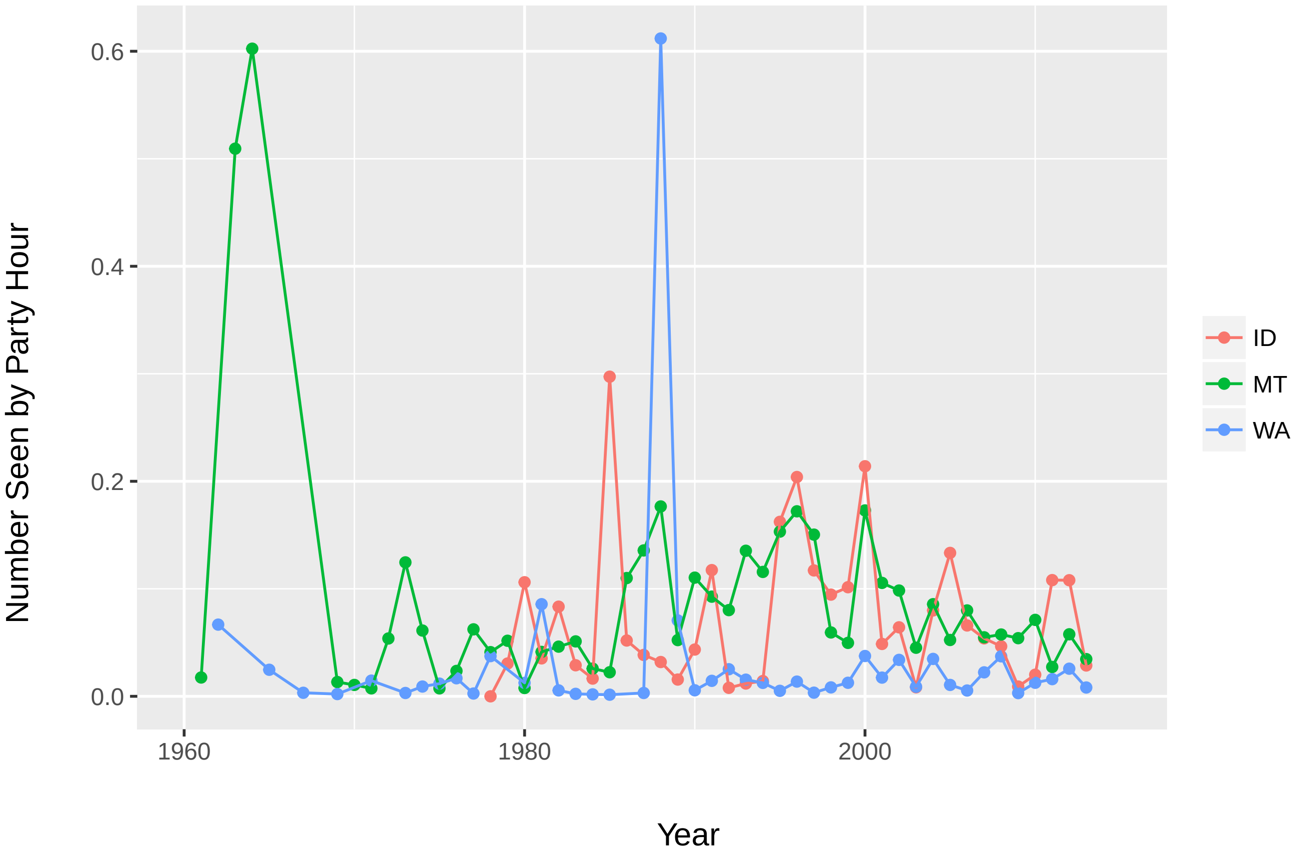


Figure 51: Cassin's Finch abundance trends and area correlations across 1st (Canadian) latitudinal tier, CBC data.

In the second latitudinal tier, there are no relationships in the abundance trends of Cassin's Finches (Fig. 52).



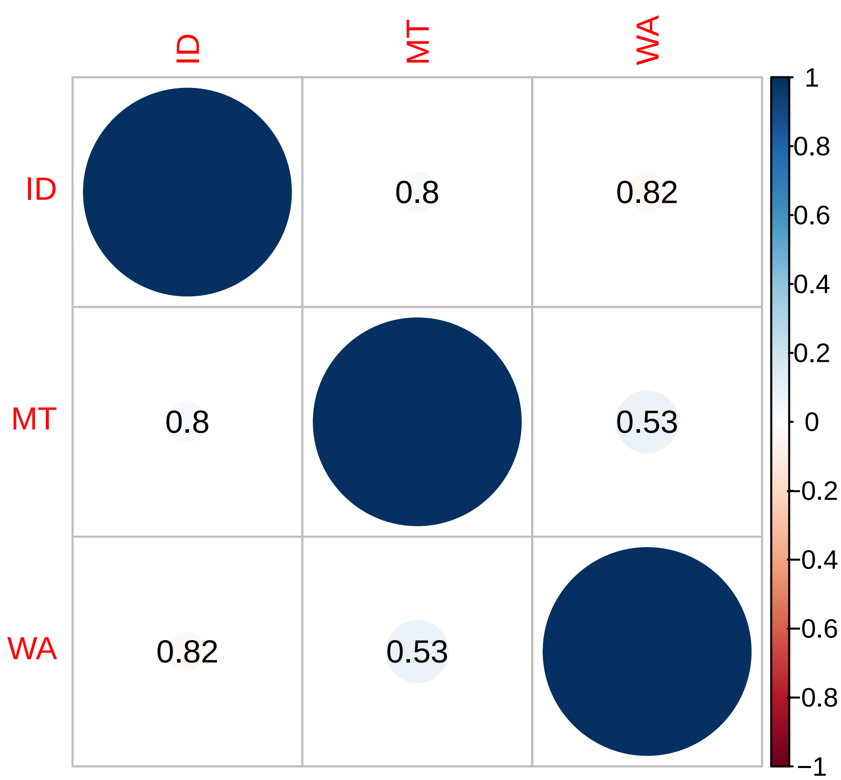


Figure 52: Cassin's Finch abundance trends and area correlations across 2nd (northern US) latitudinal tier, CBC data.

In the third latitudinal tier, different areas mostly show differently timed rises and falls in abundance, with a moderately strong positive correlation between Wyoming and Oregon (Fig. 53).

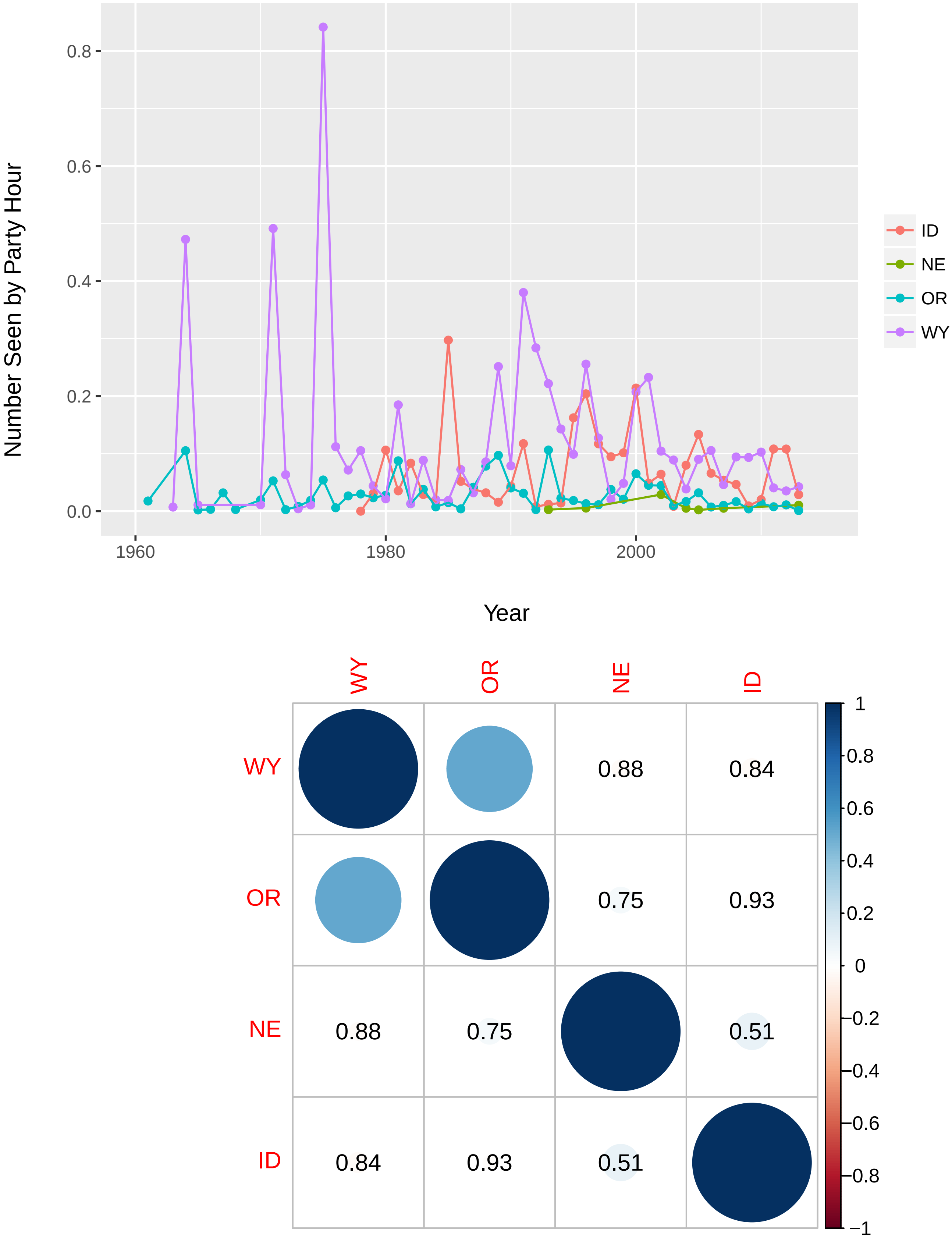


Figure 53: Cassin's Finch abundance trends and area correlations across 3rd (mid US) latitudinal tier, CBC data.

In the fourth latitudinal tier, only New Mexico and Arizona show sizeable abundance spikes during the study period. Most areas show moderate positive correlations with each other (Fig. 54).

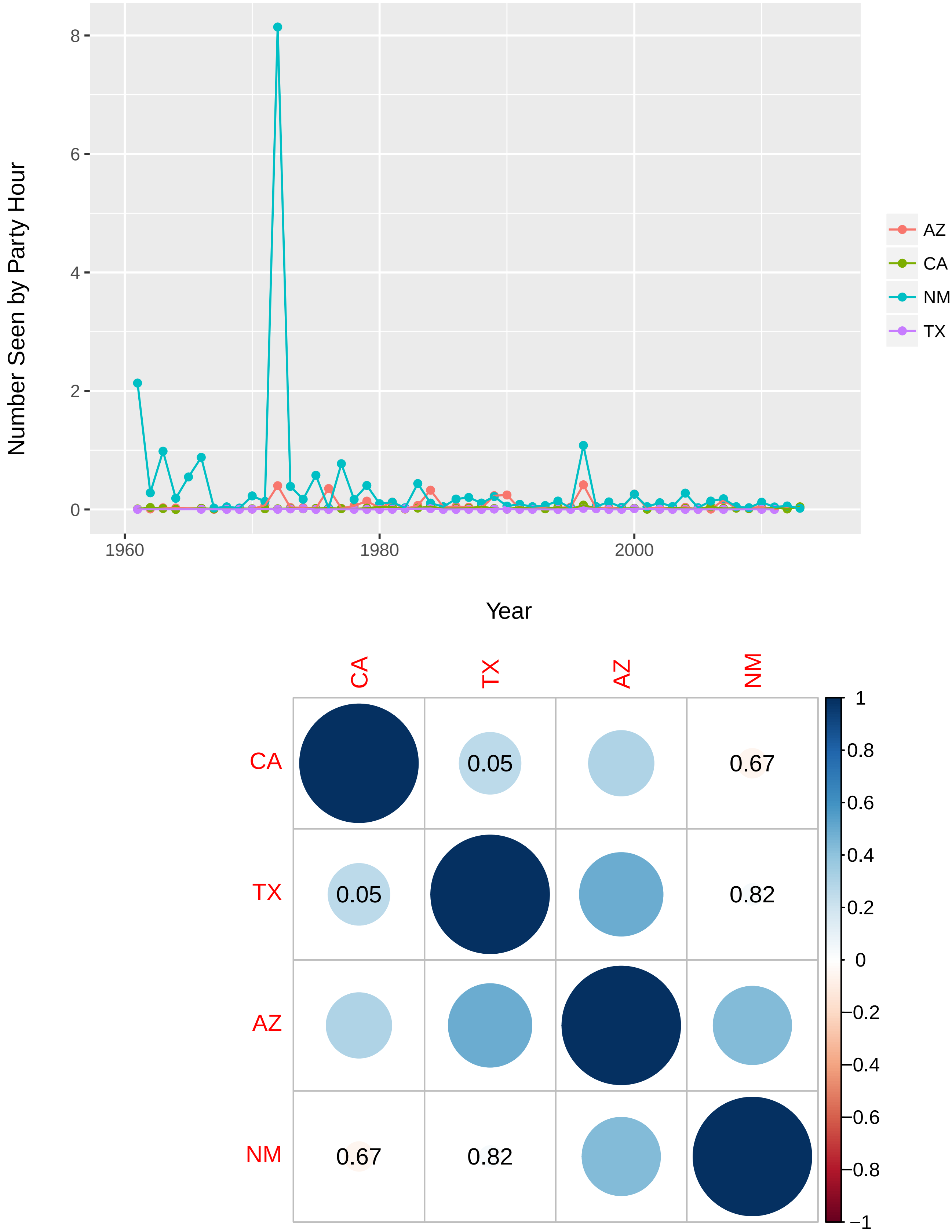


Figure 54: Cassin's Finch abundance trends and area correlations across 4th (southern US) latitudinal tier, CBC data.

Due to lack of data, I excluded the first and second longitudinal tiers from analyses. In the third longitudinal tier, there is a strong positive correlation between Cassin's Finch abundance trends in Colorado and Montana (Fig. 55).

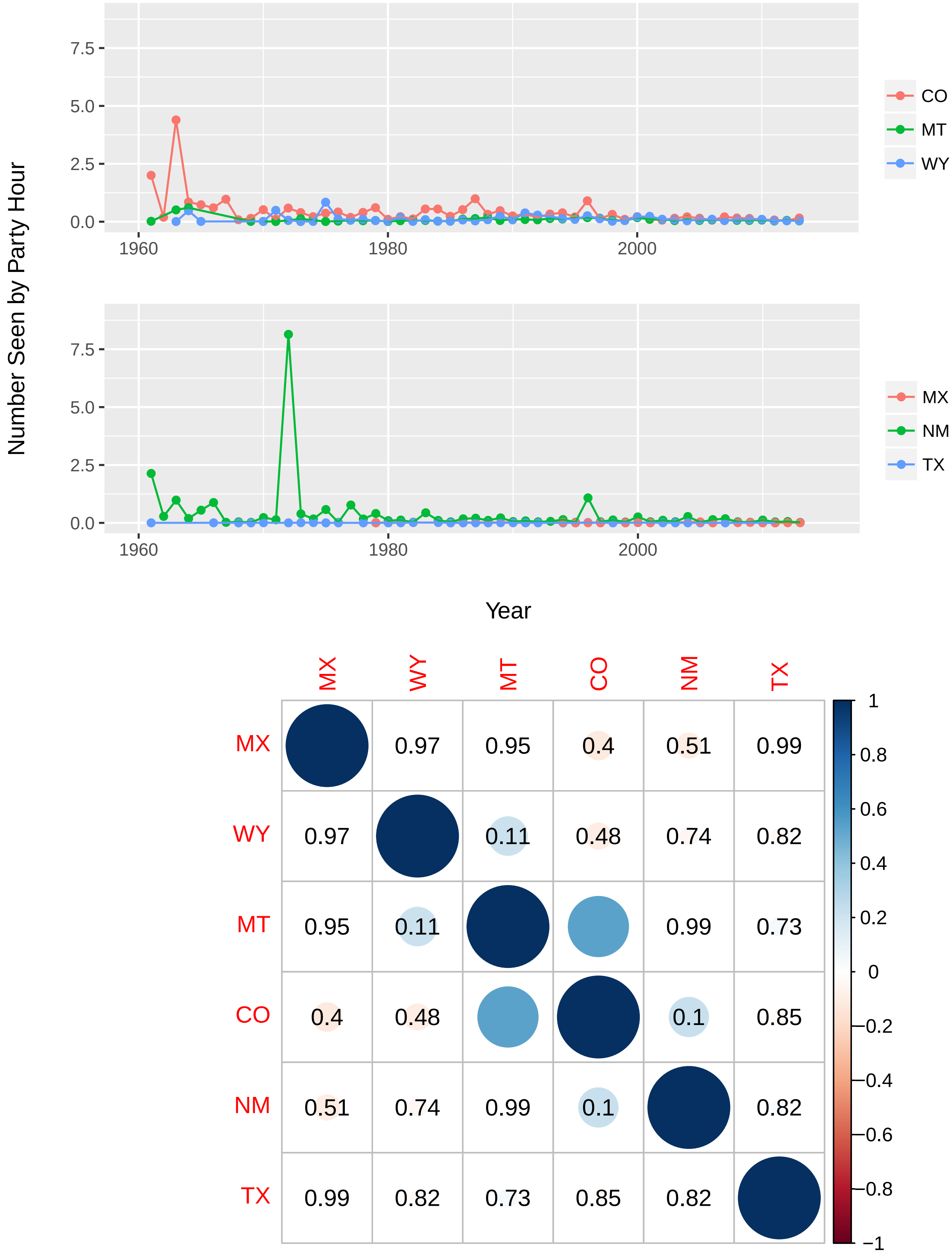


Figure 55: Cassin's Finch abundance trends and area correlations across 3rd (Rocky Mountains) longitudinal tier, CBC data.

In the fourth longitudinal tier, all areas with the exception of Mexico show weak to strong positive correlations with other (Fig. 56).

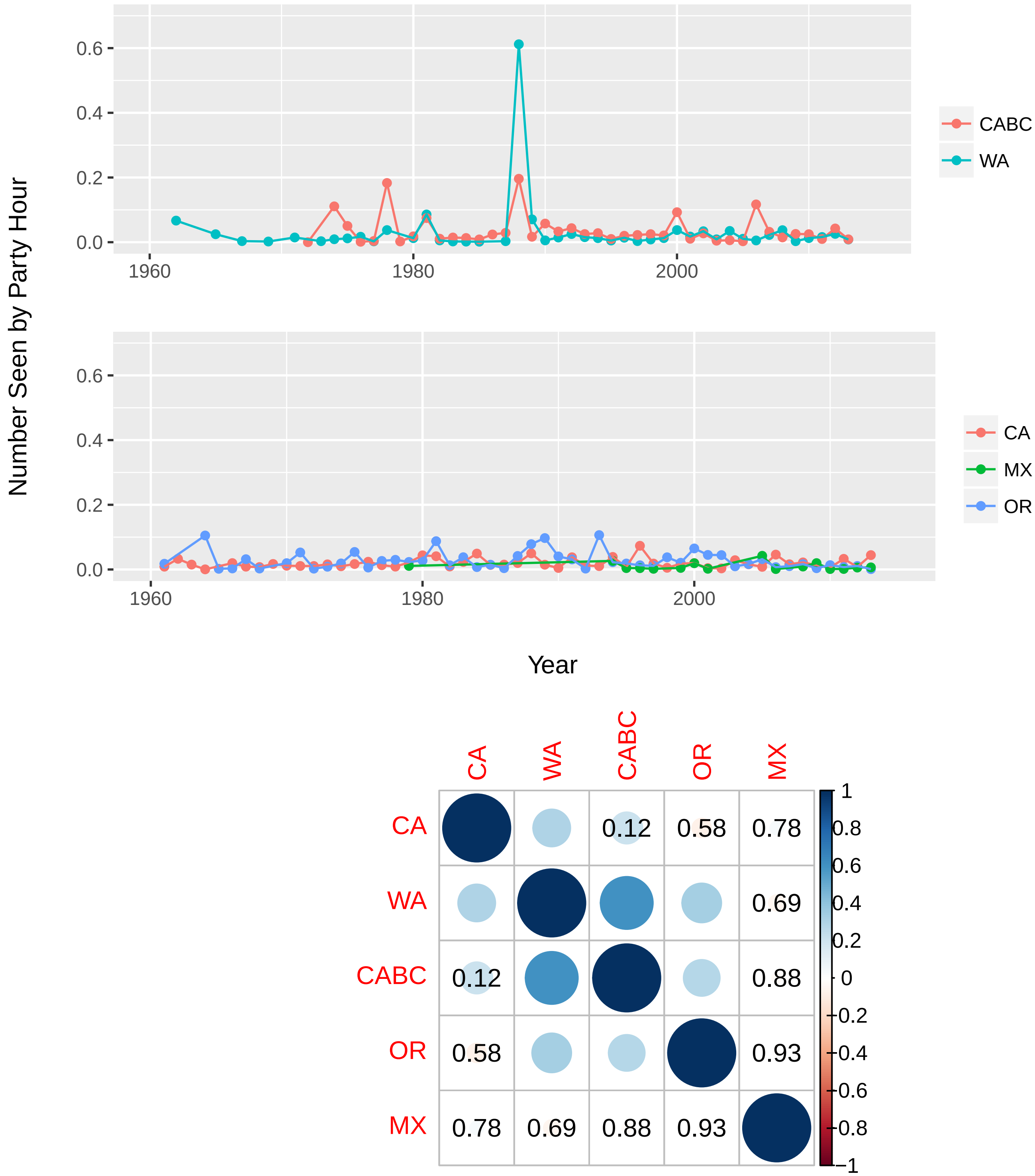


Figure 56: Cassin's Finch abundance trends and area correlations across 4th (Pacific) longitudinal tier, CBC data.

eBird Analyses

Across the second latitudinal tier, daily eBird data show moderate to strong positive correlations for Cassin's Finch abundance in the three included states and moderate to strong positive correlations between years. The most recent years show the strongest correlations with each other (Fig. 57).

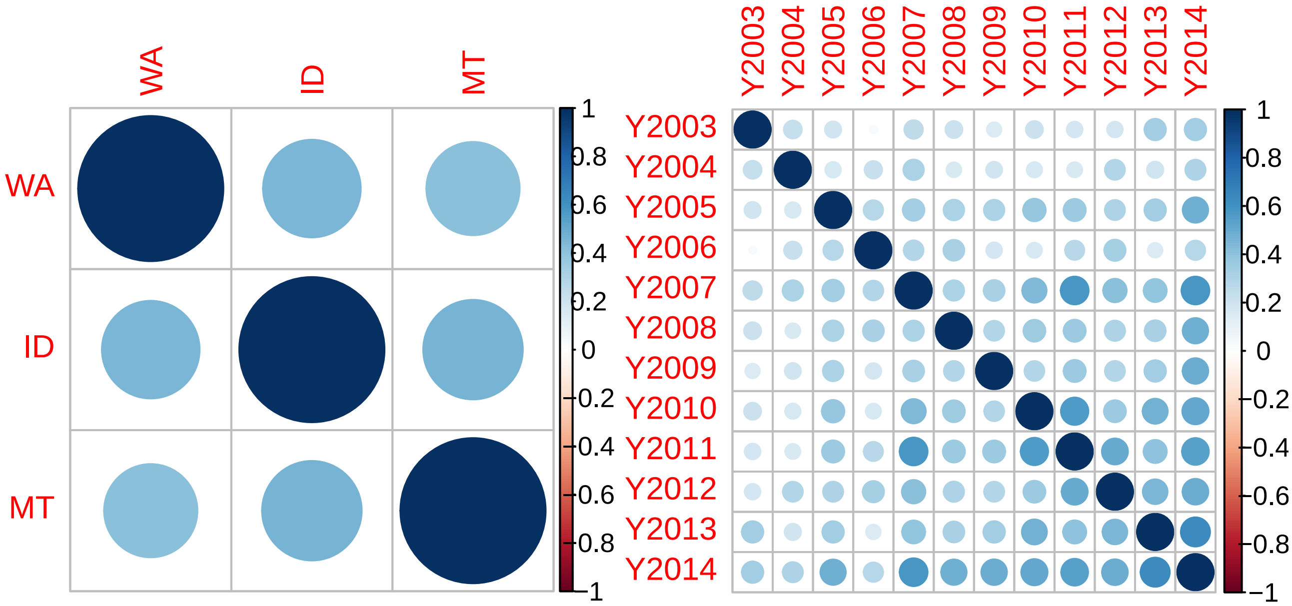


Figure 57: Correlations of Cassin's Finch invasion pattern between individual areas and between years for the 2nd (northern US) latitudinal tier, eBird data.

Across the third latitudinal tier, daily eBird data show several weak positive correlations between states, with weak to moderate positive correlations between recent years (Fig. 58).

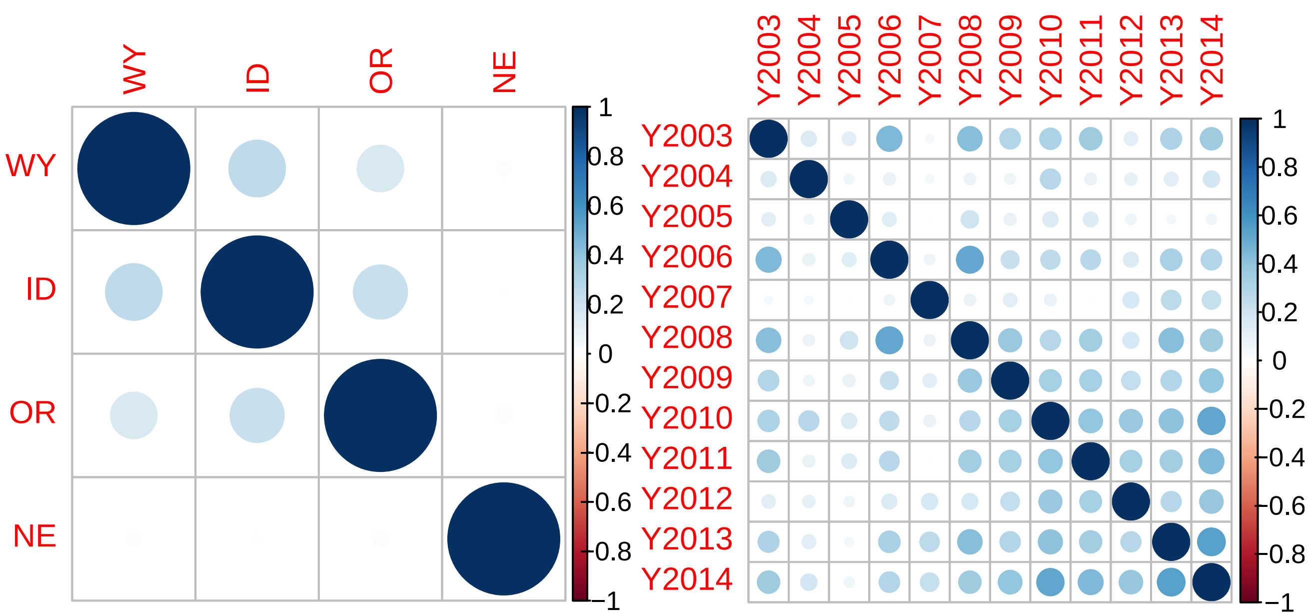


Figure 58: Correlations of Cassin's Finch invasion pattern between individual areas and between years for the 3rd (mid US) latitudinal tier, eBird data.

Across the fourth latitudinal tier, daily eBird data show several weak positive correlations between states, with weak positive correlations between recent years (Fig. 59).

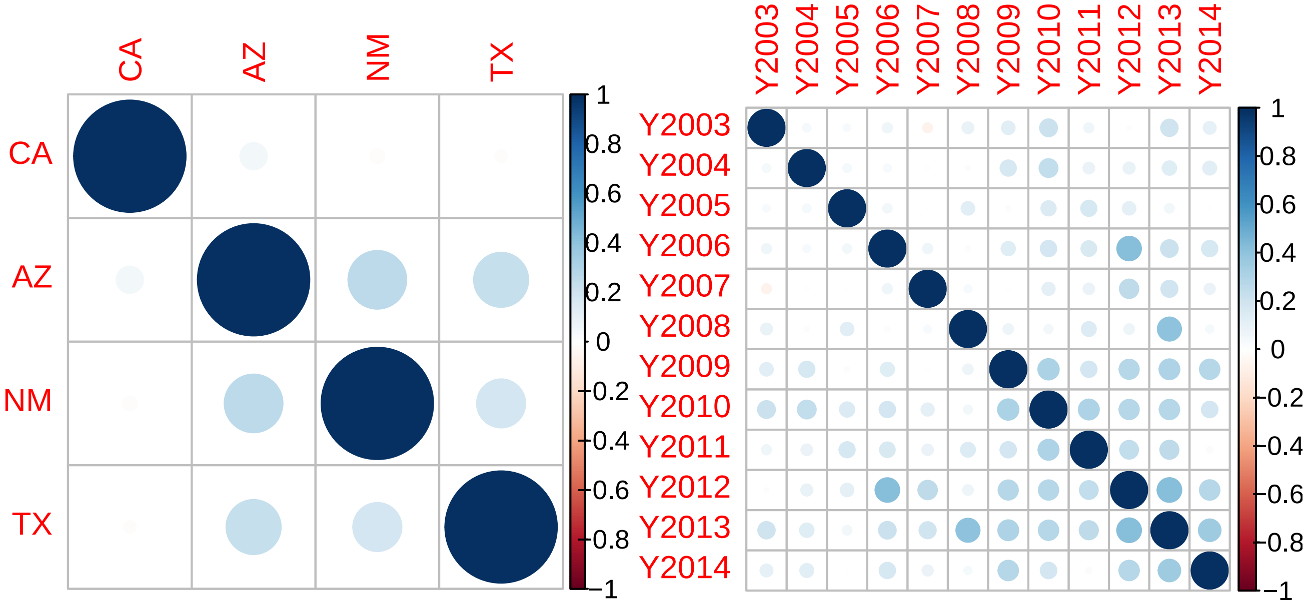


Figure 59: Correlations of Cassin's Finch invasion pattern between individual areas and between years for the 4th (southern US) latitudinal tier, eBird data.

Across the third longitudinal tier, daily eBird data show several weak positive correlations between states, with a moderately strong positive correlation between Wyoming and Montana. There are weak to moderate positive correlations between recent years (Fig. 60).

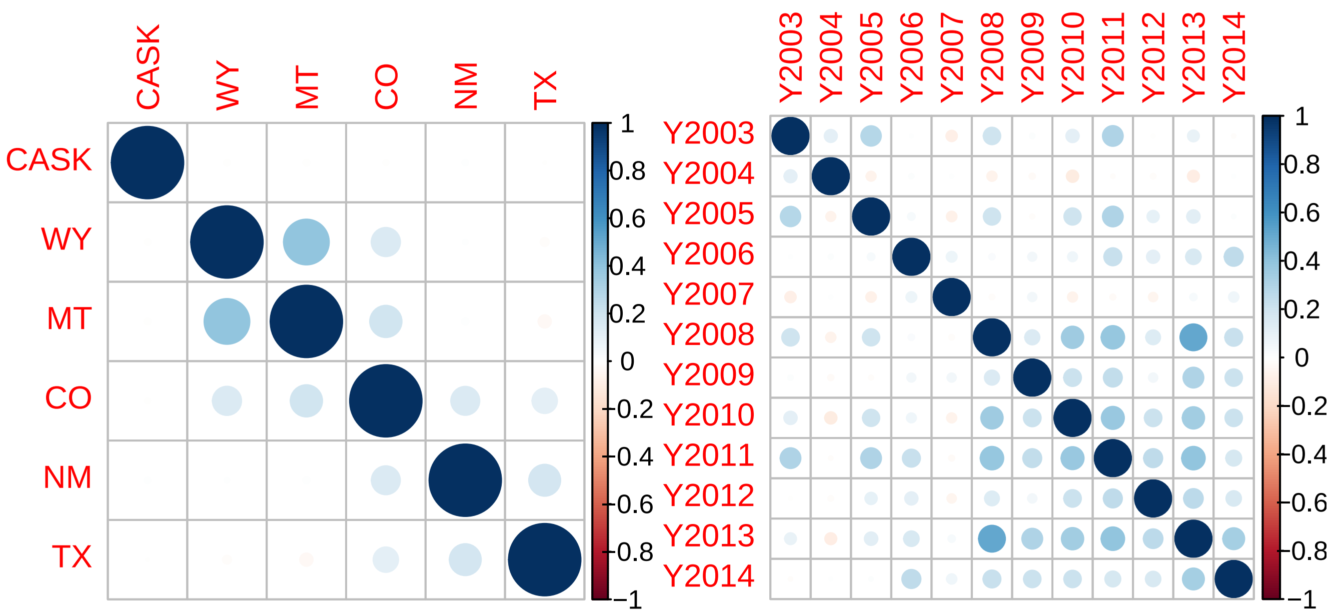


Figure 60: Correlations of Cassin's Finch invasion pattern between individual areas and between years for the 3rd (Rocky Mountains) longitudinal tier, eBird data.

Across the fourth longitudinal tier, daily eBird data show weak to moderate positive correlations between all states, and weak to strong positive correlations between years, with the strongest positive correlations between recent (Fig. 61).

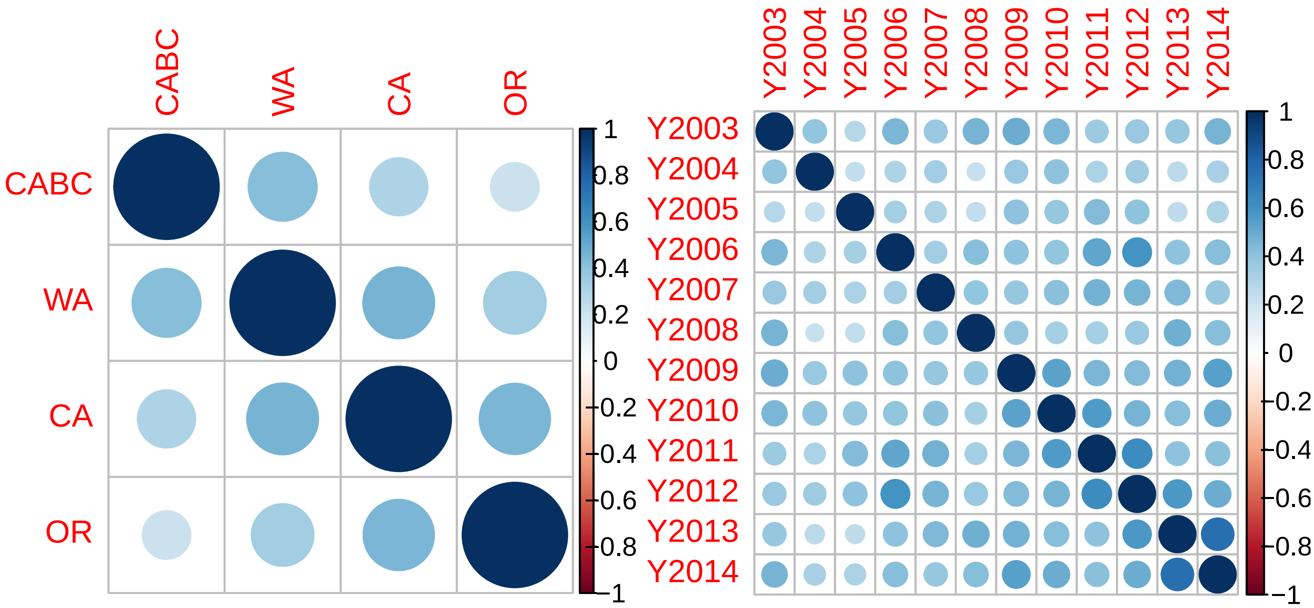


Figure 61: Correlations of Cassin's Finch invasion pattern between individual areas and between years for the 4th (Pacific) longitudinal tier, eBird data.

Purple Finch

CBC Analyses

The abundance and variance maps for the Purple Finch are distorted by its ongoing population trends. A high coefficient of variation occurs in areas of historic abundance and population declines, continued abundance and irruptive cycles, and areas of low abundance but occasional population spikes. The central United States, where distinct spikes occur but the winter population rarely reaches zero, appear least variable (Figs. 62 and 63).

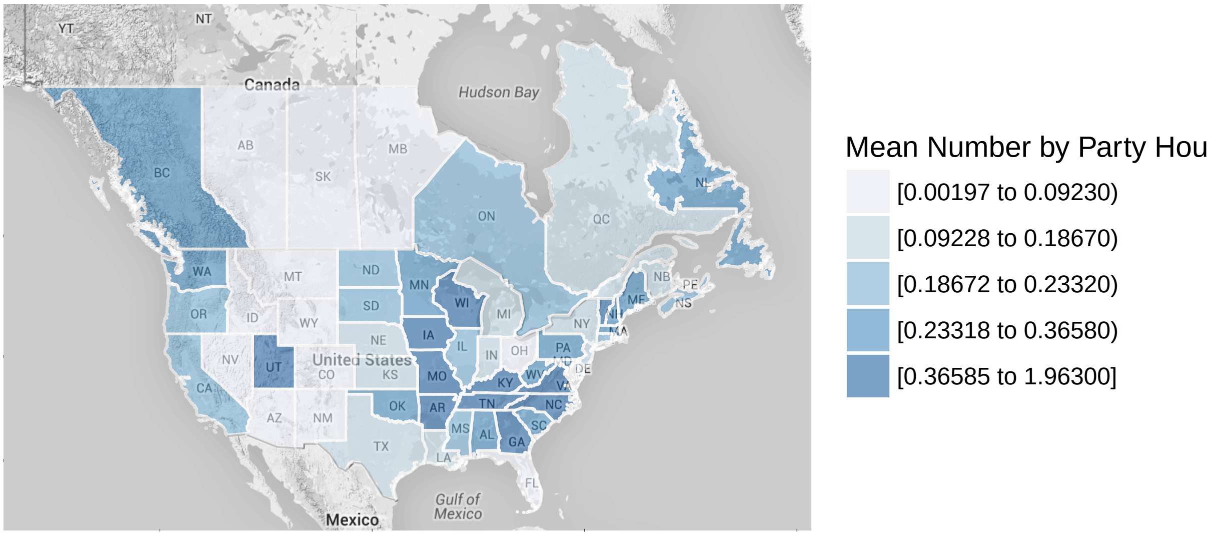


Figure 62: Purple Finch abundance by area, CBC data.

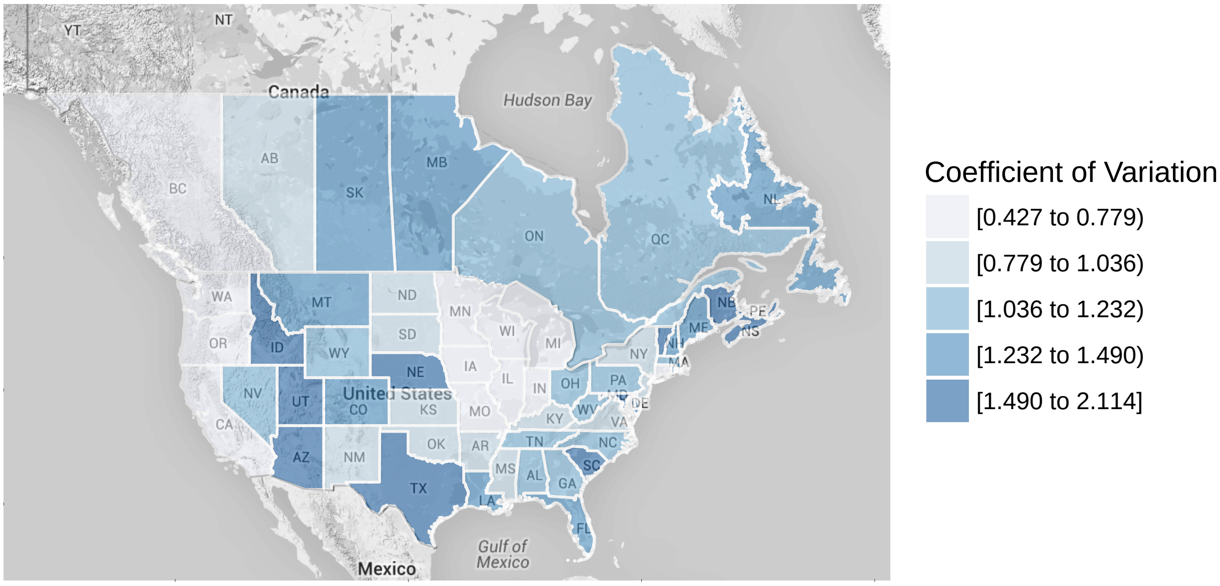


Figure 63: Coefficient of variation for Purple Finch abundance by area, CBC data.

Across the first latitudinal tier, CBC records show rises in abundance that are not concurrent in different provinces. The records for different provinces show few significant positive correlations (Fig. 64).

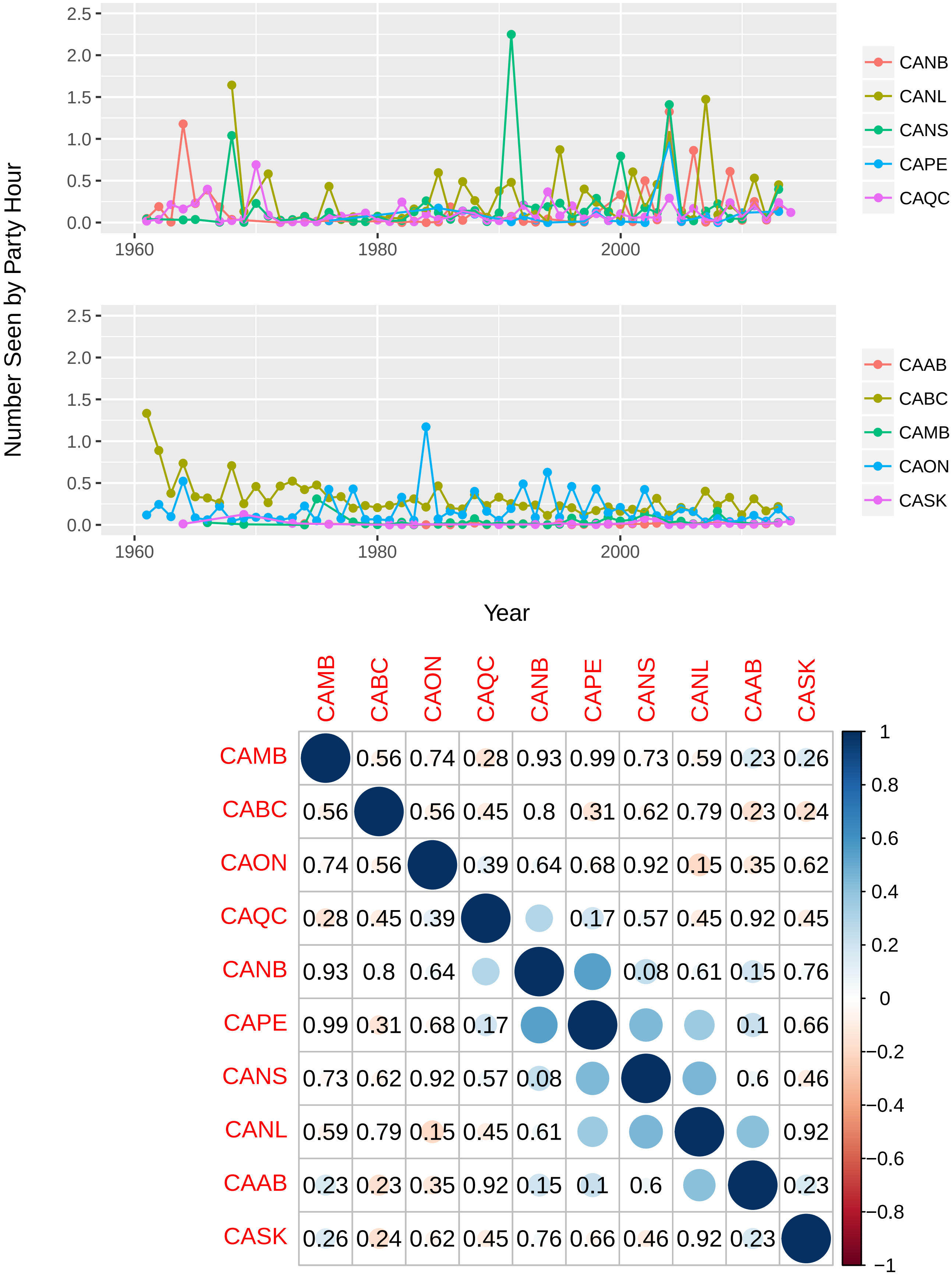


Figure 64: Purple Finch abundance trends and area correlations across 1st (Canadian) latitudinal tier, CBC data.

Across the Northern United States, CBC records appear to show more rises in abundance that are concurrent in different areas. However, the records for different areas show few significant positive correlations (Fig. 65).

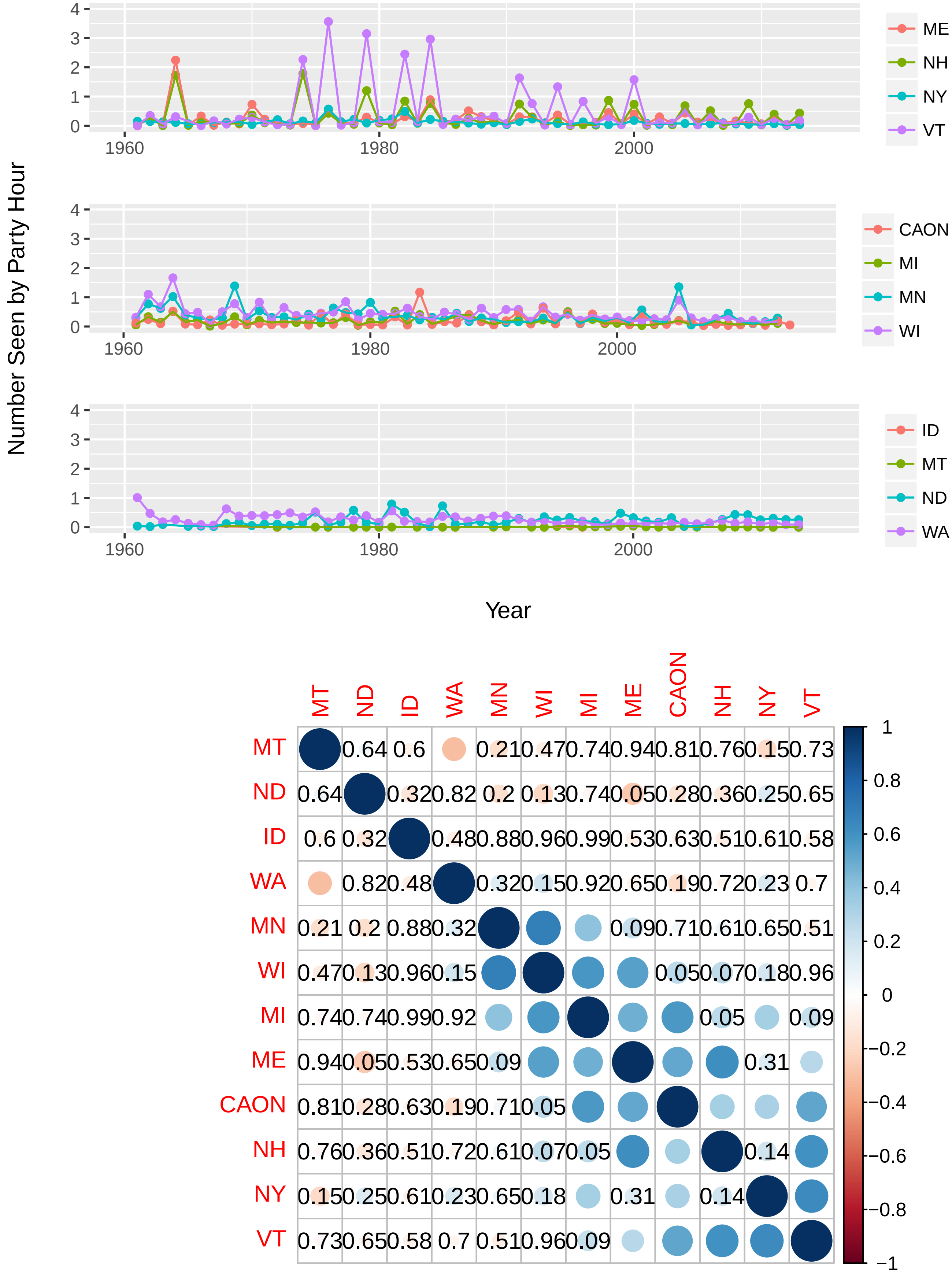


Figure 65: Purple Finch abundance trends and area correlations across 2nd (northern US) latitudinal tier, CBC data.

Across the mid United States, more areas show records that have strong positive correlations with each other (Fig. 66).

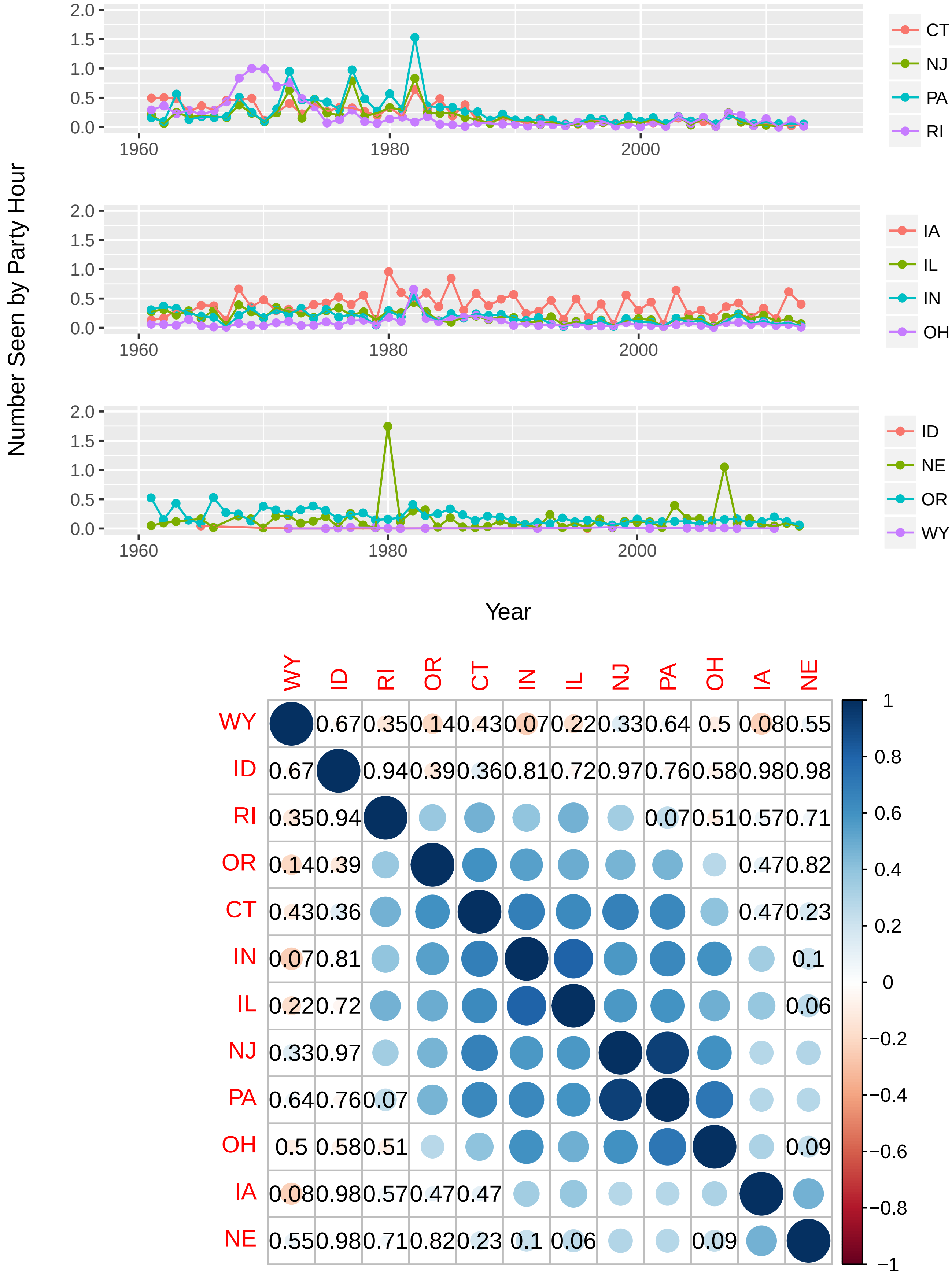


Figure 66: Purple Finch abundance trends and area correlations across 3rd (mid US) latitudinal tier, CBC data.

Across the southern United States, all areas with the exception of states in the southwest where Purple Finches do not usually occur show significant positive correlations with each other. Many states, especially those in the east, show declines in abundance over time (Fig. 67).

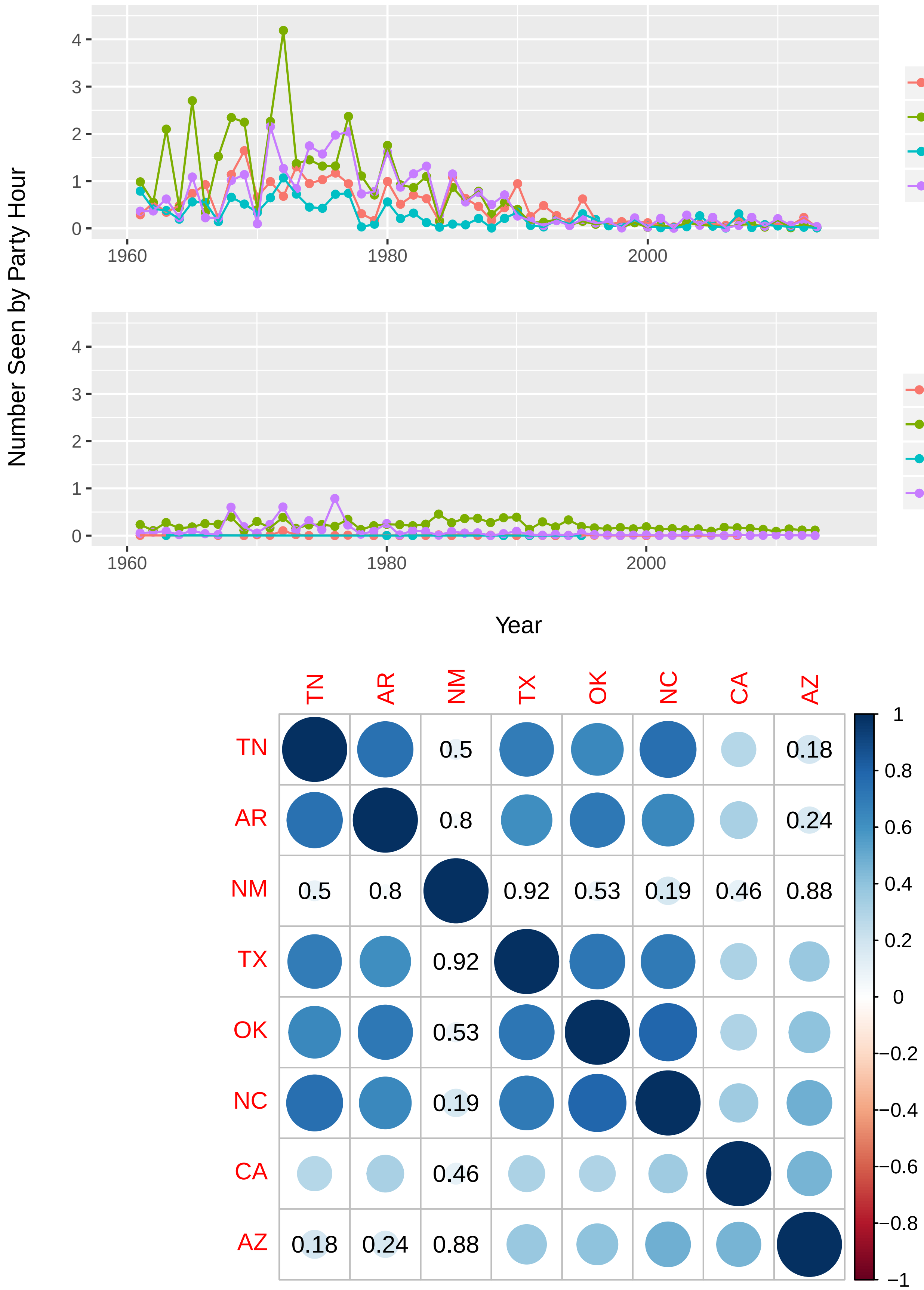


Figure 67: Purple Finch abundance trends and area correlations across 4th (southern US) latitudinal tier, CBC data.

Across the first longitudinal tier, only areas in the south to mid United States show significant positive correlations in CBC records (Fig. 68).

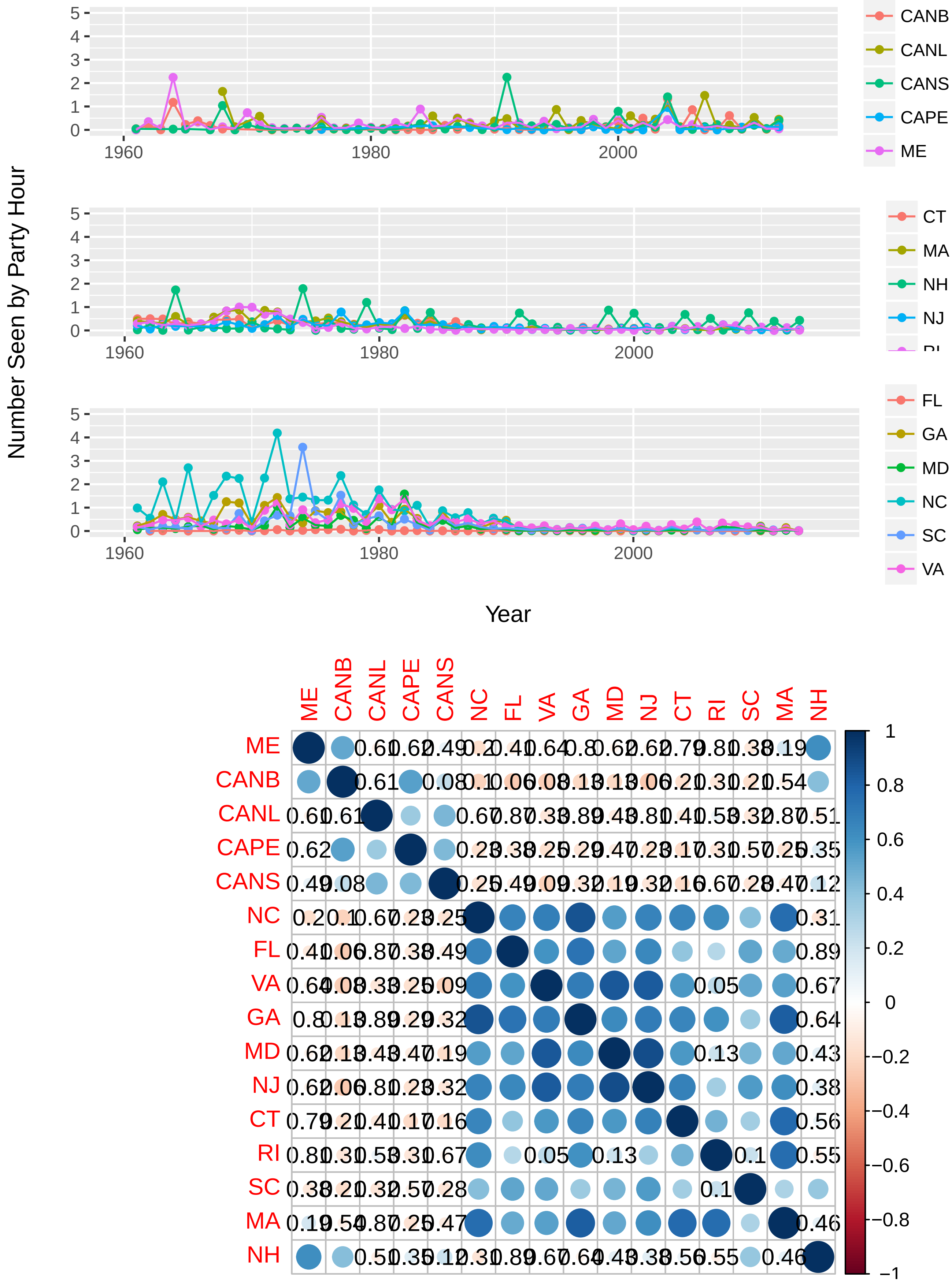


Figure 68: Purple Finch abundance trends and area correlations across 1st (Atlantic) longitudinal tier, CBC data.

In the second longitudinal tier, different areas show some alternation in abundance spikes over time. States in the south show significant positive correlations in CBC records (Fig. 69).

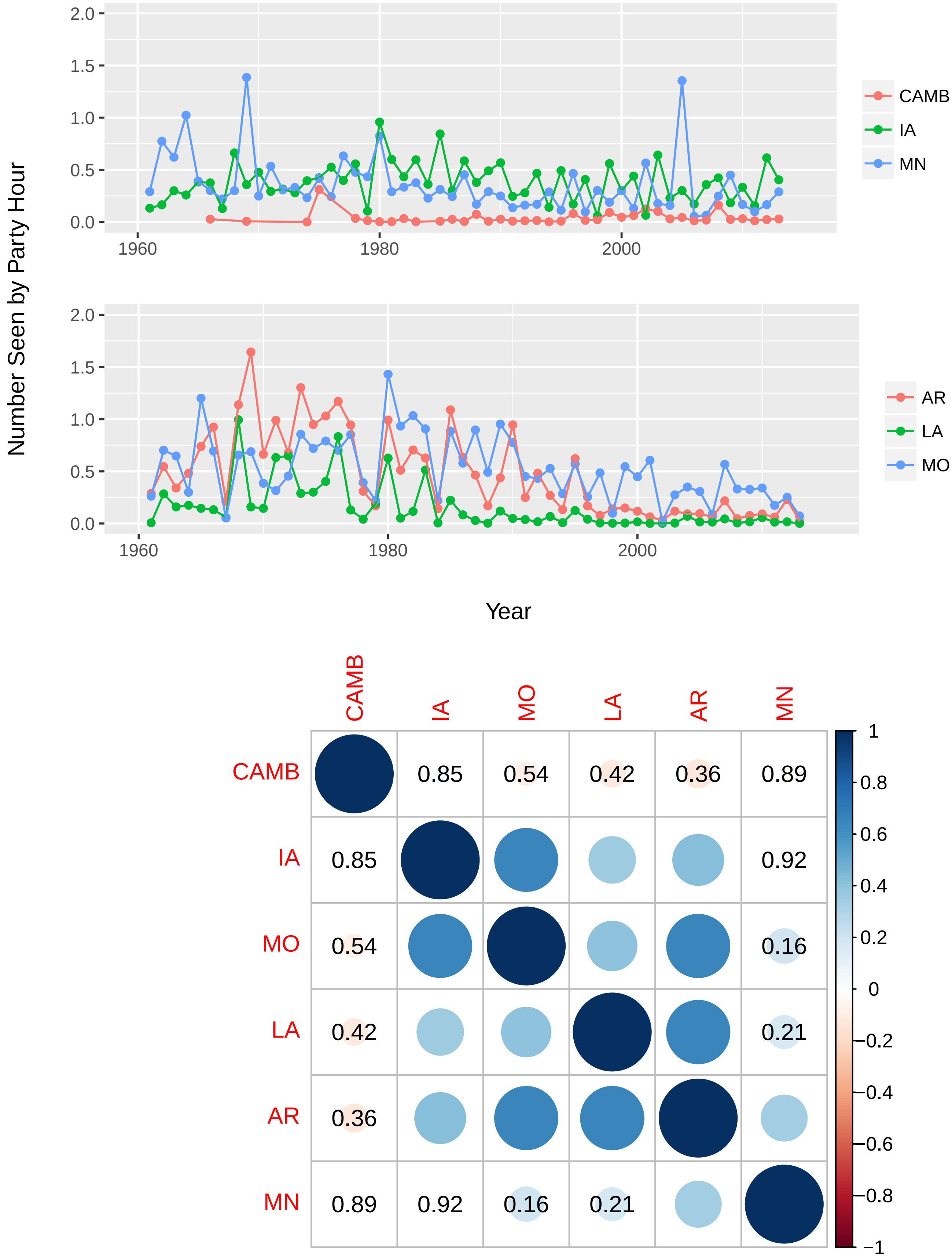


Figure 69: Purple Finch abundance trends and area correlations across 2nd (midwest) longitudinal tier, CBC data.

Across the third longitudinal tier, most areas do not show high abundances of Purple Finches over time. Areas with hardly any records during the focal period show significant positive correlations (Fig. 70).

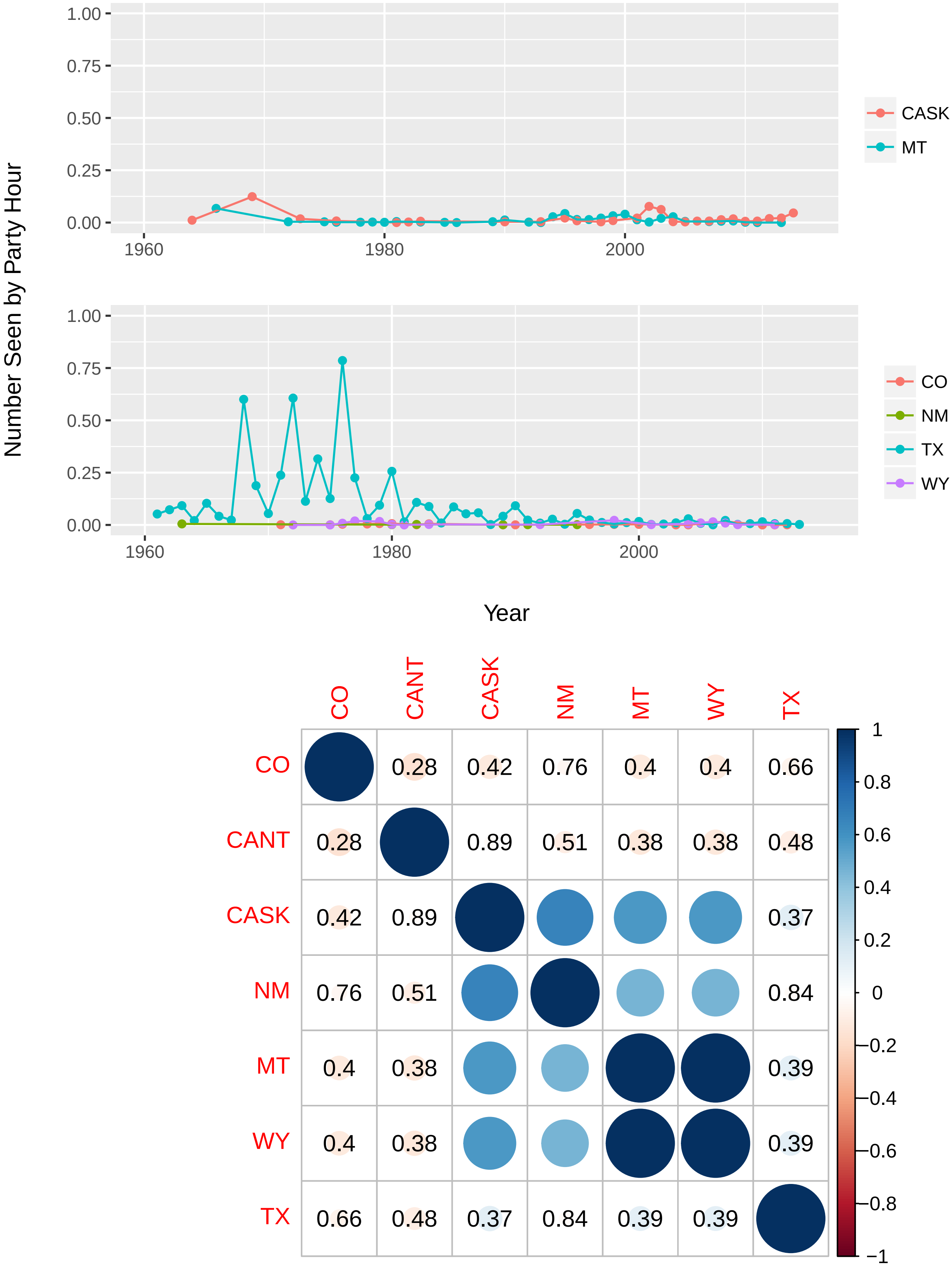


Figure 70: Purple Finch abundance trends and area correlations across 3rd (Rocky Mountains) longitudinal tier, CBC data.

Across the fourth longitudinal tier, Purple Finches do not show tremendous variation in abundance over time, and most areas show significant positive correlations with each other (Fig. 71).

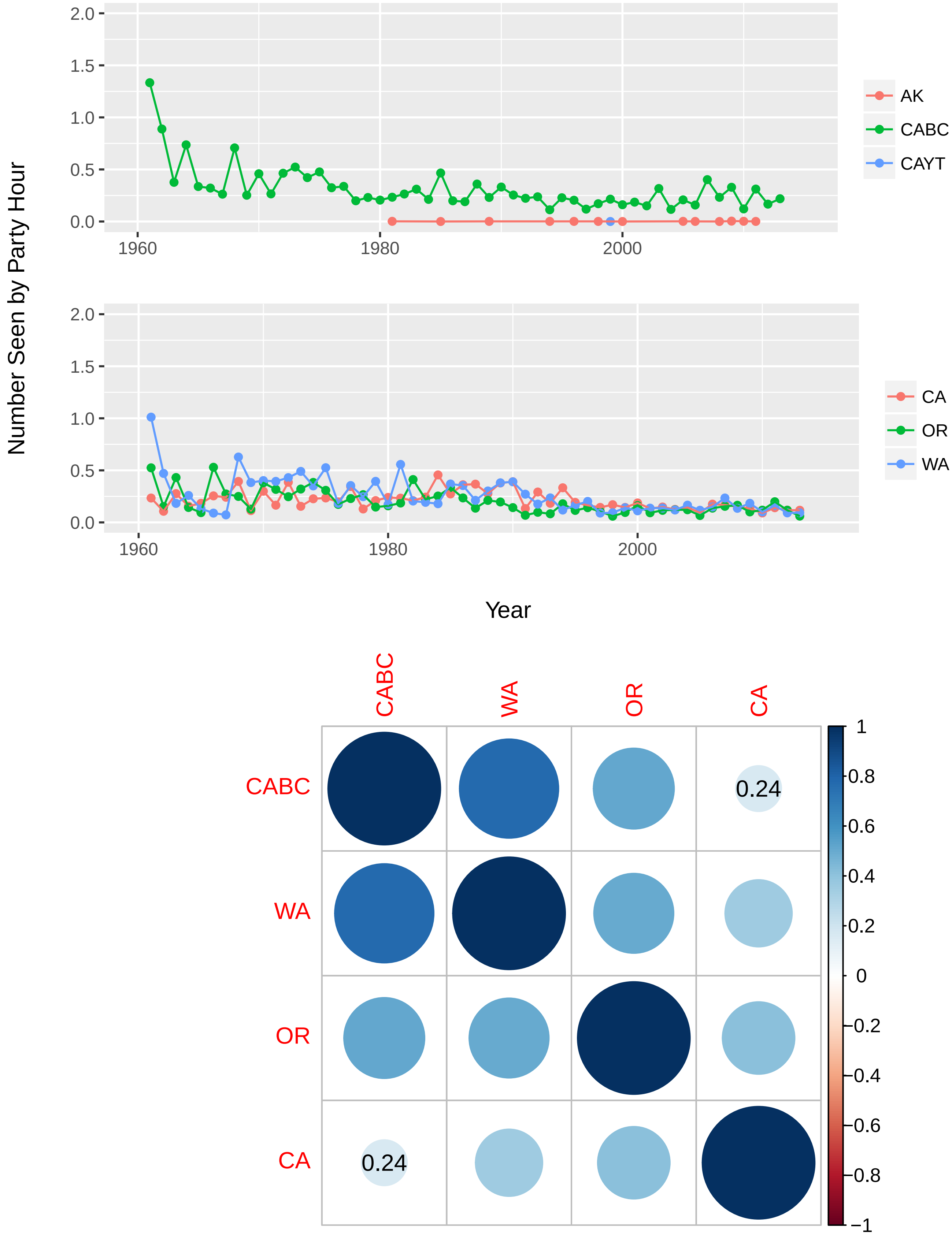


Figure 71: Purple Finch abundance trends and area correlations across 4th (Pacific) longitudinal tier, CBC data.

eBird Analyses

Across the first latitudinal tier, daily eBird records show many strong positive correlations between areas and between different years (Fig. 72).

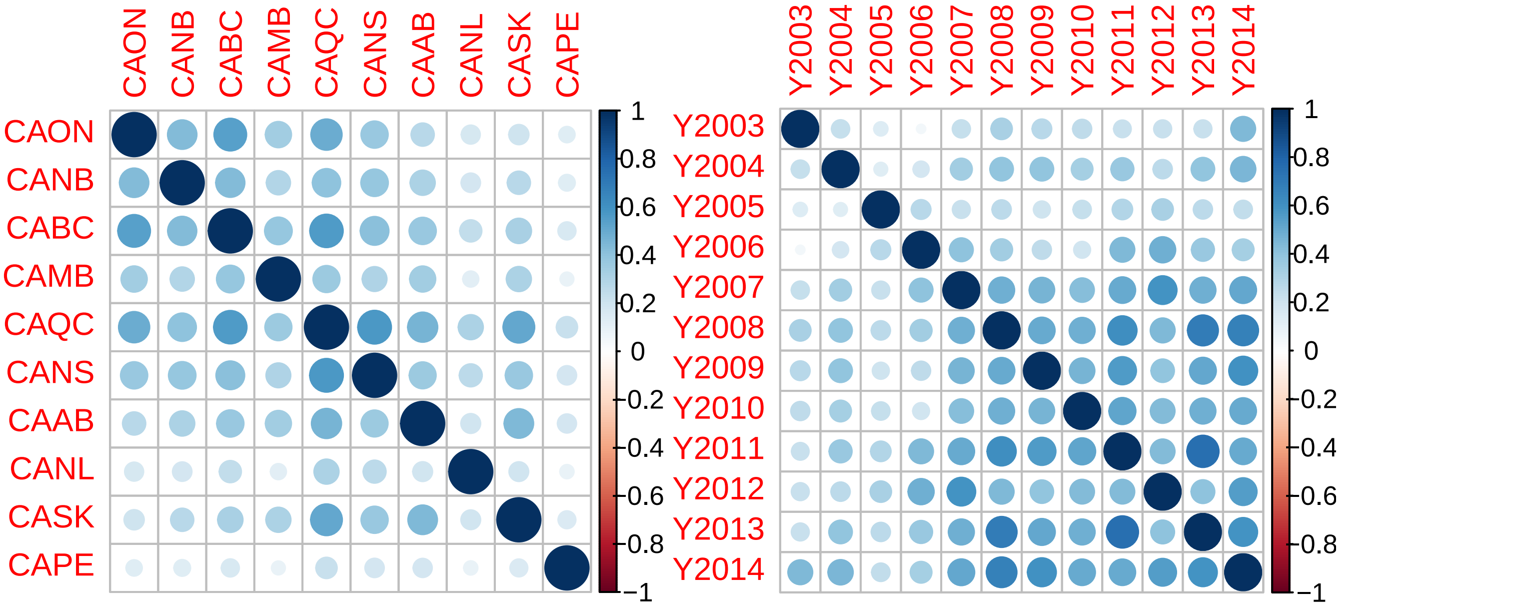


Figure 72: Correlations of Purple Finch invasion pattern between individual areas and between years for the 1st (Canadian) latitudinal tier, eBird data.

Across the second latitudinal tier, daily eBird records show many strong positive correlations between areas and between different years. The strongest positive correlations between years occur in years that are two years apart (Fig. 73).

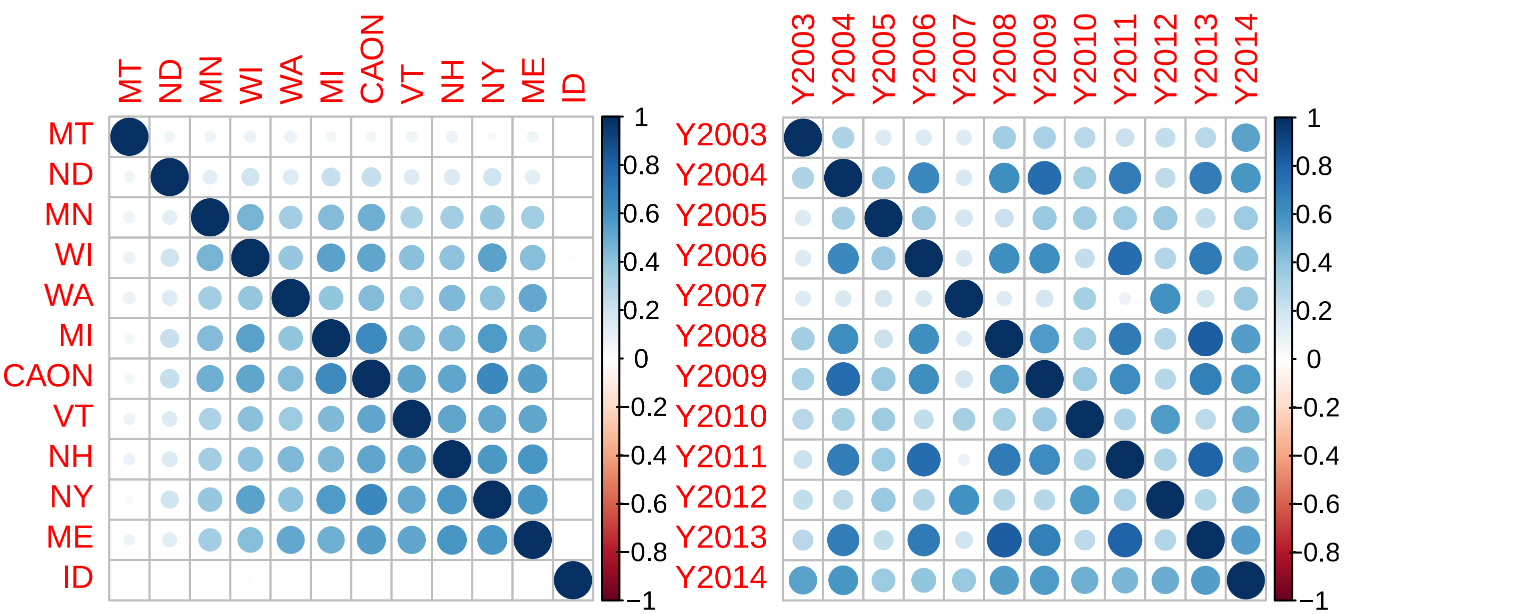


Figure 73: Correlations of Purple Finch invasion pattern between individual areas and between years for the 2nd (northern US) latitudinal tier, eBird data.

Across the third latitudinal tier, daily eBird records show strong positive correlations only between states in the east, and show strong positive correlations between every other year (Fig. 74).

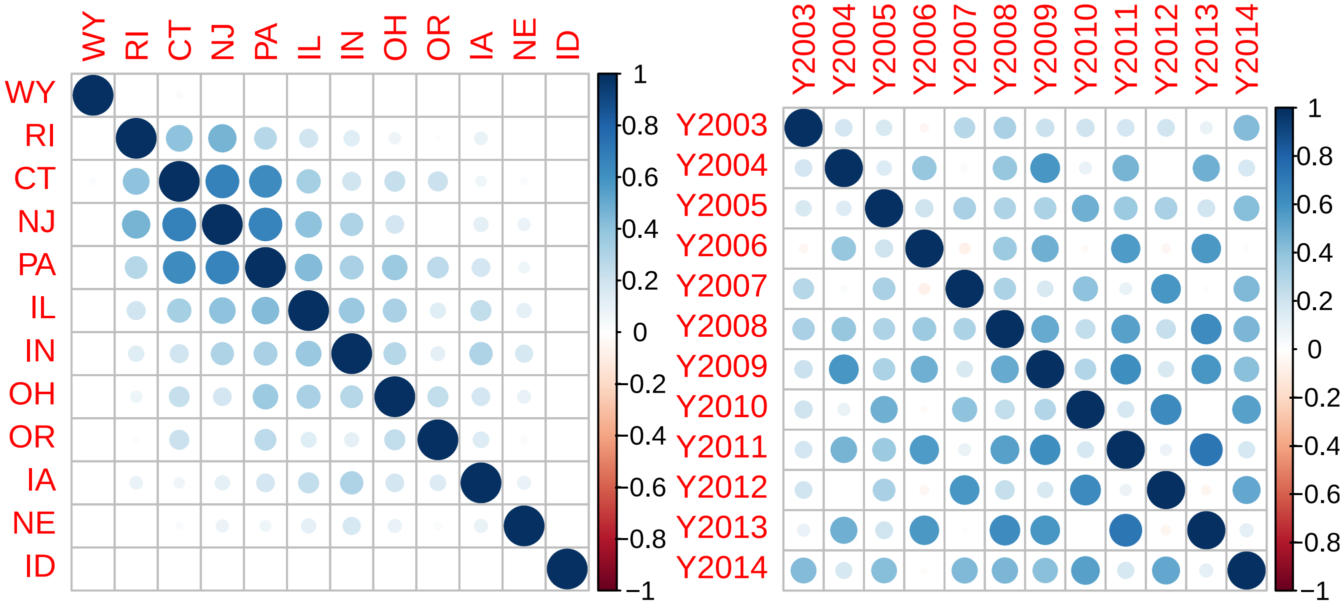


Figure 74: Correlations of Purple Finch invasion pattern between individual areas and between years for the 3rd (mid US) latitudinal tier, eBird data.

Across the southernmost latitudinal tier, daily eBird records show few positive correlations between areas, and strong positive correlations between years that are six years apart (Fig. 75).

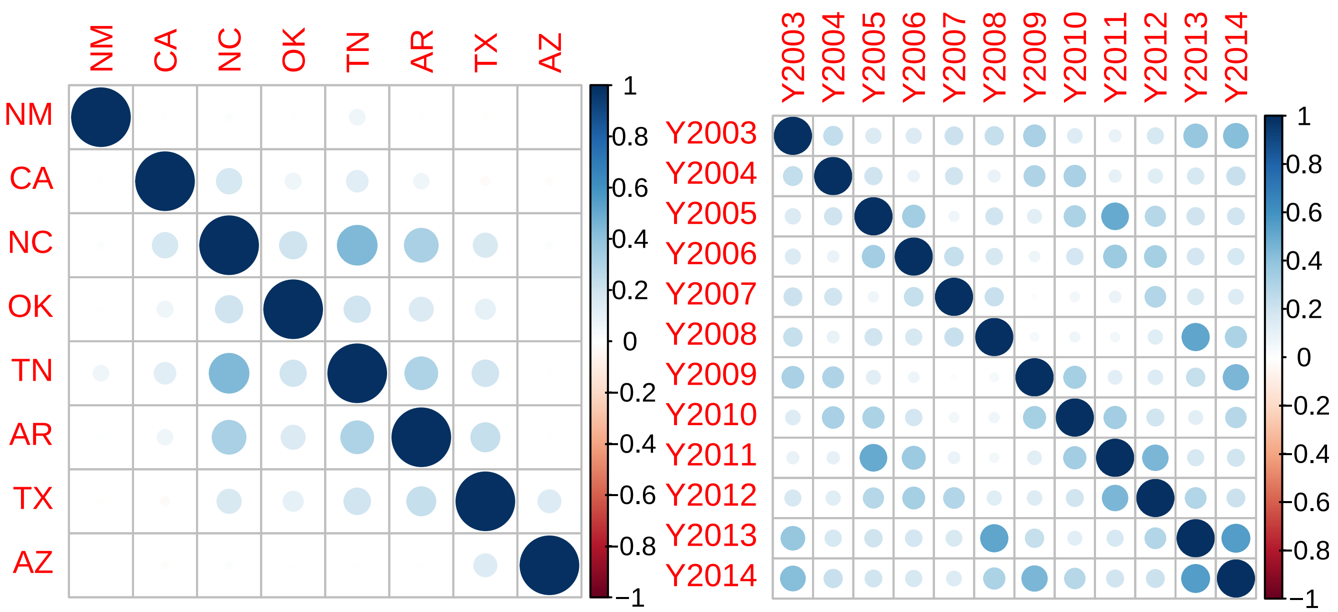


Figure 75: Correlations of Purple Finch invasion pattern between individual areas and between years for the 4th (southern US) latitudinal tier, eBird data.

Down the first longitudinal tier, daily eBird records show strong positive correlations between nearby areas in the northeast United States. Correlatins between years alternate between being strongly positive anf weakly negative (Fig. 76).

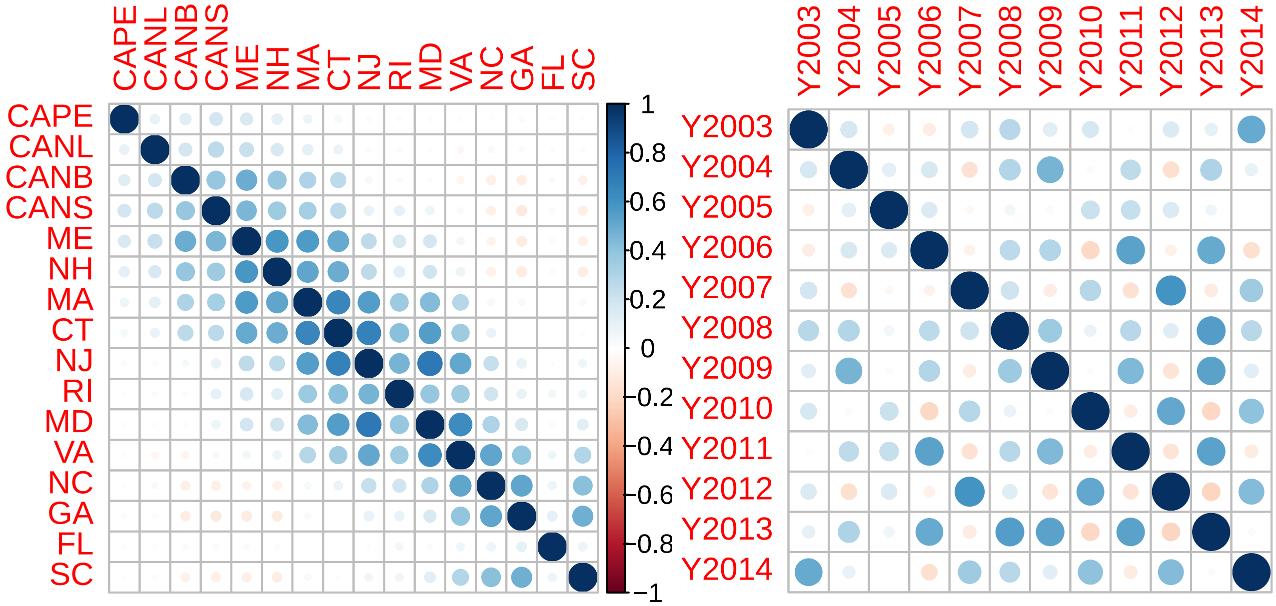


Figure 76: Correlations of Purple Finch invasion pattern between individual areas and between years for the 1st (Atlantic) longitudinal tier, eBird data.

Down the second longitudinal tier, some areas show weak positive correlations with each other and some years show weak positive correlations with each other (Fig. 77).

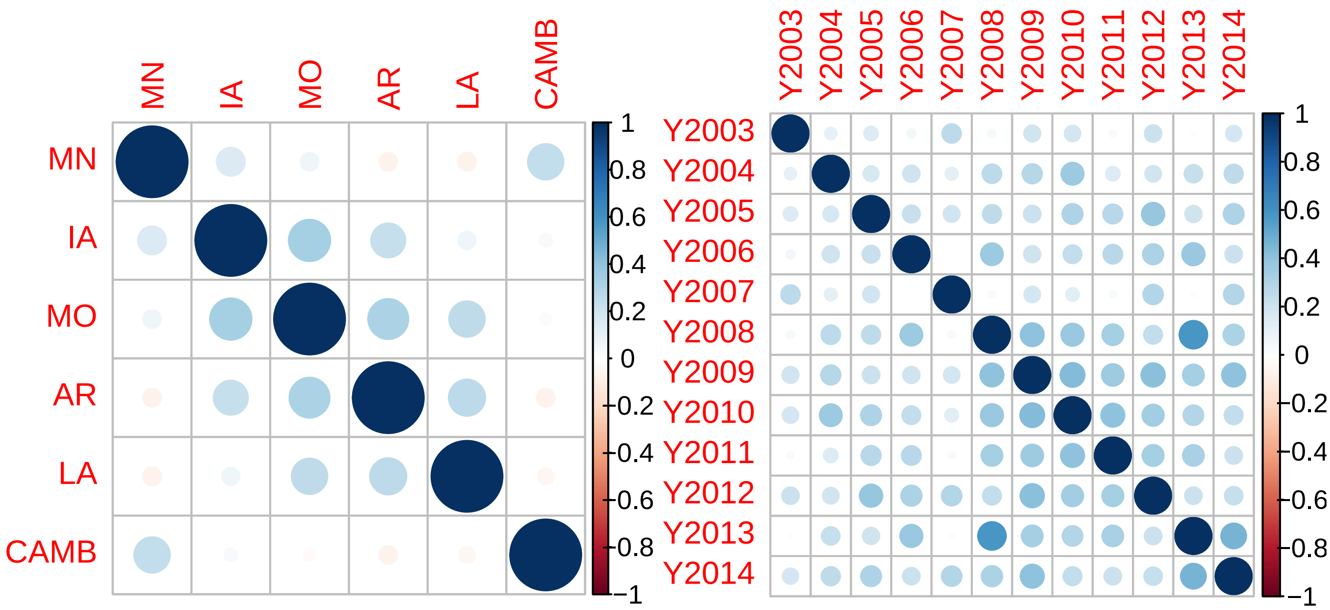


Figure 77: Correlations of Purple Finch invasion pattern between individual areas and between years for the 2nd (midwest) longitudinal tier, eBird data.

Down the third longitudinal tier, few areas show correlations in eBird records, but records show strong positive correlations between years that are six years apart (Fig. 78).

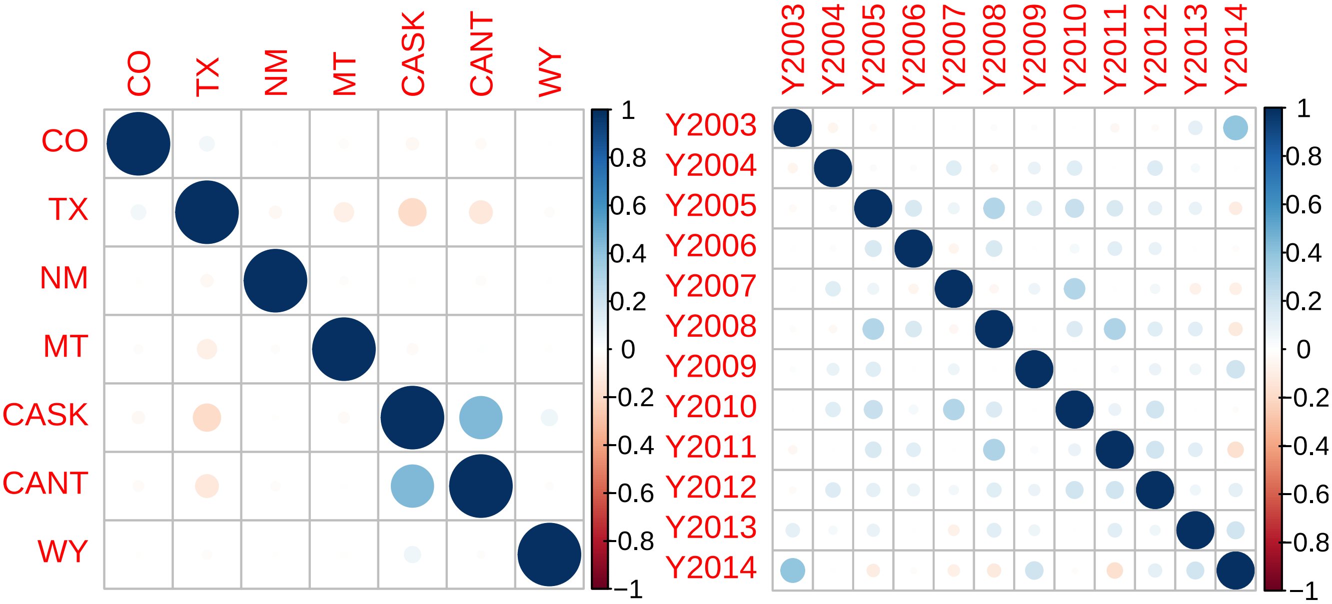


Figure 78: Correlations of Purple Finch invasion pattern between individual areas and between years for the 3rd (Rocky Mountains) longitudinal tier, eBird data.

Down the fourth longitudinal tier, daily eBird records show strong positive correlations between all years except Alaska, and strong positive correlations between most years (Fig. 79).

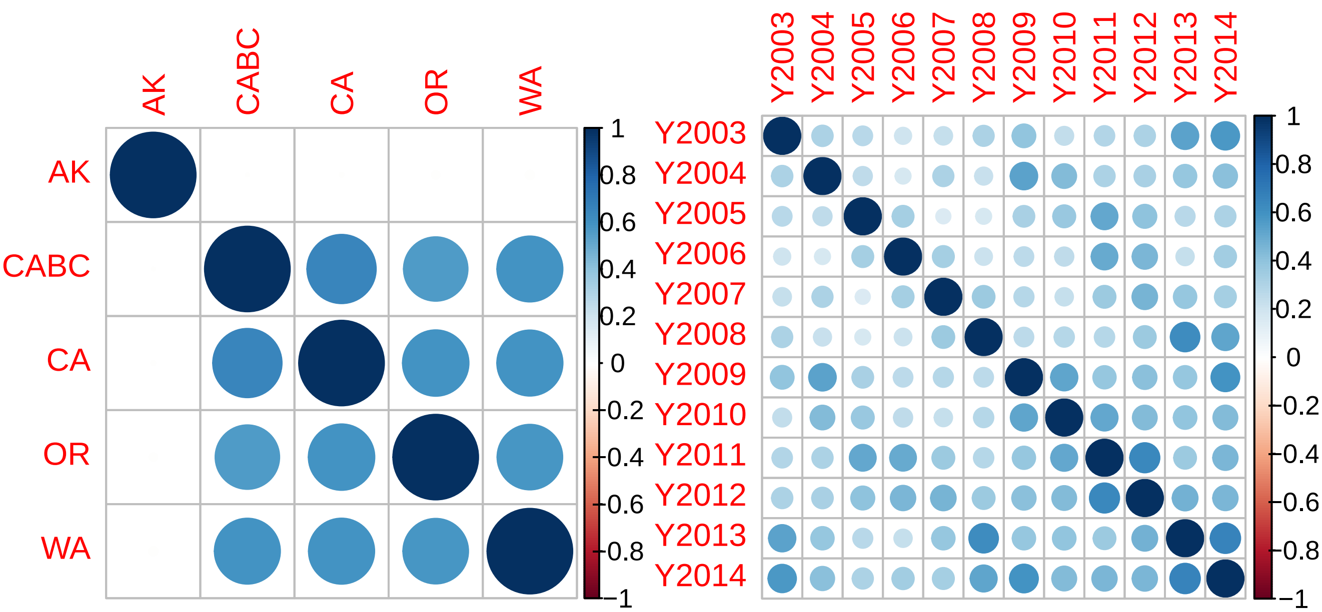


Figure 79: Correlations of Purple Finch invasion pattern between individual areas and between years for the 4th (Pacific) longitudinal tier, eBird data.

House Finch

CBC Analyses

Christmas Bird Count data since 1960 show that the highest numbers of House Finches are recorded in western and northeast North America (Fig. 80).

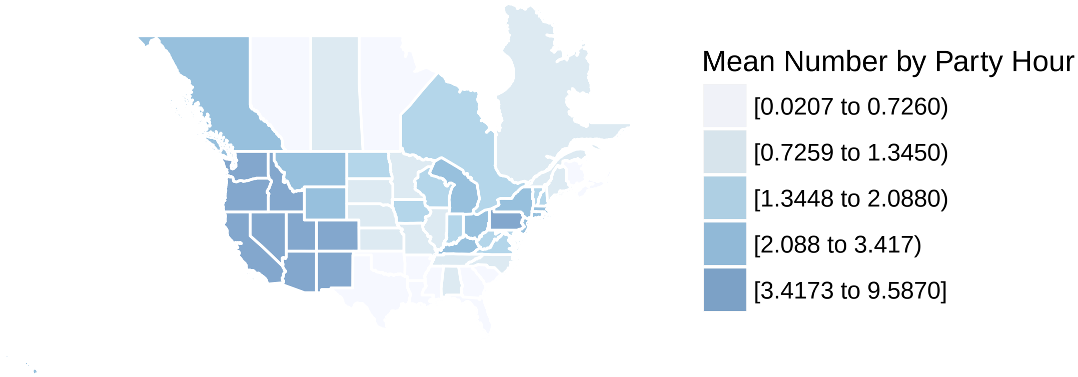


Figure 80: House Finch abundance by area, CBC data.

Christmas Bird Count data since 1960 show that the highest variation in House Finch numbers occurs in eastern and central North America (Figure 81).

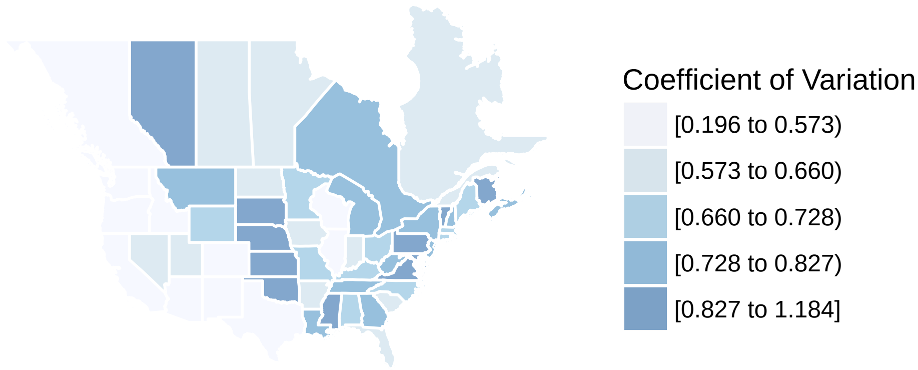


Figure 81: Coefficient of variation for House Finch abundance by area, CBC data.

CBC data show that across the northernmost latitude only British Columbia has recordrd House Finches since 1960, and other areas do not show sharp rises and falls in abundance over time. There are strong positive correlations between all provinces across the tier except for Ontario and British Columbia. Due to lack of CBC records, I excluded Prince Edward Island and Newfoundland and Labrador from analyses (Fig. 82).

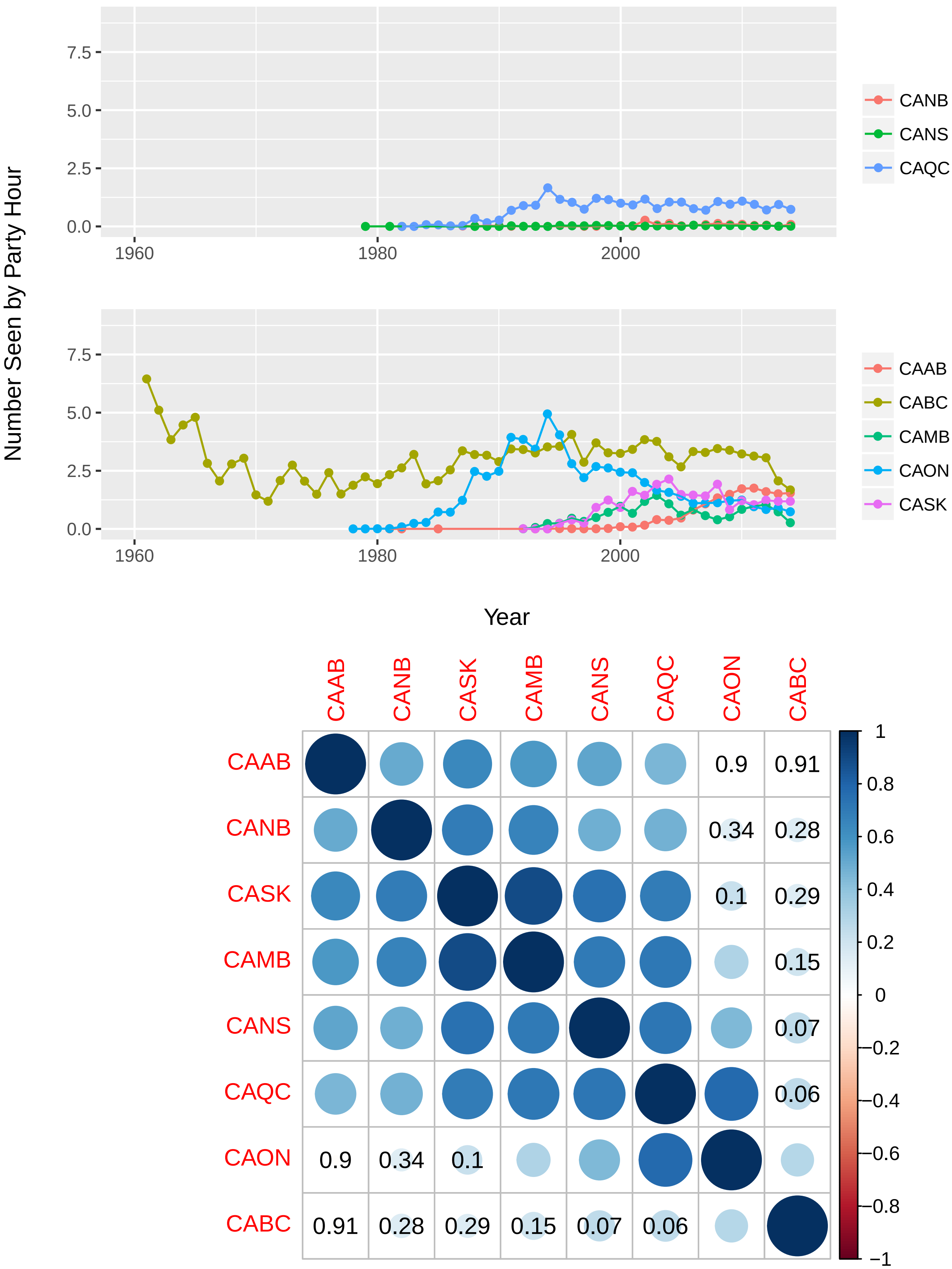


Figure 82: House Finch abundance trends and area correlations across 1st (Canadian) latitudinal tier, CBC data.

In the second latitudinal tier, rises and falls in House Finch abundance tend to be more similarly timed between different areas, although there is some alternation in high winter abundance between different areas. Most areas in the tier show strong positive correlations with each other (Fig. 83).

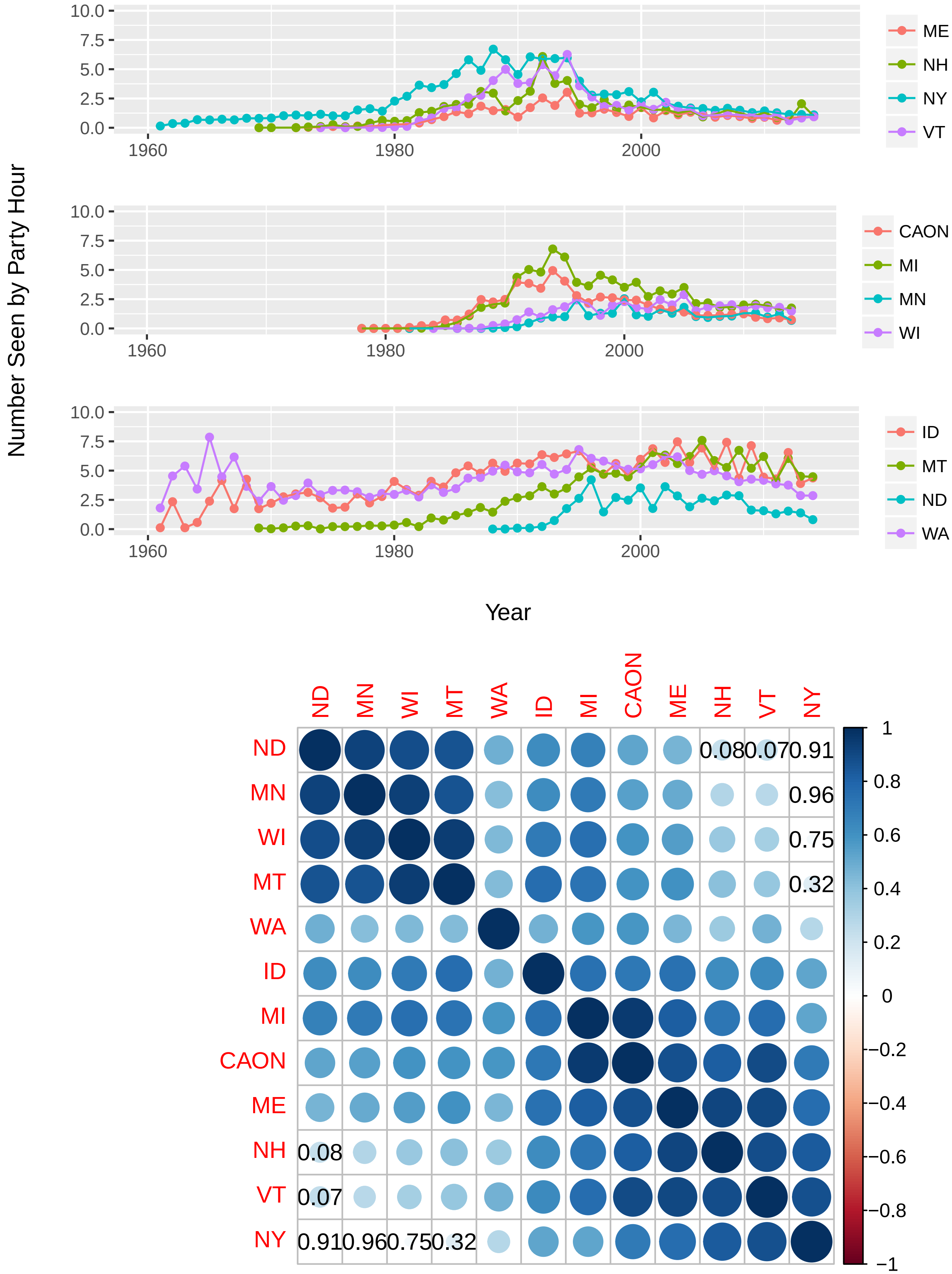


Figure 83: House Finch abundance trends and area correlations across 2nd (northern US) latitudinal tier, CBC data.

In the third latitudinal tier, rises and falls in House Finch abundance tend to be more similarly timed between different areas, although there is some alternation in high winter abundance between different areas. Most states in the tier show weak to strong positive correlations with other states, although Oregon shows weak negative correlatins with all other states (Fig. 84).

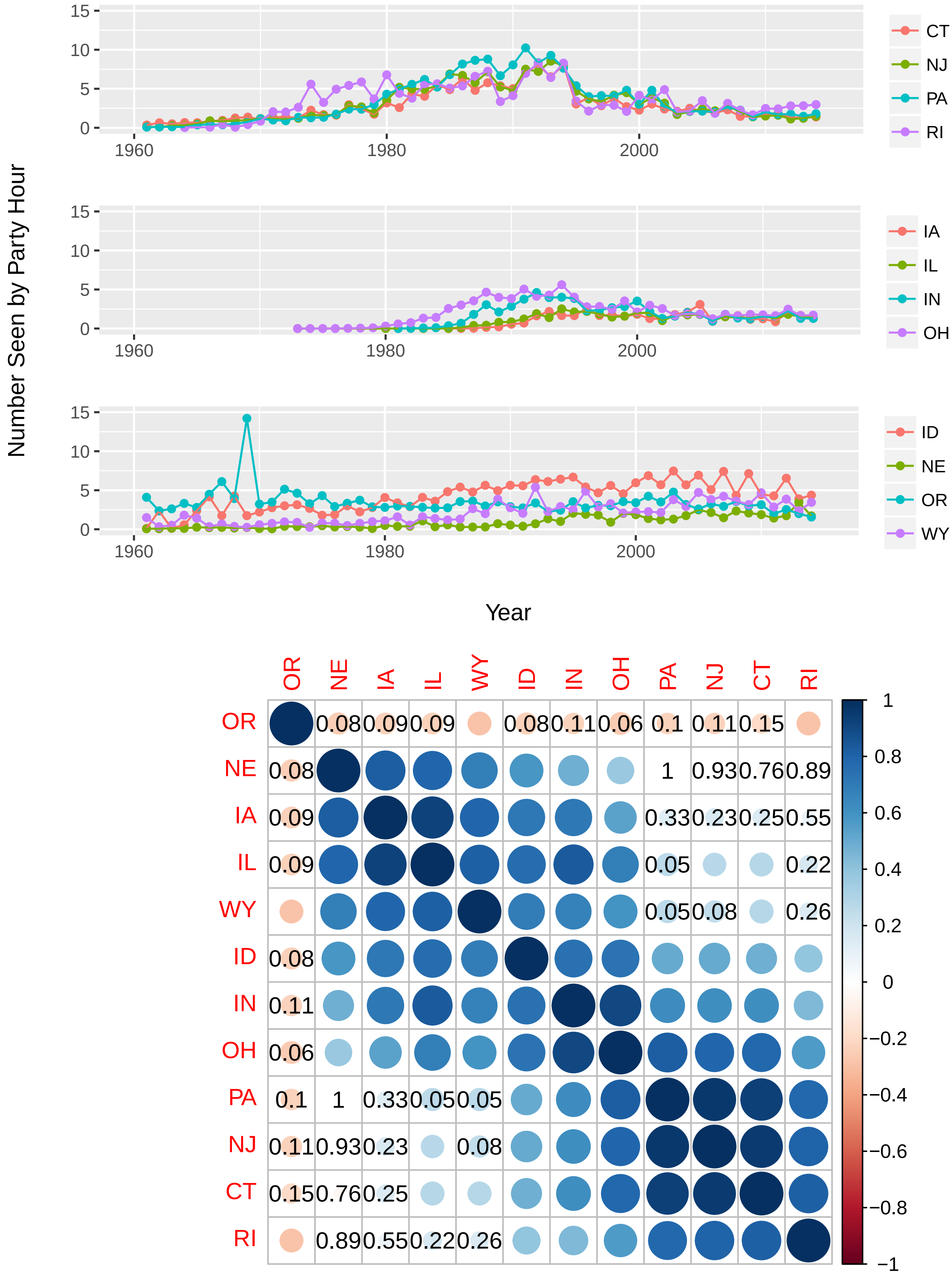


Figure 84: House Finch abundance trends and area correlations across 3rd (mid US) latitudinal tier, CBC data.

In the fourth latitudinal tier, only California and Arizona show sharp changes in House Finch abundance over time. Most states in the tier show weak to strong positive correlations with other states, although California and Arizona show strong negative correlations with all other areas except each other (Fig. 85).

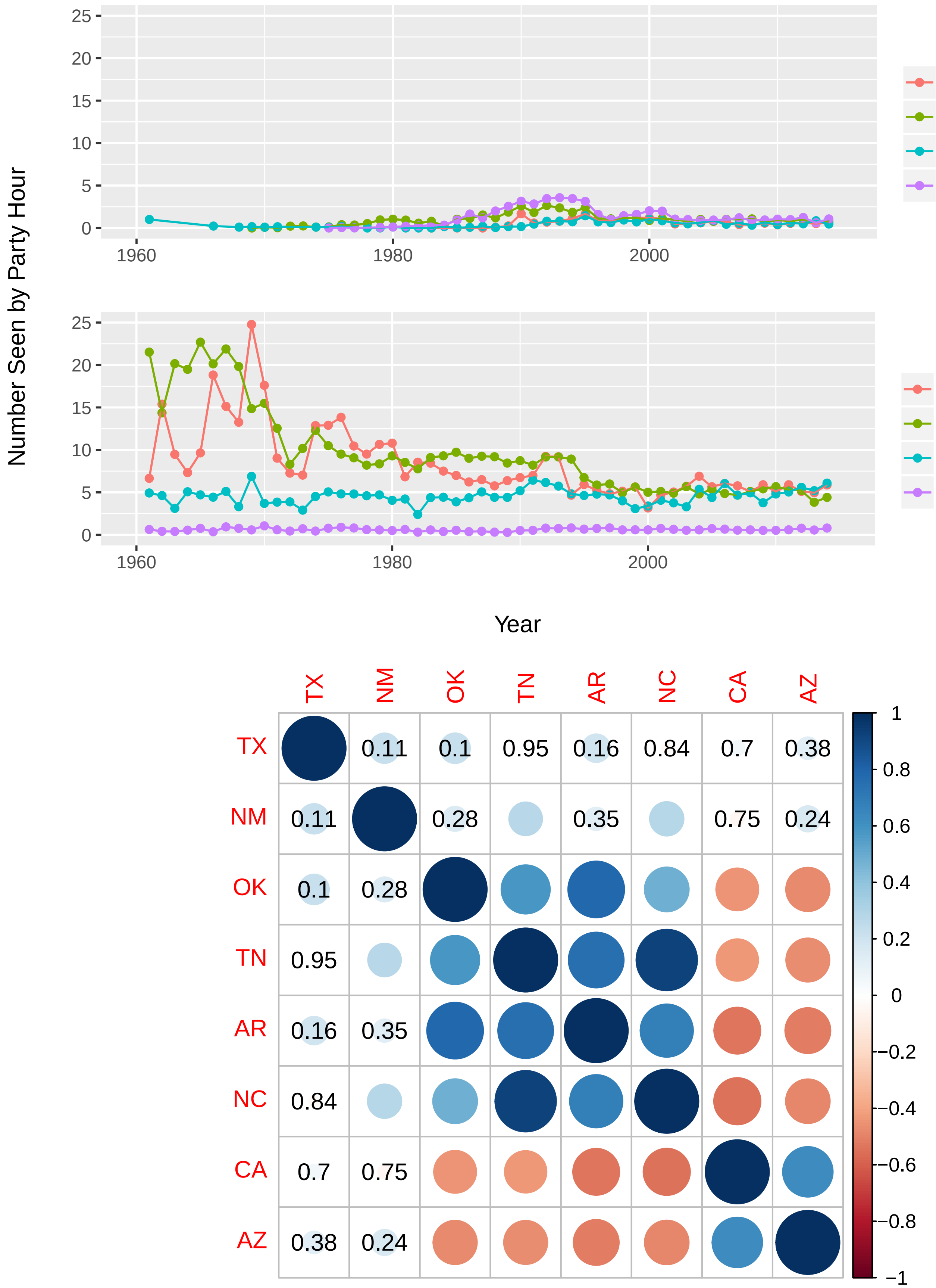


Figure 85: House Finch abundance trends and area correlations across 4th (southern US) latitudinal tier, CBC data.

Down the first longitudinal tier, different areas mostly show similarly timed and sized spikes in abundance, although the sizes of these spikes vary between areas during high abundance years. All areas in the tier show moderate to strong positive correlations with each other, except for Nova Scotia, New Brunswick, and Florida, which have extremely low records of House Finches throughout the study period. Due to lack of CBC records, I excluded Newfoundland and Labrador and Prince Edward Island from analyses(Fig. 86).

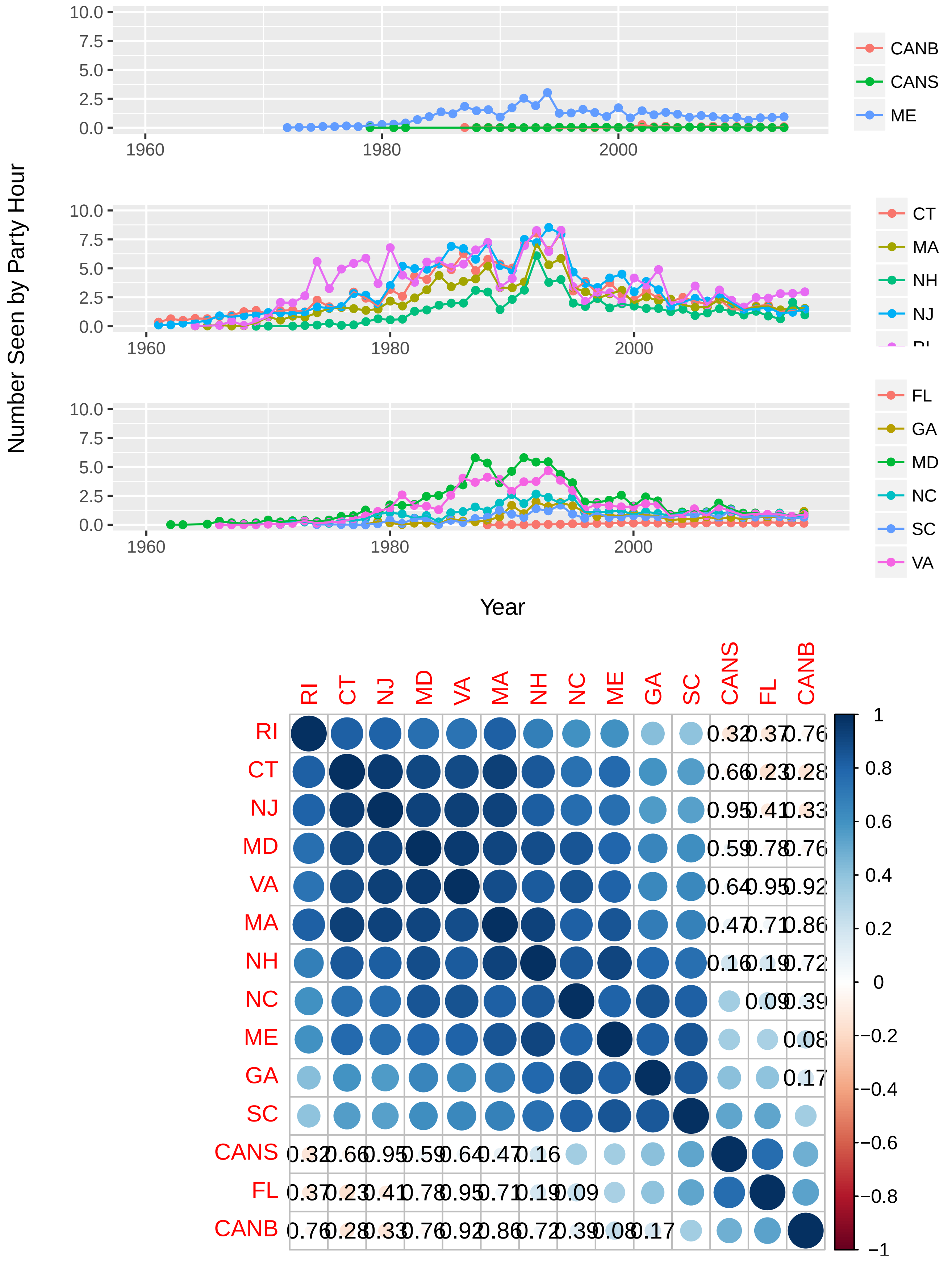


Figure 86: House Finch abundance trends and area correlations across 1st (Atlantic) longitudinal tier, CBC data.

In the second longitudinal tier, all areas show similarly timed, but often differently sized spikes in abundance. All areas show strong positive correlations in abundance trends over time (Fig. 87).

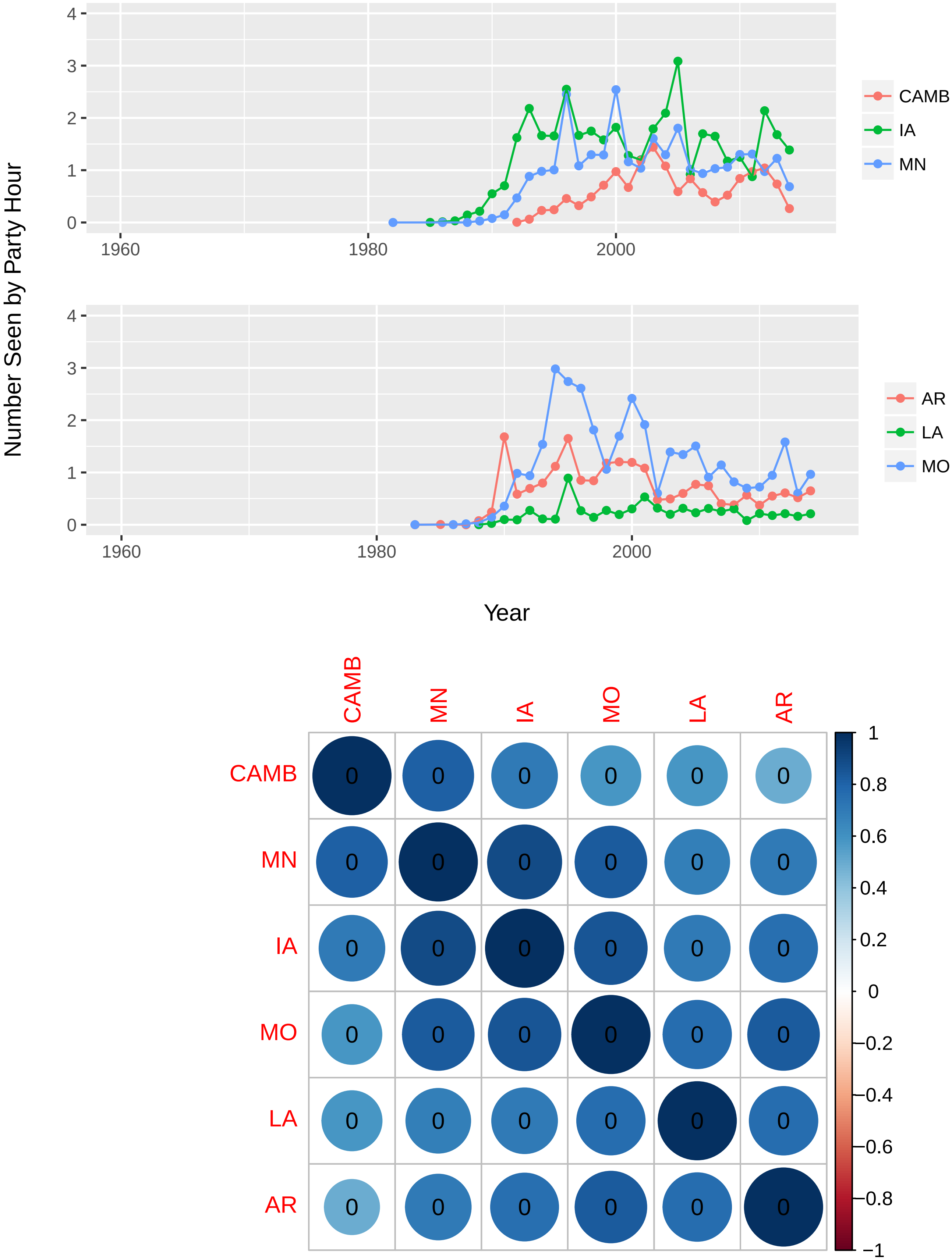


Figure 87: House Finch abundance trends and area correlations across 2nd (midwest) longitudinal tier, CBC data.

In the third longitudinal tier, all areas show similarly timed, but often differently sized spikes in abundance, although there is some alternation. All areas show strong positive correlations between each other, except for Texas and New Mexico. Due to lack of CBC records, I excluded the Northwest Territories from analyses (Fig. 88).

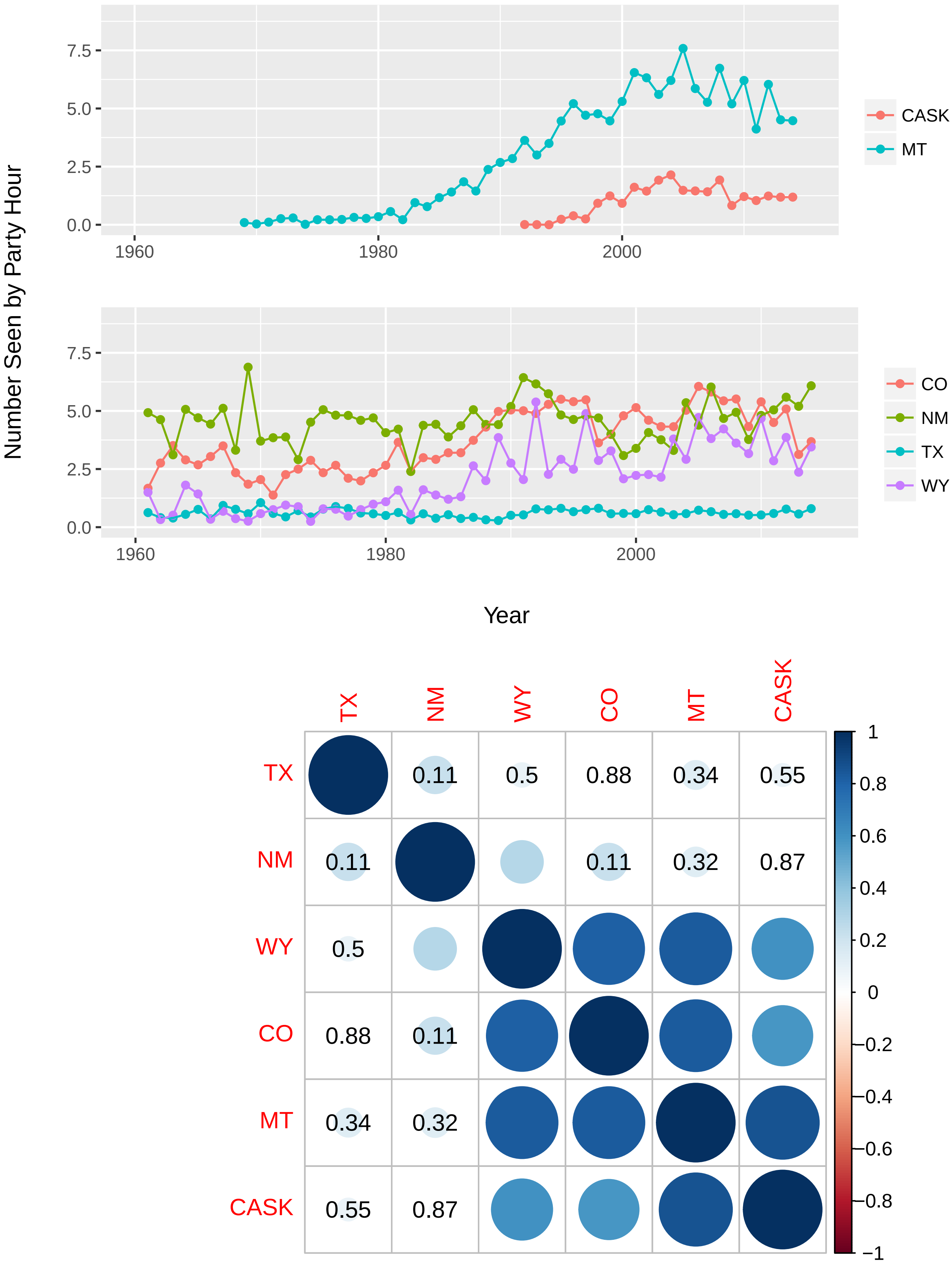


Figure 88: House Finch abundance trends and area correlations across 3rd (Rocky Mountains) longitudinal tier, CBC data.

In the fourth longitudinal tier, no areas show sharp changes in abundance over time, with the exception of California and Oregon at the beginning of the study period. There are several weak to moderate correlations between areas. Due to lack of CBC records, I excluded Alaska from analyses (Fig. 89).

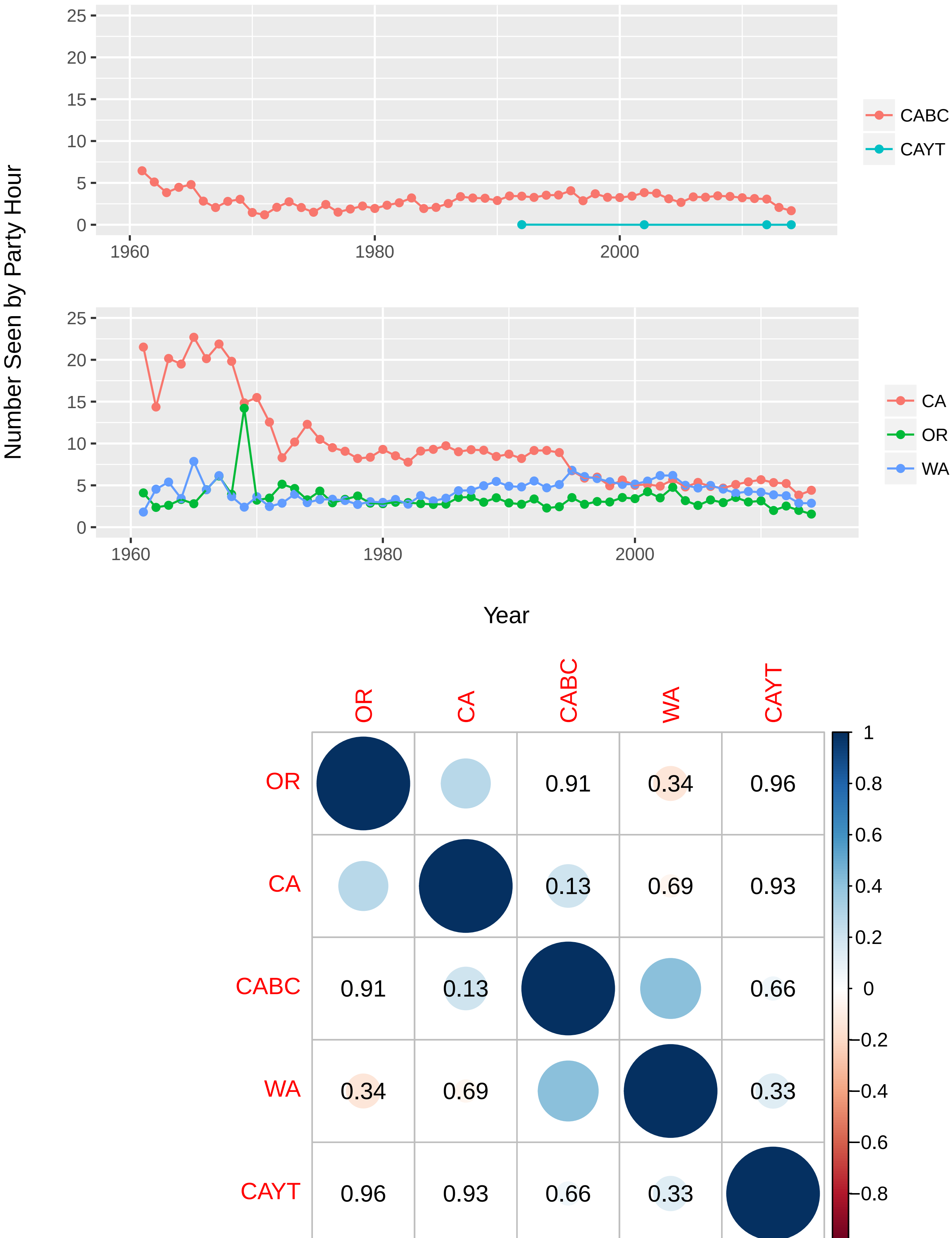


Figure 89: House Finch abundance trends and area correlations across 4th (Pacific) longitudinal tier, CBC data.

eBird Analyses

Across the northernmost latitudinal tier, daily eBird records show positive correlations between central and western provinces, and weak to strong positive correlations between most years (Fig. 90).

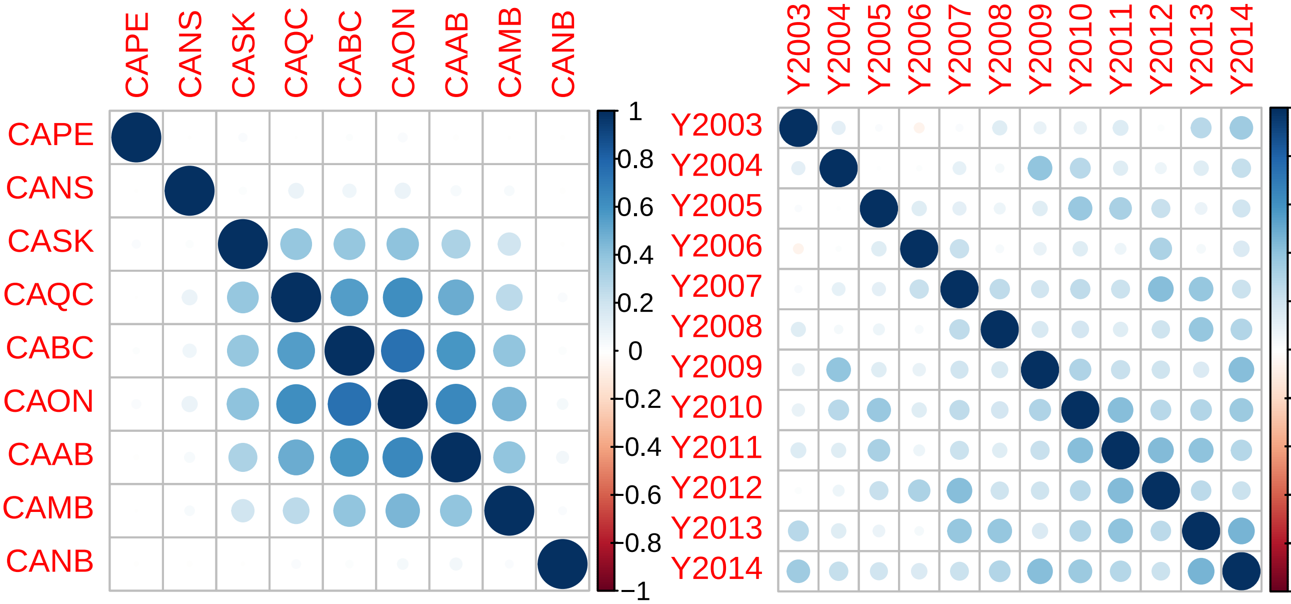


Figure 90: Correlations of House Finch invasion pattern between individual areas and between years for the 1st (Canadian) latitudinal tier, eBird data.

Across the second latitudinal tier, daily eBird records show strong positive correlations between all areas, and strong positive correlations between years that are six years apart (Fig. 91).

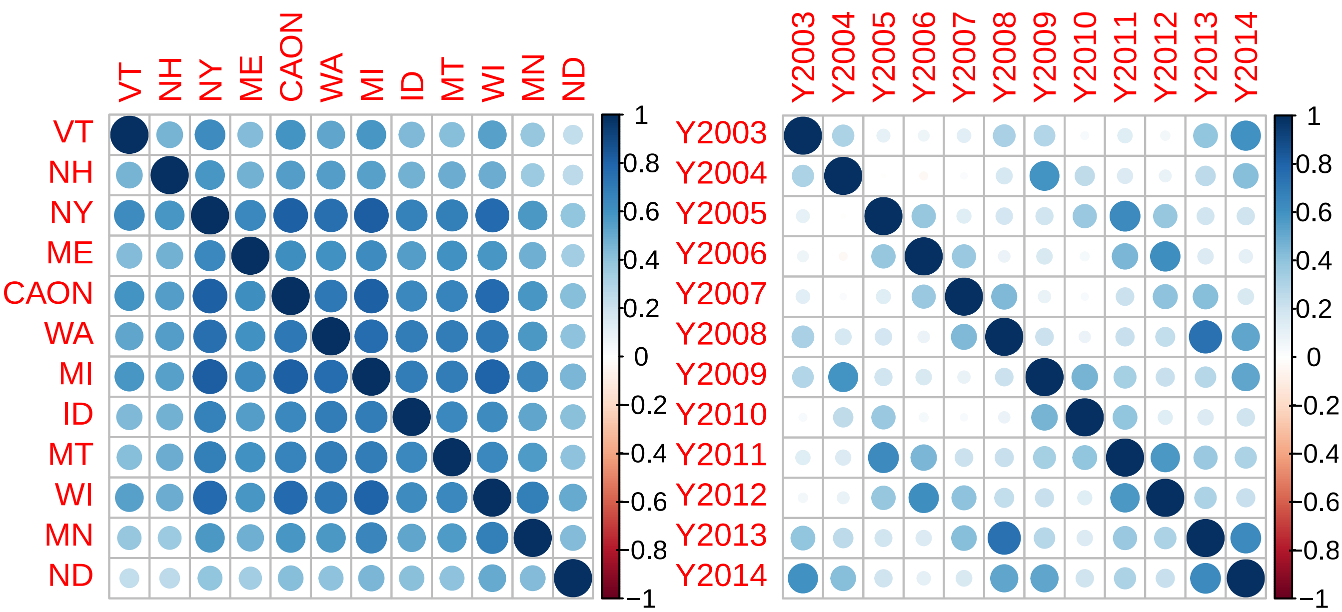


Figure 91: Correlations of House Finch invasion pattern between individual areas and between years for the 2nd (northern US) latitudinal tier, eBird data.

Across the third latitudinal tier, daily eBird records show strong positive correlations between all areas, and strong positive correlations between years that are six years apart (Fig. 92).

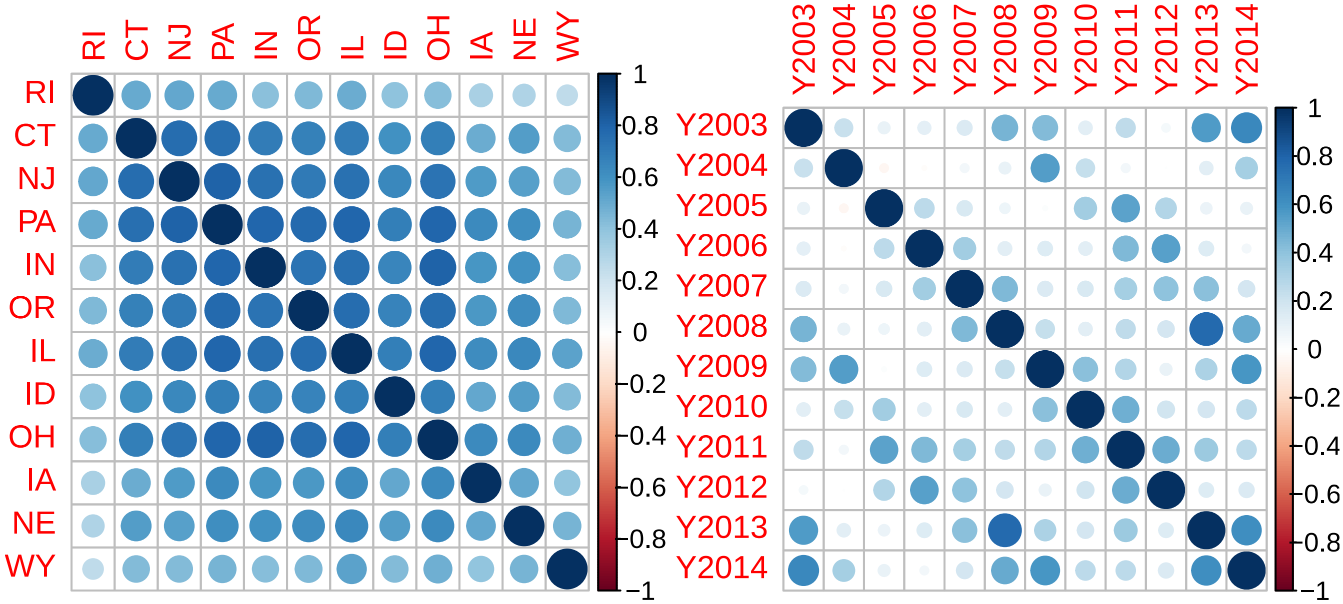


Figure 92: Correlations of House Finch invasion pattern between individual areas and between years for the 3rd (mid US) latitudinal tier, eBird data.

Across the fourth latitudinal tier, daily eBird records show strong positive correlations between all areas, and strong positive correlations between years that are six years apart (Fig. 93).

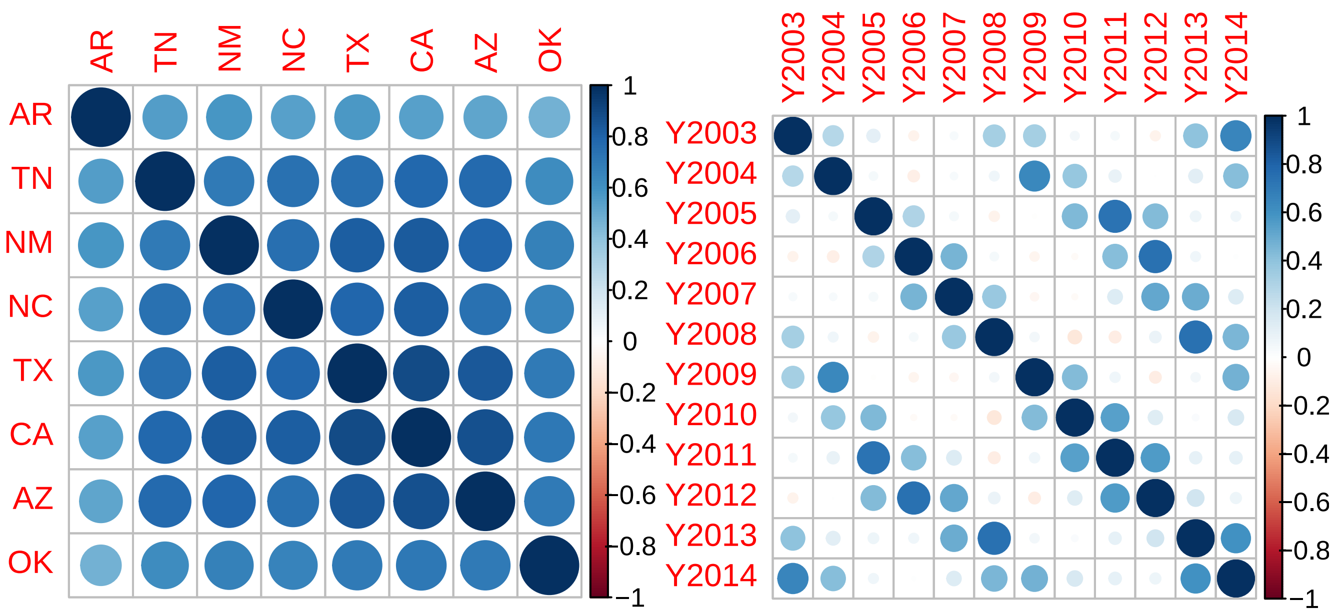


Figure 93: Correlations of House Finch invasion pattern between individual areas and between years for the 4th (southern US) latitudinal tier, eBird data.

Across the first longitudinal tier, daily eBird records show strong positive correlations between most areas, especially the mid Atlantic states, and strong positive correlations between years that are six years apart (Fig. 94).

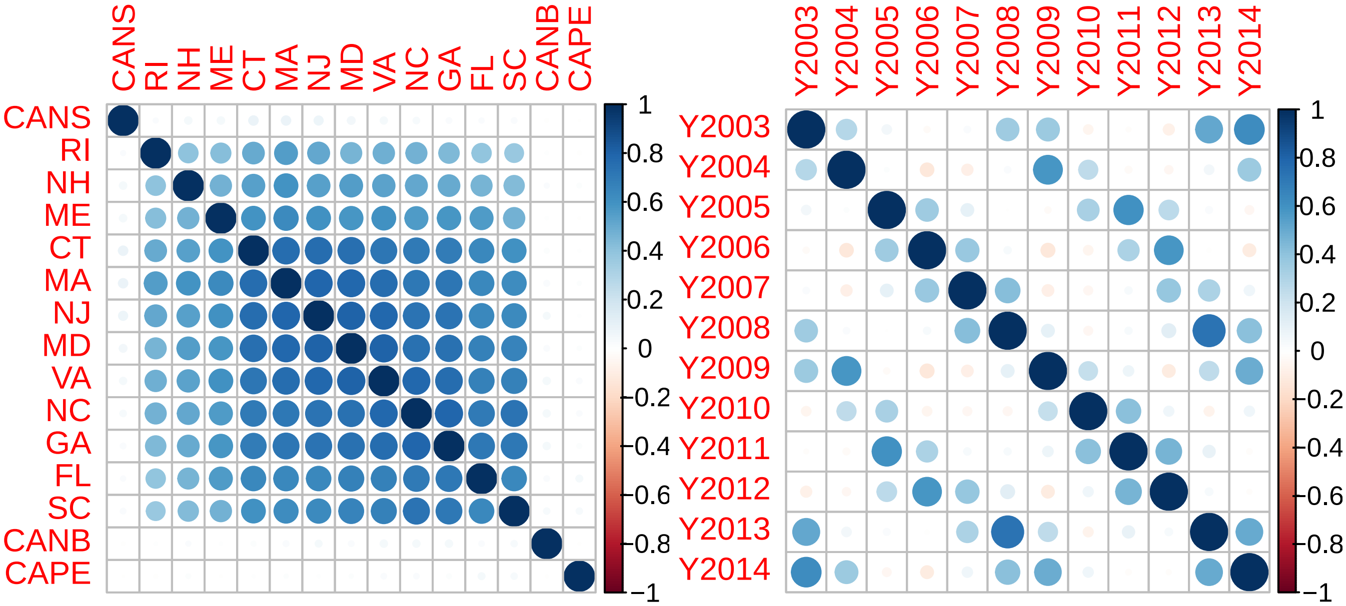


Figure 94: Correlations of House Finch invasion pattern between individual areas and between years for the 1st (Atlantic) longitudinal tier, eBird data.

Across the second longitudinal tier, daily eBird records show moderate to strong positive correlations between all areas, and weak to strong positive correlations between most years (Fig. 95).

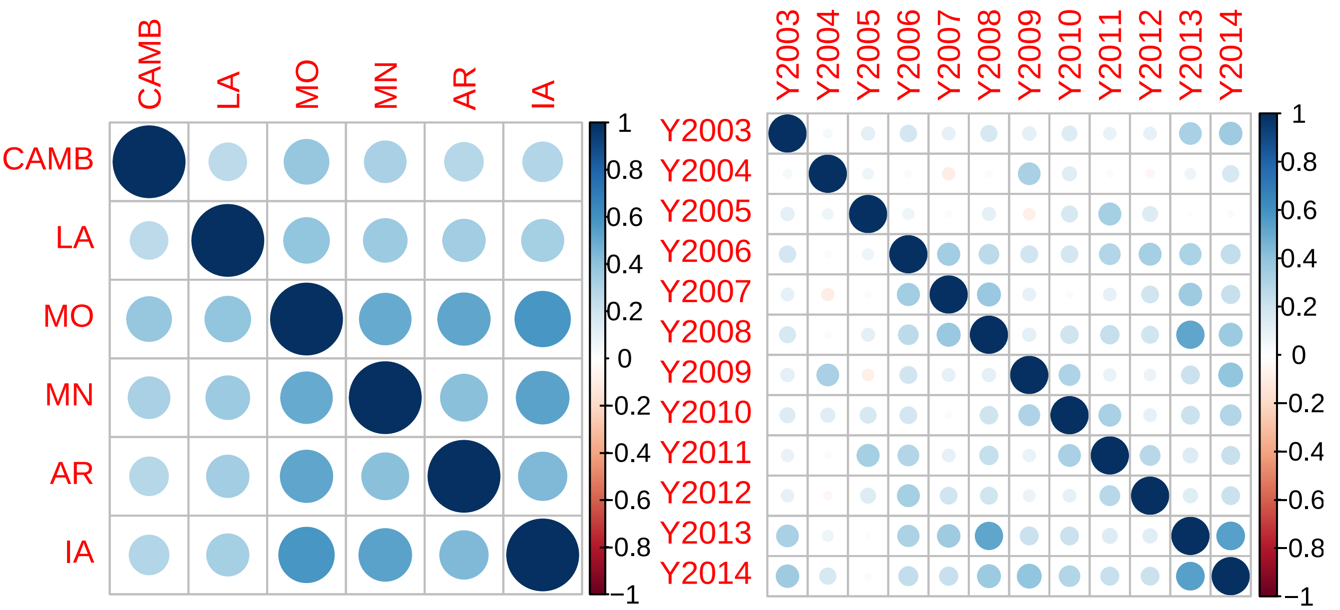


Figure 95: Correlations of House Finch invasion pattern between individual areas and between years for the 2nd (midwest) longitudinal tier, eBird data.

Across the third longitudinal tier, daily eBird records show moderate to strong positive correlations between most areas, and strong positive correlations between years that are six years apart (Fig. 96).

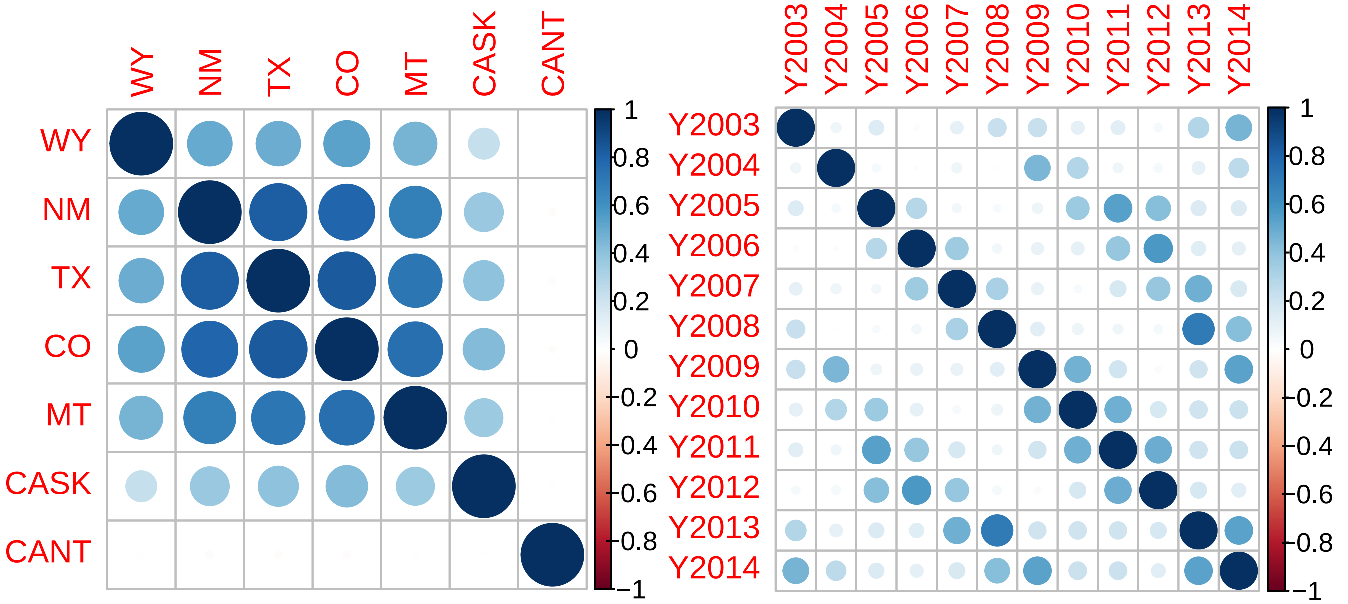


Figure 96: Correlations of House Finch invasion pattern between individual areas and between years for the 3rd (Rocky Mountains) longitudinal tier, eBird data.

Across the fourth longitudinal tier, daily eBird records show strong positive correlations between all areas except Alaska, and strong positive correlations between years that are six years apart (Fig. 97).

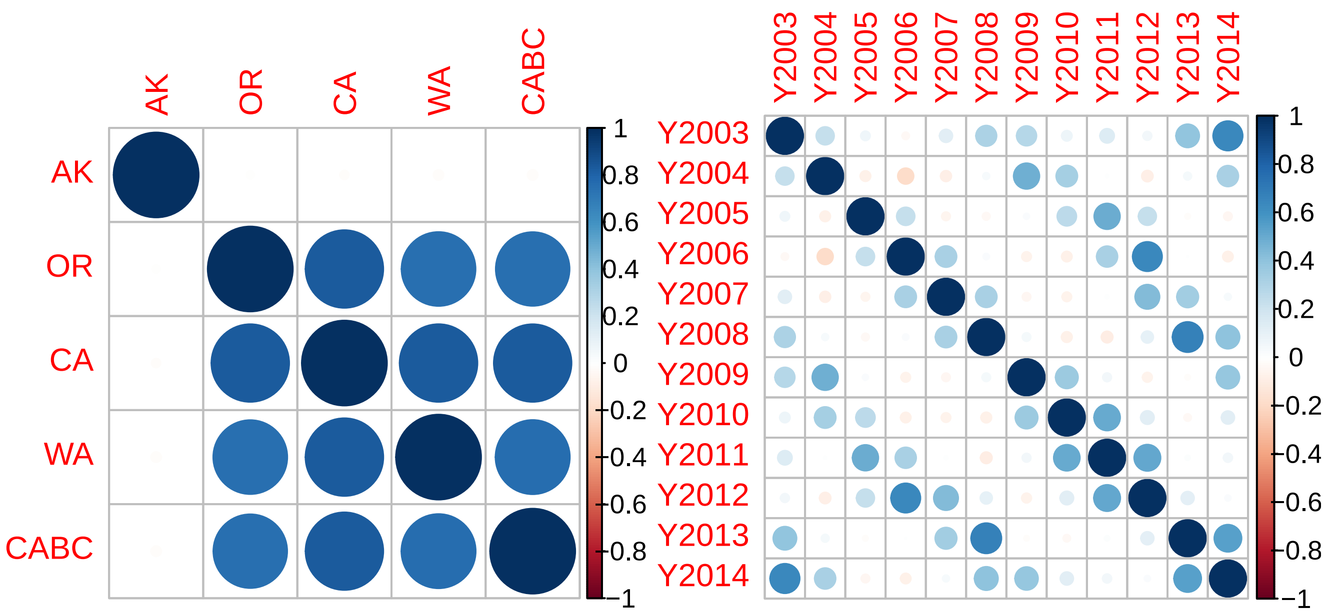


Figure 97: Correlations of House Finch invasion pattern between individual areas and between years for the 4th (Pacific) longitudinal tier, eBird data.

Hoary Repoll

CBC Analyses

Christmas Bird Count data since 1960 show that the highest numbers of Hoary Redpoll are recorded across southern Canada and the northern United States, with sizeable numbers recorded in some states down the Rocky Mountains (Fig. 98).

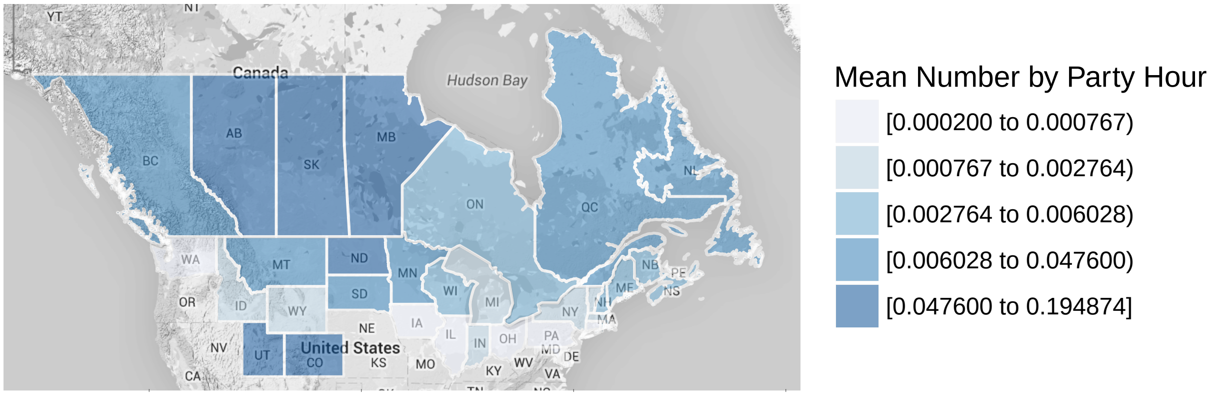


Figure 98: Hoary Redpoll abundance by area, CBC data.

Christmas Bird Count data since 1960 show that the highest variation in Hoary Redpoll numbers occurs across the northern United States, with some provinces in southern Canada and Colorado also showing strong variation over time (Fig. 99).

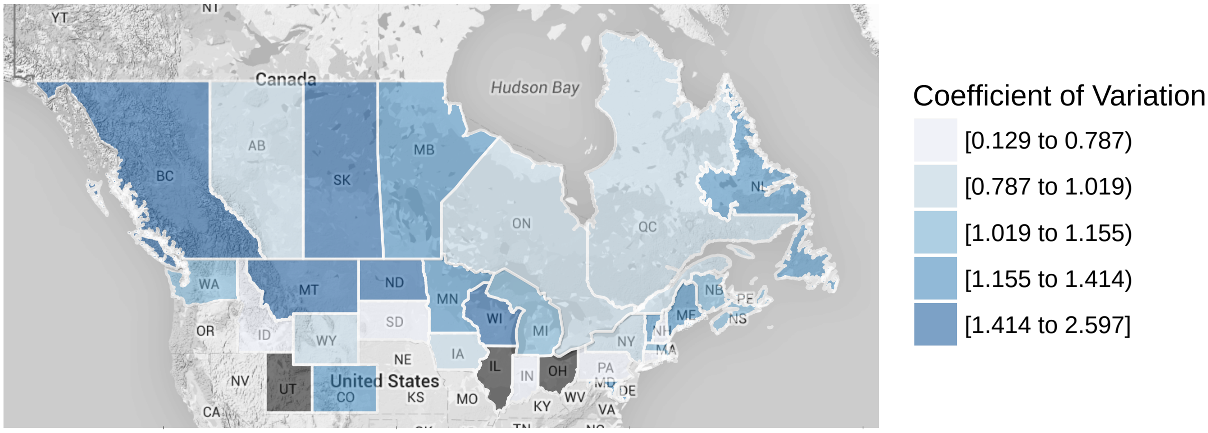


Figure 99: Coefficient of variation for Hoary Redpoll abundance by area, CBC data.

CBC data show that rises and falls in Hoary Redpoll winter abundance are relatively synchronous and of similar magnitudes in provinces in the western half of this latitude, with more constant low numbers in the eastern provinces. The strongest positive correlations are between provinces in the east with low records of Hoary Redpolls over the study period (Fig. 100).

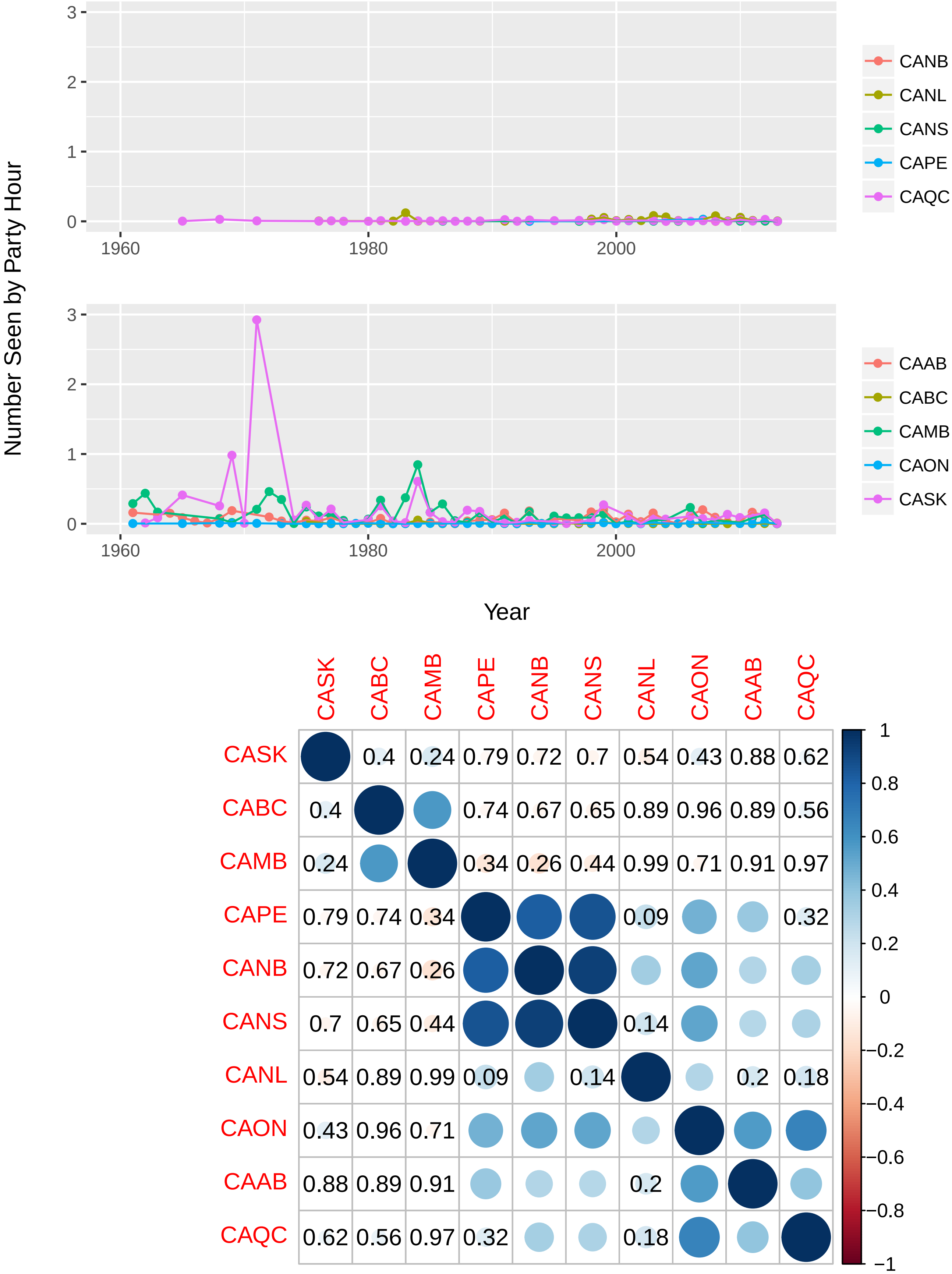


Figure 100: Hoary Redpoll abundance trends and area correlations across 1st (Canadian) latitudinal tier, CBC data.

All areas in the 2nd latitudinal tier show extremely low numbers of Hoary Redpolls throughout the study period, and certain areas show weak to strong positive correlations with each other (Fig. 101).

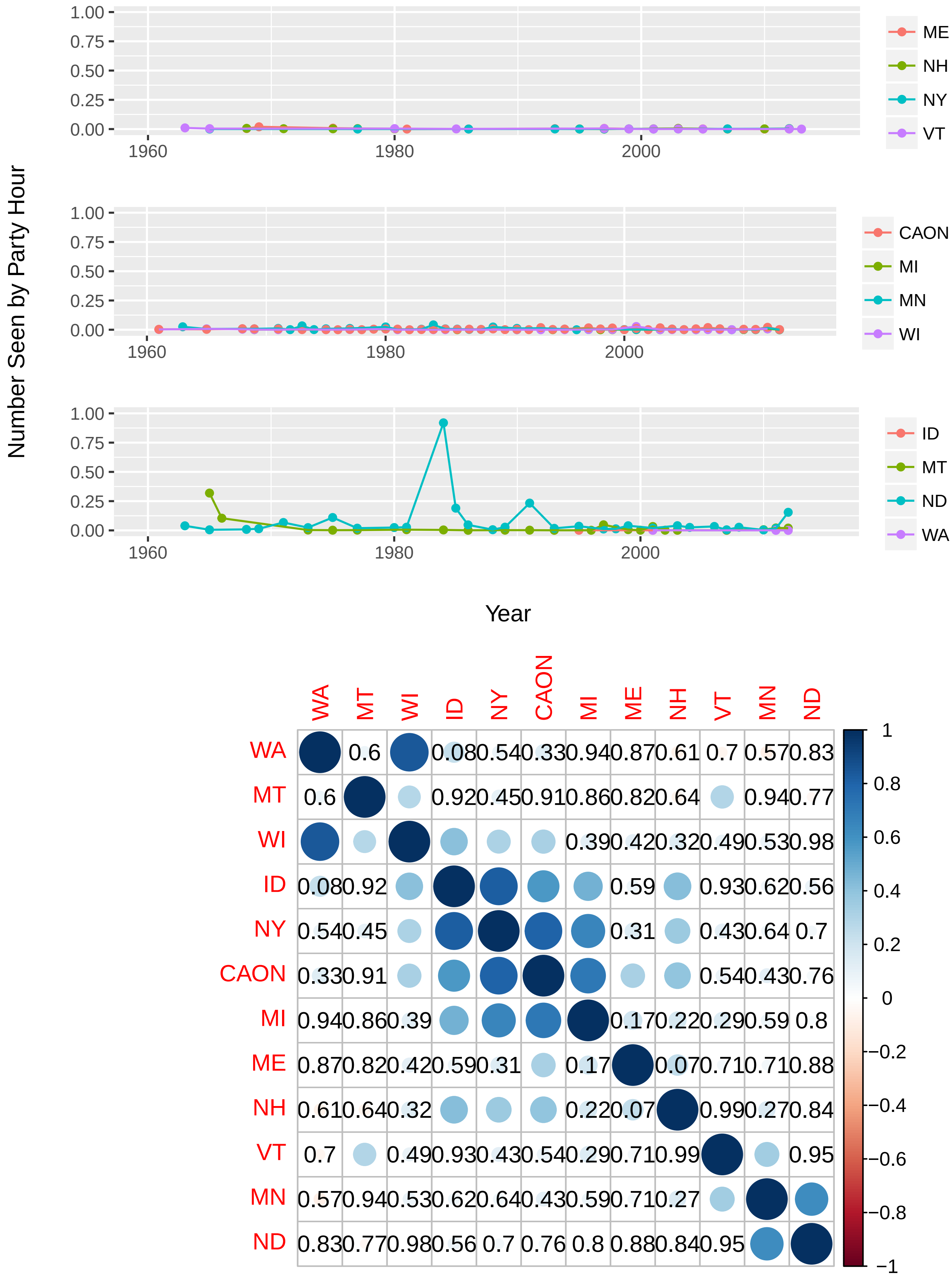


Figure 101: Hoary Redpoll abundance trends and area correlations across 2nd (northern US) latitudinal tier, CBC data.

All areas in the third latitudinal tier show extremely low numbers of Hoary Redpolls throughout the study period, and certain areas show weak to strong positive correlations with each other. Due to lack of CBC records, I excluded New Jersey, Nebraska, and Oregon from analyses (Fig. 102).

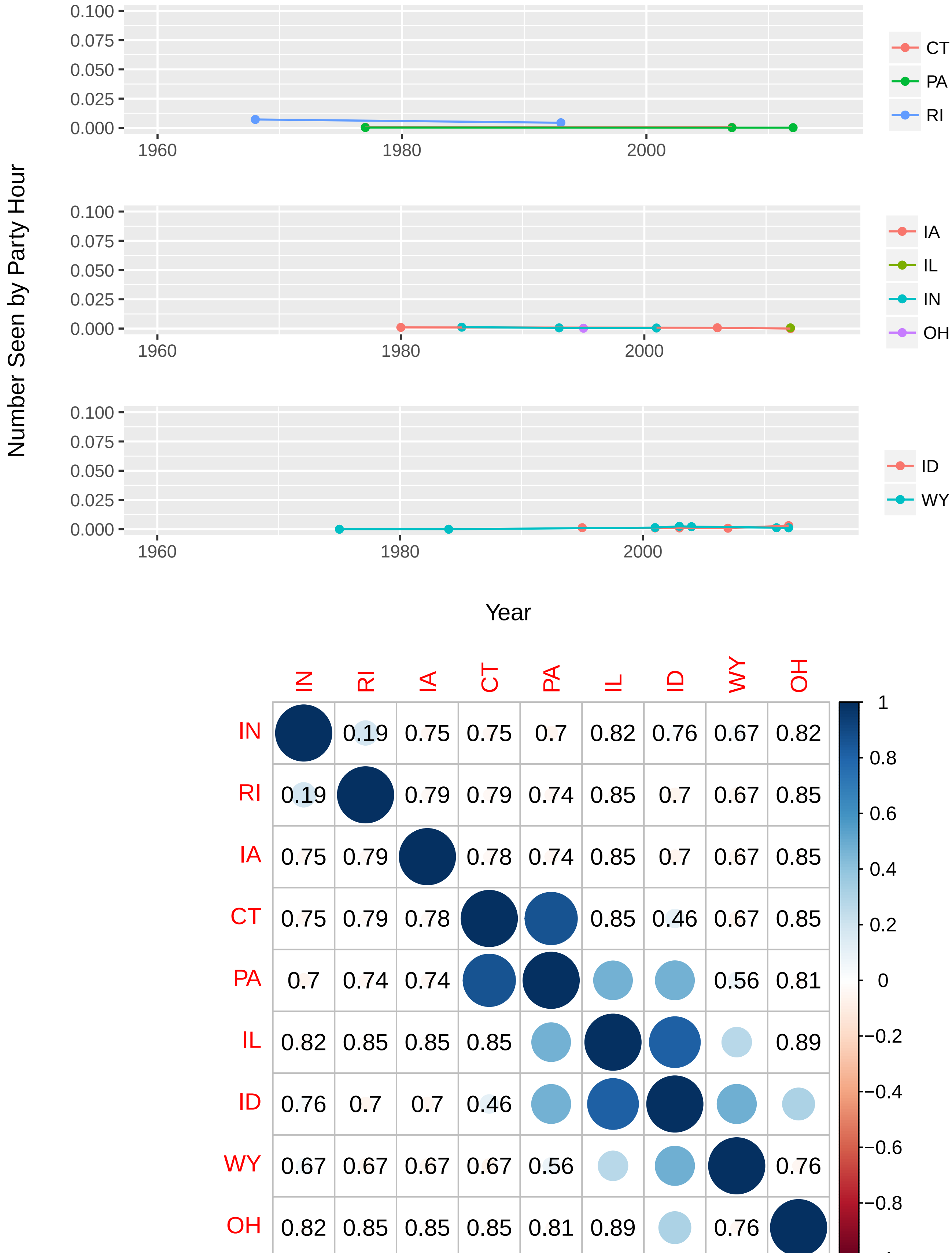


Figure 102: Hoary Redpoll abundance trends and area correlations across 3rd (mid US) latitudinal tier, CBC data.

The CBC has recorded no Hoary Redpolls in states in the southernmost latitudinal tier, so I am not able to compare abundance trends over time between these areas. Across the first longitudinal tier, all areas show very low records of Hoary Redpolls in the study period. Some areas show weak to strong positive correlations in abundance trends with each other. Due to lack of data, I excluded New Jersey, Maryland, Virginia, North Carolina, South Carolina, Georgia, and Florida from analyses (Fig. 103).

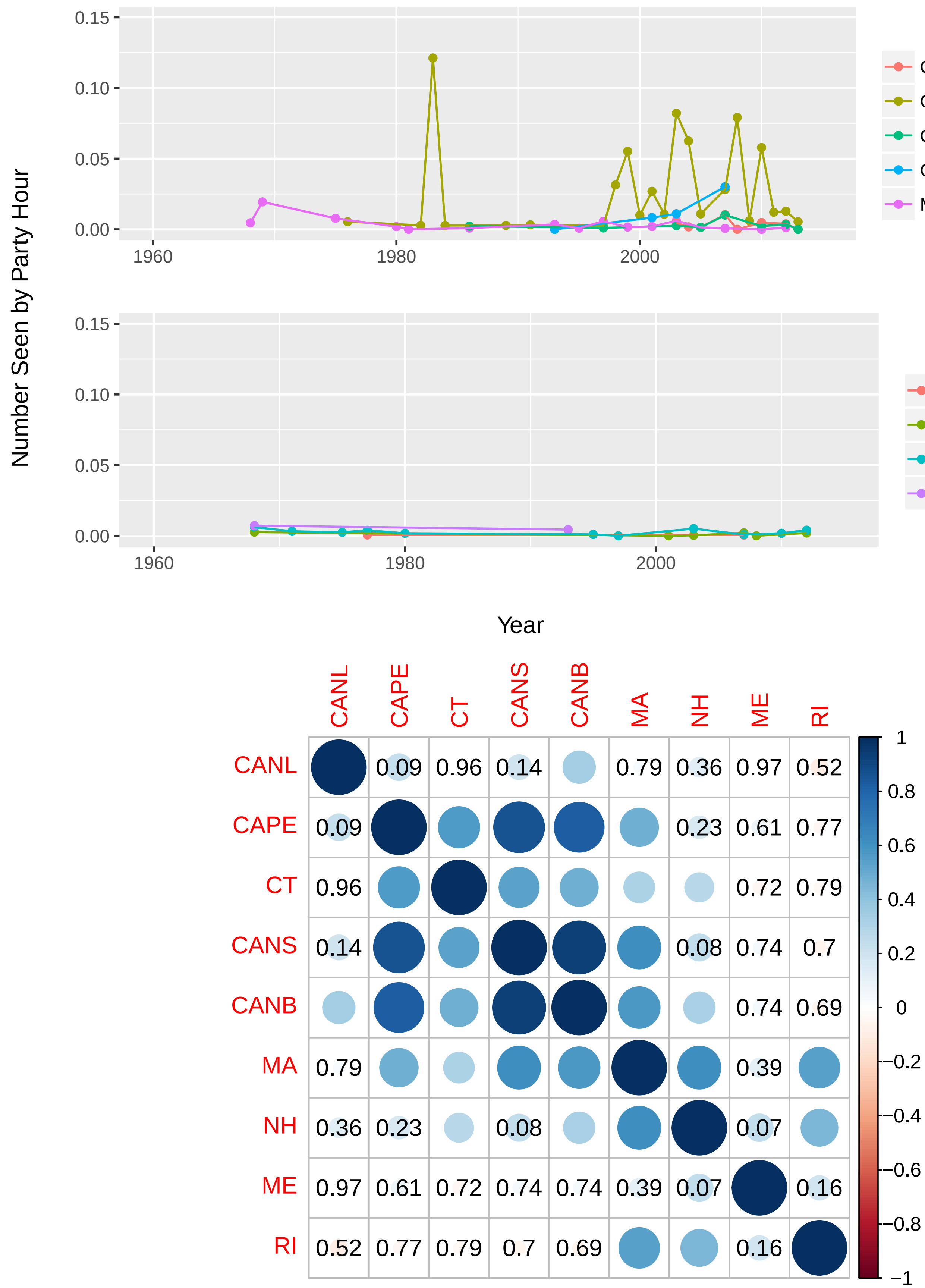
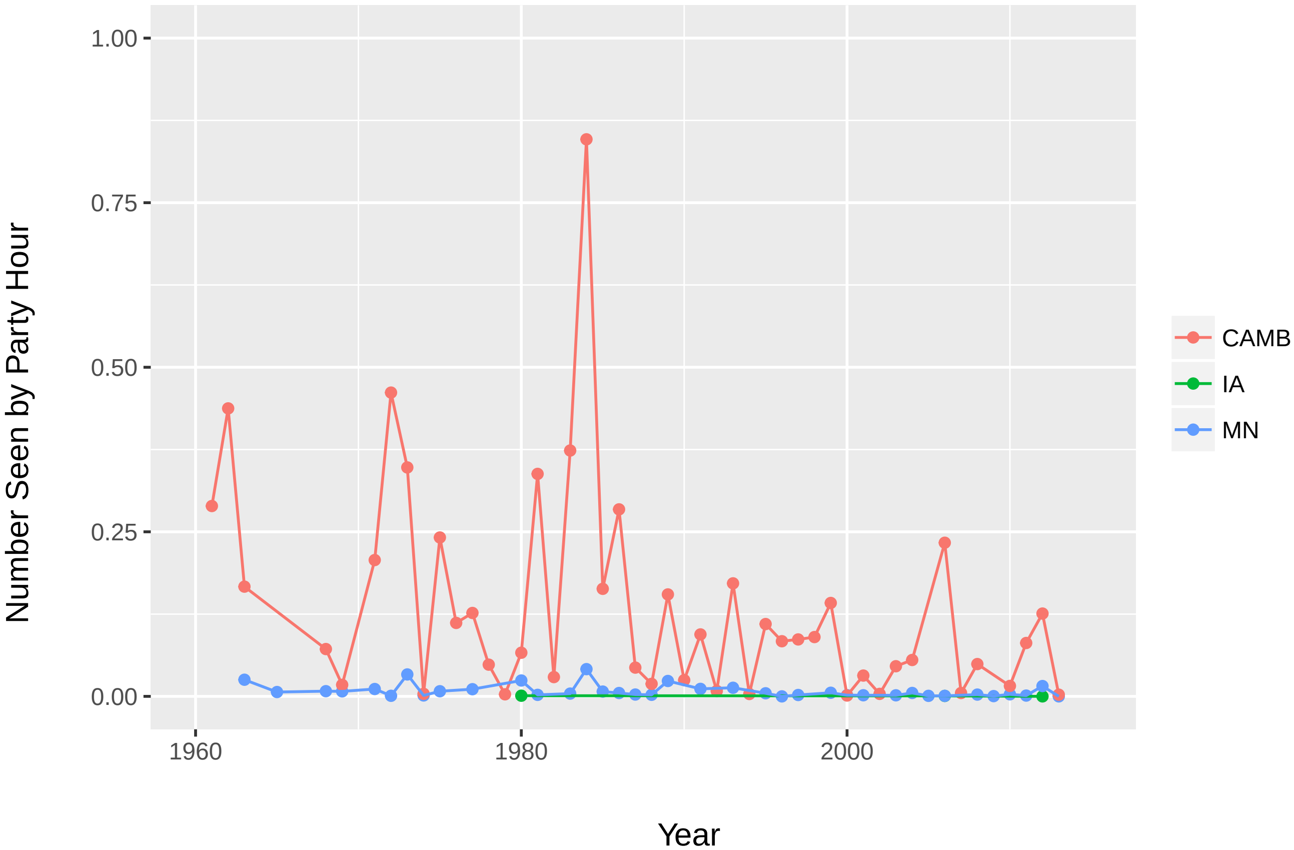


Figure 103: Hoary Redpoll abundance trends and area correlations across 1st (Atlantic) longitudinal tier, CBC data.

Down the second longitudinal tier, Manitoba, the northernmost area shows dramatic changes in Hoary Redpoll abundance over time, while the more southern areas consistently have low numbers throughout the study period. Minnesota shows a weak positive correlation with Iowa, and Manitoba shows a strong positive correlation with Minnesota. Due to lack of data, I excluded Missouri, Arkansas, and Lousiana from analyses (Fig. 104).



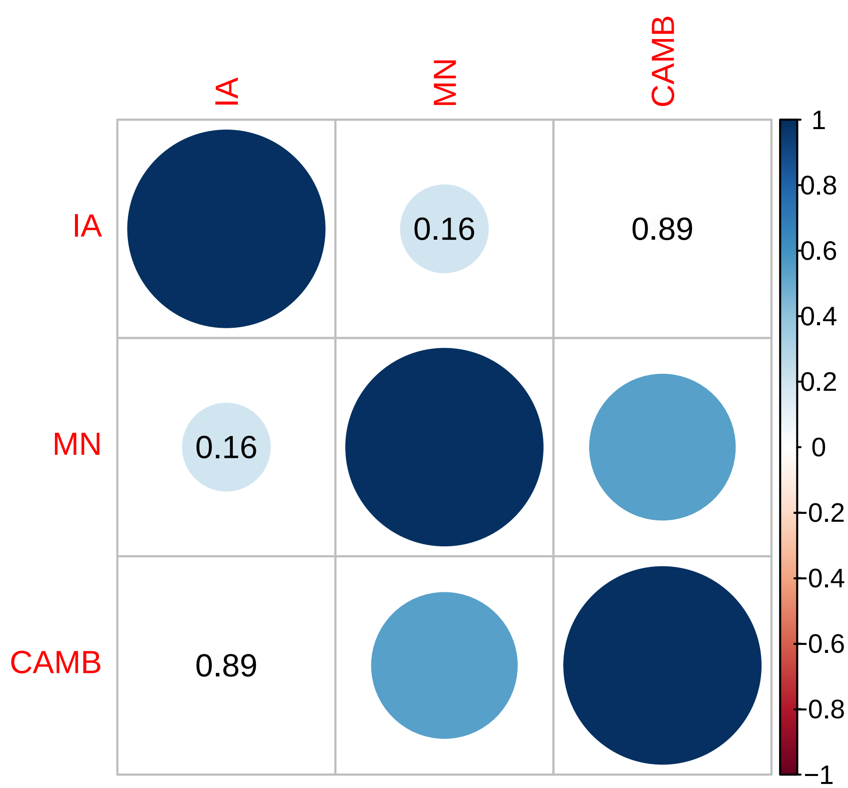


Figure 104: Hoary Redpoll abundance trends and area correlations across 2nd (midwest) longitudinal tier, CBC data.

Down the third longitudinal tier, northern areas show differently timed and sized rises and falls in Hoary Redpoll abundance, while there are few records in southern areas. There is a moderately strong positive correlation between the Northwest territories and Wyoming. Due to lack of data, I excluded New Mexico and Texas from analyses (Fig. 105).

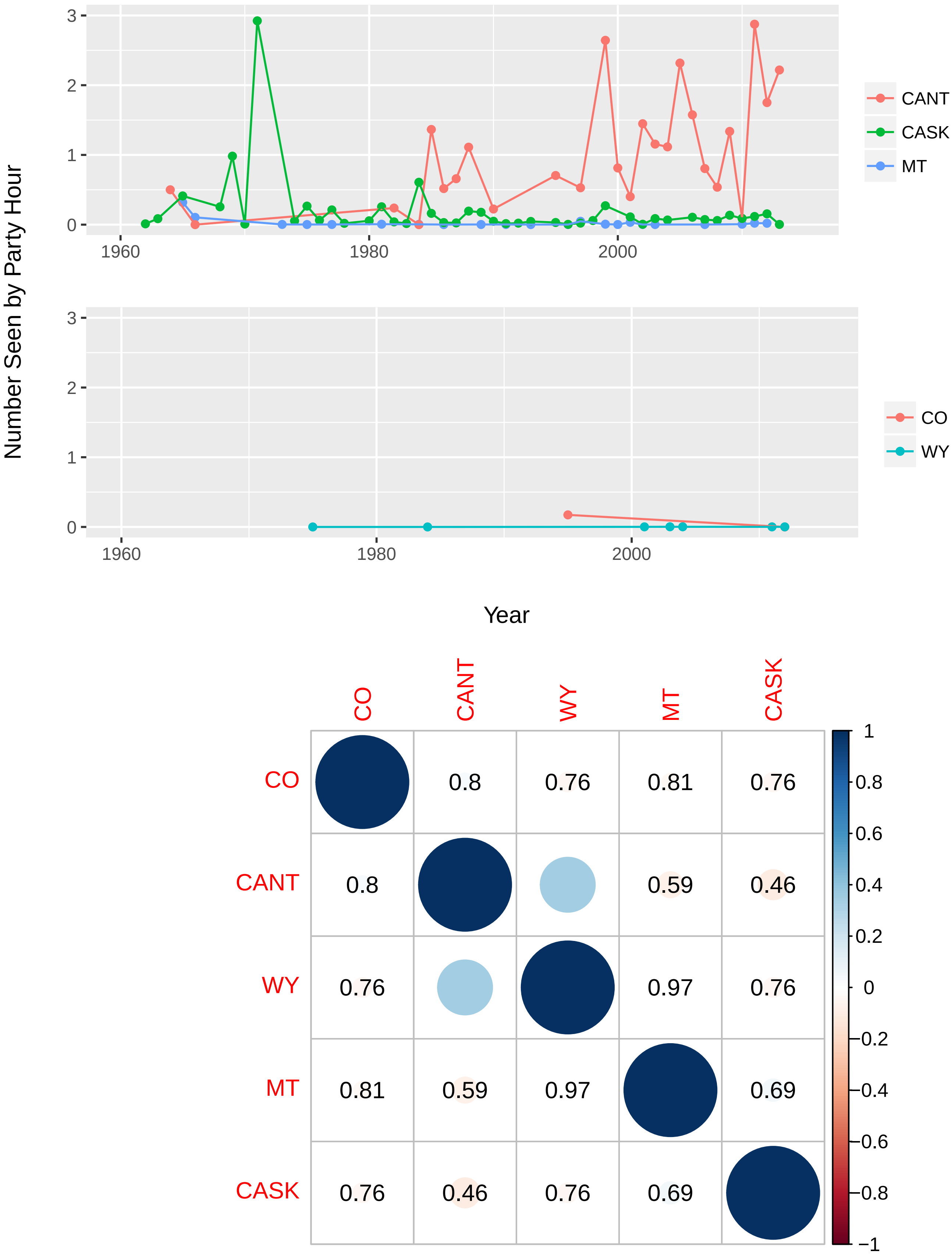
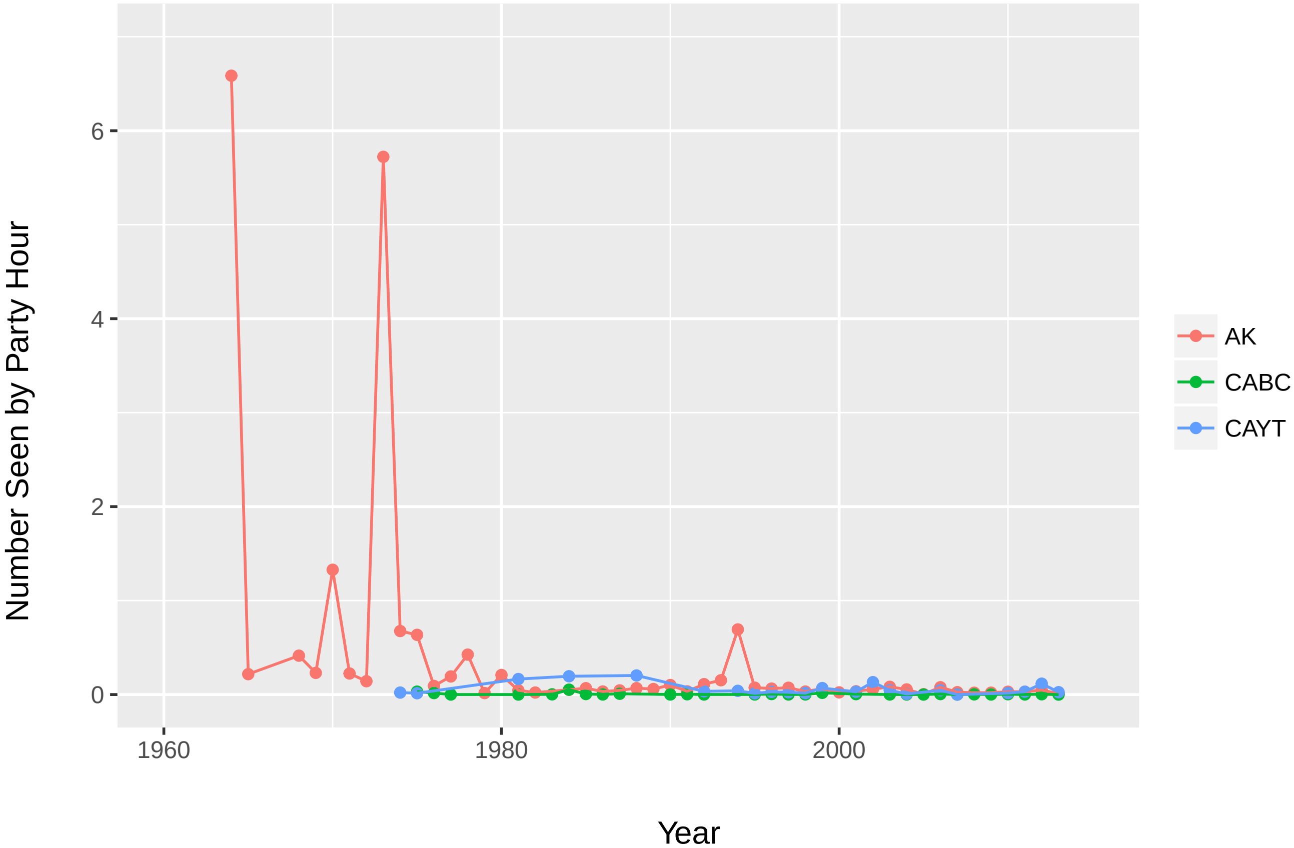


Figure 105: Hoary Redpoll abundance trends and area correlations across 3rd (Rocky Mountains) longitudinal tier, CBC data.

Down the fourth longitudinal tier, Alaska shows large changes in Hoary Redpoll abundance at the beginning of the study period, while the other areas show consistently low numbers throughout. There is a moderately strong positive correlation between the Yukon Territory and British Columbia. Due to lack of data, I excluded Washington, Oregon, and California (Fig. 106).



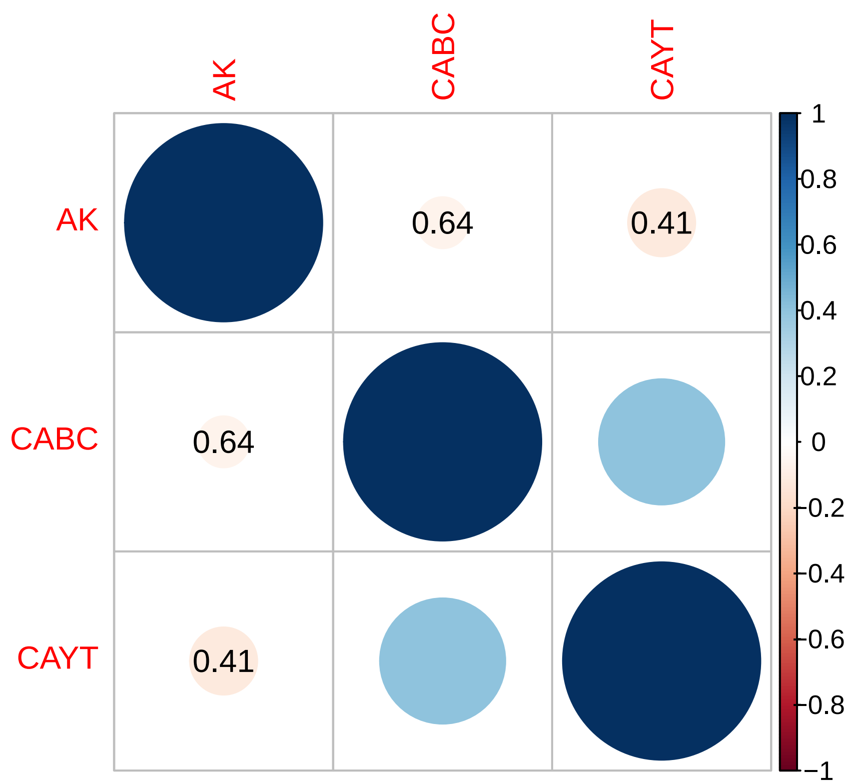


Figure 106: Hoary Redpoll abundance trends and area correlations across 4th (Pacific) longitudinal tier, CBC data.

eBird Analyses

Across the northermost latitudinal tier, daily eBird records show few correlations between different provinces, and few correlations between different years (Fig. 107).

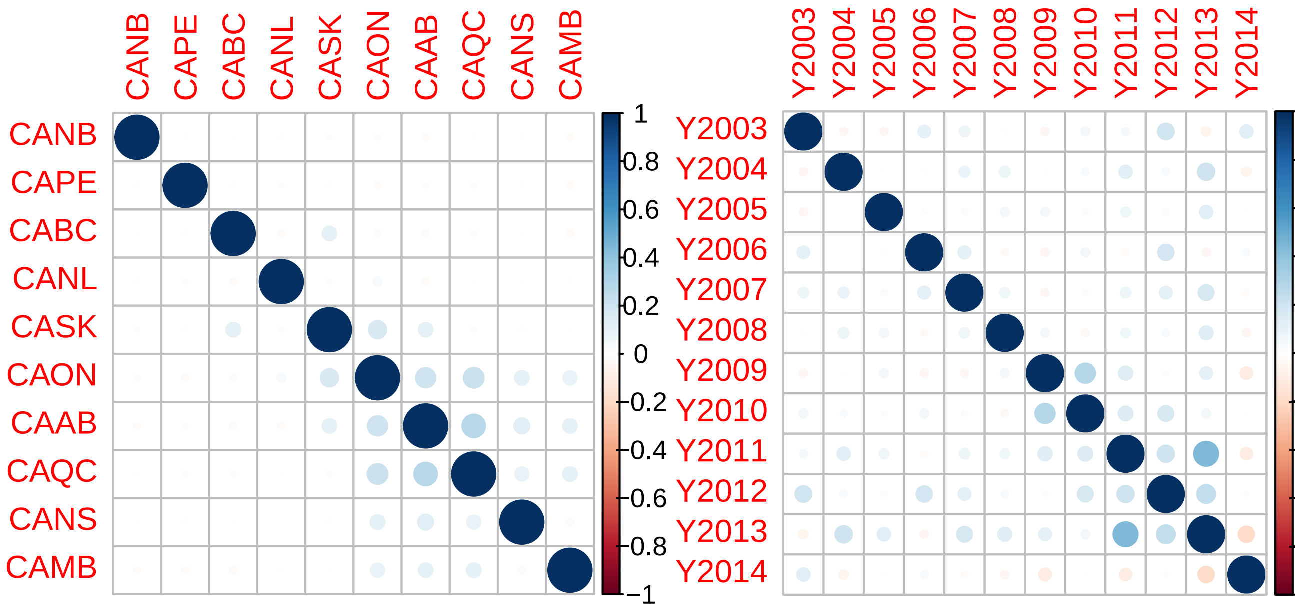


Figure 107: Correlations of Hoary Redpoll invasion pattern between individual areas and between years for the 1st (Canadian) latitudinal tier, eBird data.

Across the second latitudinal tier, daily eBird records show several weak to moderate positive correlations between different areas, and some weak to strong correlations between alternating years (Fig. 108).

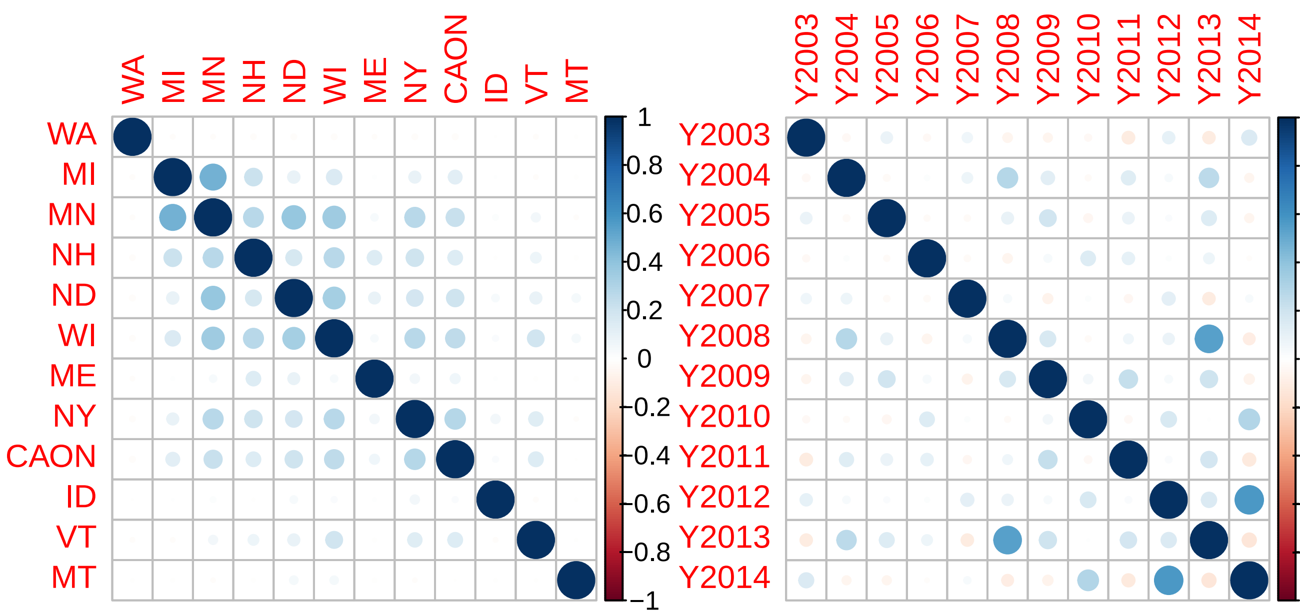


Figure 108: Correlations of Hoary Redpoll invasion pattern between individual areas and between years for the 2nd (northern US) latitudinal tier, eBird data.

Across the third latitudinal tier, daily eBird records show few correlations between different states and between different years (Fig. 109).

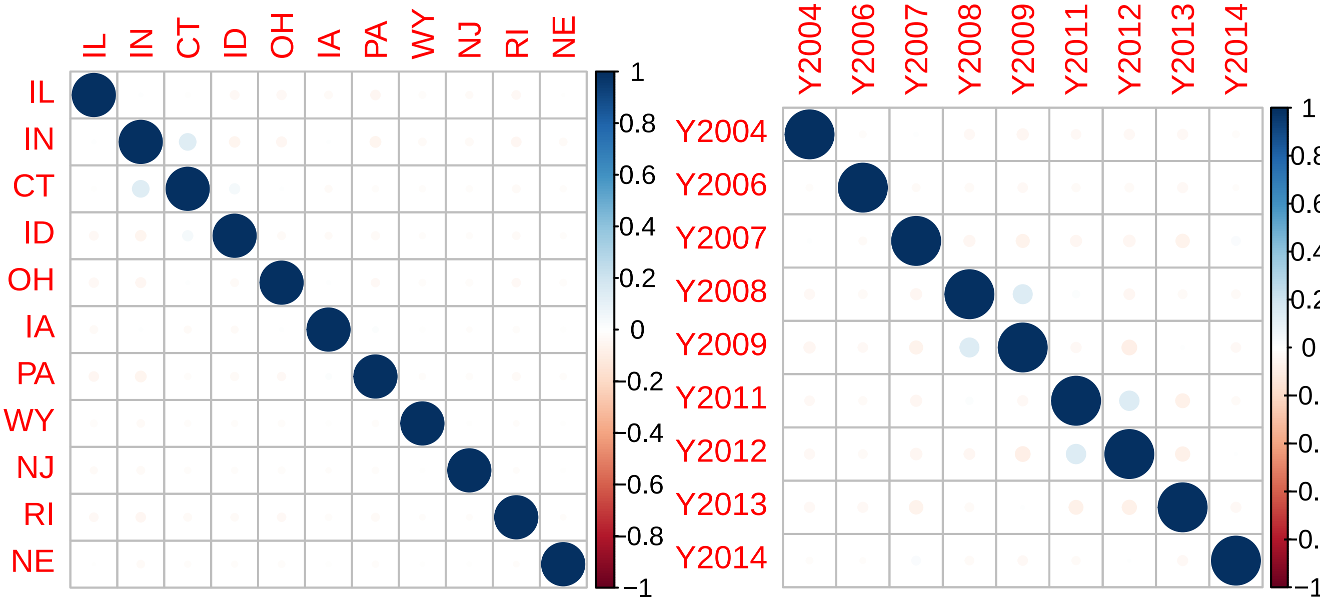


Figure 109: Correlations of Hoary Redpoll invasion pattern between individual areas and between years for the 3rd (mid US) latitudinal tier, eBird data.

Due to lack of data, I exluded the southernmost latitudinal tier from my analyses for this species. Down the first longitudinal tier, daily eBird records show few correlations between different areas and between different years (Fig. 110).

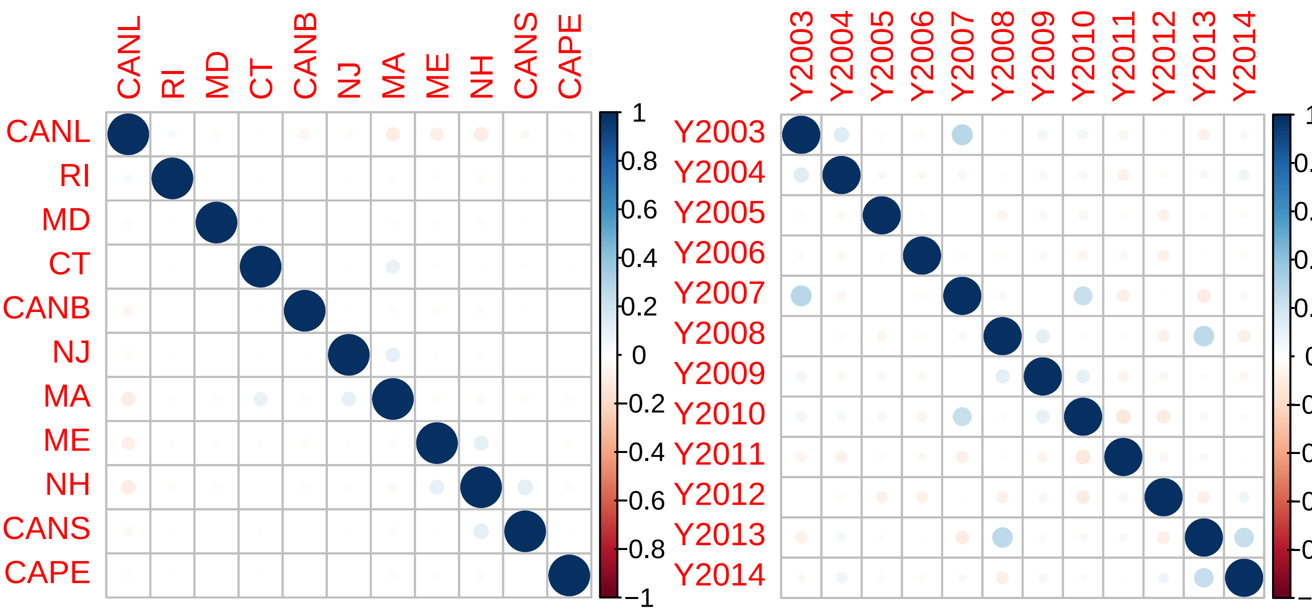


Figure 110: Correlations of Hoary Redpoll invasion pattern between individual areas and between years for the 1st (Atlantic) longitudinal tier, eBird data.

Down the second longitudinal tier, daily eBird records show few correlations between different areas and between different years (Fig. 111).

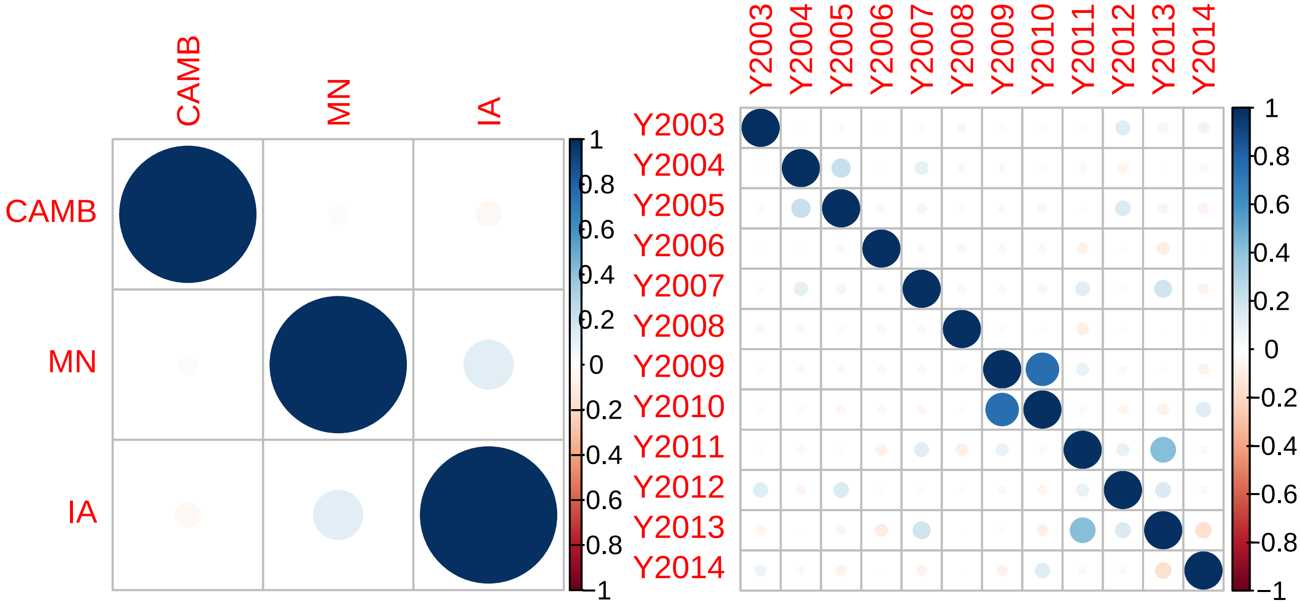


Figure 111: Correlations of Hoary Redpoll invasion pattern between individual areas and between years for the 2nd (midwest) longitudinal tier, eBird data.

Down the third longitudinal tier, daily eBird records show few correlations between different areas and between different years (Fig. 112).

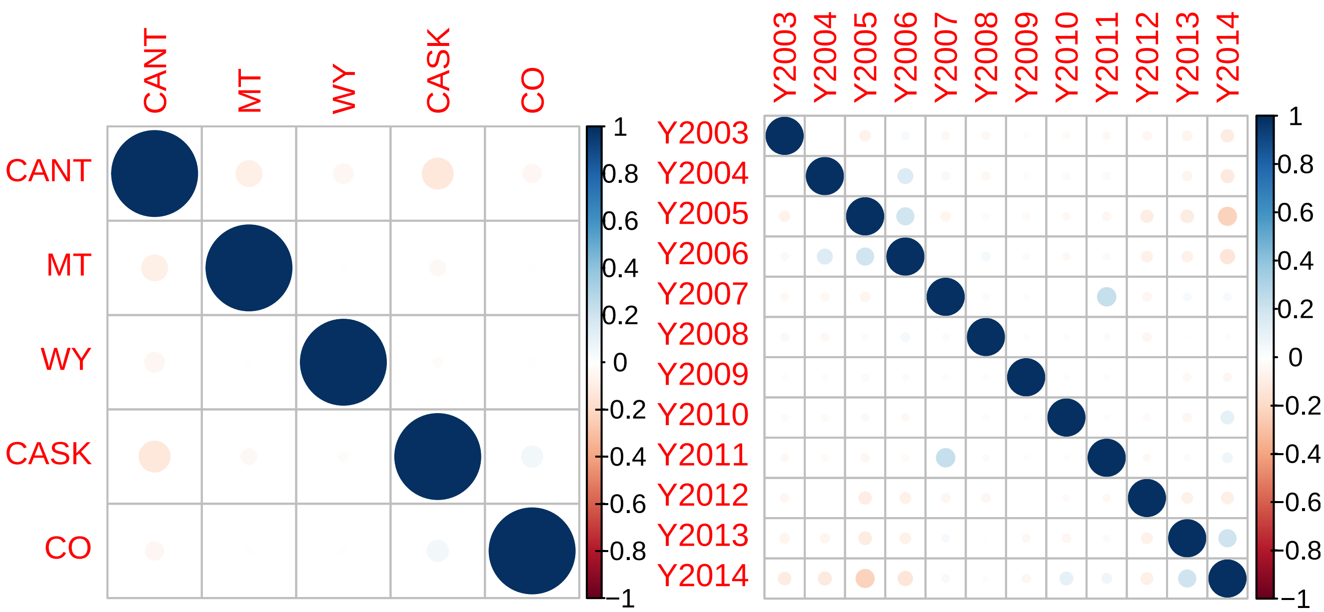


Figure 112: Correlations of Hoary Redpoll invasion pattern between individual areas and between years for the 3rd (Rocky Mountains) longitudinal tier, eBird data.

Down the fourth longitudinal tier, daily eBird records show few correlations between different areas, but strong positive correlations between recent years (Fig. 113).

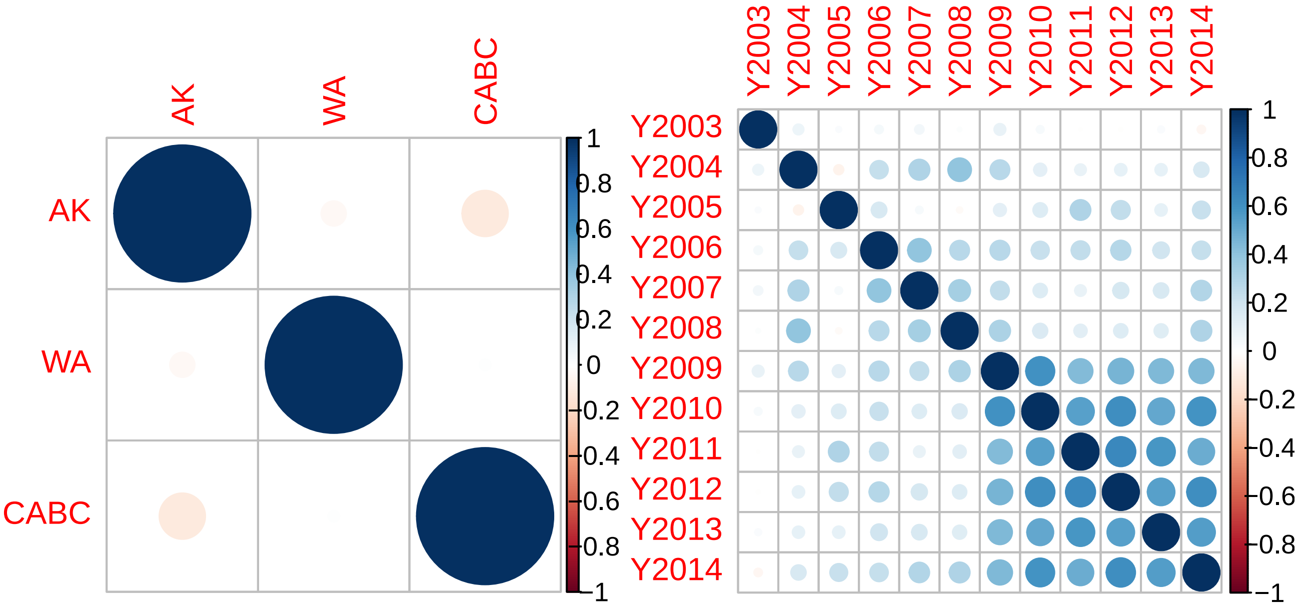


Figure 113: Correlations of Hoary Redpoll invasion pattern between individual areas and between years for the 4th (Pacific) longitudinal tier, eBird data.

Common Redpoll

CBC Analyses

During irruption years, this species regularly moves south throughout its range, and as Fig. 114 shows, the Christmas Bird Count has historically reported the highest densities across the northern United States and southern Canada. Common Redpolls rarely winter in the southern half of the United States.

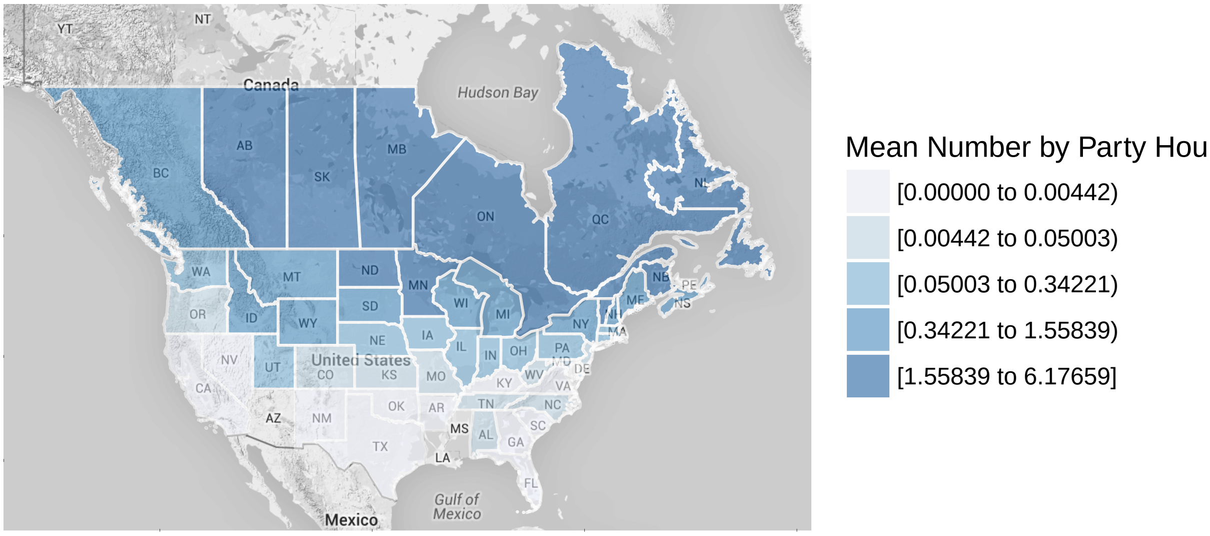


Figure 114: Abundance of Common Redpolls by area, CBC data.

CBC data also indicates that the highest variation in wintering Common Redpoll numbers occurs across the southermost latidude where sizeable irruptions regularly occur (Fig. 115).

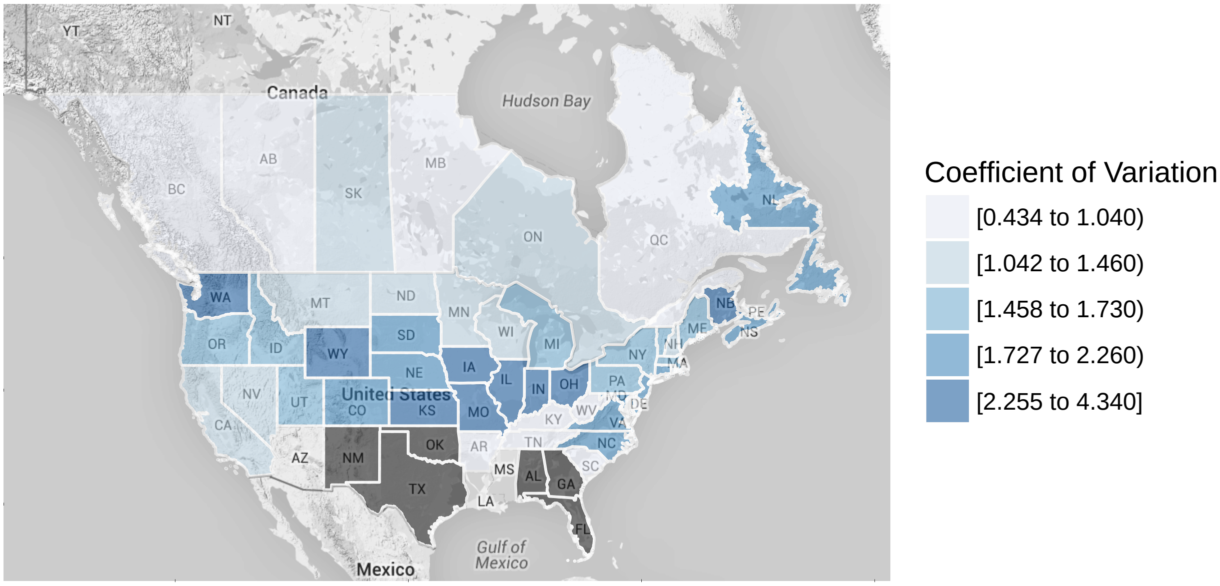


Figure 115: Coefficient of variation for Common Redpoll abundance by area, CBC data.

I found strong correlations in abundance over time between most areas across southern Canada (Fig. 116). This latitude represents the northern extent of the species' wintering range during irruption years. When southward irruptions do not occur, the majority of individuals remain above this latidude throughout the winter.

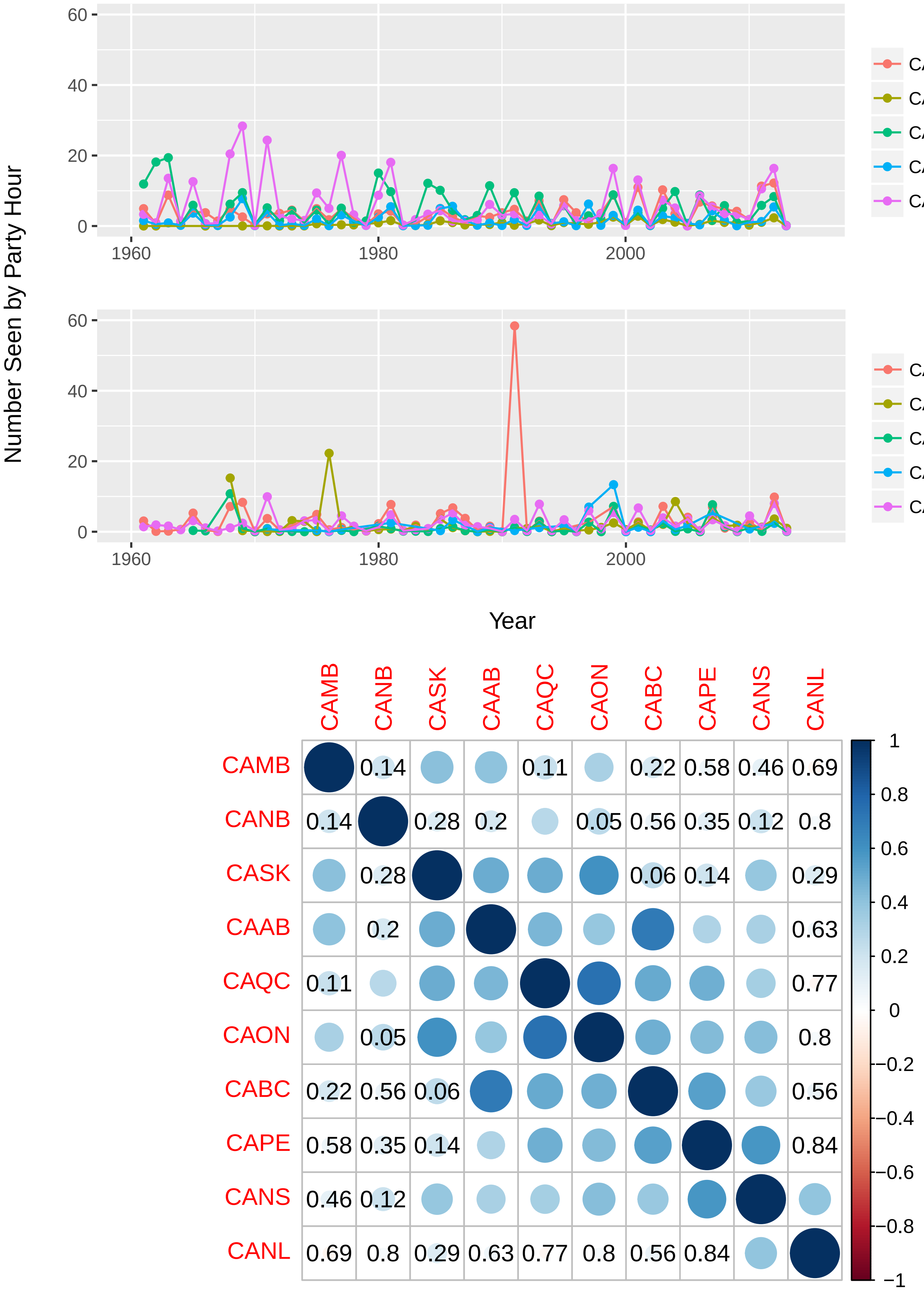


Figure 116: Common Redpoll abundance trends and area correlations across northern (Canadian) latitudinal tier, CBC data.

Similarly, I found strong correlations between areas across the northern United States. This zone displays high Common Redpoll abundances in irruption years (Fig. 117).

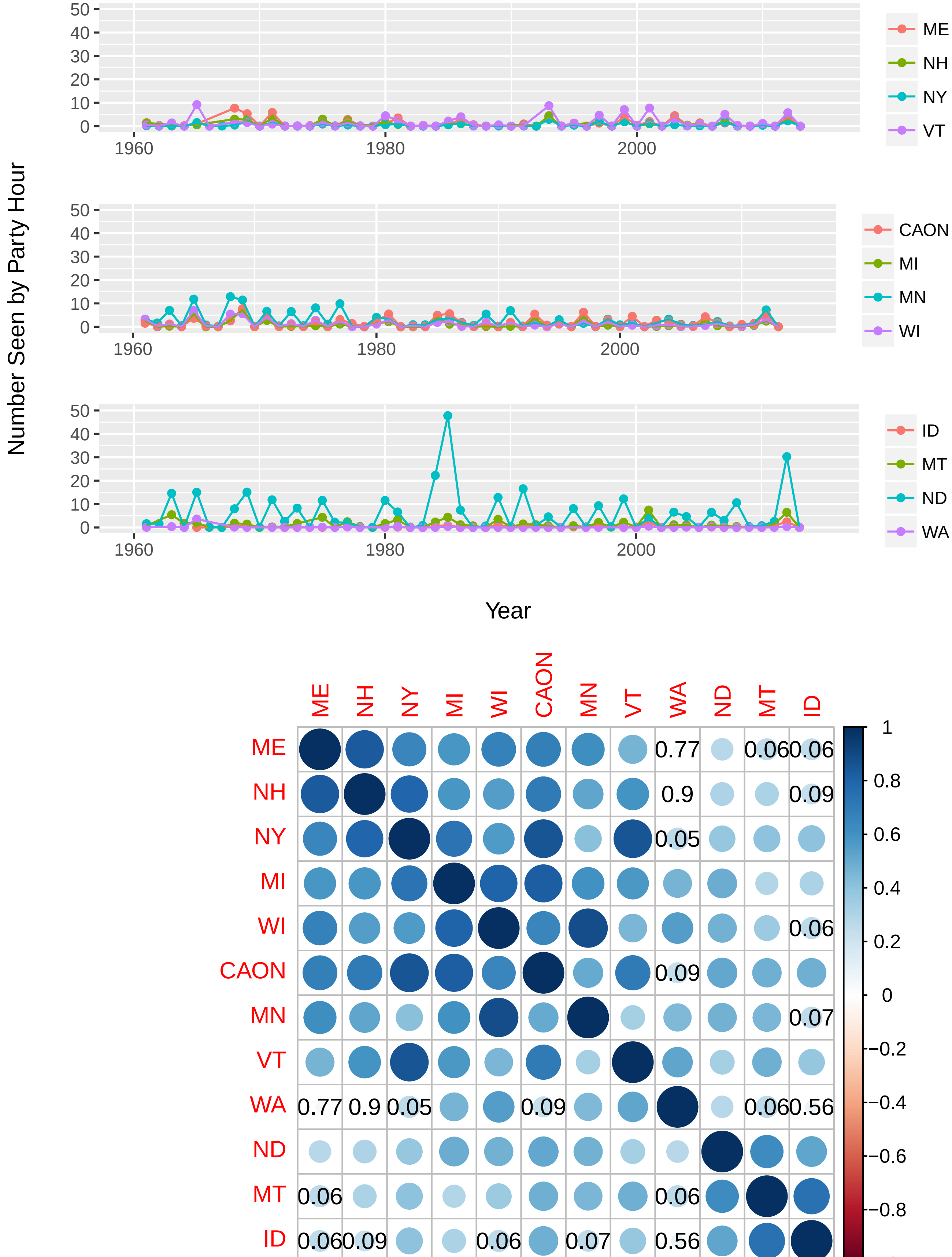


Figure 117: Common Redpoll abundance trends and area correlations across 2nd (northern US) latitudinal tier, CBC data.

I also observed correlations in Common Redpoll abundance patterns across the third latitudinal tier, but the small numbers of redpolls at this latitude during the time of the Christmas Bird Count, even during irruption years, limit the strength of these correlations (Fig. 118). This tier comprises the typical southern extent of winter Common Redpoll abundances. As such, I could not compare winter abundance trends for this species in my designated fourth latitude due to lack of data.

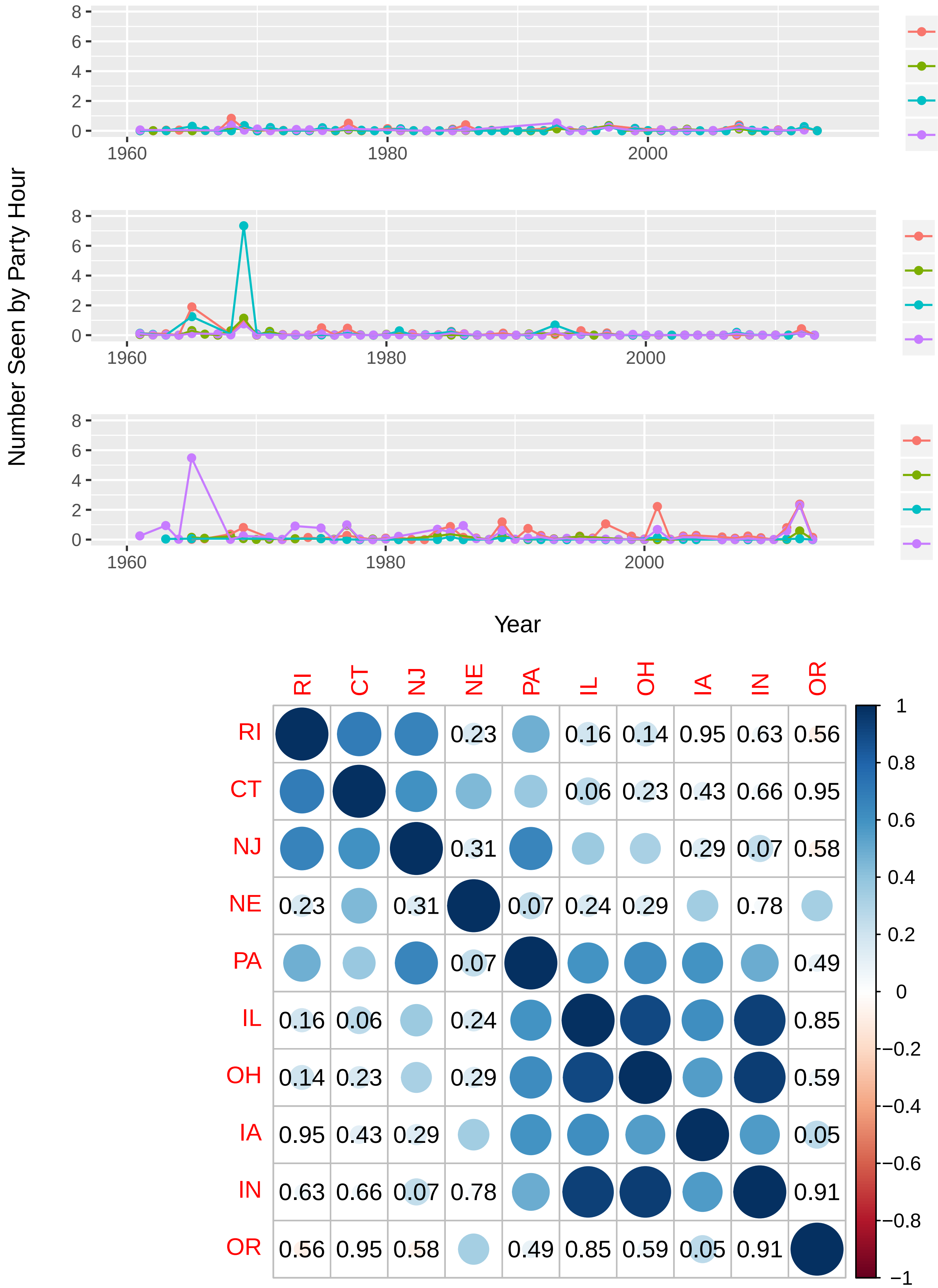


Figure 118: Common Redpoll abundance trends and area correlations across 3rd (mid US) latitudinal tier, CBC data.

Down the easternmost longitude, CBC records show strong correlations between areas in the north that share concentric abundance spikes and between areas in the south that have few records of Common Redpolls (Fig. 119).

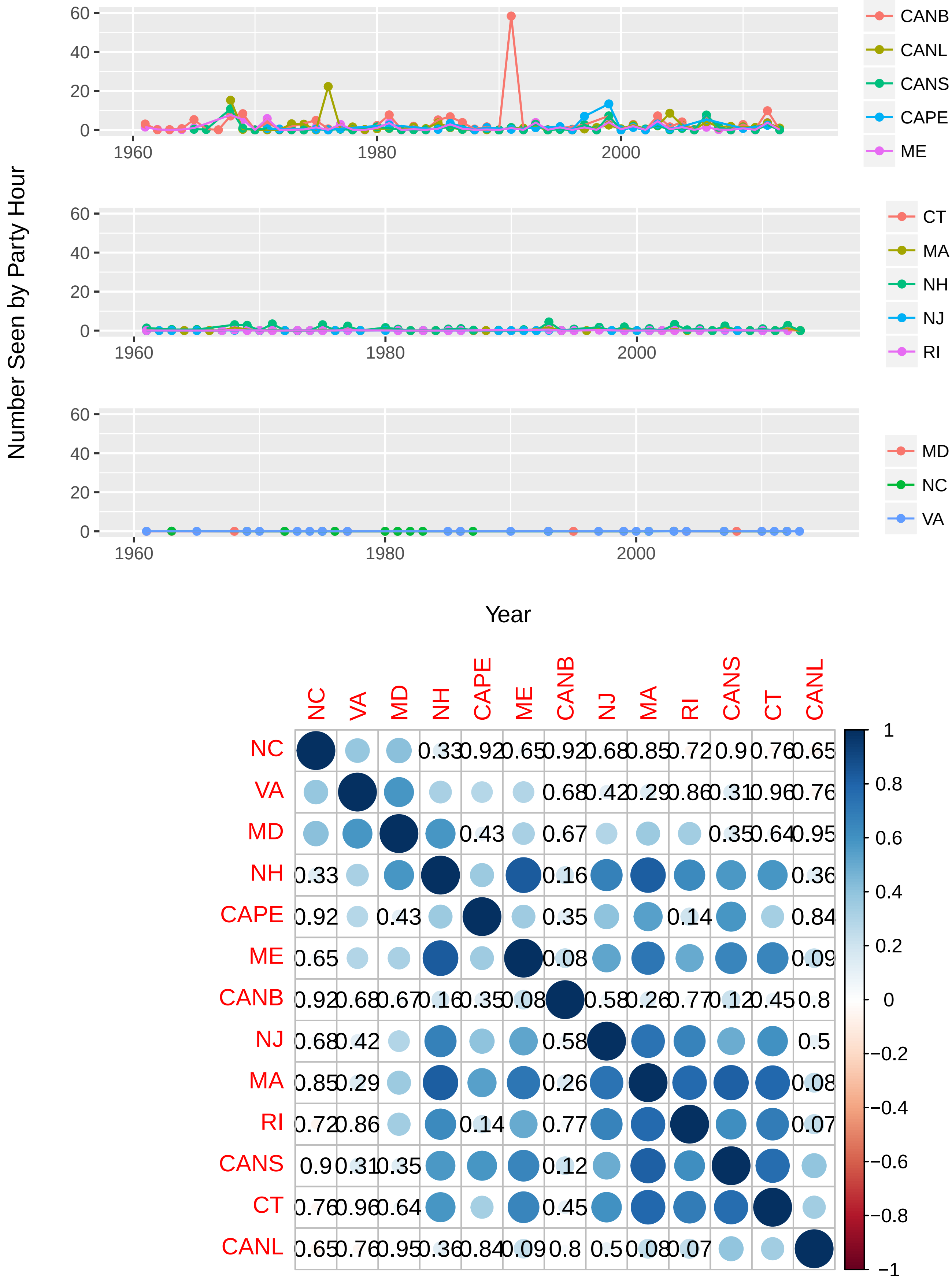


Figure 119: Common Redpoll abundance trends and area correlations across 1st (Atlantic) longitudinal tier, CBC data.

Down the second longitudinal tier, CBC records show significant positive correlations between northern areas, which show concentric but differently sized abundance spikes during the study period, and between southern areas with few records of Common Redpolls (Fig. 120).

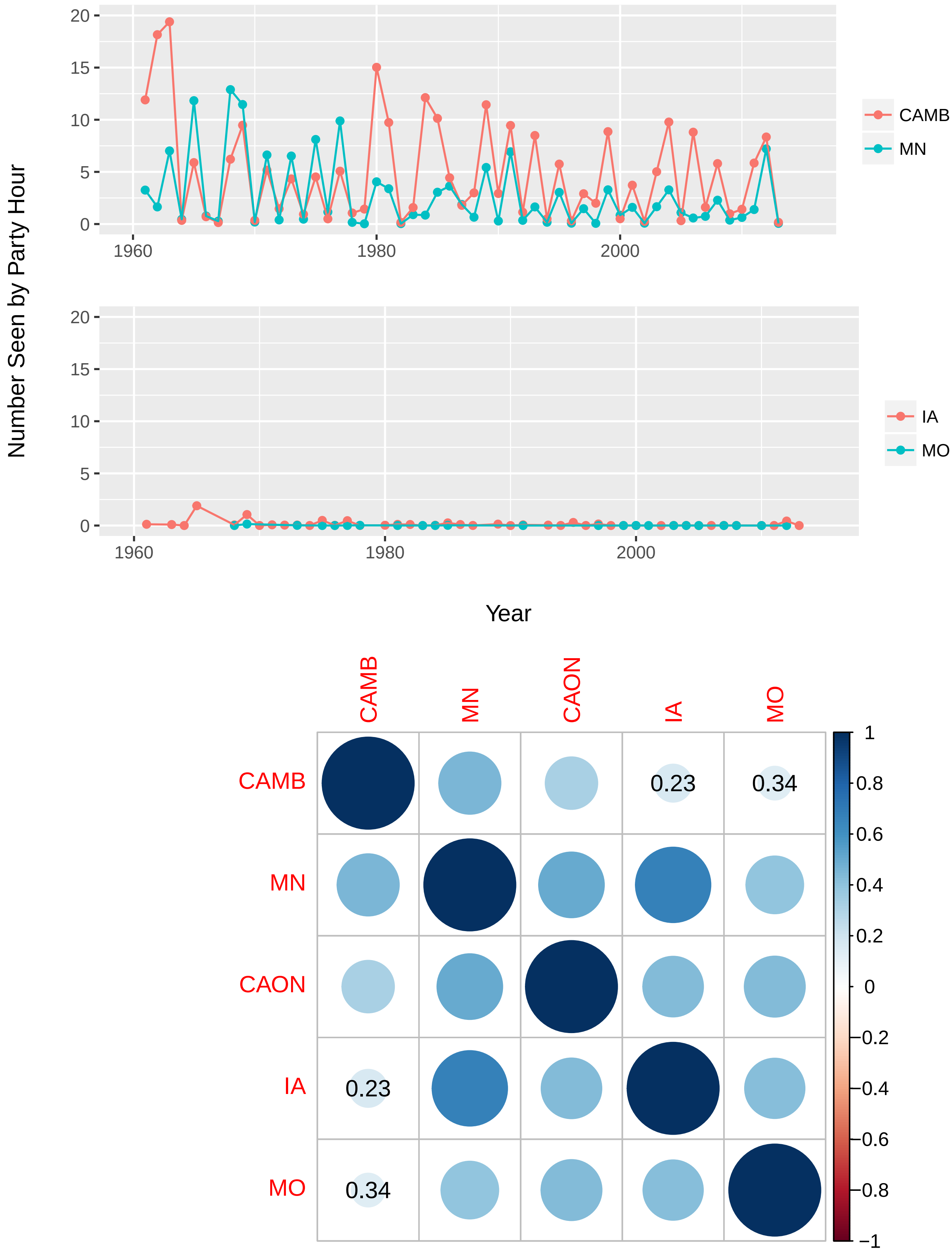


Figure 120: Common Redpoll abundance trends and area correlations across 2nd (midwest) longitudinal tier, CBC data.

Down the third longitudinal tier, CBC records show significant positive correlations between nearly all areas, as they show concentric but differently sized abundance spikes during the study period (Fig. 121).

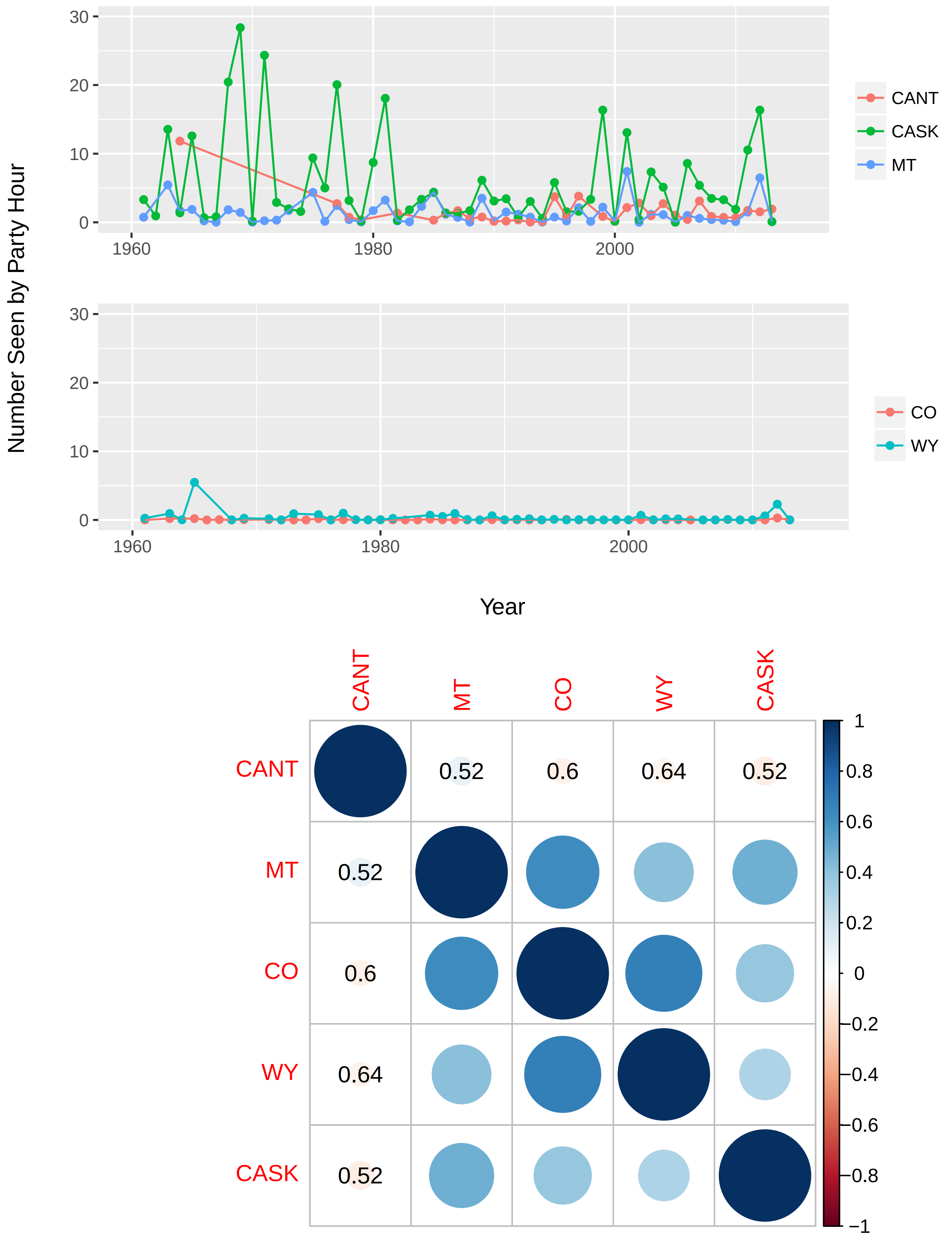


Figure 121: Common Redpoll abundance trends and area correlations across 3rd (Rocky Mountains) longitudinal tier, CBC data.

Down the fourth longitudinal tier, CBC records show significant positive correlations between neighboring areas (Fig. 122).

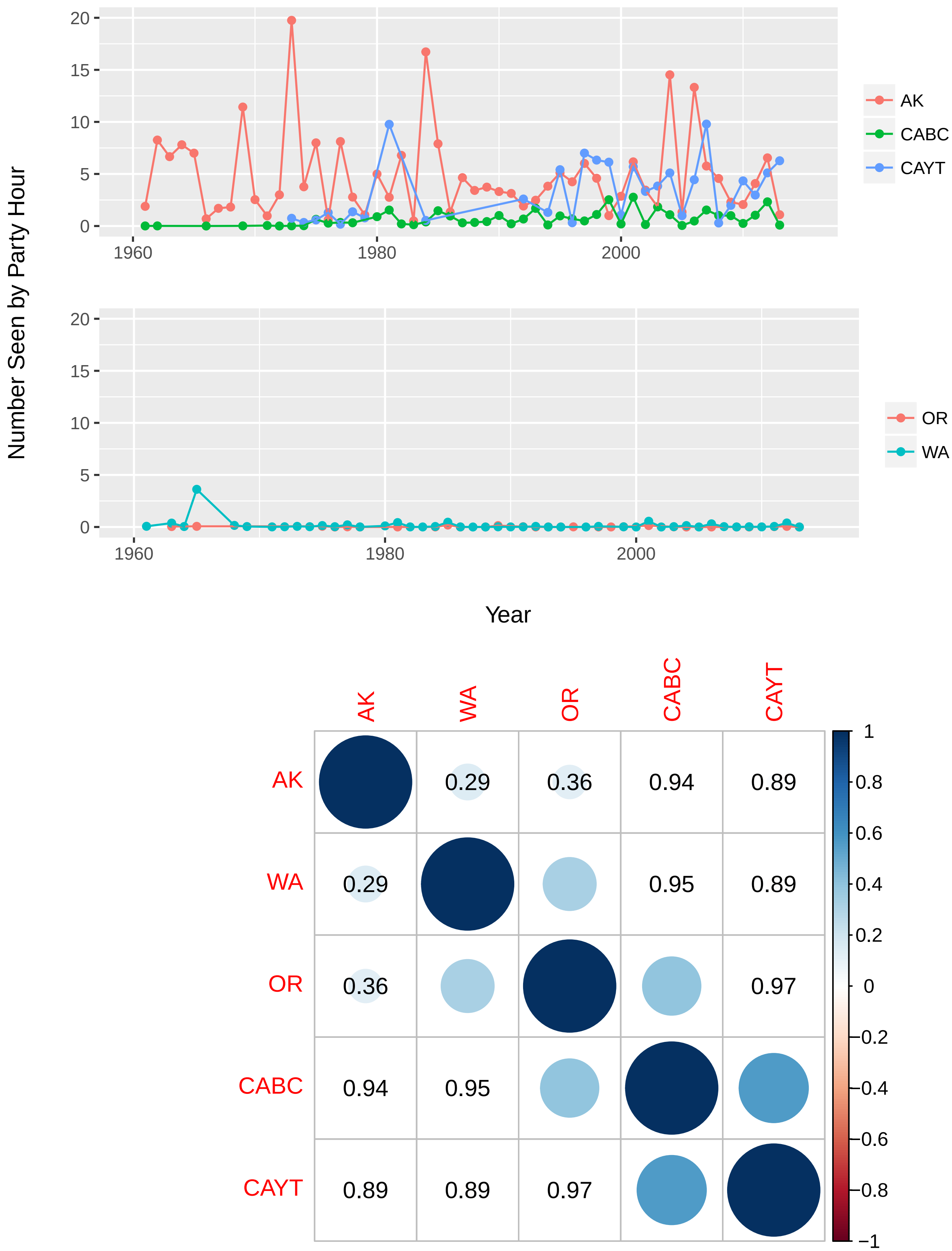


Figure 122: Common Redpoll abundance trends and area correlations across 4th (Pacific) longitudinal tier, CBC data.

eBird Analyses

Across the first latitudinal tier, daily eBird records show weak to strong positive correlations between most areas, and strong positive correlations between years that are two years apart (Fig. 123).

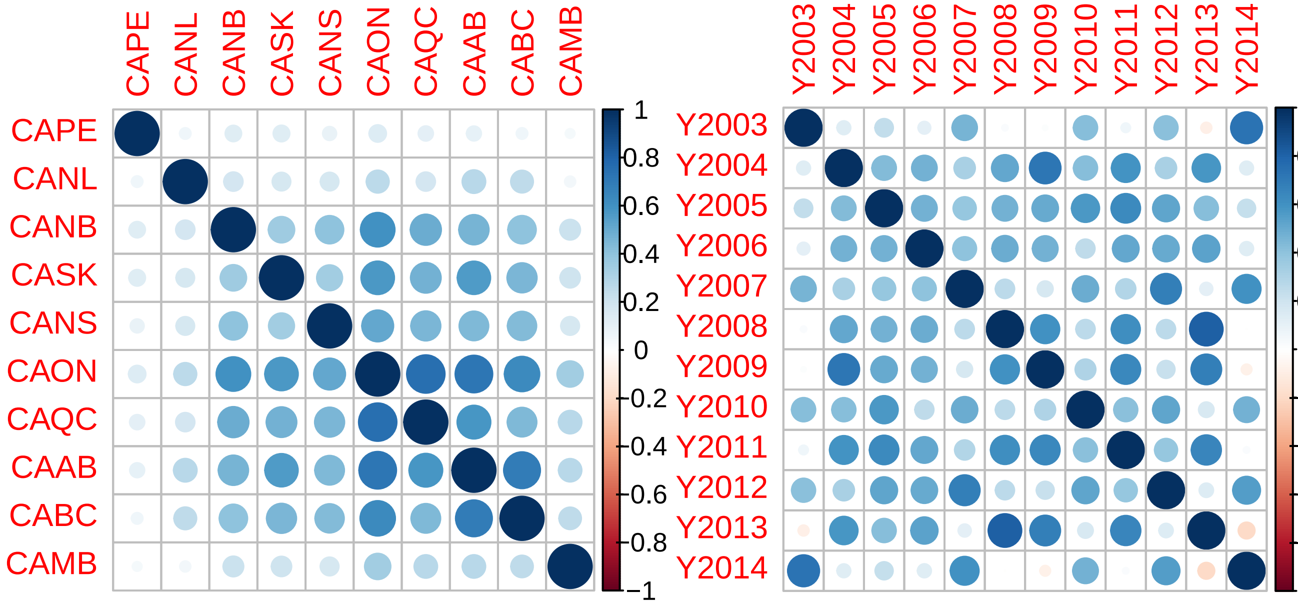


Figure 123: Correlations of Common Redpoll invasion pattern between individual areas and between years for the 1st (Canadian) latitudinal tier, eBird data.

Across the second latitudinal tier, daily eBird records show weak to strong positive correlations between most areas, and strong positive correlations between years that are two years apart (Fig. 124).

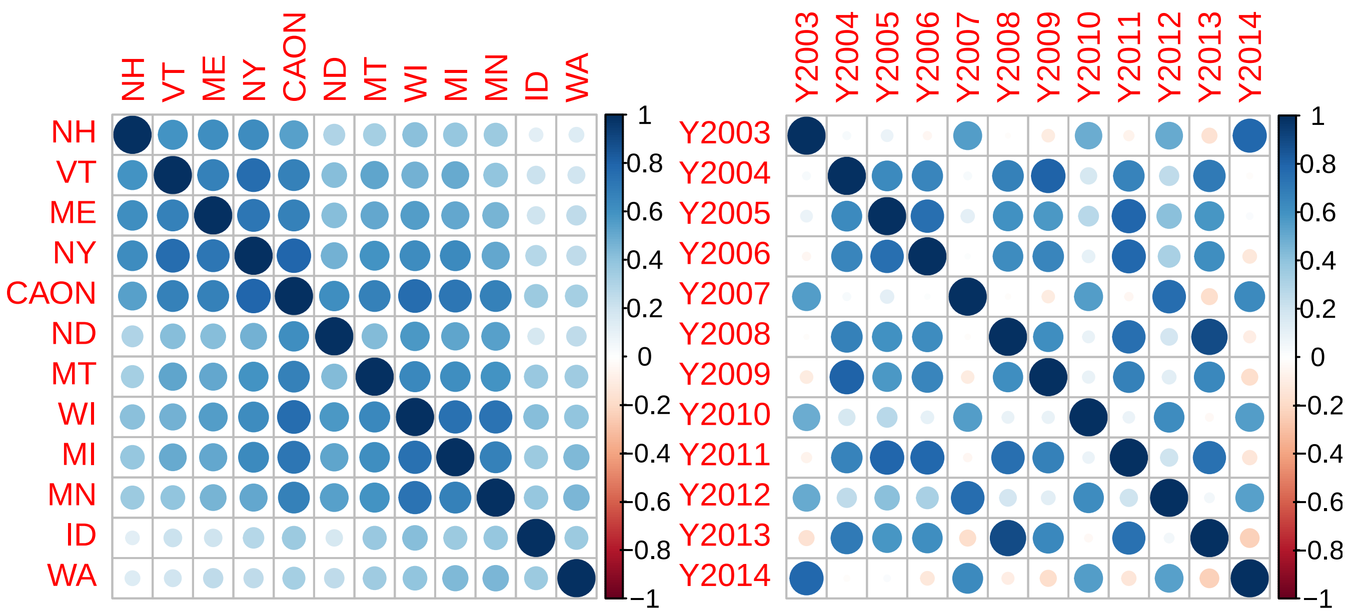


Figure 124: Correlations of Common Redpoll invasion pattern between individual areas and between years for the 2nd (northern US) latitudinal tier, eBird data.

Across the third latitudinal tier, daily eBird records show weak to moderate positive correlations between most areas. There are alternating weak to moderate negative and positive correlations between years (Fig. 125).

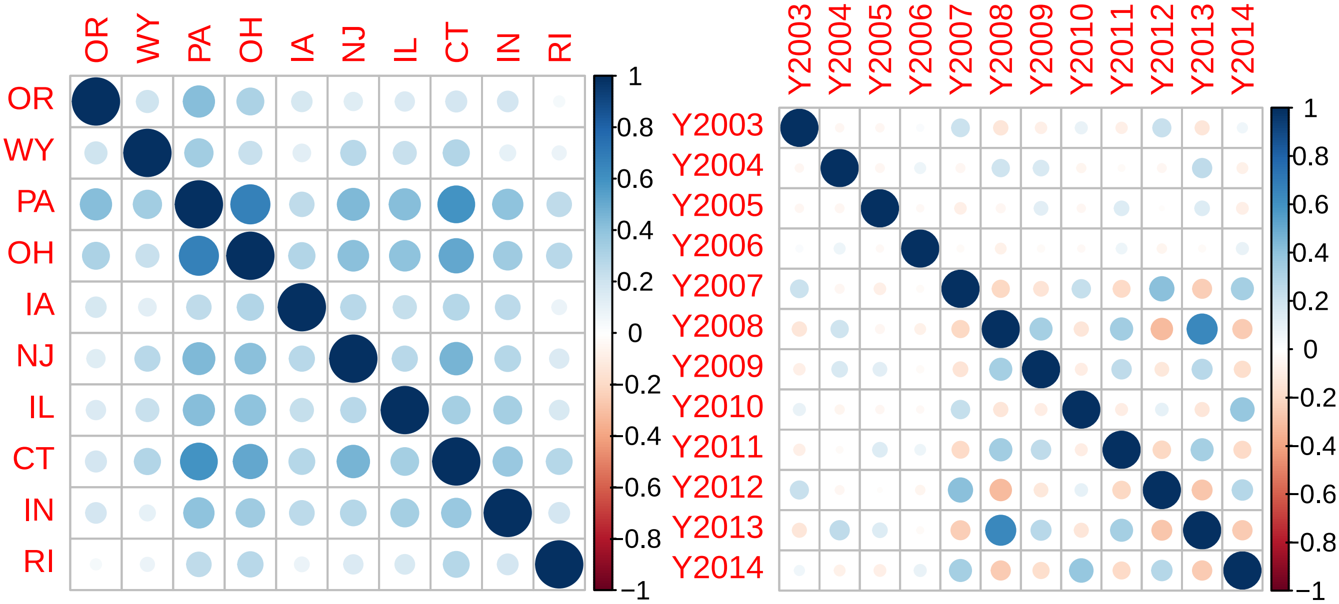


Figure 125: Correlations of Common Redpoll invasion pattern between individual areas and between years for the 3rd (mid US) latitudinal tier, eBird data.

Across the first longitudinal tier, daily eBird records show weak to strong positive correlations between some areas in the north. There are alternating weak to strong negative and positive correlations between years (Fig. 126).

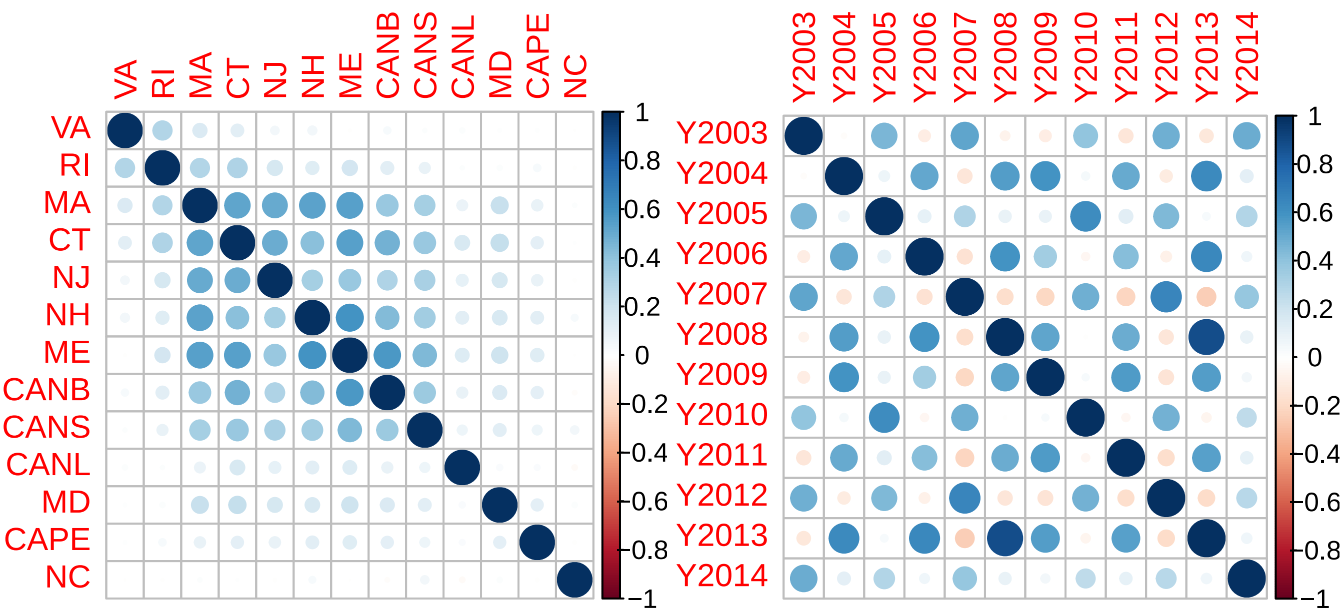


Figure 126: Correlations of Common Redpoll invasion pattern between individual areas and between years for the 1st (Atlantic) longitudinal tier, eBird data.

Across the second longitudinal tier, daily eBird records show weak to moderate positive correlations between some areas. There are few correlations between years (Fig. 127).

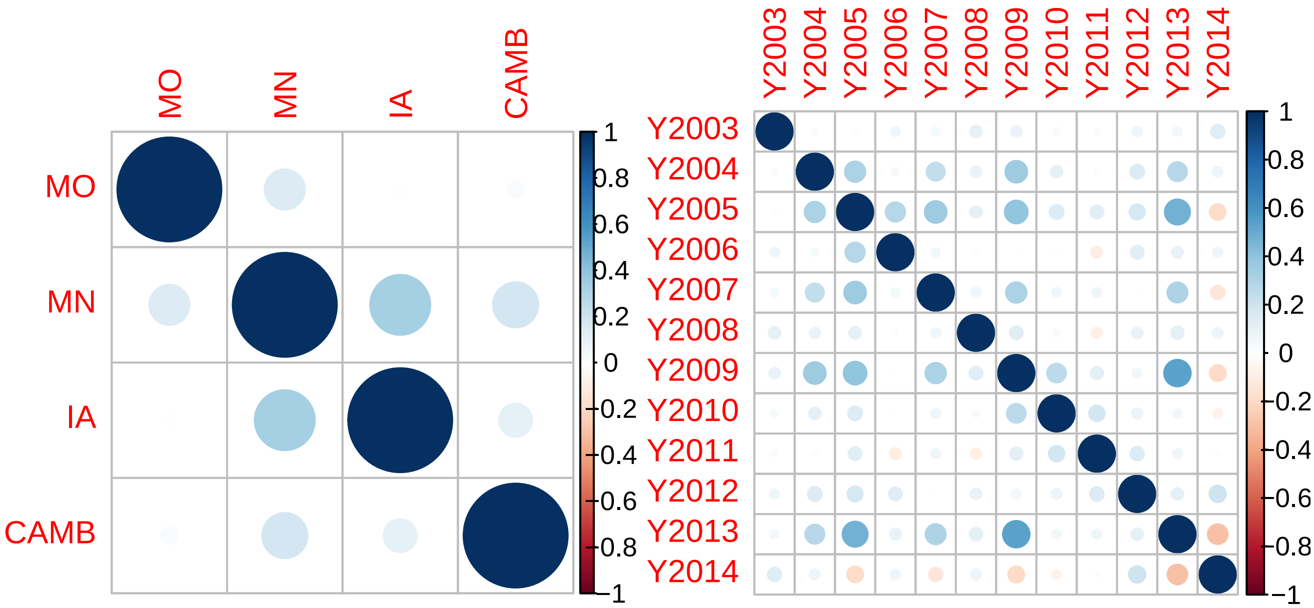


Figure 127: Correlations of Common Redpoll invasion pattern between individual areas and between years for the 2nd (midwest) longitudinal tier, eBird data.

Across the third longitudinal tier, daily eBird records show weak to strong correlations between some areas. There are few correlations between years (Fig. 128).

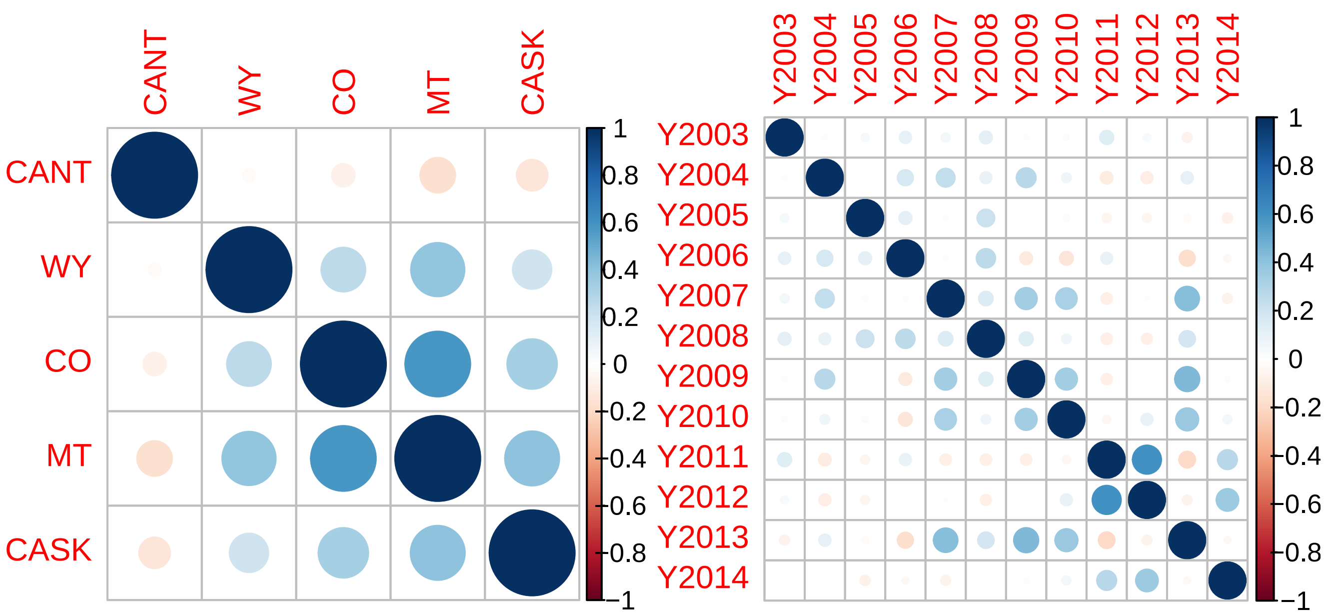


Figure 128: Correlations of Common Redpoll invasion pattern between individual areas and between years for the 3rd (Rocky Mountains) longitudinal tier, eBird data.

Across the third longitudinal tier, daily eBird records show weak to strong positive correlations between all different areas. There are few correlations between years (Fig. 129).

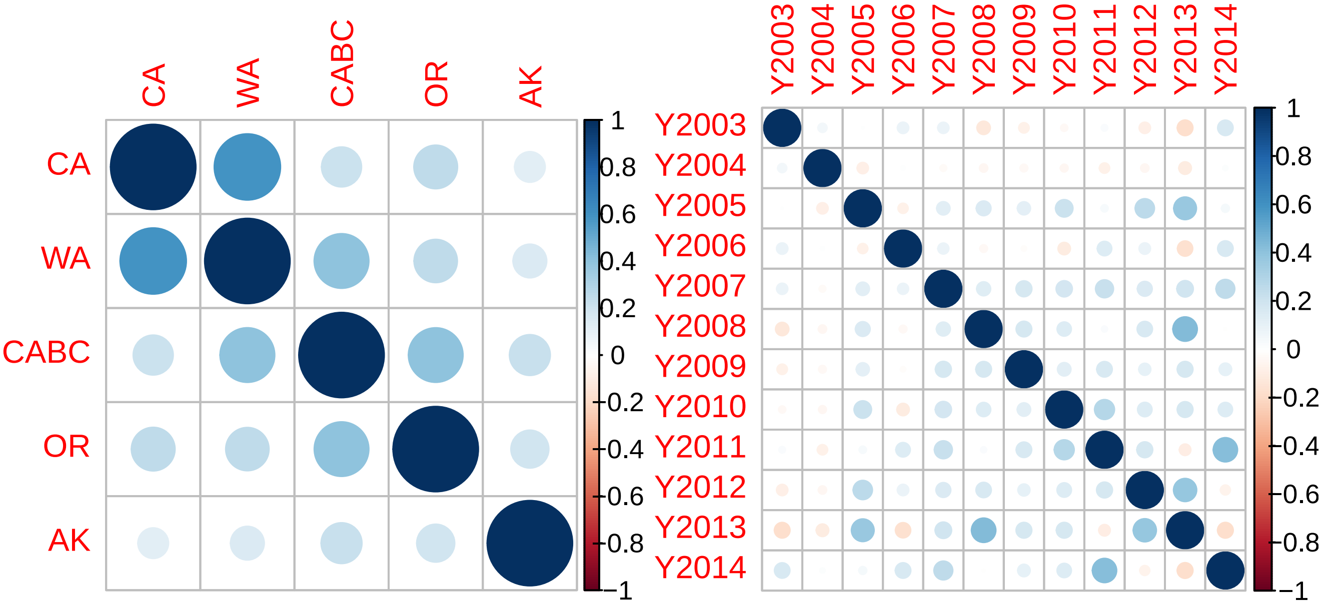


Figure 129: Correlations of Common Redpoll invasion pattern between individual areas and between years for the 4th (Pacific) longitudinal tier, eBird data.

Red Crossbill

CBC Analyses

Christmas Bird Count data since 1960 show that the highest numbers of Red Crossbills are recorded across in northwestern North America, with high numbers also reported in certain areas in the east (Fig. 130).

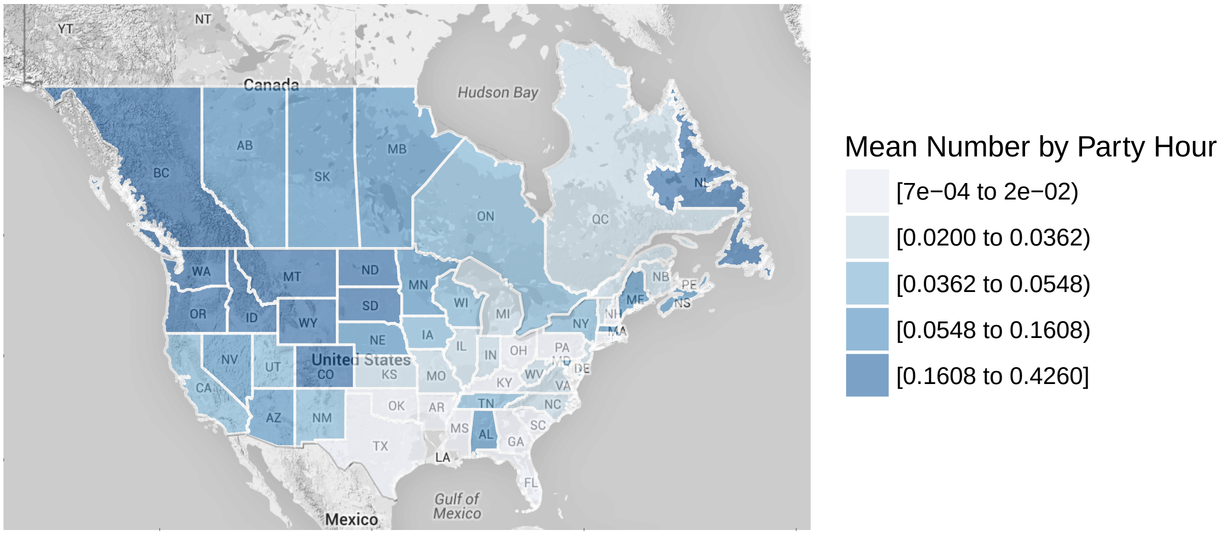


Figure 130: Red Crossbill abundance by area, CBC data.

Christmas Bird Count data since 1960 show that the highest variation in Red Crossbill numbers occurs across the north east and central United States, with California and Newfoundland and Labrador also having large coefficients of variation (Fig. 131).

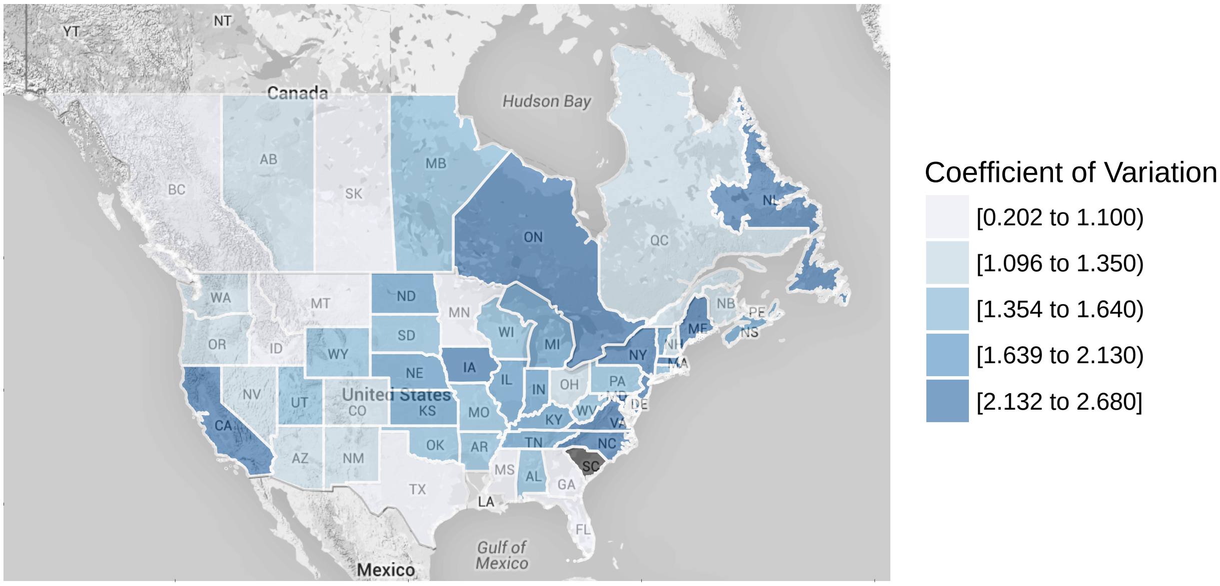


Figure 131: Coefficient of variation for Red Crossbill abundance by area, CBC data.

In the northermost latitudinal tier, CBC data show rises and falls in Red Crossbill winter abundance that are mostly differently timed in different provinces. There are several weak to moderate correlations between different provinces (Fig. 132).

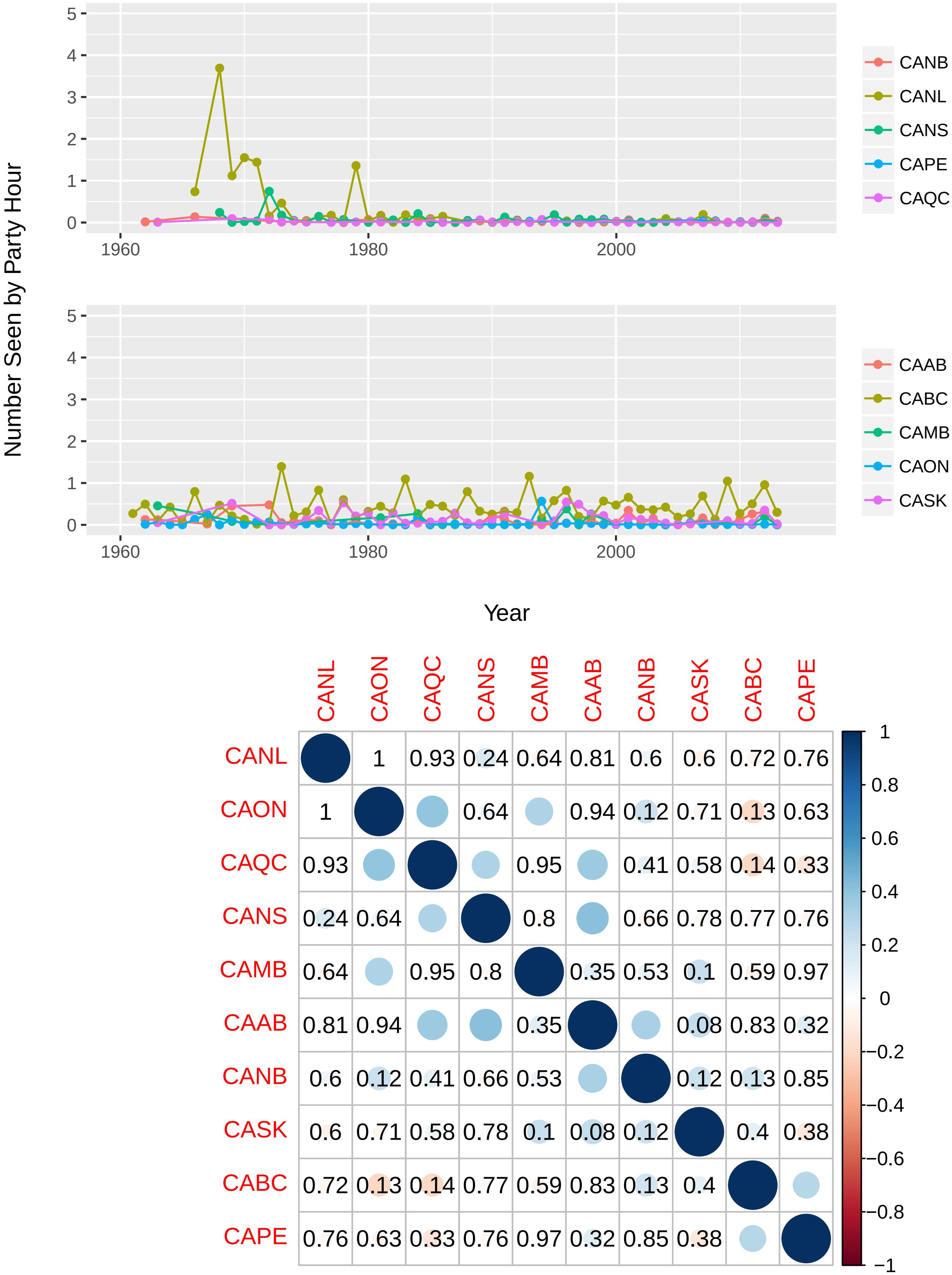


Figure 132: Red Crossbill abundance trends and area correlations across 1st (Canadian) latitudinal tier, CBC data.

In the second latitudinal tier, CBC data show rises and falls in Red Crossbill winter abundance that are mostly differently timed in different areas. There are several weak to strong positive correlations between neighboring areas (Fig. 133).

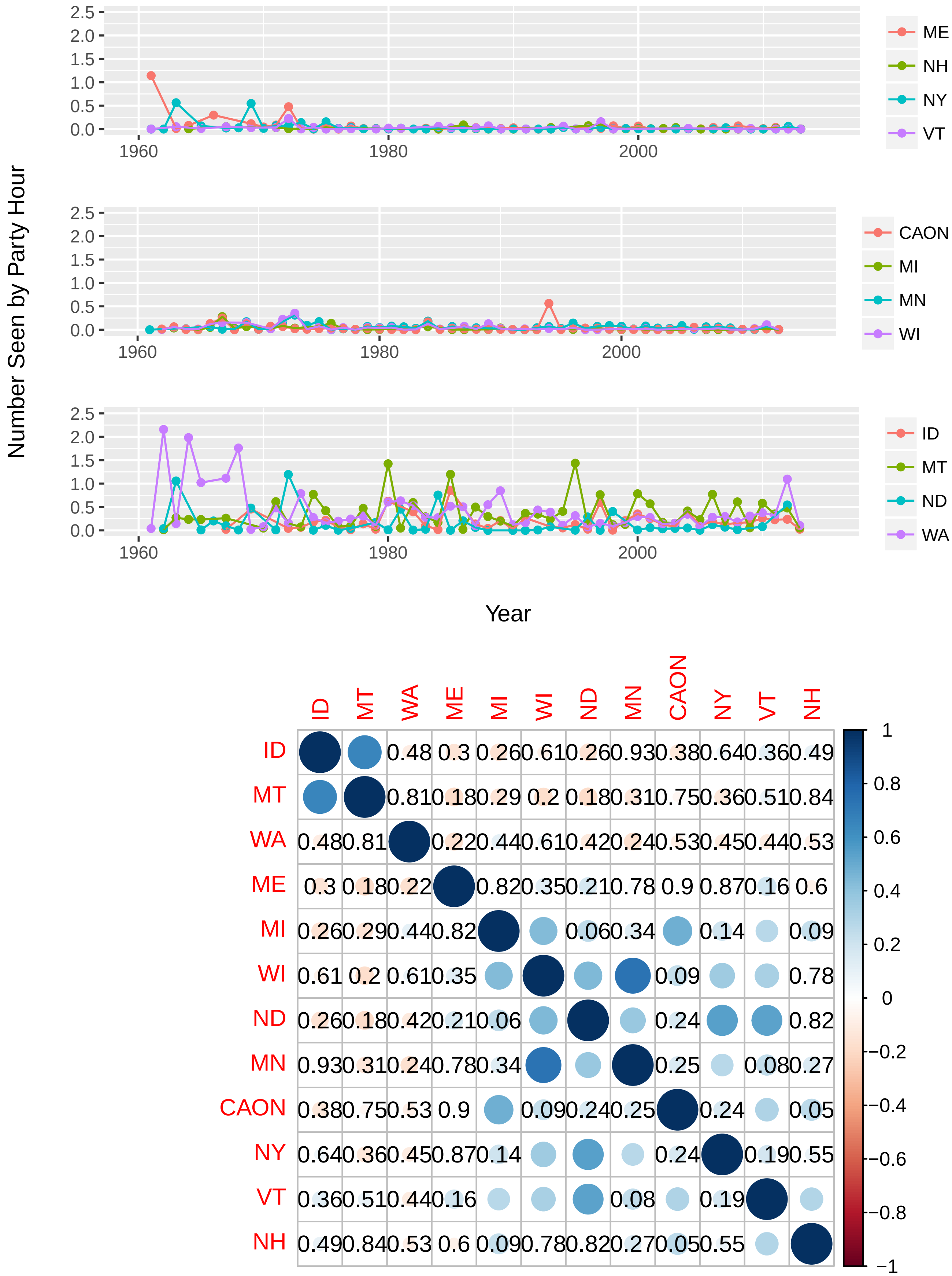


Figure 133: Red Crossbill abundance trends and area correlations across 2nd (northern US) latitudinal tier, CBC data.

In the third latitudinal tier, CBC data show more similarly timed rises and falls in winter abundance in different areas, although there is still some alternation. All states except the three westernmost states in the tier show weak to strong positive correlations with each other (Fig. 134).

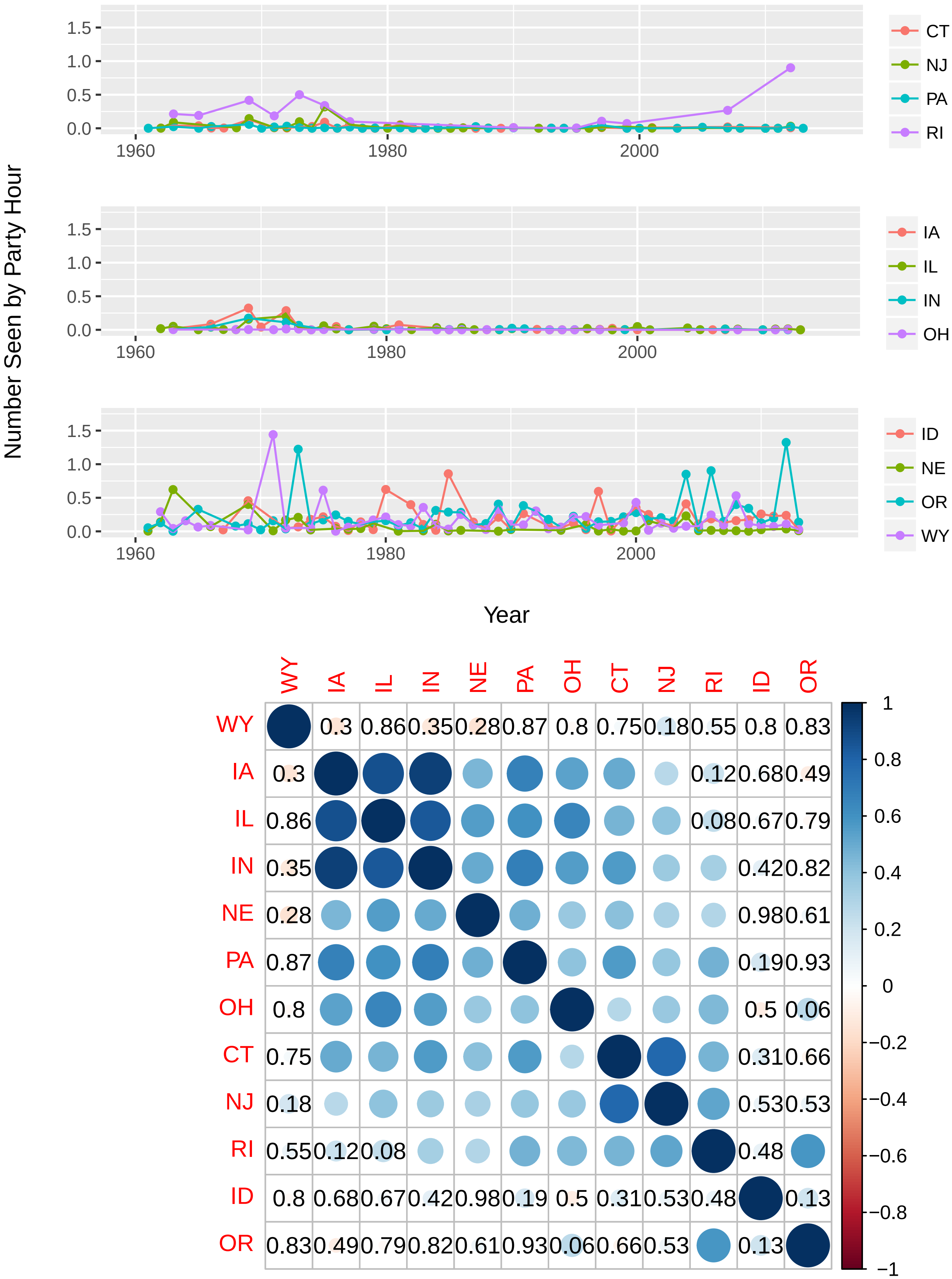


Figure 134: Red Crossbill abundance trends and area correlations across 3rd (mid US) latitudinal tier, CBC data.

In the fourth latitudinal tier, CBC data show some similarly timed rises and falls in Red Crossbill abundance over time in different areas. Most areas show weak to strong positive correlations with each other, with states in the east having the strongest positive correlations (Fig. 135).

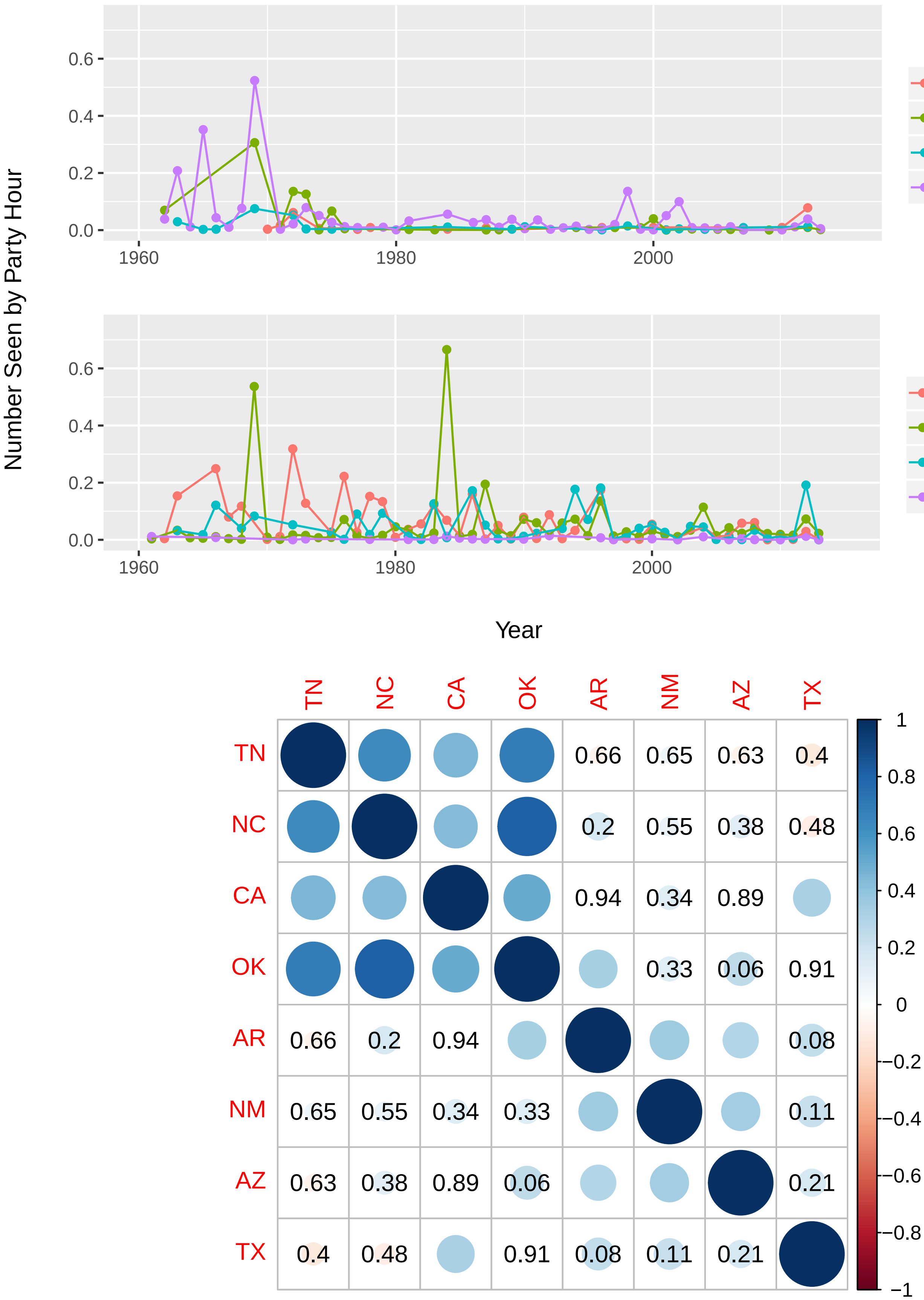


Figure 135: Red Crossbill abundance trends and area correlations across 4th (southern US) latitudinal tier, CBC data.

In the easternmost longitudinal tier, most areas show small numbers of Red Crossbills reported by the CBC over time. The strongest positive correlations are between states in the middle of the tier (Fig. 136).

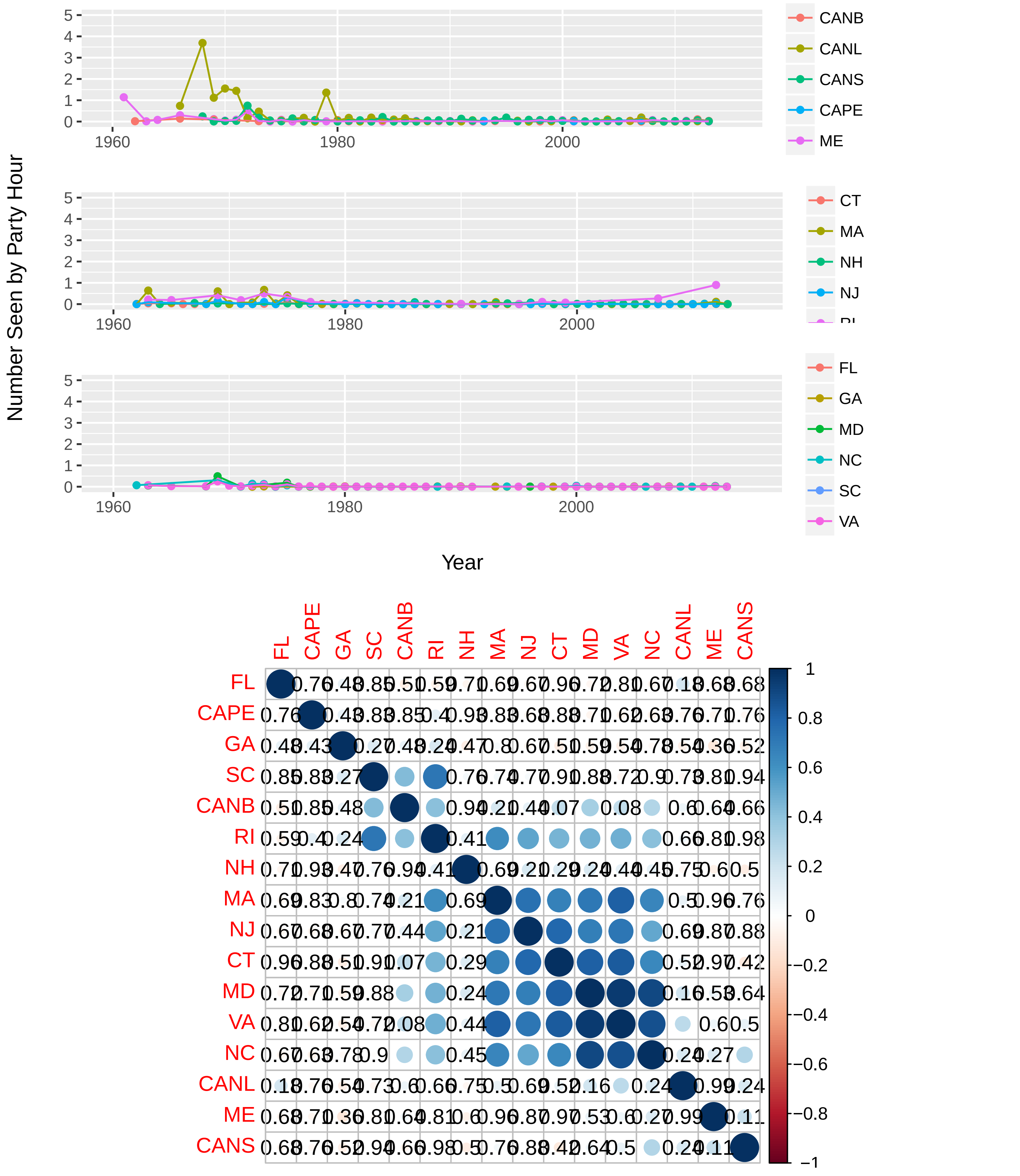


Figure 136: Red Crossbill abundance trends and area correlations across 1st (Atlantic) longitudinal tier, CBC data.

In the second longitudinal tier, different areas show mostly alternations in differently sized spikes in abundance. Most areas show weak to strong positive correlations with each other. Due to lack of CBC records, I excluded Louisiana from analyses (Fig. 137).

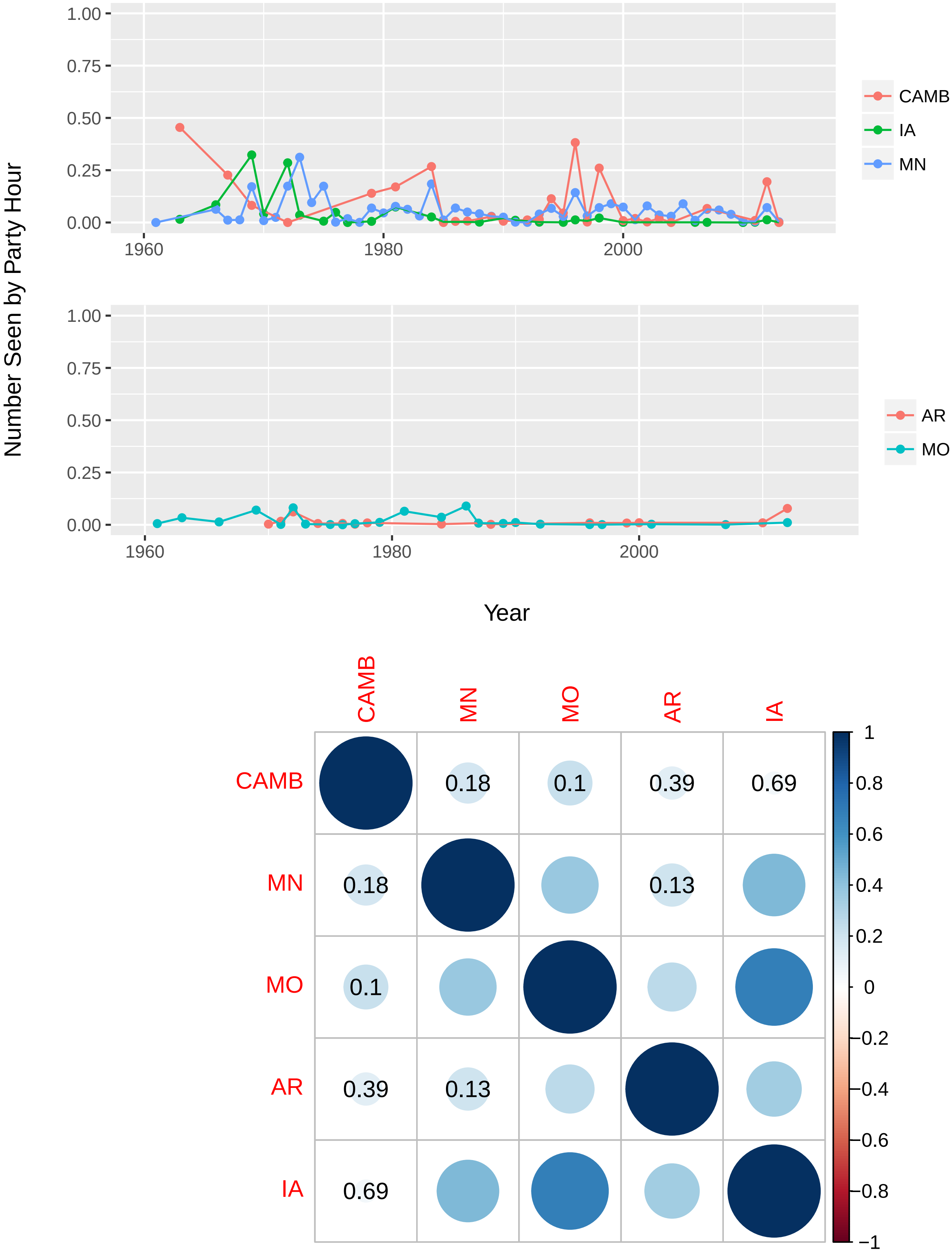


Figure 137: Red Crossbill abundance trends and area correlations across 2nd (midwest) longitudinal tier, CBC data.

In the third longitudinal tier, different areas mostly show differently timed rises and falls in Red Crossbill abundance. There are several weak correlations between different areas (Fig. 138).

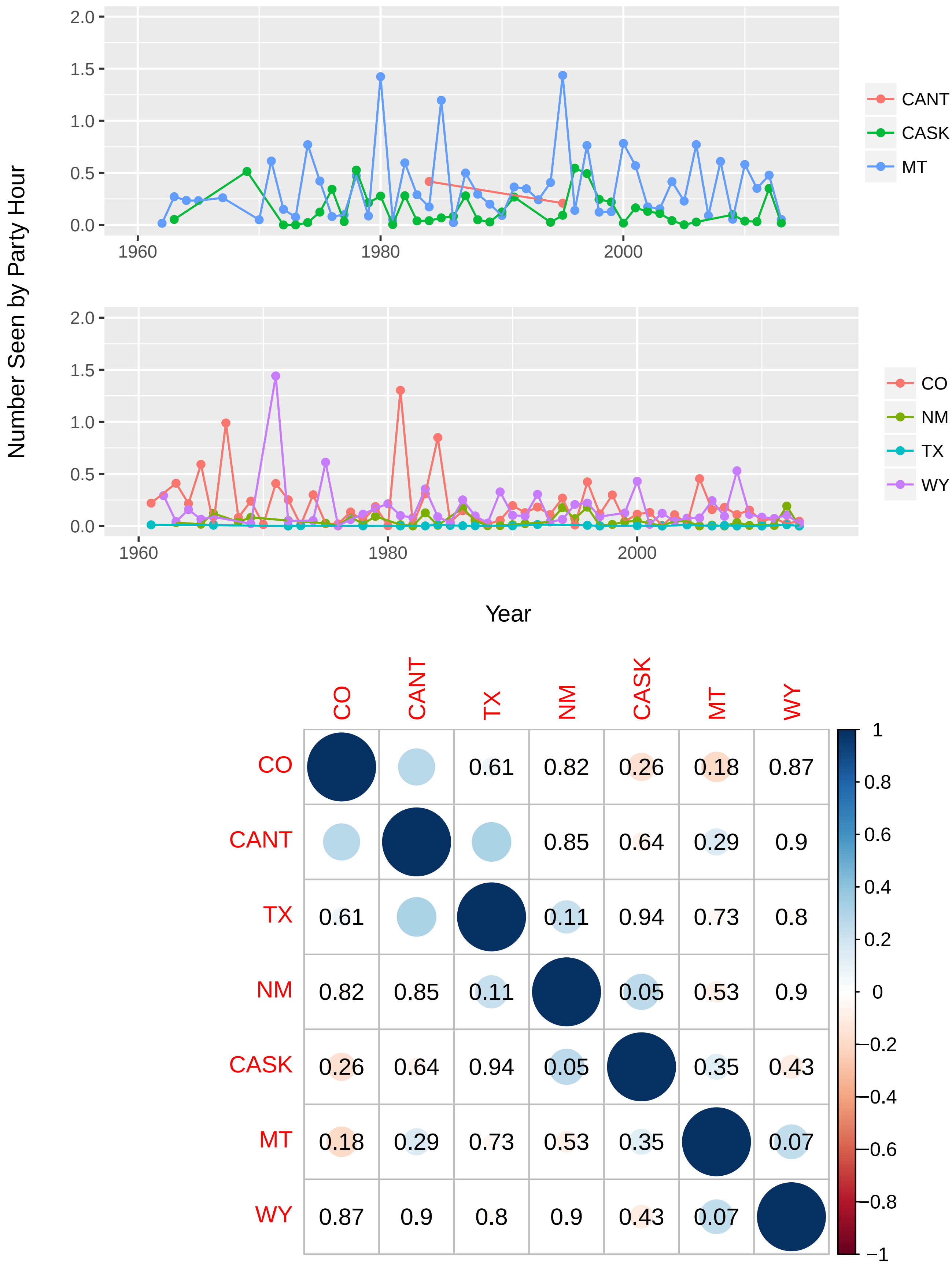


Figure 138: Red Crossbill abundance trends and area correlations across 3rd (Rocky Mountains) longitudinal tier, CBC data.

In the westernmost longitudinal tier, different areas mostly show differently timed rises and falls in Red Crosbill abundance, although there are some shared spikes. There are several weak correlations between different areas (Fig. 139).

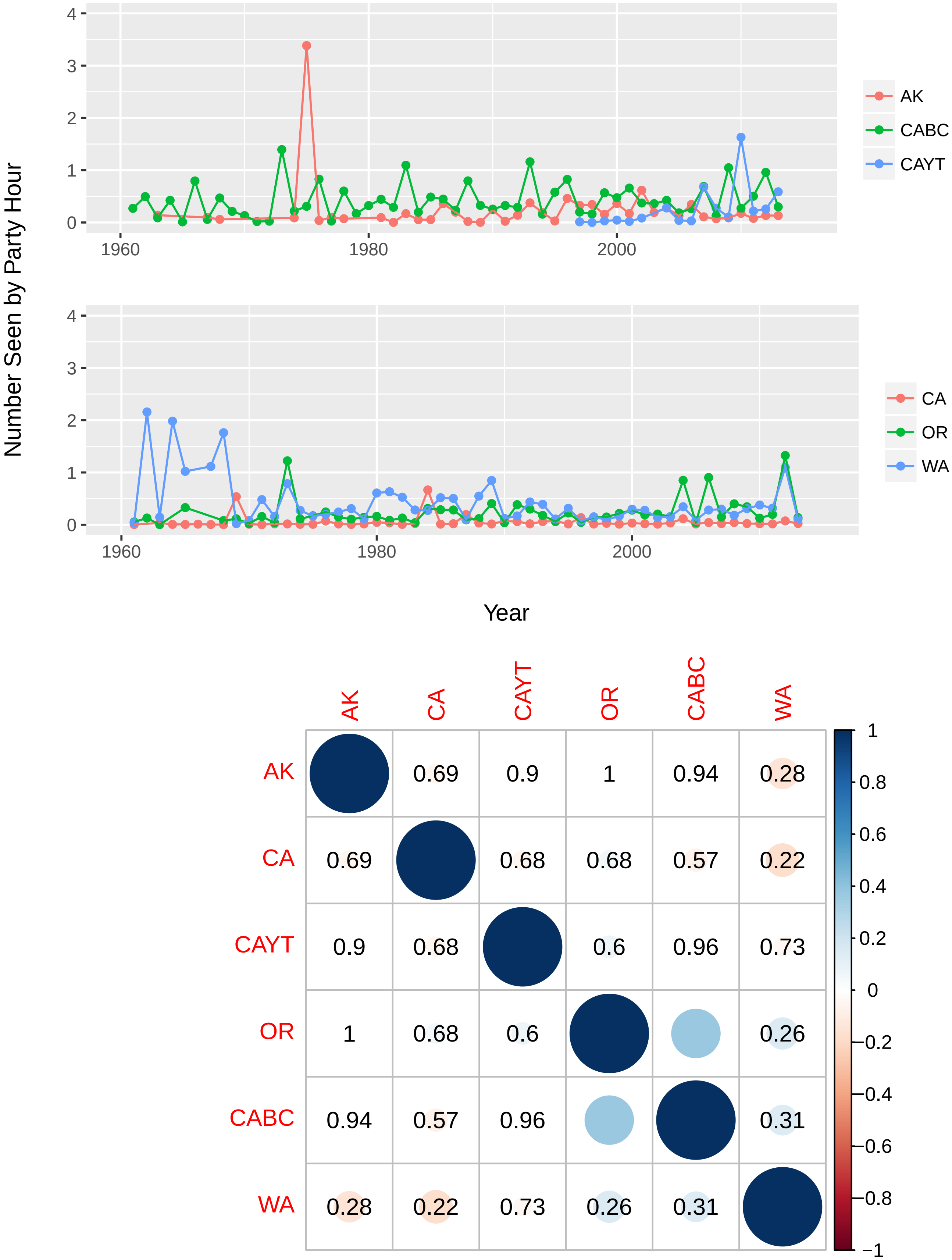


Figure 139: Red Crossbill abundance trends and area correlations across 4th (Pacific) longitudinal tier, CBC data.

eBird Analyses

Across the northernmost latitudinal tier, daily eBird records show few correlations between different provinces, and weak correlations between different years. In more recent years, correlations between years alternate between weakly positive and weakly negative (Fig. 140).

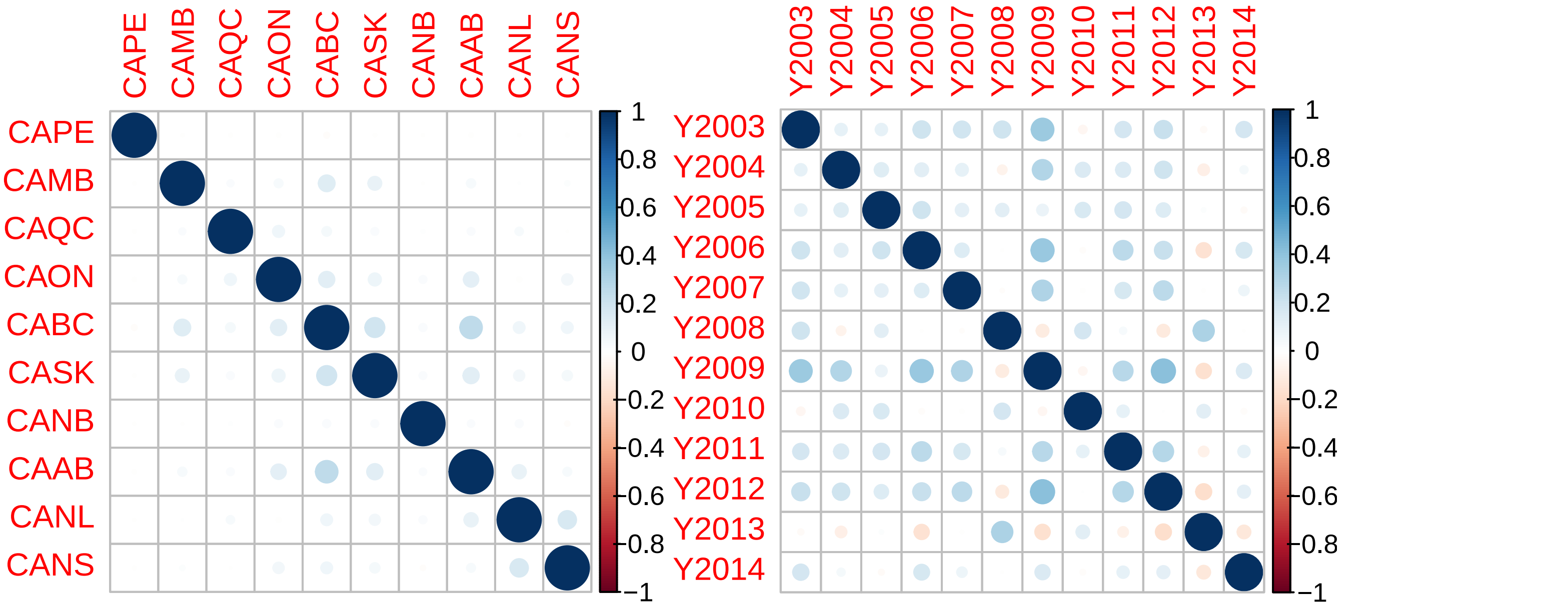


Figure 140: Correlations of Red Crossbill invasion pattern between individual areas and between years for the 1st (Canadian) latitudinal tier, eBird data.

Across the second latitudinal tier, daily eBird records show few correlations between different areas, and weak correlations between different years. In more recent years, correlations between years alternate between weakly positive and weakly negative (Fig. 141).

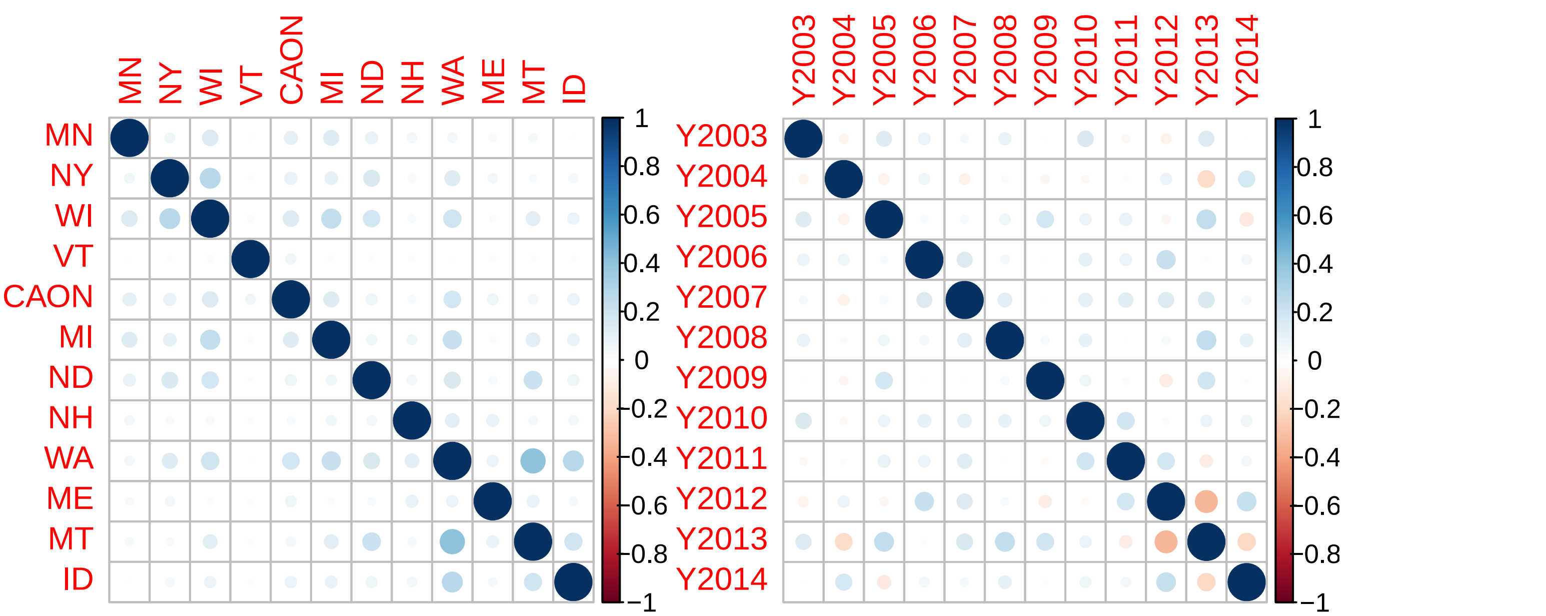


Figure 141: Correlations of Red Crossbill invasion pattern between individual areas and between years for the 2nd (northern US) latitudinal tier, eBird data.

Across the third latitudinal tier, daily eBird records show weak to strong positive correlations between nearby areas, and few correlations between different years. In more recent years, correlations between years alternate between weakly positive and weakly negative (Fig. 142).

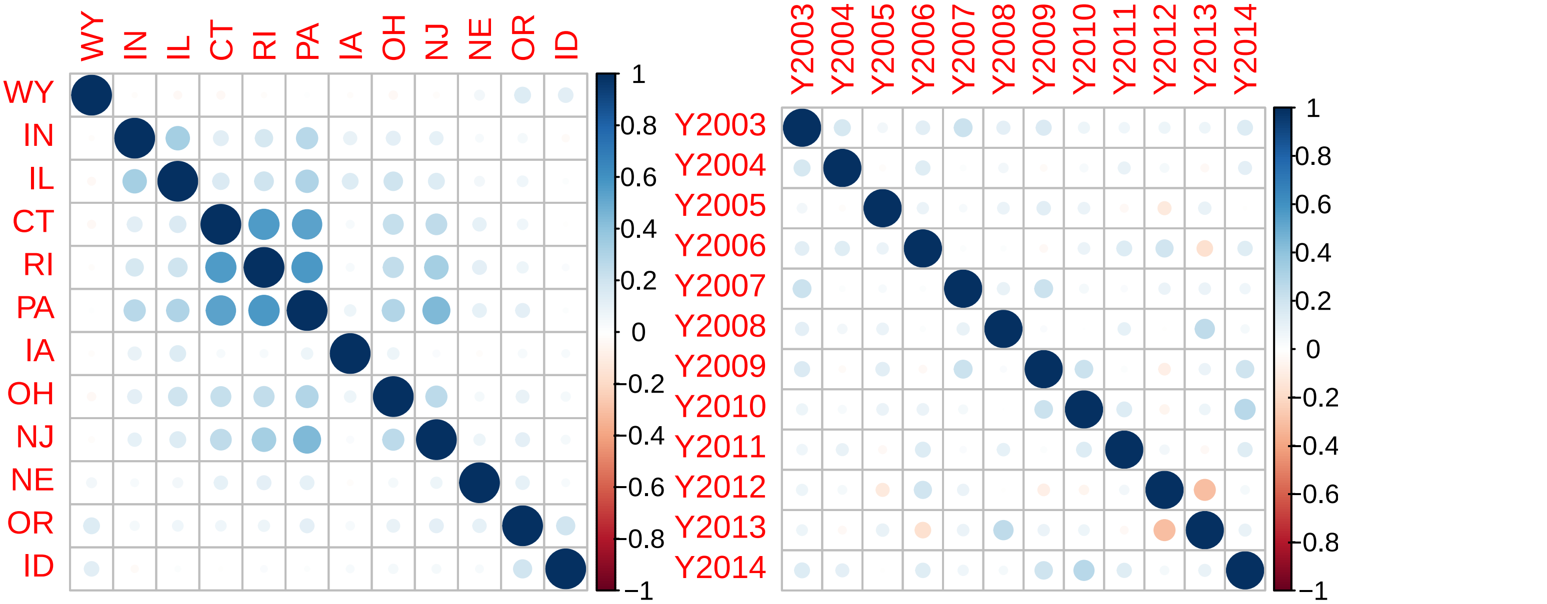


Figure 142: Correlations of Red Crossbill invasion pattern between individual areas and between years for the 3rd (mid US) latitudinal tier, eBird data.

Across the southernmost latitudinal tier, daily eBird records show few correlations between different areas, and weak to moderate correlations between different years. In more recent years, correlations between years alternate between positive and negative (Fig. 143).

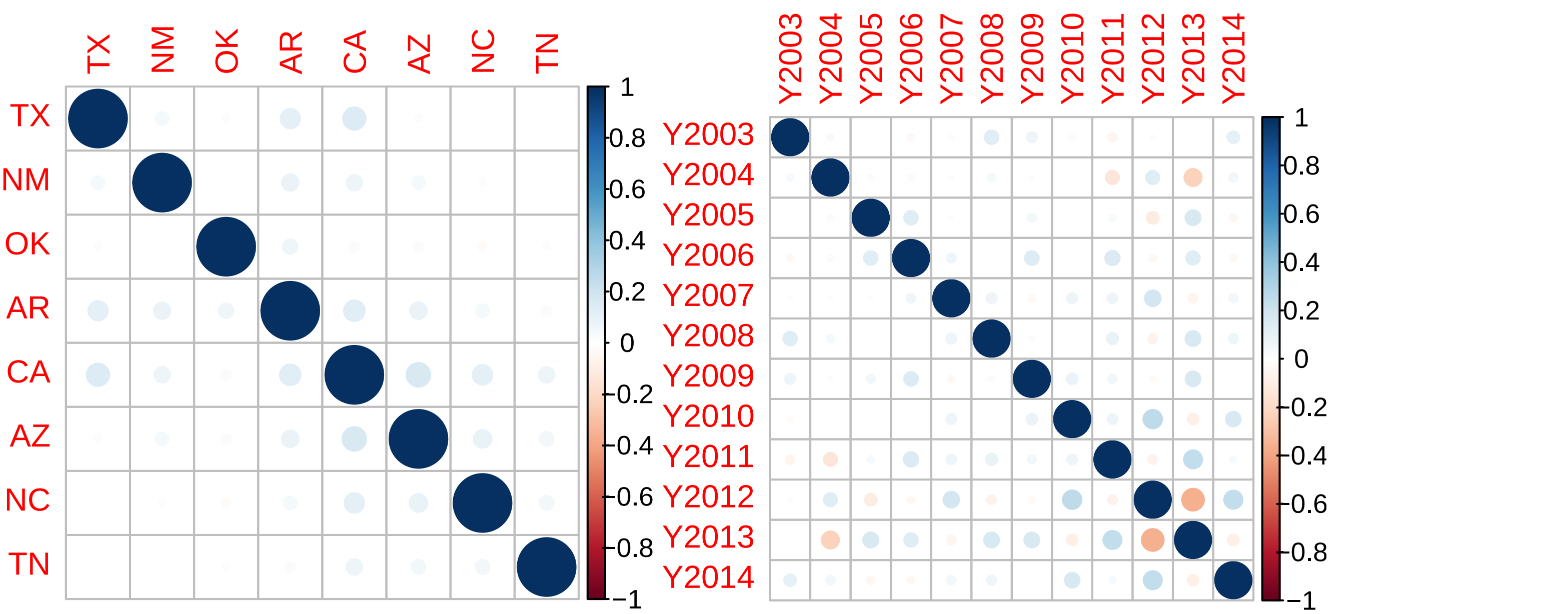


Figure 143: Correlations of Red Crossbill invasion pattern between individual areas and between years for the 4th (southern US) latitudinal tier, eBird data.

Down the easternmost latitudinal tier, daily eBird records show weak to strong correlatins between areas in the middle of the tier. There are few correlations between different years (Fig. 144).

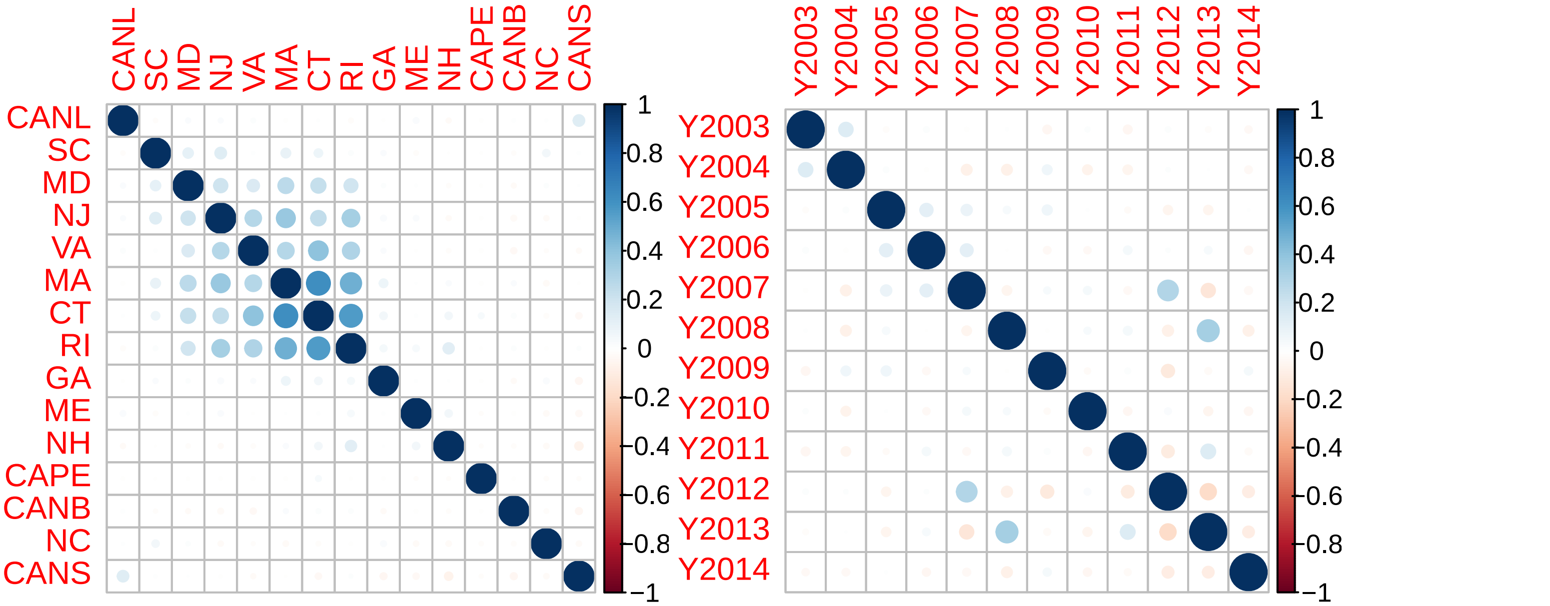


Figure 144: Correlations of Red Crossbill invasion pattern between individual areas and between years for the 1st (Atlantic) longitudinal tier, eBird data.

Down the second latitudinal tier, daily eBird records show few correlations between different areas, and weak to moderate correlations between different years. In more recent years, correlations between years alternate between positive and negative (Fig. 145).

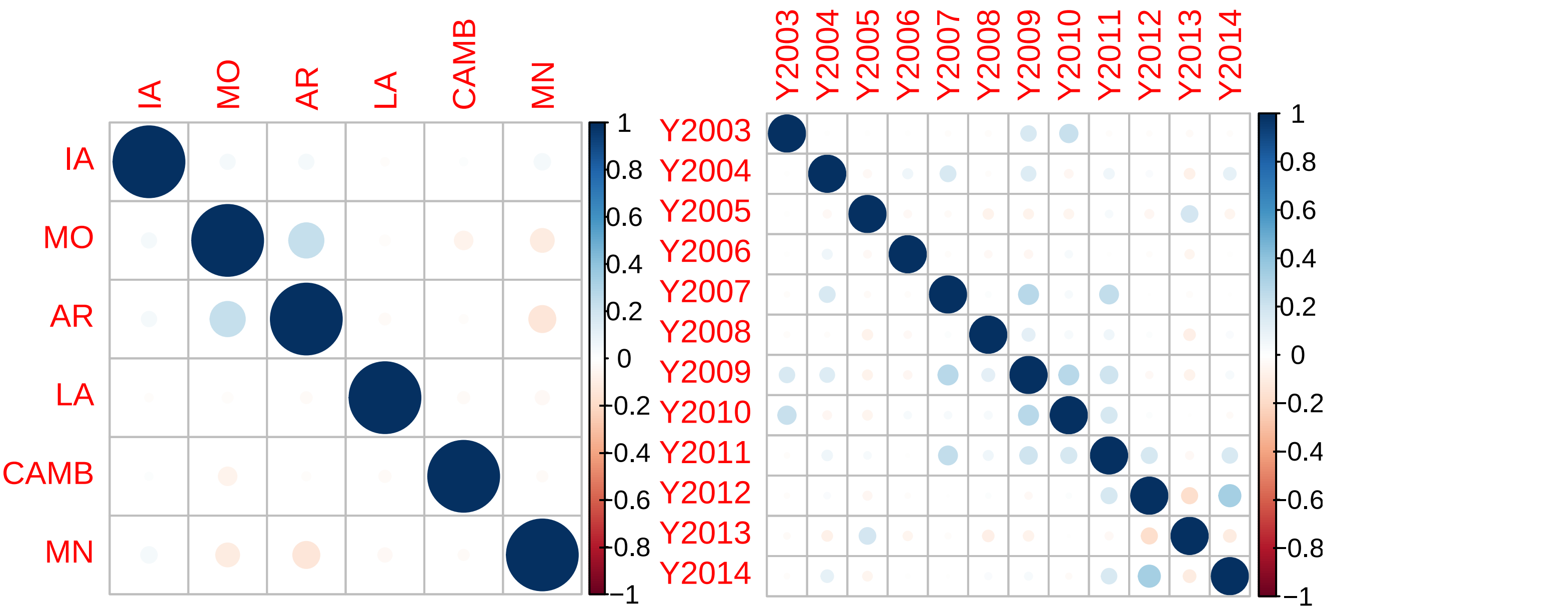


Figure 145: Correlations of Red Crossbill invasion pattern between individual areas and between years for the 2nd (midwest) longitudinal tier, eBird data.

Down the third latitudinal tier, daily eBird records show few correlations between different areas, and weak to moderate correlations between different years. In more recent years, correlations between years alternate between positive and negative (Fig. 146).

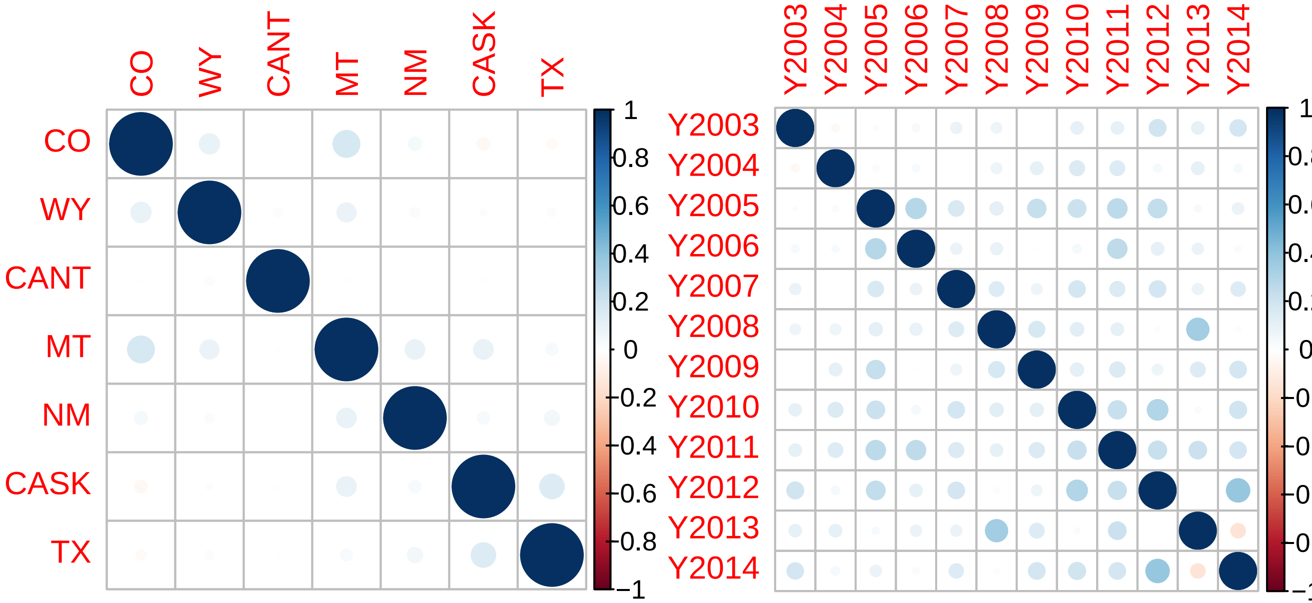


Figure 146: Correlations of Red Crossbill invasion pattern between individual areas and between years for the 3rd (Rocky Mountains) longitudinal tier, eBird data.

Down the fourth longitudinal tier, daily eBird records show weak to strong positive correlations between different areas, and weak to moderate correlations between different years. In more recent years, correlations between years alternate between positive and negative (Fig. 147).

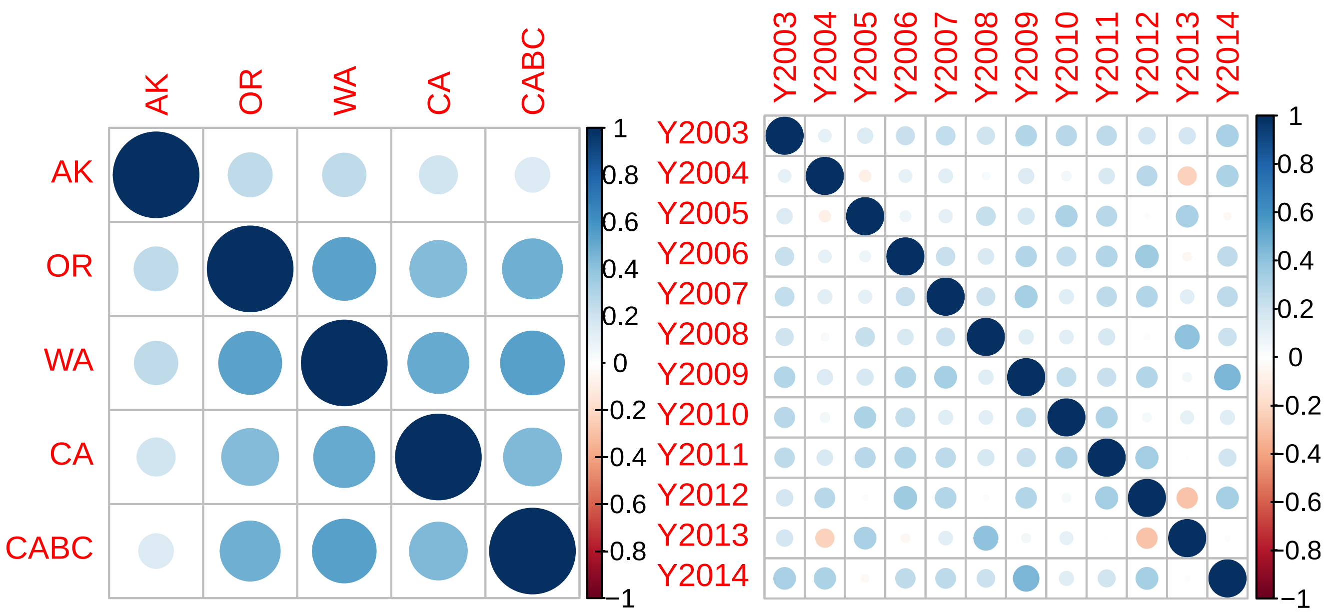


Figure 147: Correlations of Red Crossbill invasion pattern between individual areas and between years for the 4th (Pacific) longitudinal tier, eBird data.

White-winged Crossbill

CBC Analyses

Christmas Bird Count data since 1960 show that the highest numbers of White-winged Crossbills are recorded across southern Canada and the northern United States, with the eastern United States having higher records than the west (Fig. 148).

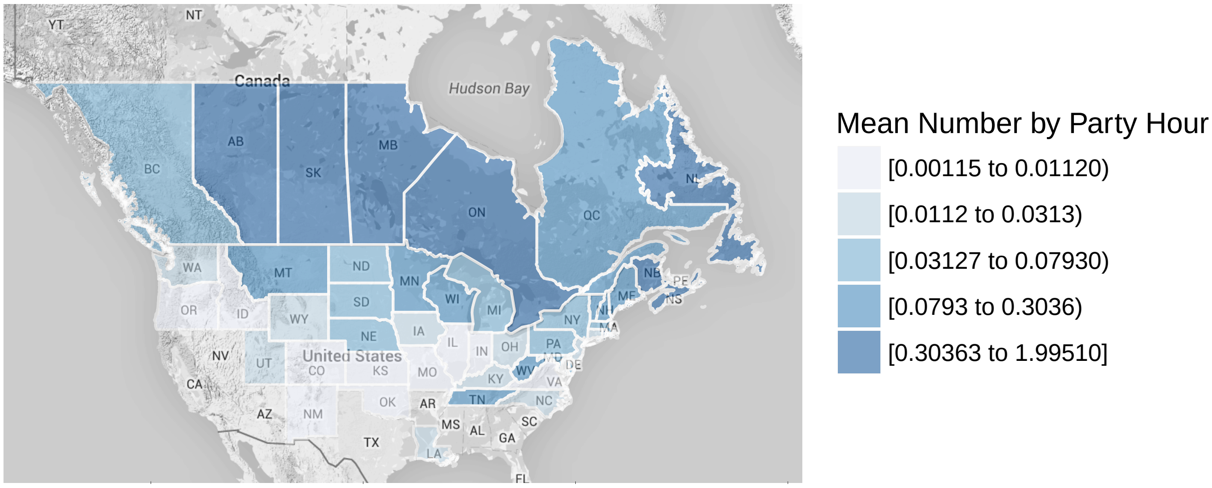


Figure 148: White-winged Crossbill abundance by area, CBC data.

Christmas Bird Count data since 1960 show that the highest variation in White-winged Crossbill numbers occurs in the northeast United States and down the Rocky Mountains (Fig. 149).

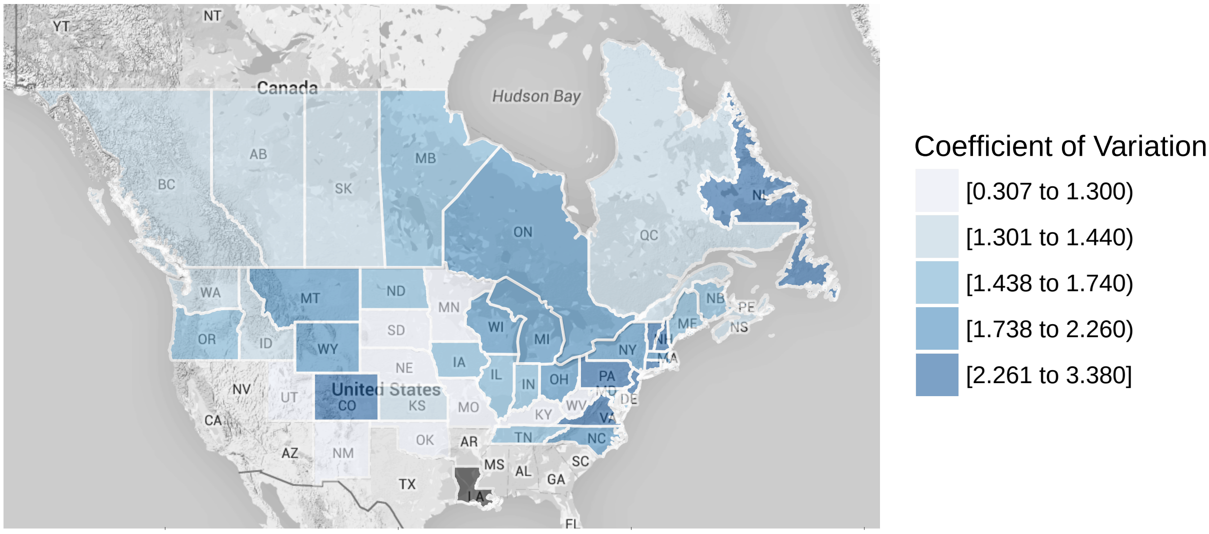


Figure 149: Coefficient of variation for White-winged Crossbill abundance by area, CBC data.

CBC data show rises and falls in White-winged Crossbill winter abundance across the northernmost latitude over time, with most spikes similarly timed in different provinces. There are weak to strong positive correlations between most provinces (Fig. 150).

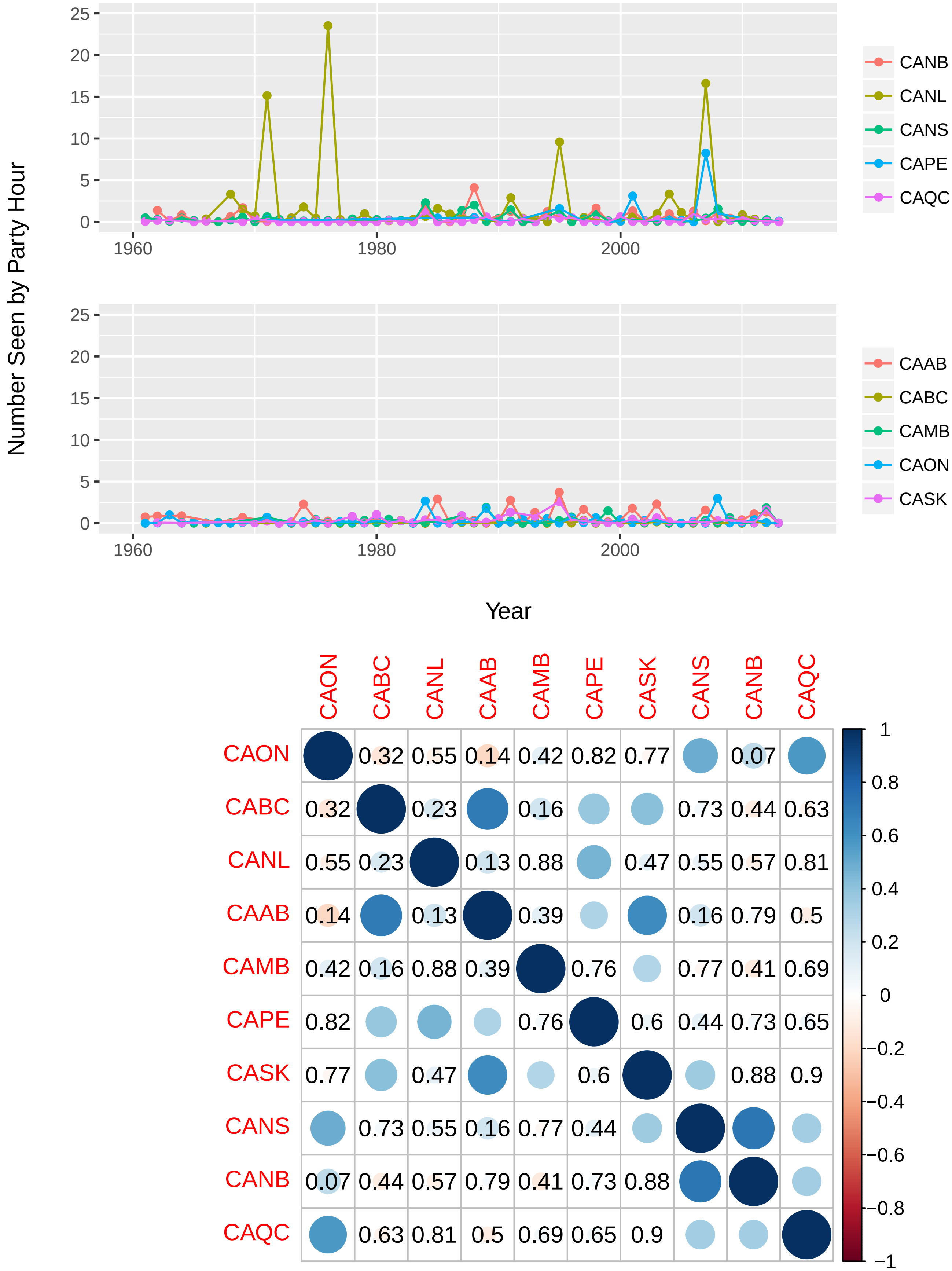


Figure 150: White-winged Crossbill abundance trends and area correlations across 1st (Canadian) latitudinal tier, CBC data.

CBC data show rises and falls in White-winged Crossbill winter abundance across the second latitude over time, with most spikes similarly timed in different areas. There are weak to strong positive correlations between most areas (Fig. 151).

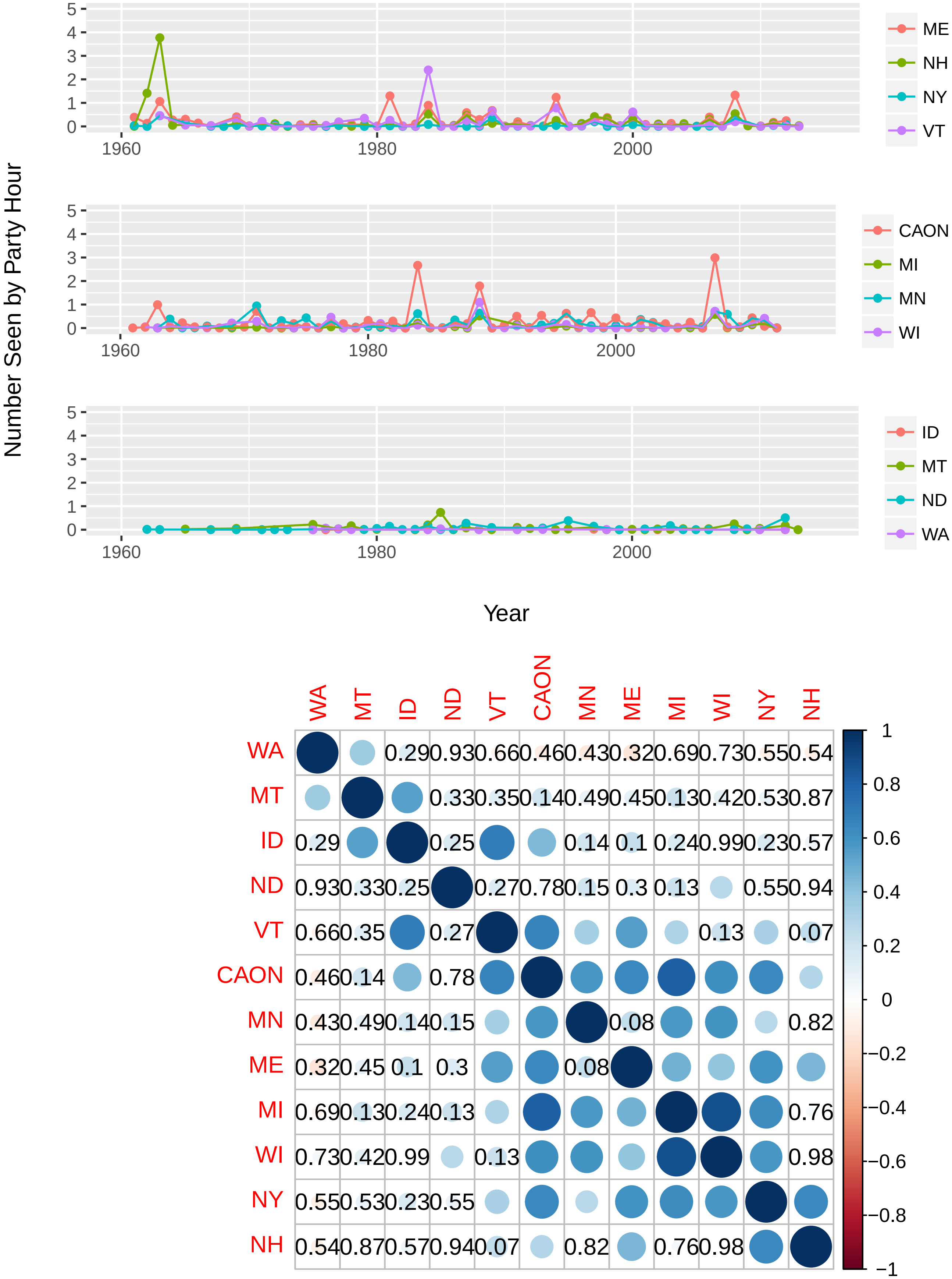
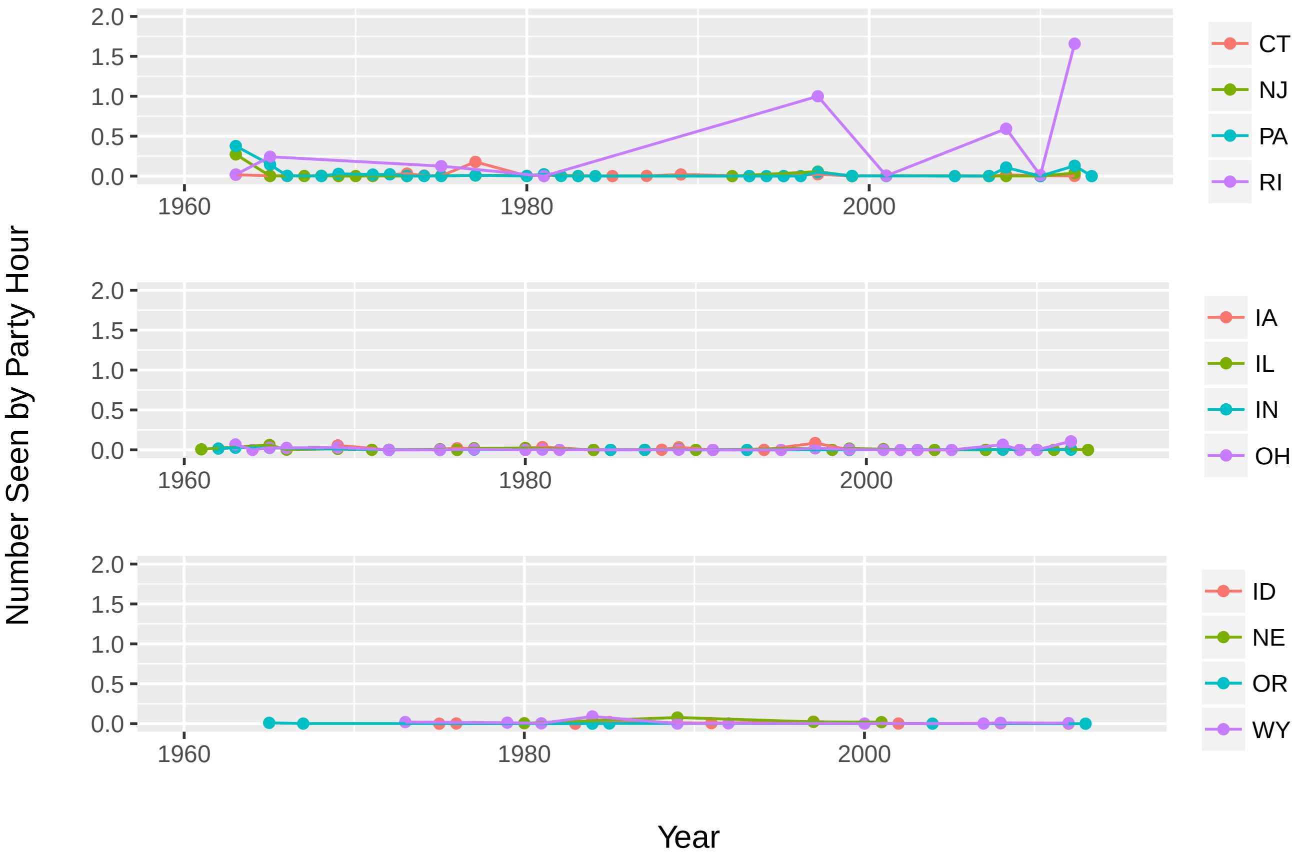


Figure 151: White-winged Crossbill abundance trends and area correlations across 2nd (northern US) latitudinal tier, CBC data.

In the third latitudinal tier, only Rhode Island has sizeable records of White-winged Crossbills. There are some weak to strong positive correlations between different areas (Fig. 152).



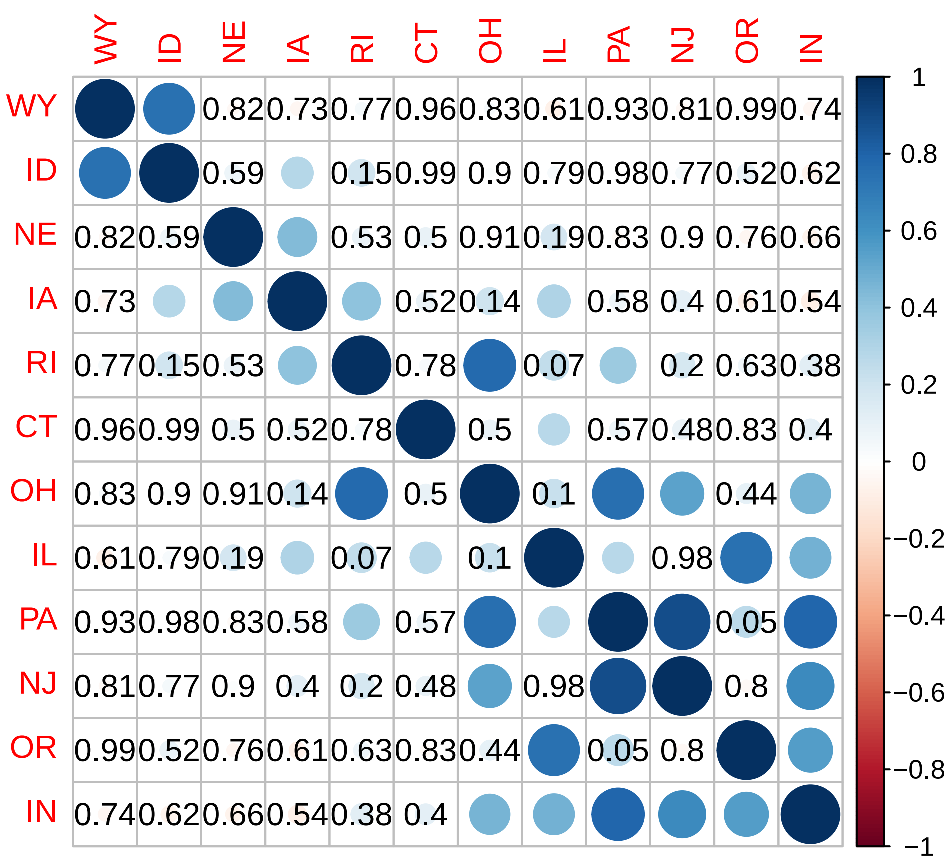


Figure 152: White-winged Crossbill abundance trends and area correlations across 3rd (mid US) latitudinal tier, CBC data.

In the southernmost latitudinal tier, no areas show large CBC records of White-winged Crossbills. There is moderate positive correlation between North Carolina and Tennessee. Due to lack of CBC records, I removed Arkansas, Texas, New Mexico, Arizona, and California from my analyses (Fig. 153).

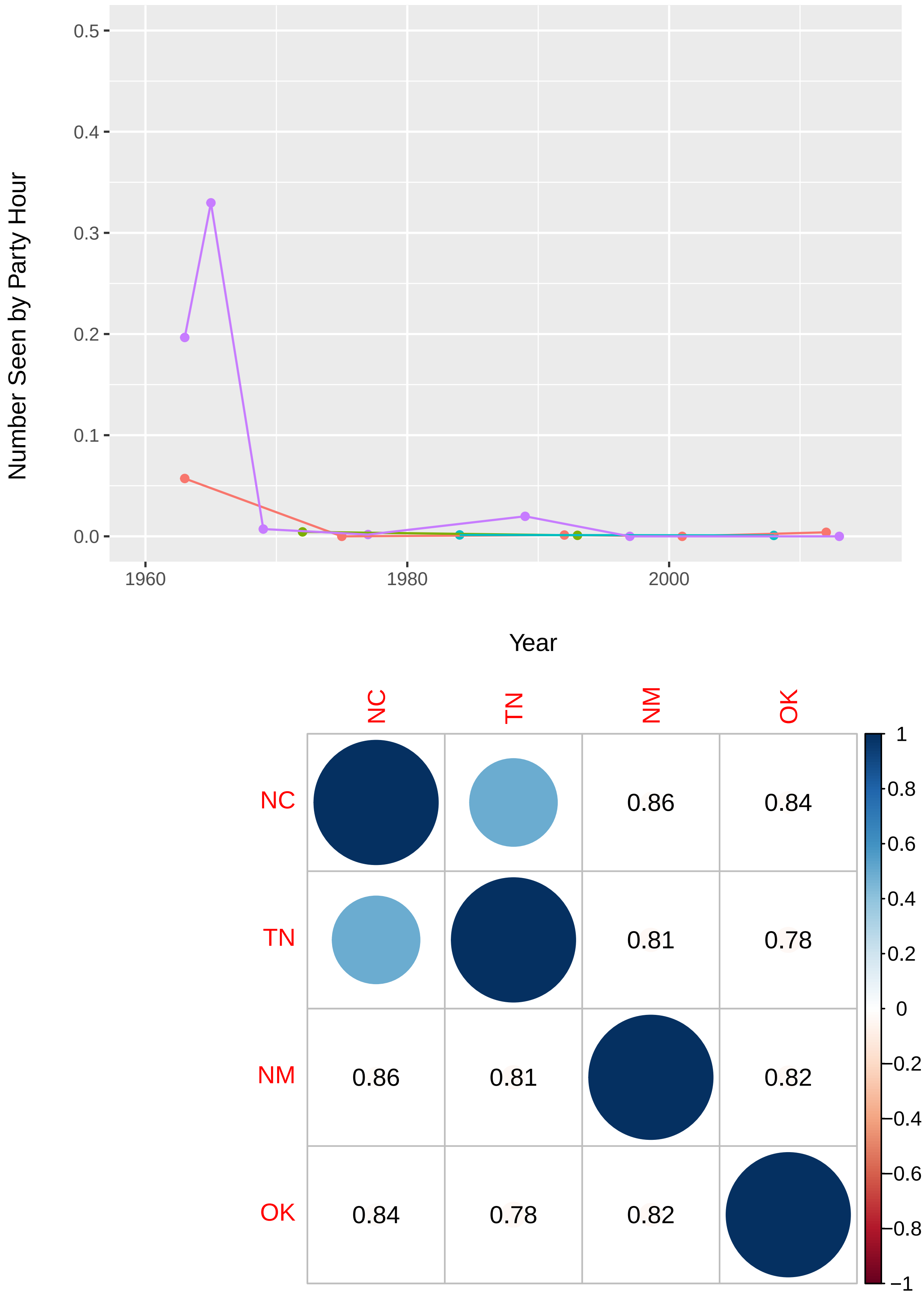


Figure 153: White-winged Crossbill abundance trends and area correlations across 4th (southern US) latitudinal tier, CBC data.

In the easternmost longitudinal tier, only northern areas show sizeable CBC records of White-winged Crossbills, which sometimes show similarly timed rises and falls in abundance. There are some weak to strong positive correlations between different areas. Due to lack of data I excluded South Carolina, Georgia, and Florida from my analyses (Fig. 154).

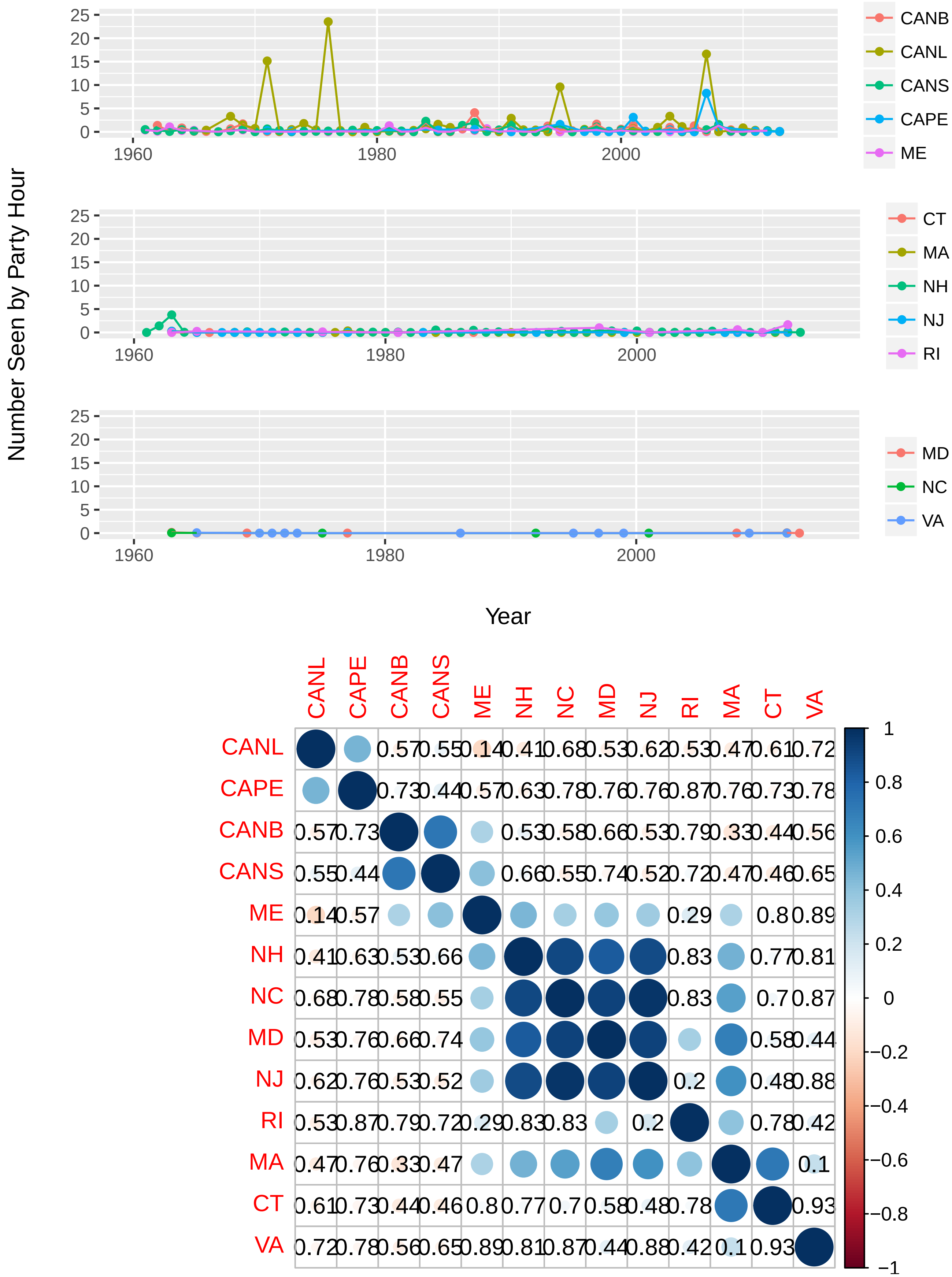


Figure 154: White-winged Crossbill abundance trends and area correlations across 1st (Atlantic) longitudinal tier, CBC data.

In the second longitudinal tier, there is a moderately strong positive correlation in the CBC records for Manitoba and Minnesota. I excluded Missouri, Arkansas, and Lousiana from my analyses (Fig. 155).

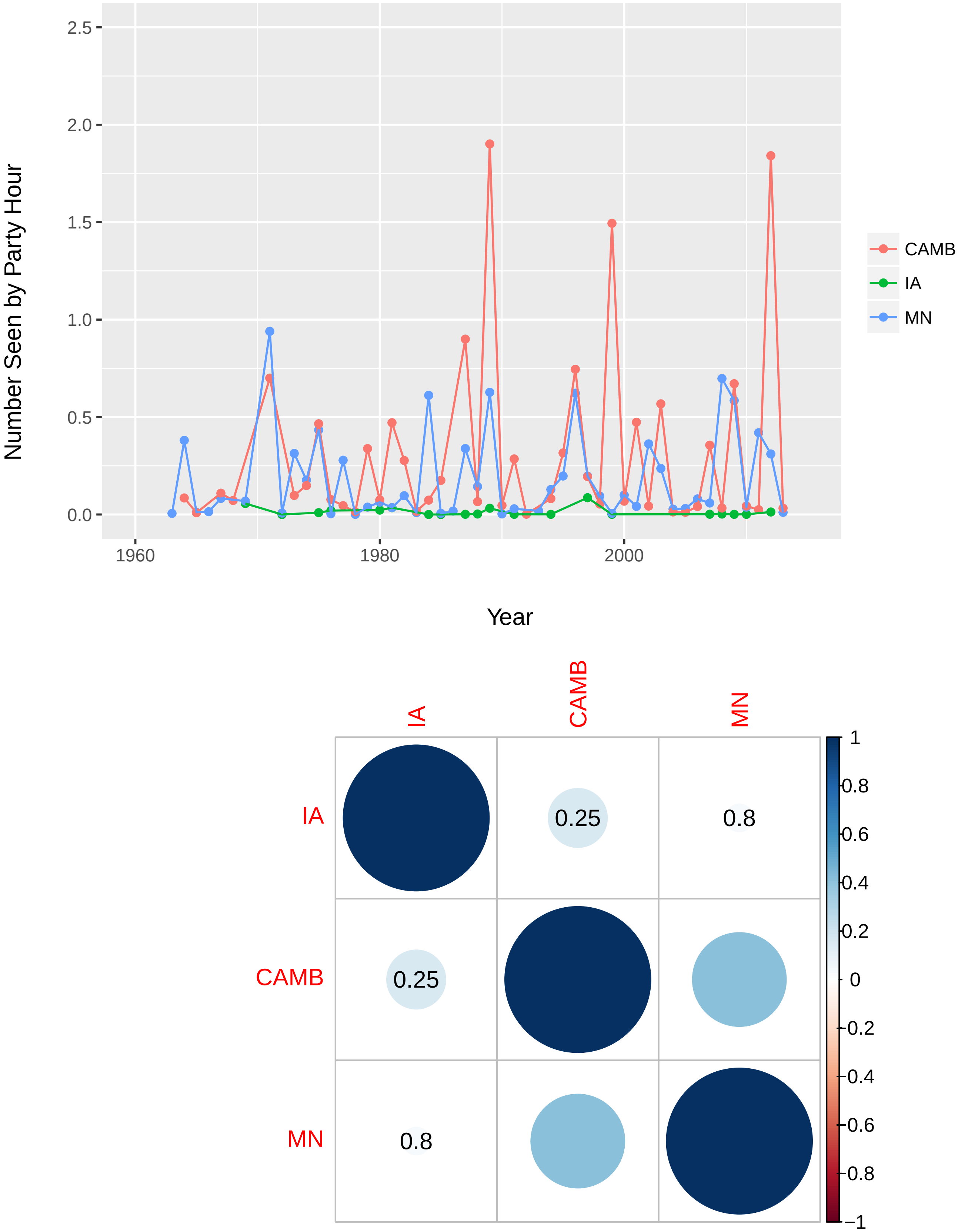


Figure 155: White-winged Crossbill abundance trends and area correlations across 2nd (midwest) longitudinal tier, CBC data.

In the third longitudinal tier, the northern areas show alternations in abundance spikes. There are few correlations between different areas, I excluded Texas from my analyses (Fig. 156).

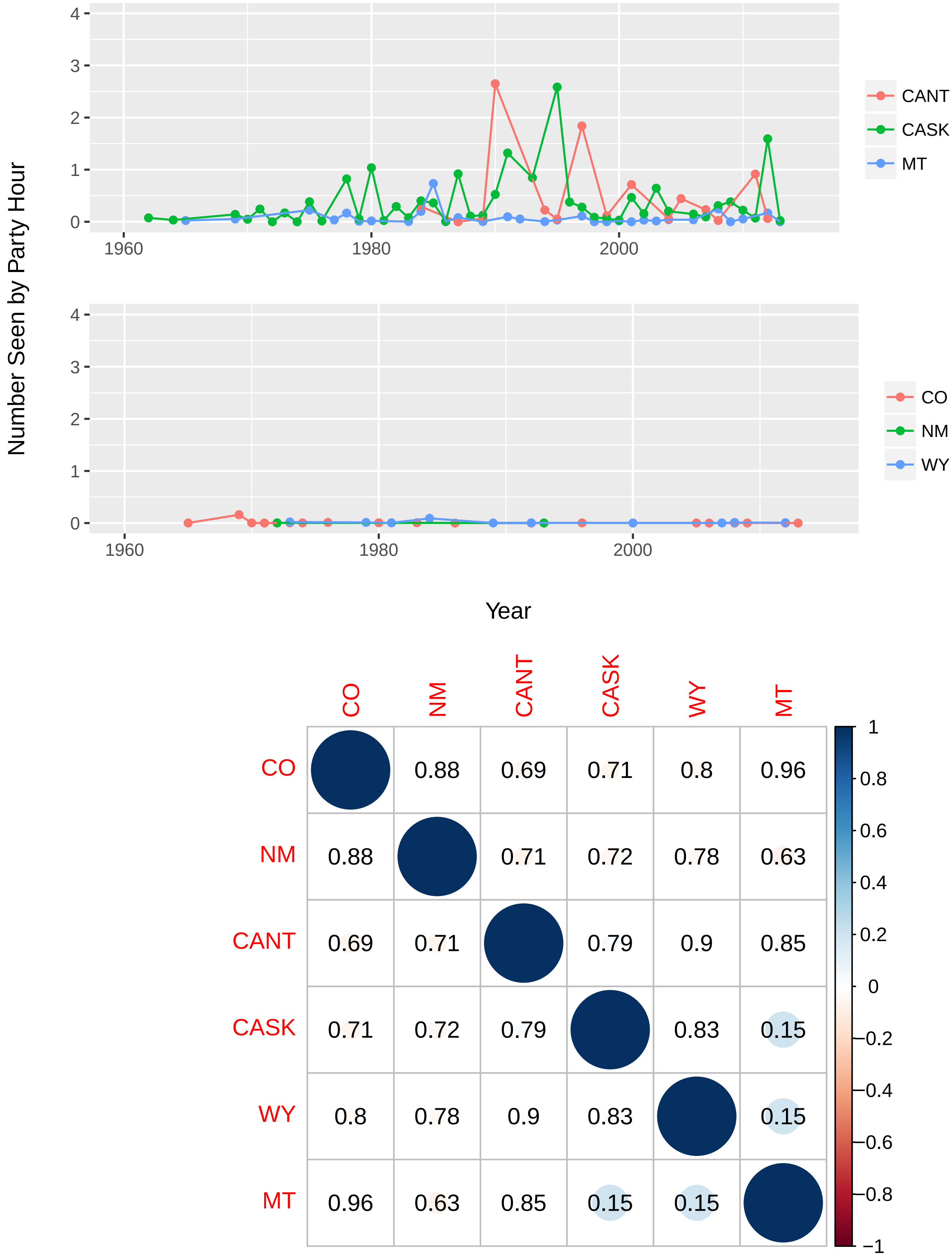


Figure 156: White-winged Crossbill abundance trends and area correlations across 3rd (Rocky Mountains) longitudinal tier, CBC data.

In the fourth longitudinal tier, the northern areas often show alternations in abundance spikes. There are some weakly positive and negative correlations between different areas. Due to lack of CBC records for this species, I excluded Texas from my analyses (Fig. 157).

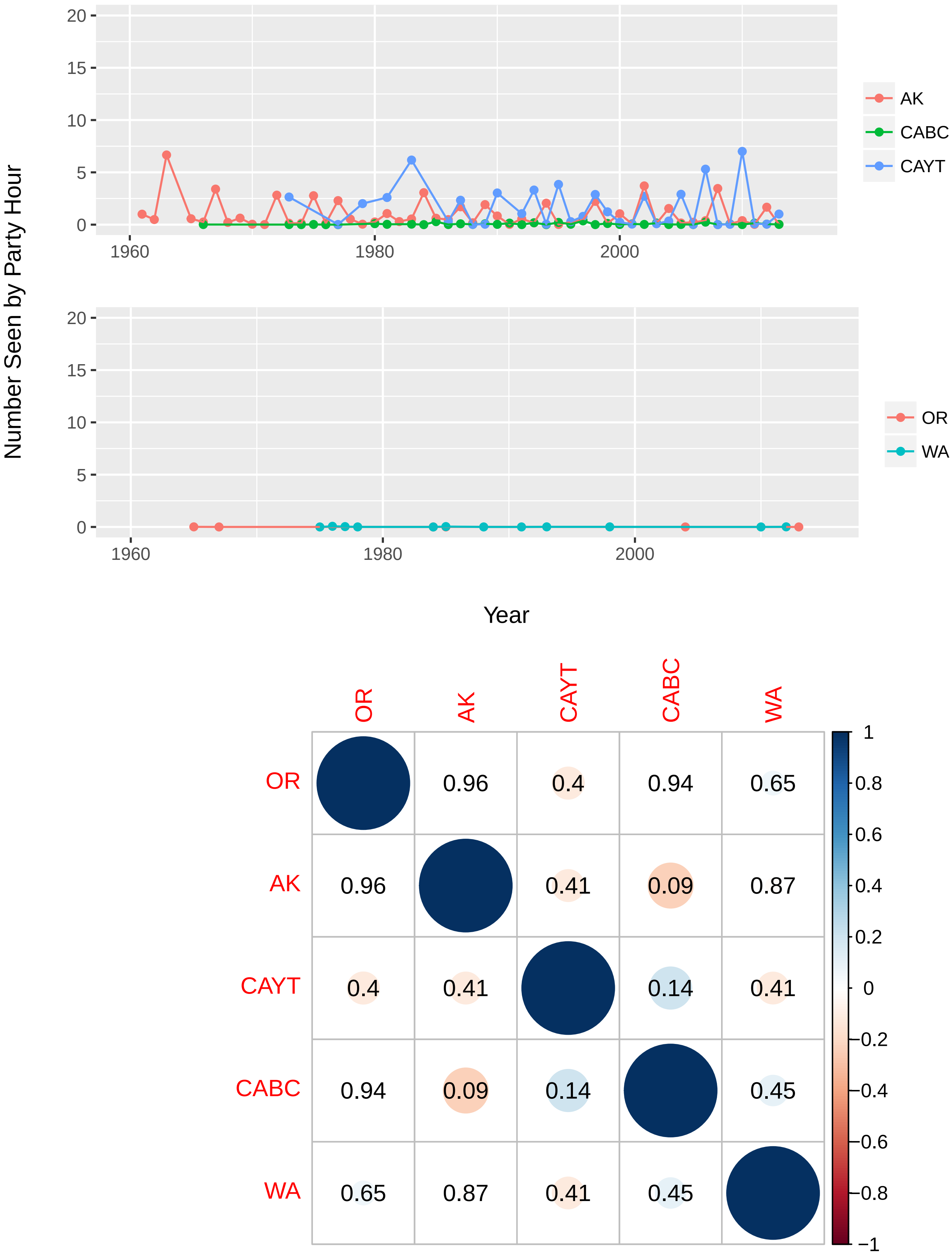


Figure 157: White-winged Crossbill abundance trends and area correlations across 4th (Pacific) longitudinal tier, CBC data.

eBird Analyses

Across the northermost latitudinal tier, daily eBird records show few correlations between different provinces, and weak to strong positive correlations between different years (Fig. 158).

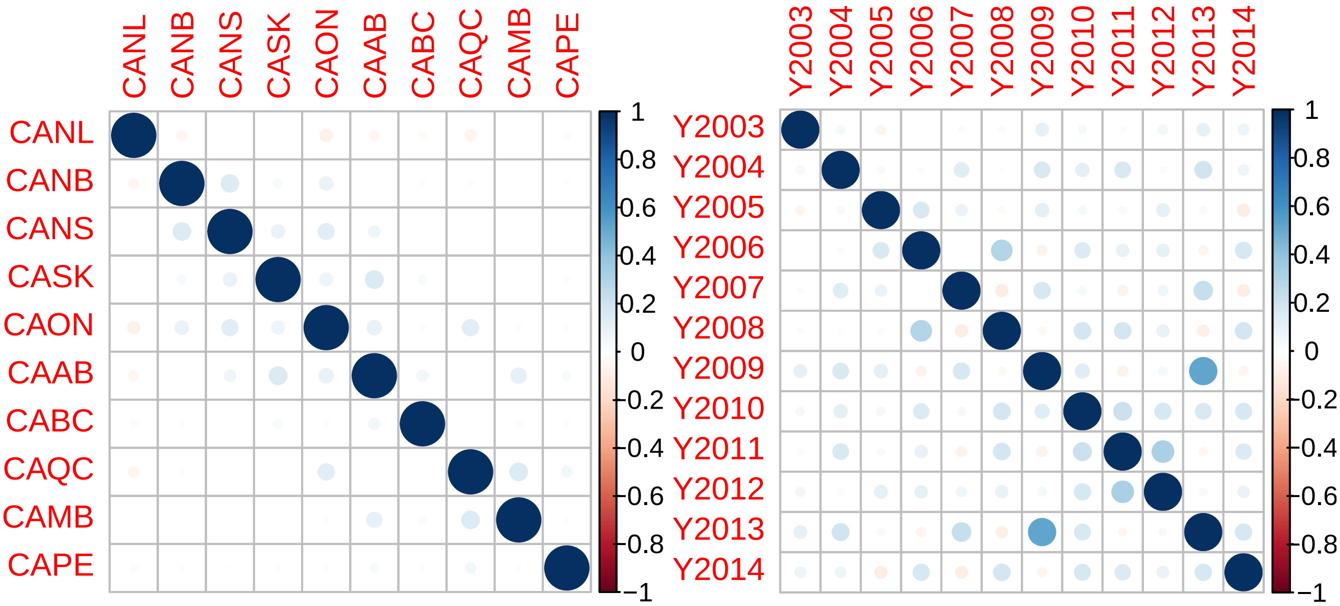


Figure 158: Correlations of White-winged Crossbill invasion pattern between individual areas and between years for the 1st (Canadian) latitudinal tier, eBird data.

Across the second latitudinal tier, daily eBird records show weak to strong positive correlations between different areas, and weak negative to strong positive correlations between different years (Fig. 159).

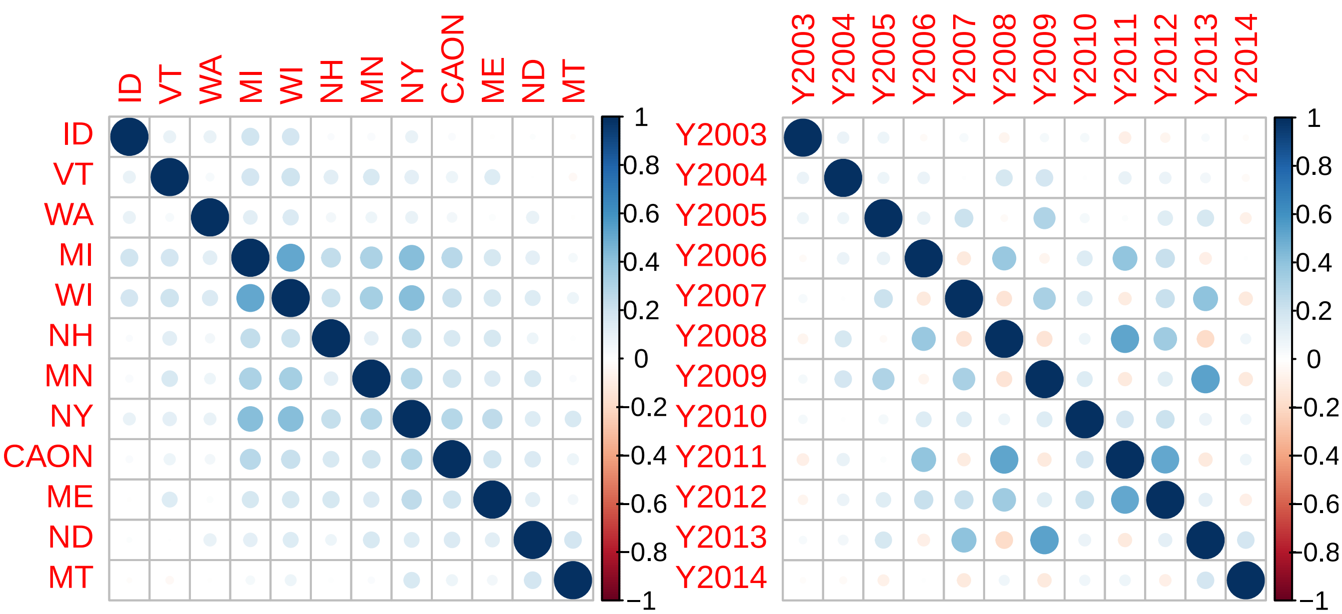


Figure 159: Correlations of White-winged Crossbill invasion pattern between individual areas and between years for the 2nd (northern US) latitudinal tier, eBird data.

Across the third latitudinal tier, daily eBird records show weak to strong positive correlations between different states, and weak negative to strong positive correlations between different years. The negative and positive correlations occasionally alternate between every other year (Fig. 160).

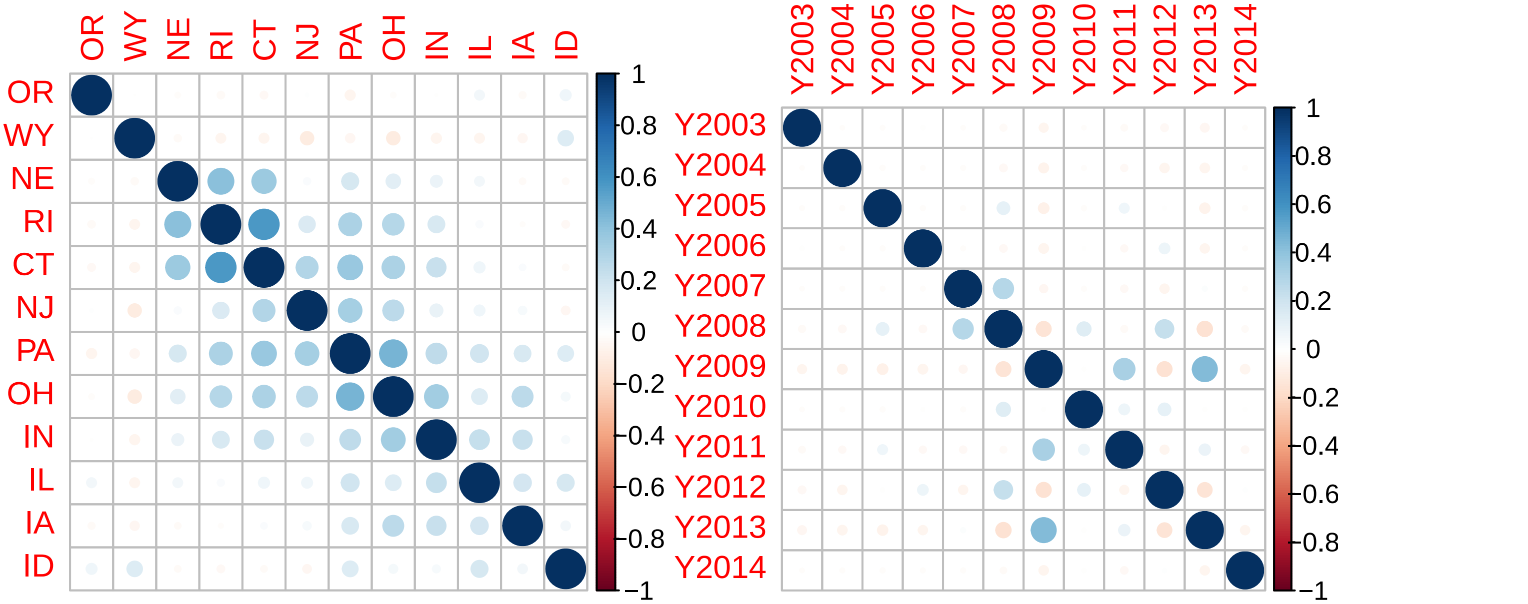


Figure 160: Correlations of White-winged Crossbill invasion pattern between individual areas and between years for the 3rd (mid US) latitudinal tier, eBird data.

Across the southernmost latitudinal tier, daily eBird records show weak to moderate negative correlations between different states, and weak to moderate negative correlations between different years (Fig. 161).

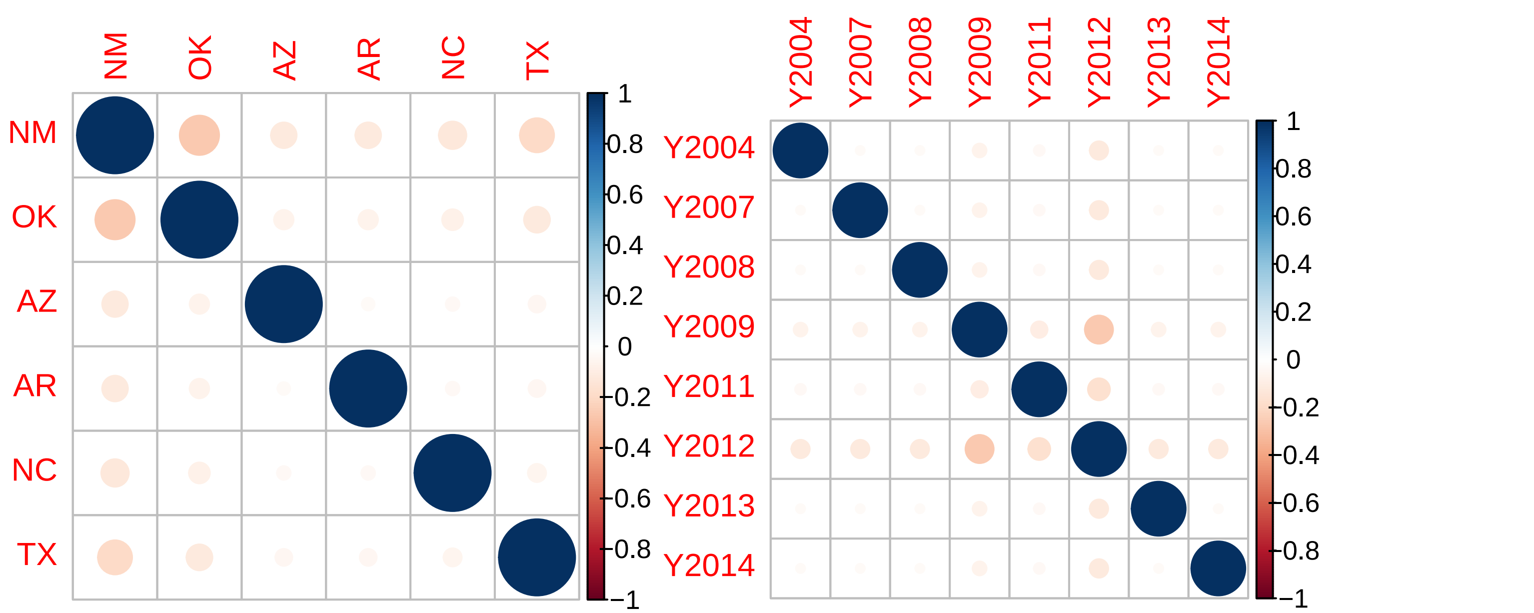


Figure 161: Correlations of White-winged Crossbill invasion pattern between individual areas and between years for the 4th (southern US) latitudinal tier, eBird data.

Across the easternmost longitudinal tier, daily eBird records show weak to strong positive correlations between neighboring areas, and weak negative to strong positive correlations between different years. The negative and positive correlations occasionally alternate between every other year (Fig. 162).

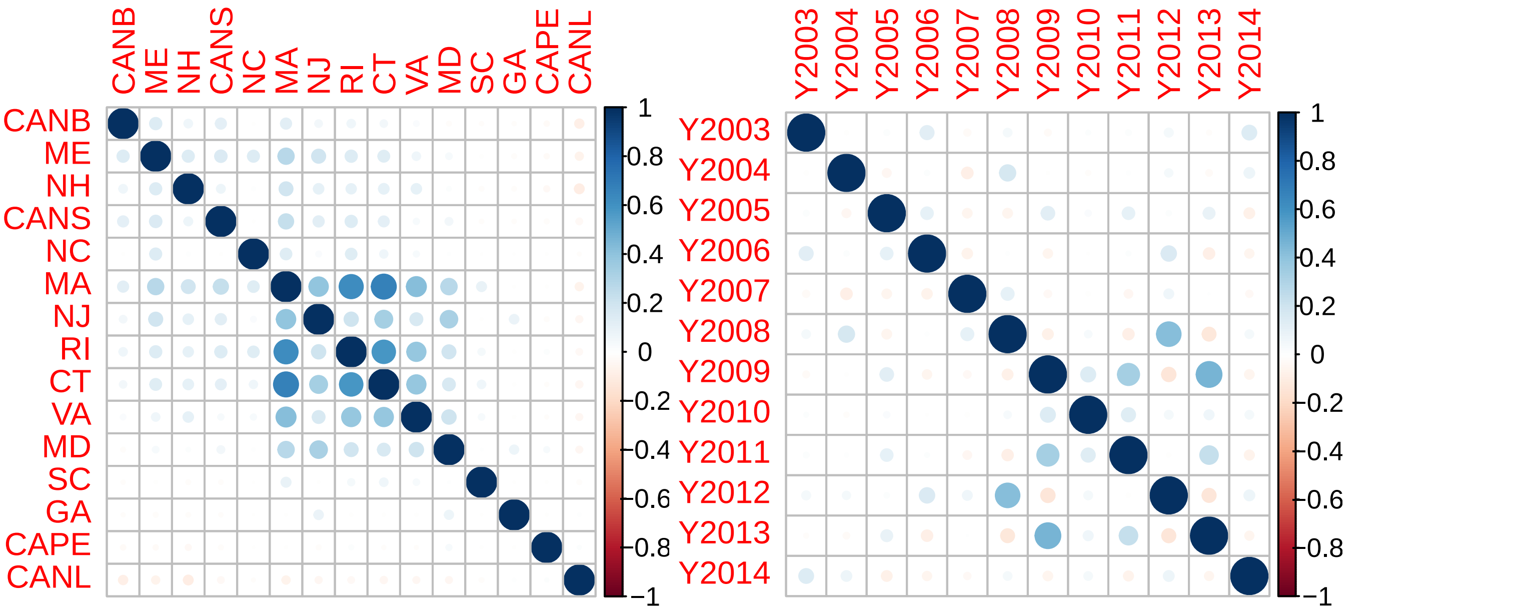


Figure 162: Correlations of White-winged Crossbill invasion pattern between individual areas and between years for the 1st (Atlantic) longitudinal tier, eBird data.

Across the second longitudinal tier, daily eBird records show weak to moderate positive and negative correlations between different areas, and several weak correlations between different years (Fig. 163).

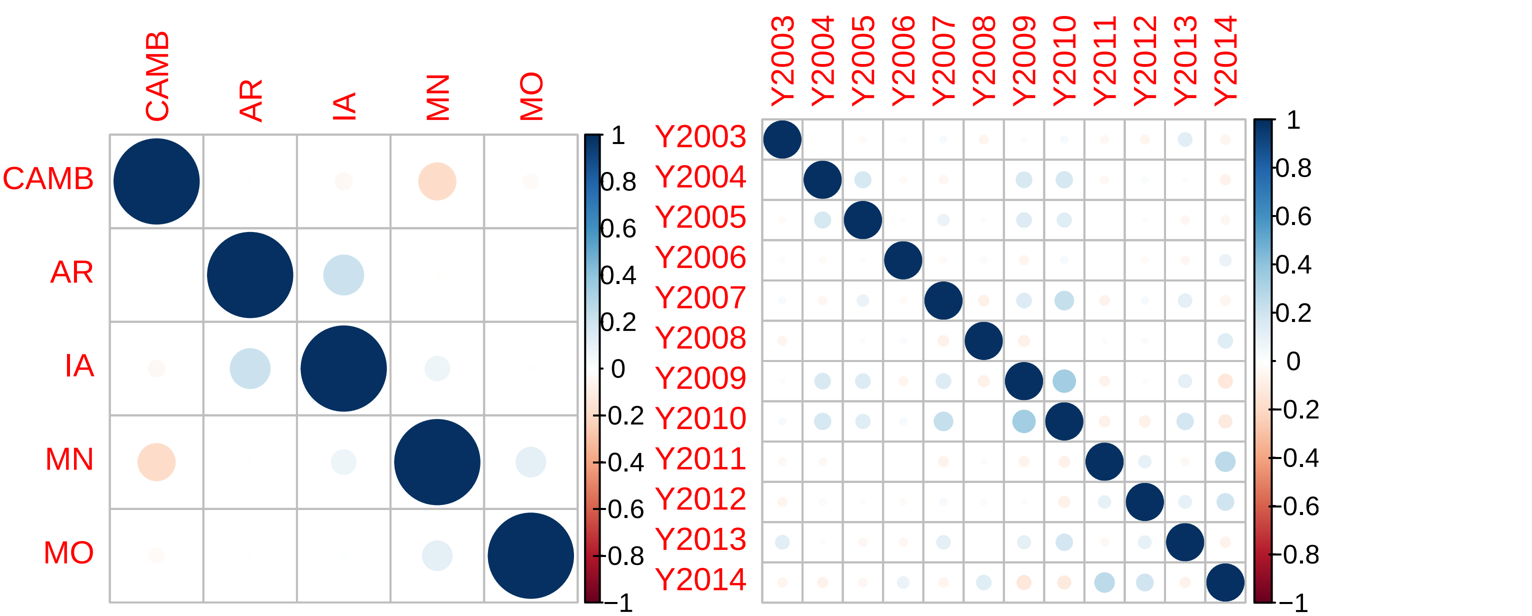


Figure 163: Correlations of White-winged Crossbill invasion pattern between individual areas and between years for the 2nd (midwest) longitudinal tier, eBird data.

Across the third longitudinal tier, daily eBird records show several weak negative correlations between different areas, and several weak to moderate correlations between the early years of the study (Fig. 164).

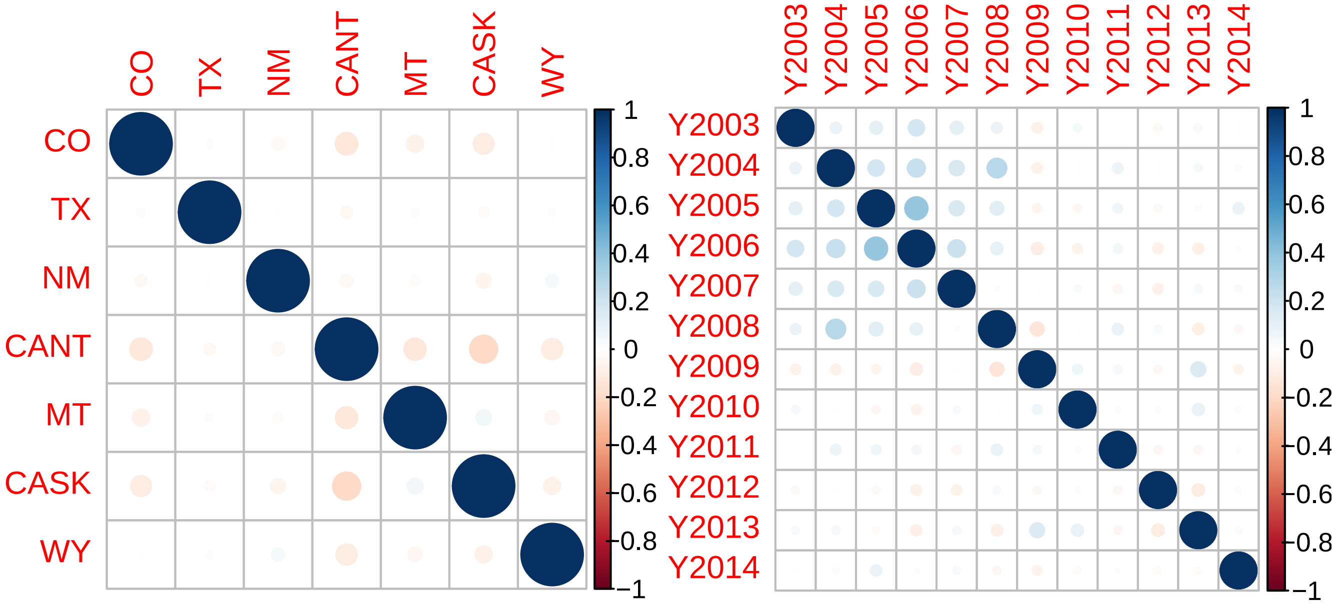


Figure 164: Correlations of White-winged Crossbill invasion pattern between individual areas and between years for the 3rd (Rocky Mountains) longitudinal tier, eBird data.

Across the fourth longitudinal tier, daily eBird records show few correlations between different areas, and several weak correlations between different years. The weak correlations between years often alternate between positive and negative (Fig. 165).

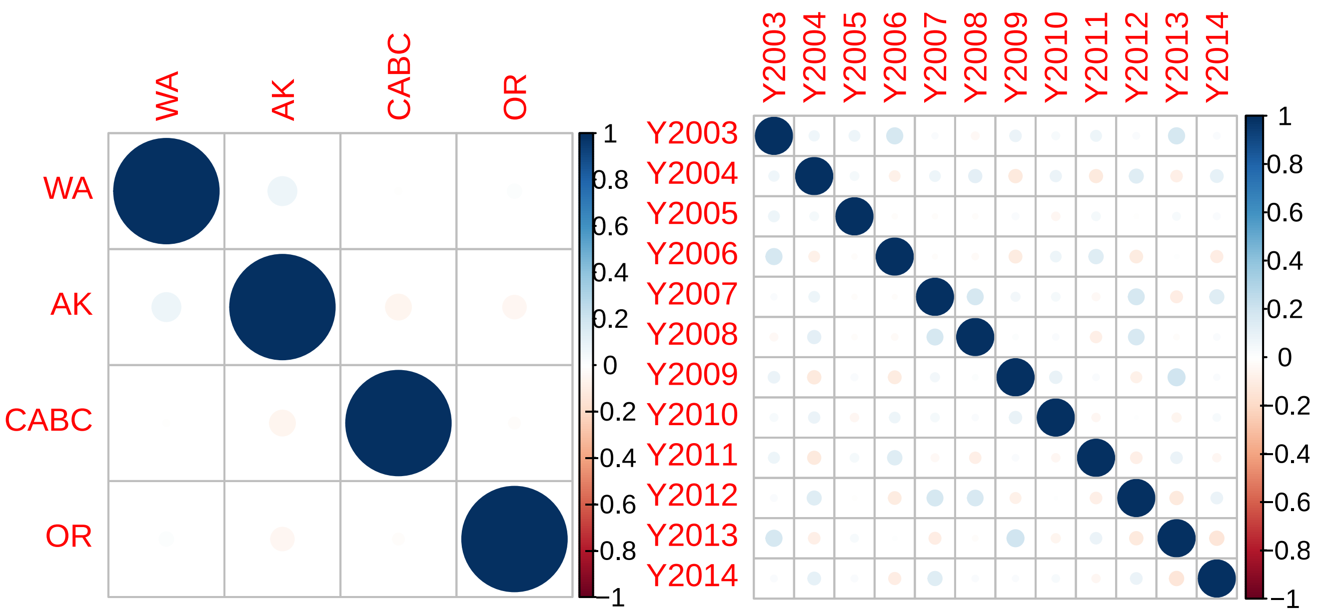


Figure 165: Correlations of White-winged Crossbill invasion pattern between individual areas and between years for the 4th (Pacific) longitudinal tier, eBird data.

American Goldfinch

CBC Analyses

Christmas Bird Count data since 1960 show that the highest numbers of American Goldfinches are recorded in the eastern and central United States (Fig. 166).

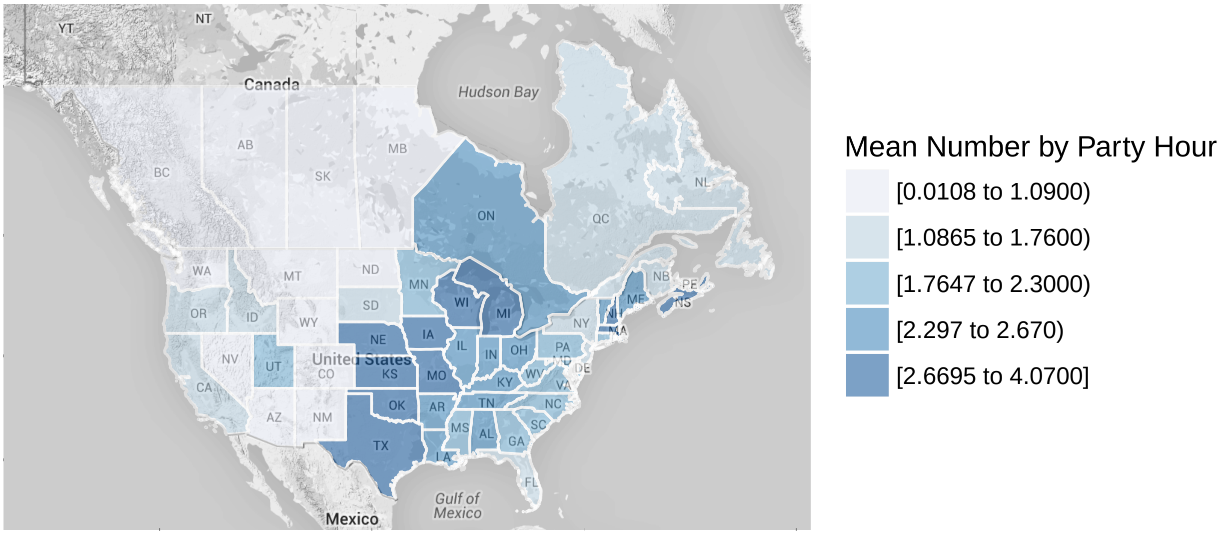


Figure 166: American Goldfinch abundance by area, CBC data.

Christmas Bird Count data since 1960 show that the highest variation in American Goldfinch numbers occurs across southern Canada, and the western and southeastern United States (Fig. 167).

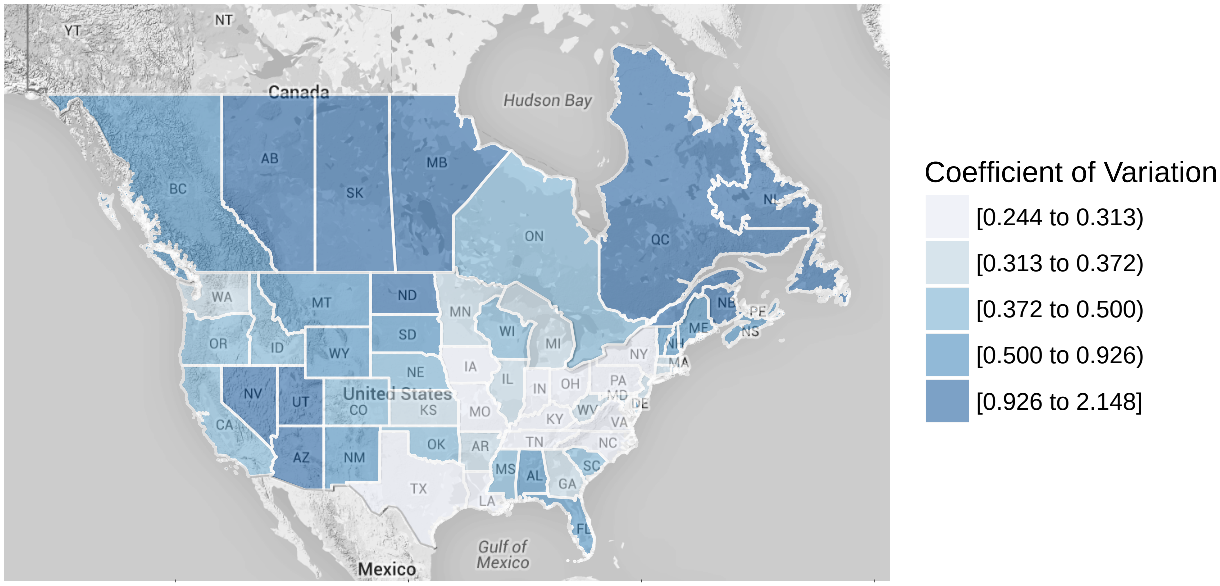


Figure 167: Coefficient of variation for American Goldfinch abundance by area, CBC data.

CBC data show that in the northernmost latitudinal tier, rises and falls in American Goldfinch winter abundance are mostly similarly timed in different provinces. There are weak to strong positive correlations between the different provinces (Fig. 168).

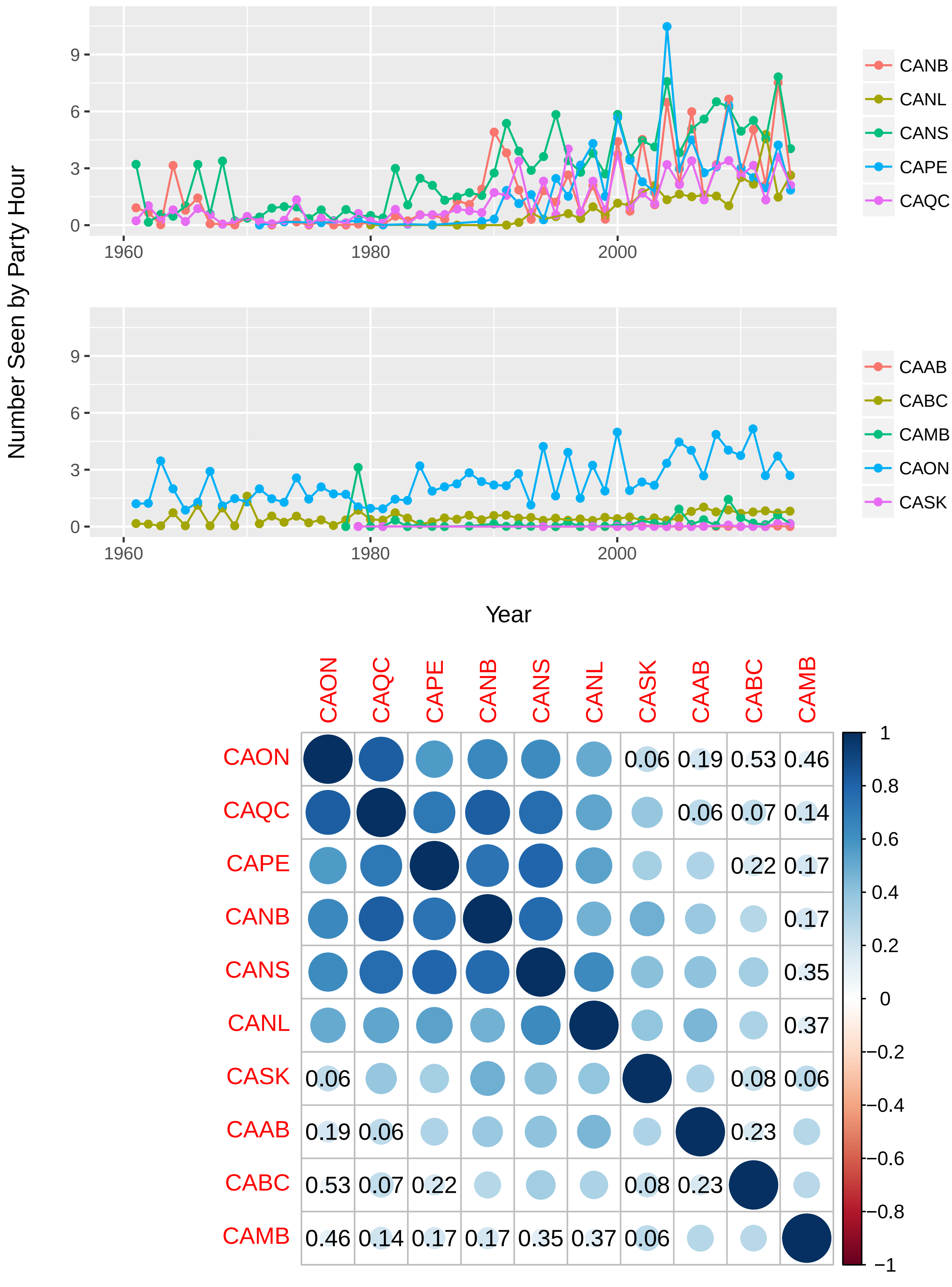


Figure 168: American Goldfinch abundance trends and area correlations across 1st (Canadian) latitudinal tier, CBC data.

CBC data show that in the second latitudinal tier, rises and falls in American Goldfinch winter abundance are mostly similarly timed in different areas. There are mostly weak to strong positive correlations between the different areas (Fig. 169).

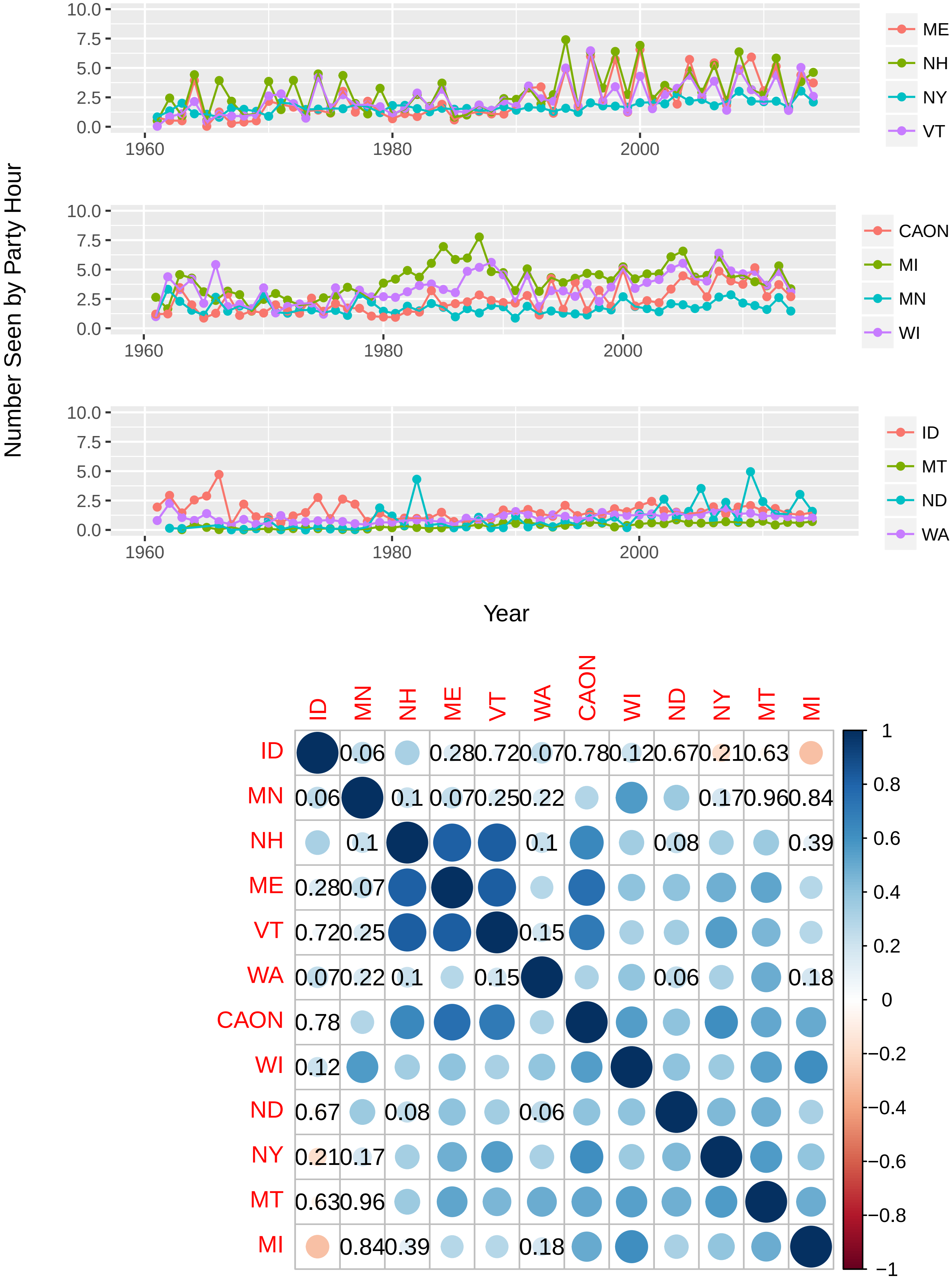


Figure 169: American Goldfinch abundance trends and area correlations across 2nd (northern US) latitudinal tier, CBC data.

CBC data show that in the third latitudinal tier, most areas do not show dramatic increases and decreases in American Goldfinch winter abundance, although the existing spikes in abundance are mostly shared across states. There are moderate negative to strong positive correlations between the different states (Fig. 170).

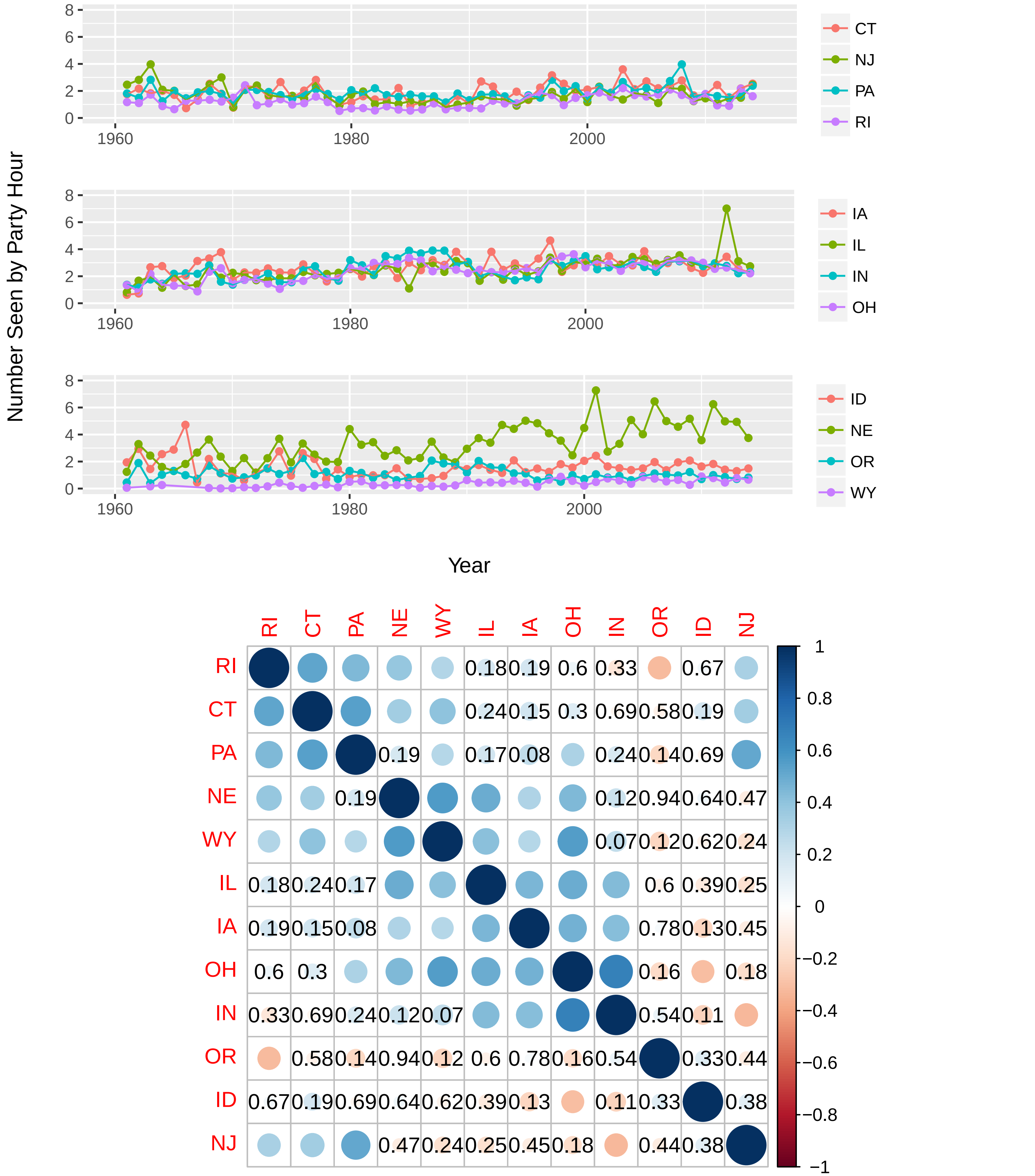


Figure 170: American Goldfinch abundance trends and area correlations across 3rd (mid US) latitudinal tier, CBC data.

CBC data show that in the fourth latitudinal tier, most areas do not show dramatic increases and decreases in American Goldfinch winter abundance, although the existing spikes in abundance are mostly shared across states. There are weak to strong positive correlations between the different states (Fig. 171).

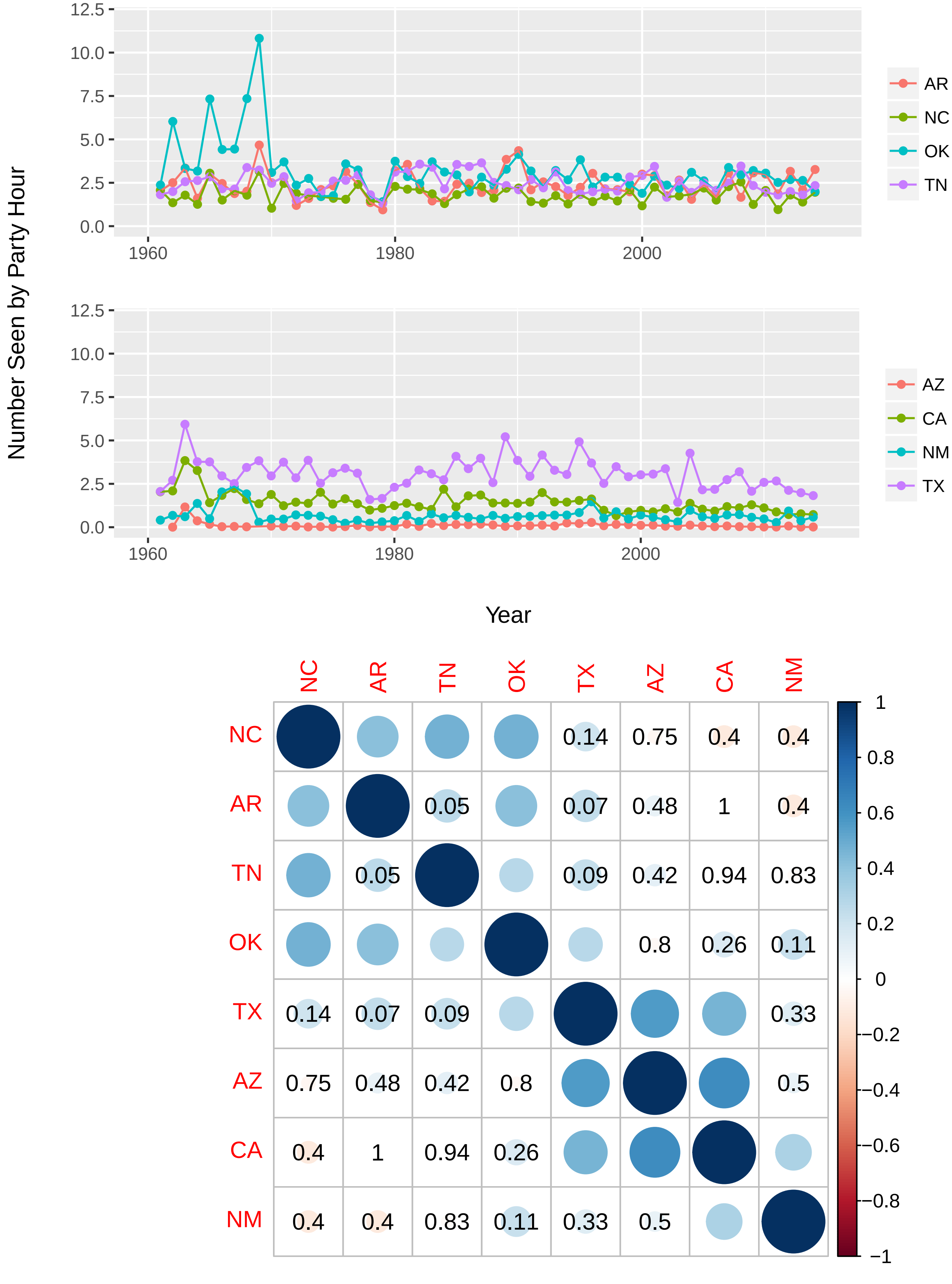


Figure 171: American Goldfinch abundance trends and area correlations across 4th (southern US) latitudinal tier, CBC data.

CBC data show that in the easternmost longitudinal tier, northern areas show the most variation in American Goldfinch winter abundance, and often alternate in having high abundance with southern areas. There are moderate to strong positive correlations between the southern areas in the tier, and between the northern areas in the tier. Northern and southern areas show weak to strong negative correlations with each other (Fig. 172).

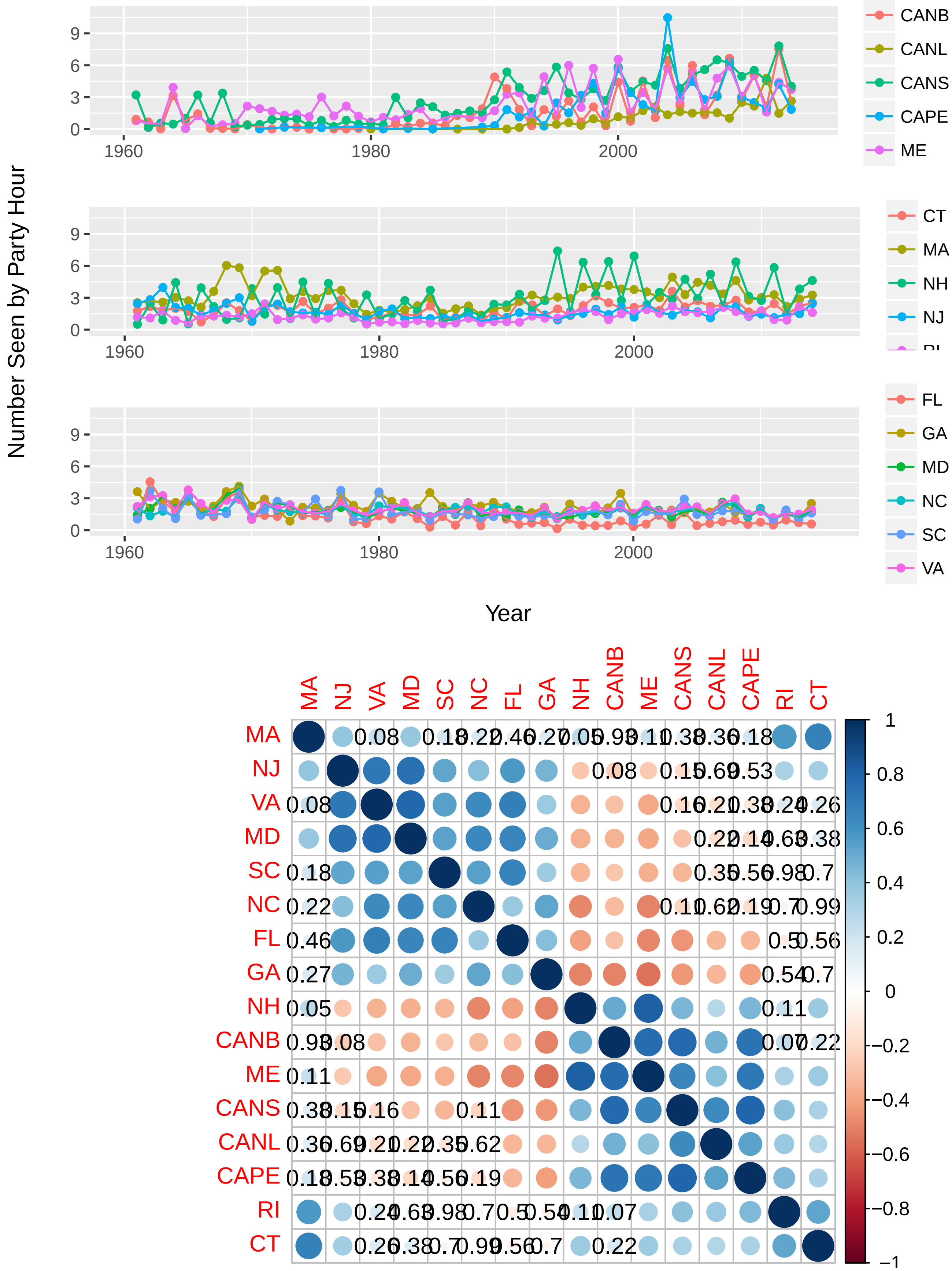


Figure 172: American Goldfinch abundance trends and area correlations across 1st (Atlantic) longitudinal tier, CBC data.

CBC data show that in the second, different areas sometimes alternate in having high winter abundances of American Goldfinch, although sometimes they show similarly timed rises and falls in abundance. There are weak to moderate correlations between different areas (Fig. 173).

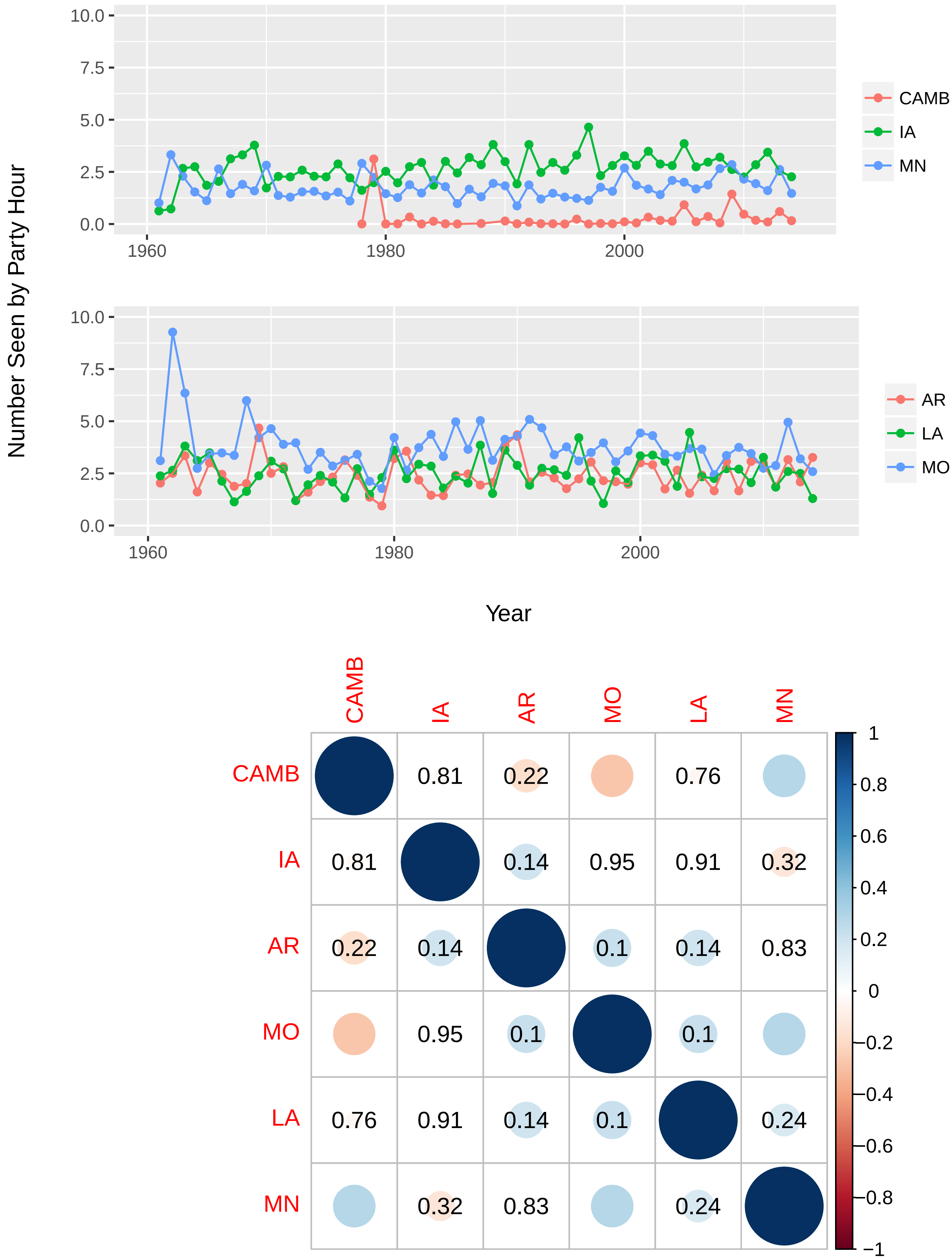


Figure 173: American Goldfinch abundance trends and area correlations across 2nd (midwest) longitudinal tier, CBC data.

CBC data show that in the third longitudinal tier, different areas show different winter abundances of American Goldfinch, and most show little variation in abundance over time. There are weak to strong correlations between different areas. Due to lack of CBC records, I excluded data from the Northwest Territories from my analyses (Fig. 174).

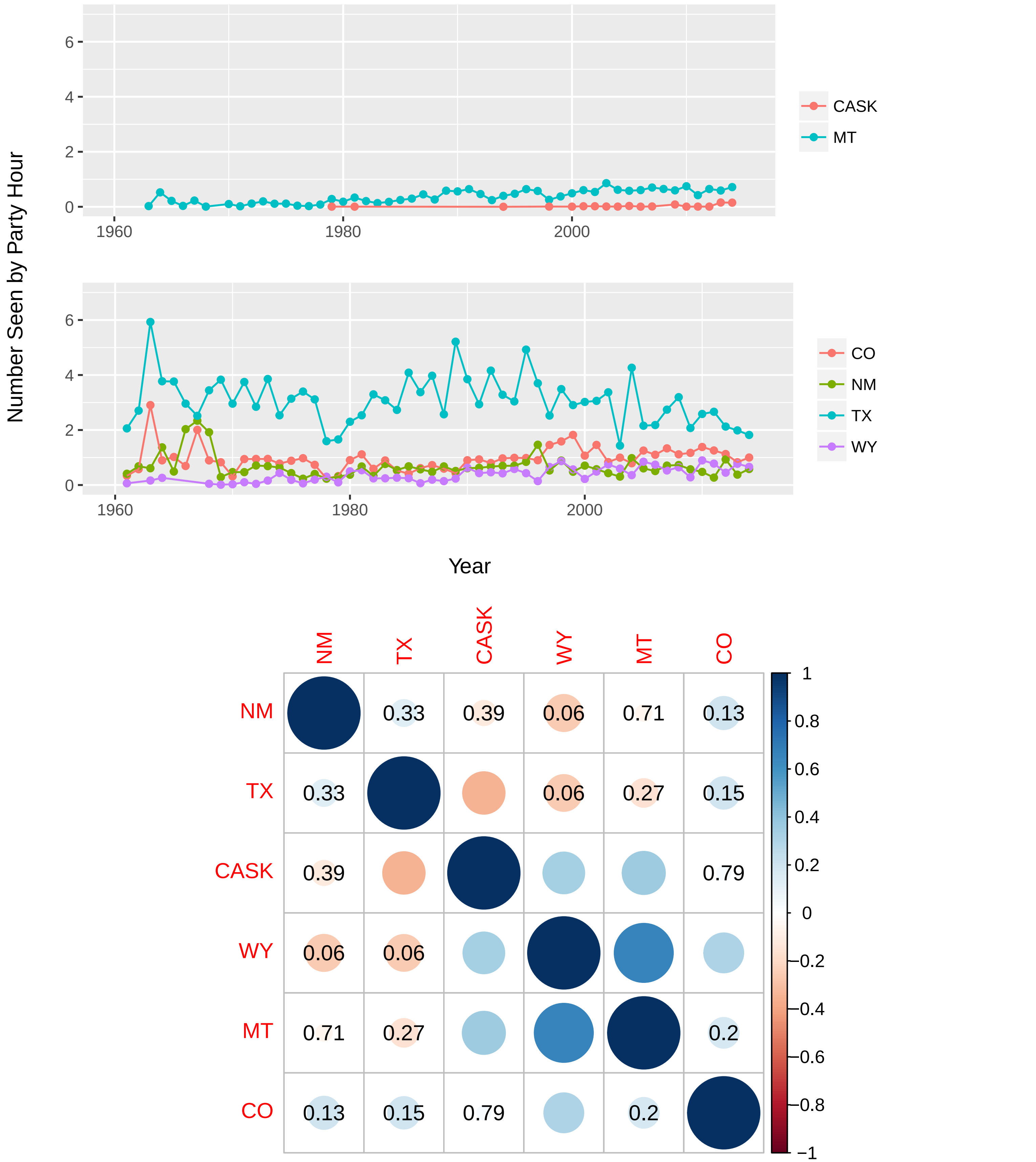


Figure 174: American Goldfinch abundance trends and area correlations across 3rd (Rocky Mountains) longitudinal tier, CBC data.

CBC data show that in the fourth longitudinal tier, different areas mostly alternatie in having high winter abundances of American Goldfinch, California shows weak negative correlations with British Columbia and Washington. Due to lack of CBC records, I excluded data from Alaska and British Columbia from my analyses (Fig. 175).

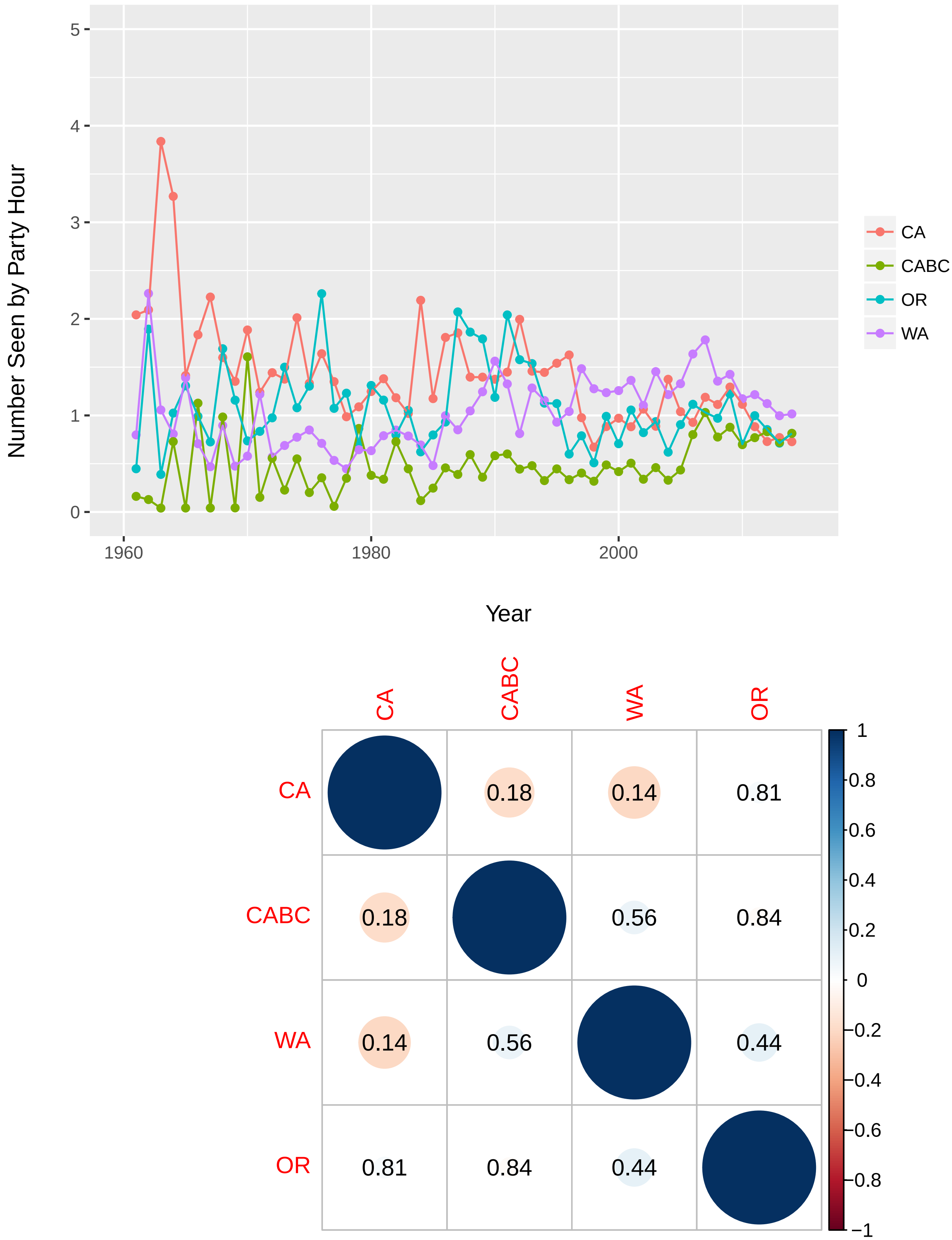


Figure 175: American Goldfinch abundance trends and area correlations across 4th (Pacific) longitudinal tier, CBC data.

eBird Analyses

Across the northermost latitudinal tier, daily eBird records show weak to strong positive correlations between all areas and strong positive correlations between most years (Fig. 176).

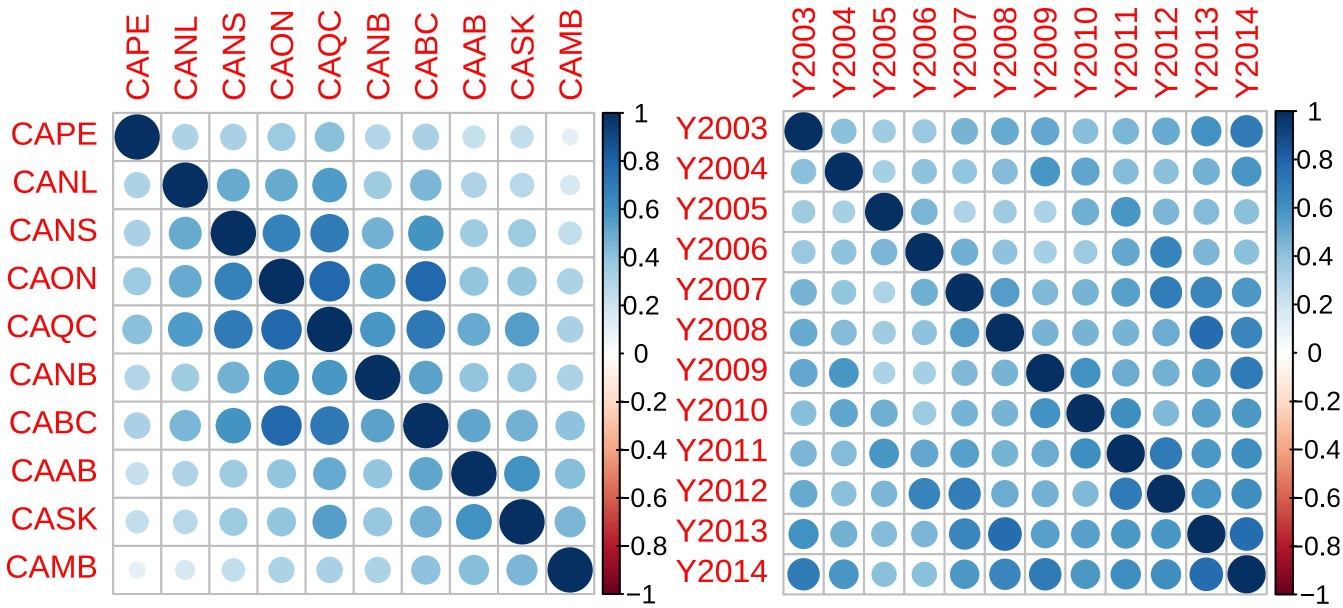


Figure 176: Correlations of American Goldfinch invasion pattern between individual areas and between years for the 1st (Canadian) latitudinal tier, eBird data.

Across the second latitudinal tier, daily eBird records show weak to strong positive correlations between most areas and strong positive correlations between most years (Fig. 177).

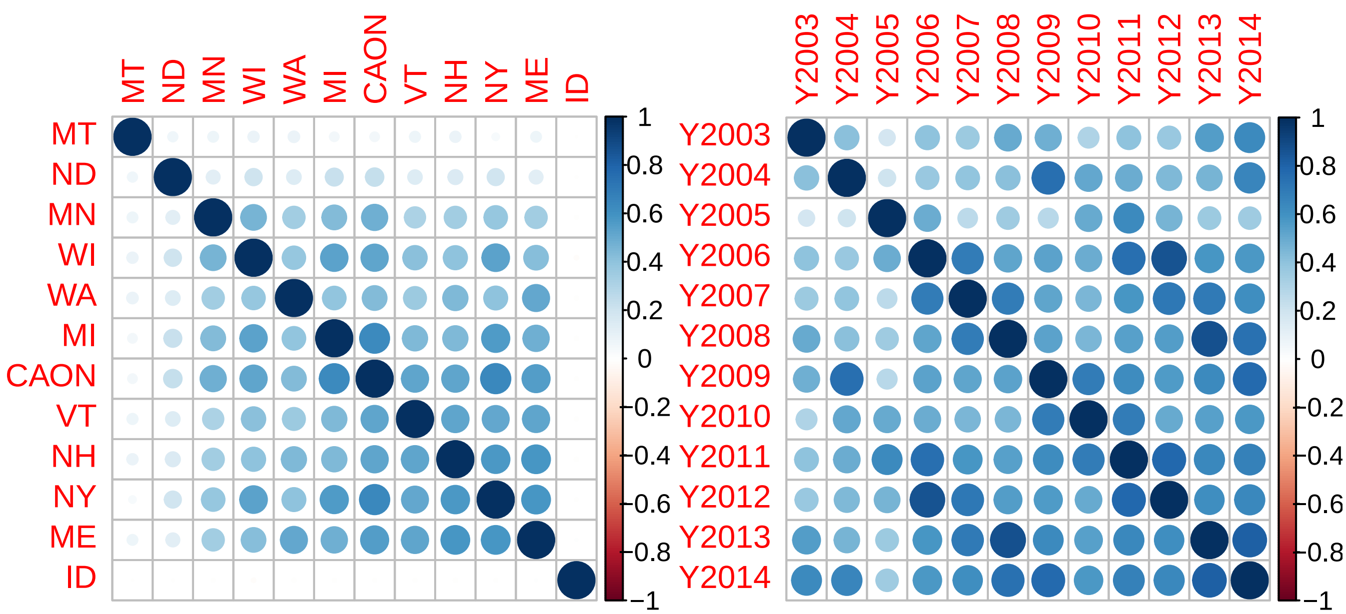


Figure 177: Correlations of American Goldfinch invasion pattern between individual areas and between years for the 2nd (northern US) latitudinal tier, eBird data.

Across the third latitudinal tier, daily eBird records show weak to strong positive correlations between all areas and weak to strong positive correlations between all years (Fig. 178).

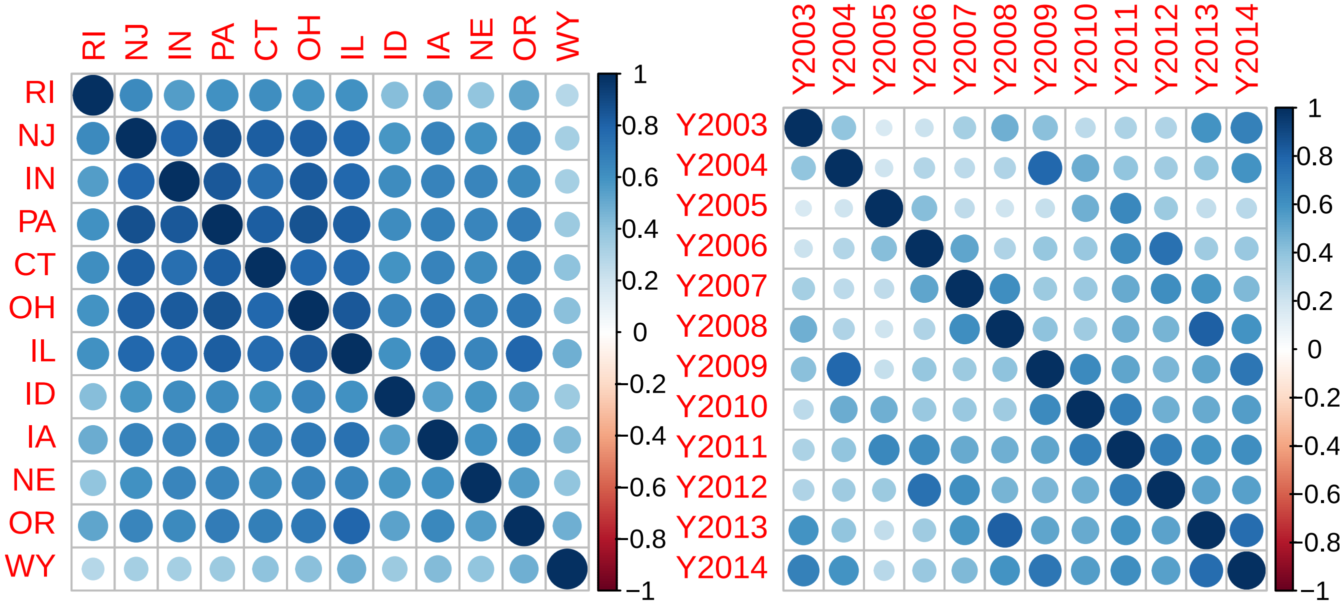


Figure 178: Correlations of American Goldfinch invasion pattern between individual areas and between years for the 3rd (mid US) latitudinal tier, eBird data.

Across the fourth latitudinal tier, daily eBird records show moderate to strong positive correlations between all areas and weak to strong positive correlations between all years, The strongest positive correlations between years are between years that are six years apart (Fig. 179).

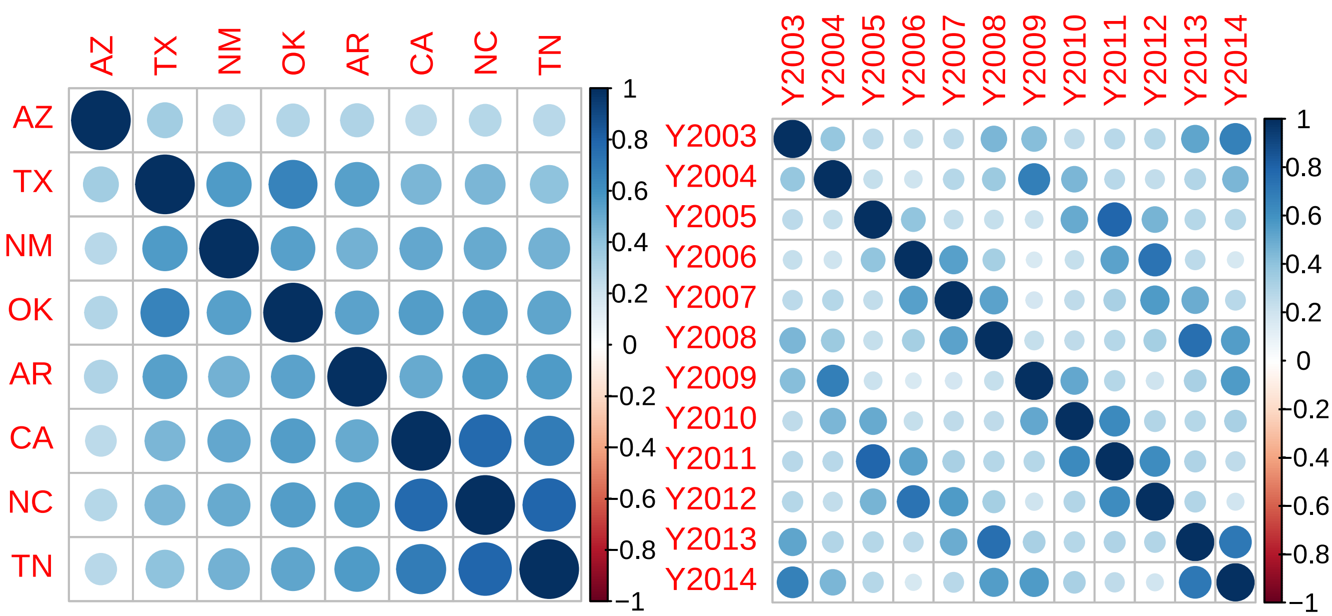


Figure 179: Correlations of American Goldfinch invasion pattern between individual areas and between years for the 4th (southern US) latitudinal tier, eBird data.

Across the easternmost longitudinal tier, daily eBird records show the strongest positive correlations between states in the middle of the tier, and strong positive correlations between years that are six years apart (Fig. 180).

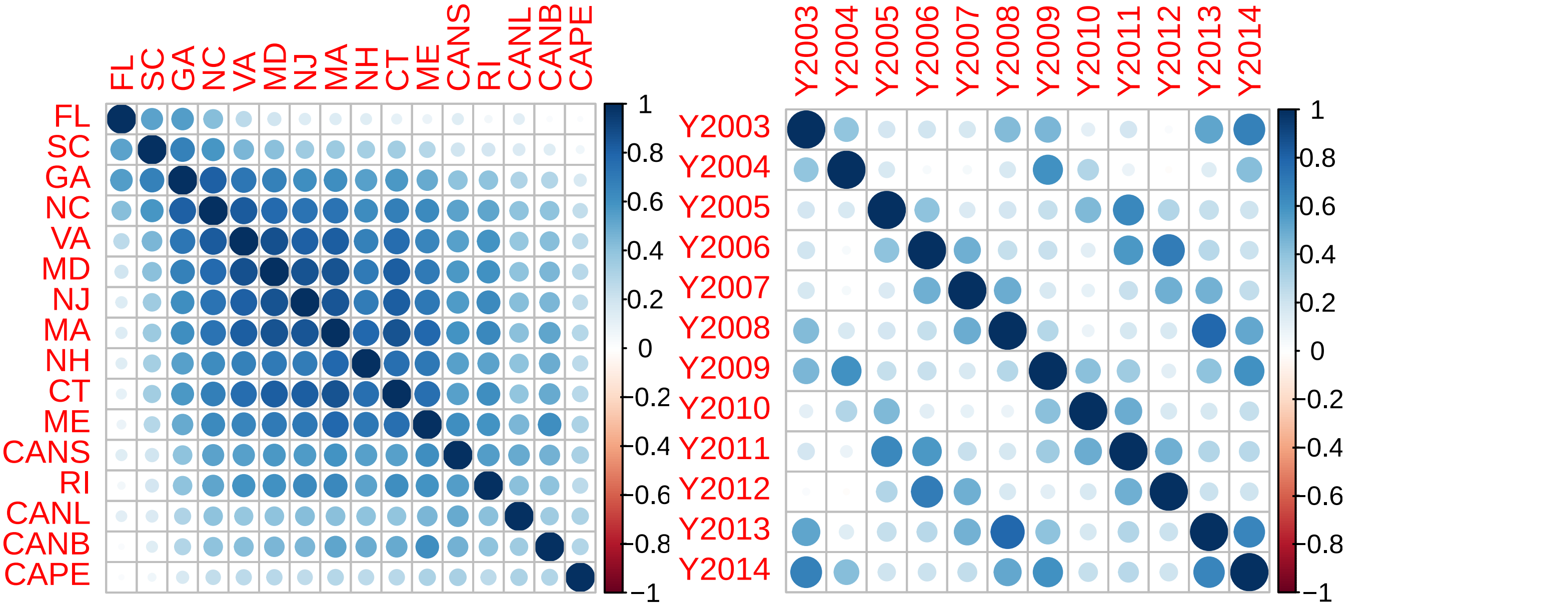


Figure 180: Correlations of American Goldfinch invasion pattern between individual areas and between years for the 1st (Atlantic) longitudinal tier, eBird data.

Across the second longitudinal tier, daily eBird records show weak to strong positive correlations between some different areas, and weak to strong positive correaltions between years. Years that are six years apart show the strongest positive correlations with each other (Fig. 181).

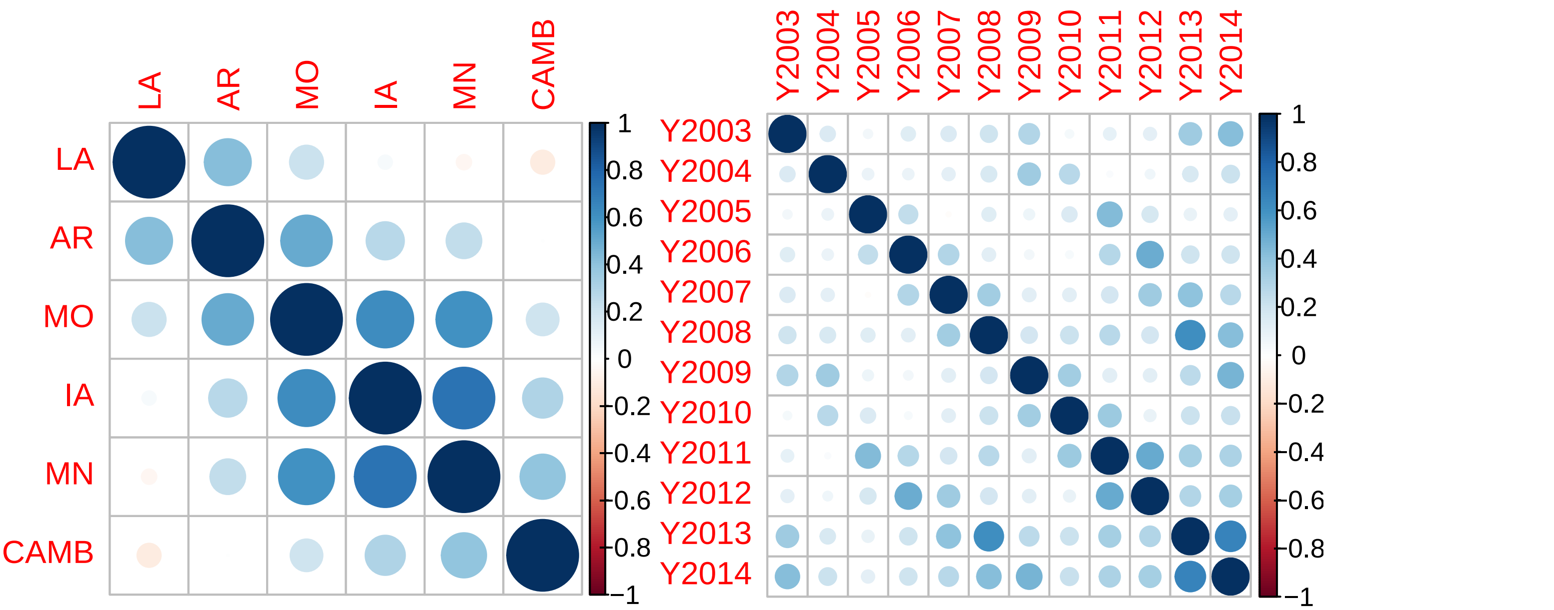


Figure 181: Correlations of American Goldfinch invasion pattern between individual areas and between years for the 2nd (midwest) longitudinal tier, eBird data.

Across the third longitudinal tier, daily eBird records show weak to strong positive correlations between some different areas, and weak to strong positive correaltions between all years (Fig. 182).

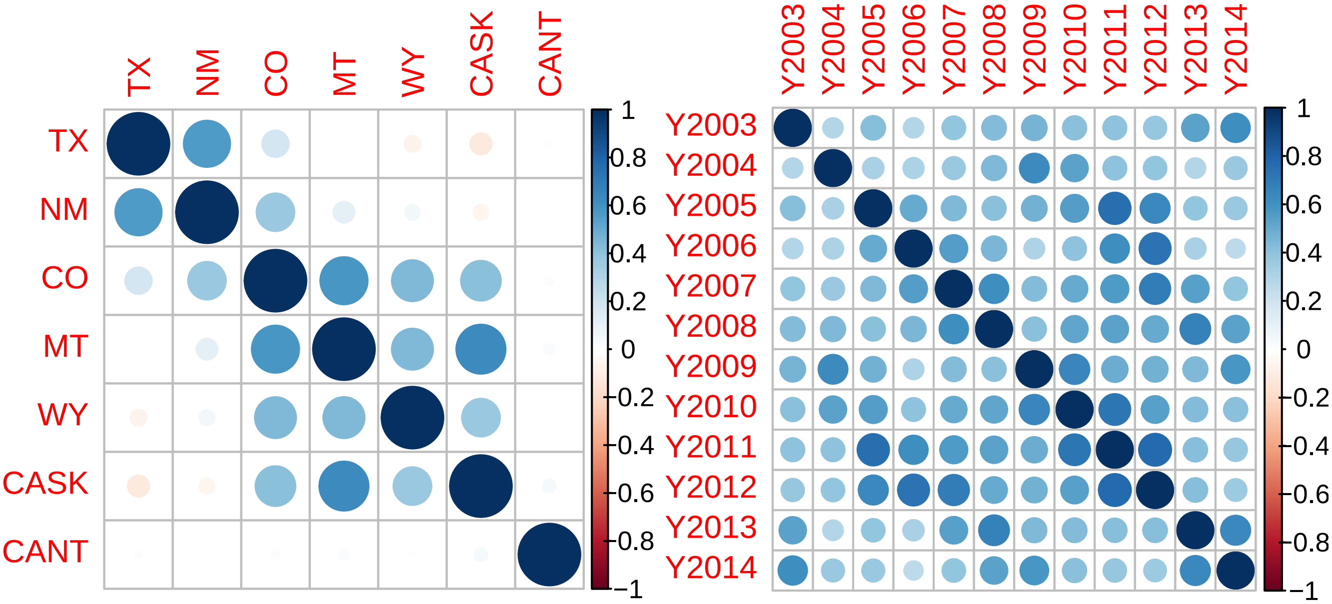


Figure 182: Correlations of American Goldfinch invasion pattern between individual areas and between years for the 3rd (Rocky Mountains) longitudinal tier, eBird data.

Across the fourth longitudinal tier, daily eBird records show strong positive correlations between all areas, and weak to strong positive correaltions between years. Years that are six years apart show the strongest positive correlations with each other (Fig. 183).

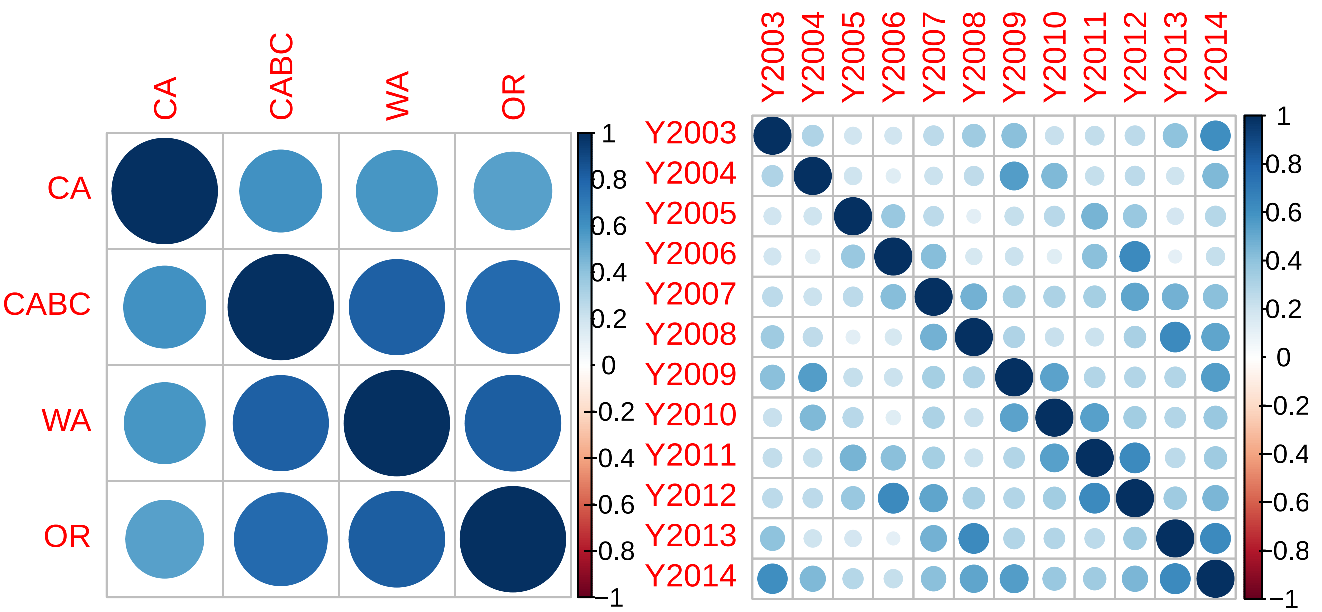


Figure 183: Correlations of American Goldfinch invasion pattern between individual areas and between years for the 4th (Pacific) longitudinal tier, eBird data.

Lesser Goldfinch

CBC Analyses

Christmas Bird Count data since 1960 show that the highest numbers of Lesser Goldfinches are recorded in the southeastern United States (Fig. 184).

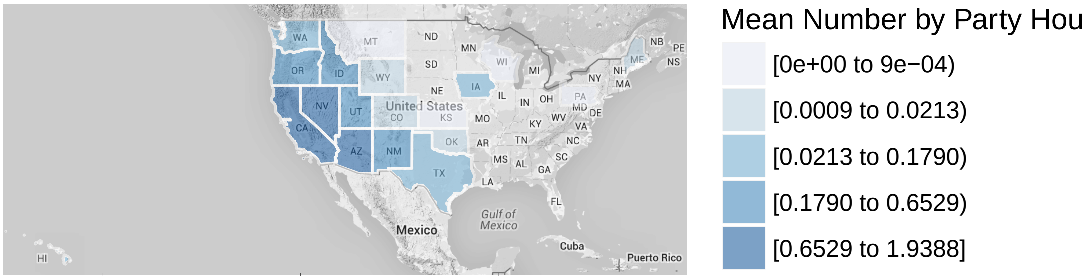


Figure 184: Lesser Goldfinch abundance by area, CBC data.

Christmas Bird Count data since 1960 show that the highest variation in Lesser Goldfinch numbers occurs in the central-west United States (Fig. 185).

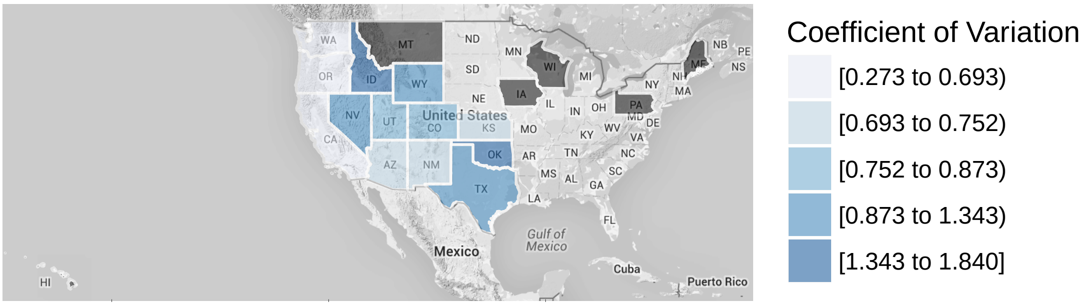


Figure 185: Coefficient of variation for Lesser Goldfinch abundance by area, CBC data.

In the second latitudinal tier, only Idaho and Washington have records of Lesser Goldfinches. The two states have a moderately-strong positive correlartion (both siginficant) (Fig. 186).

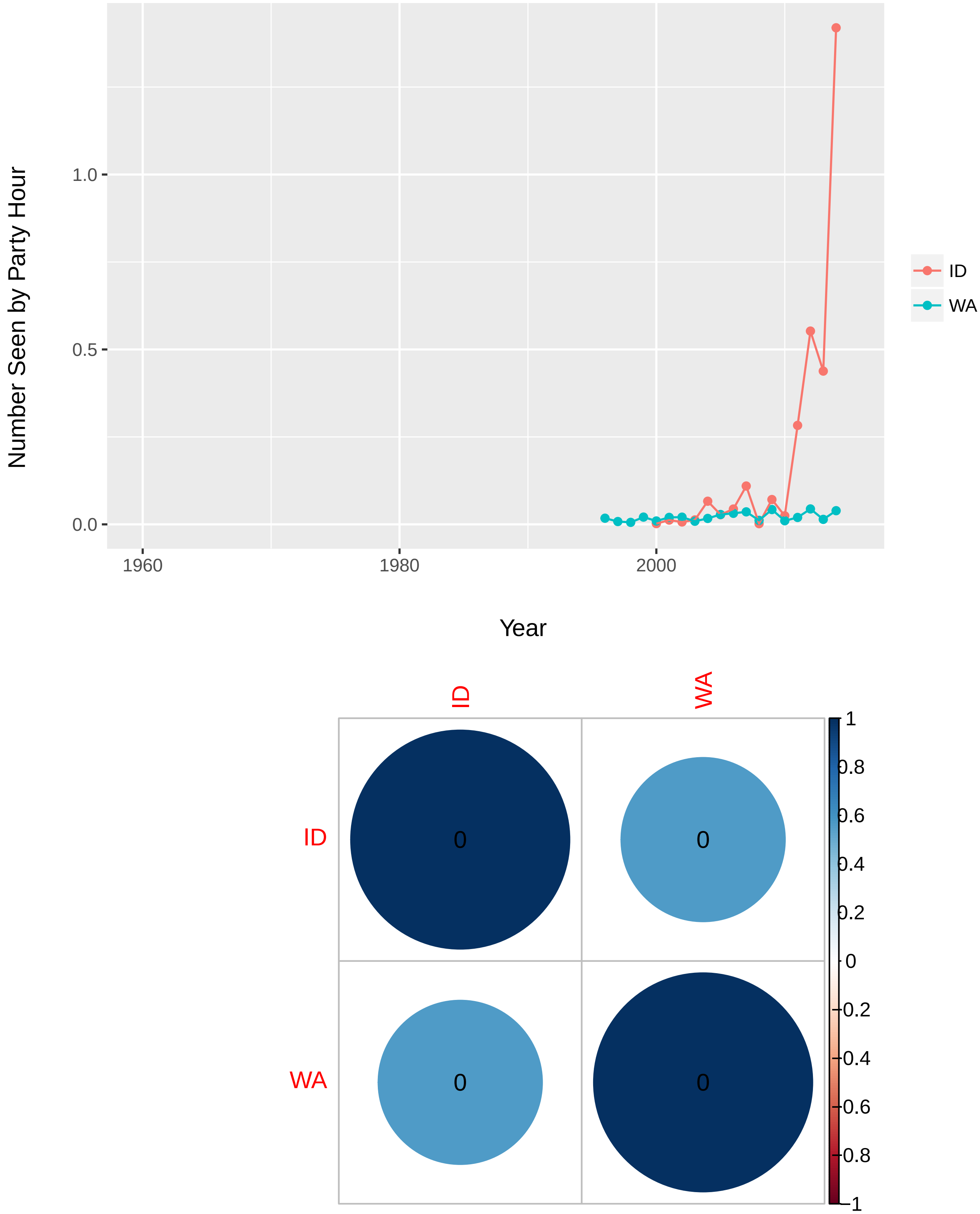
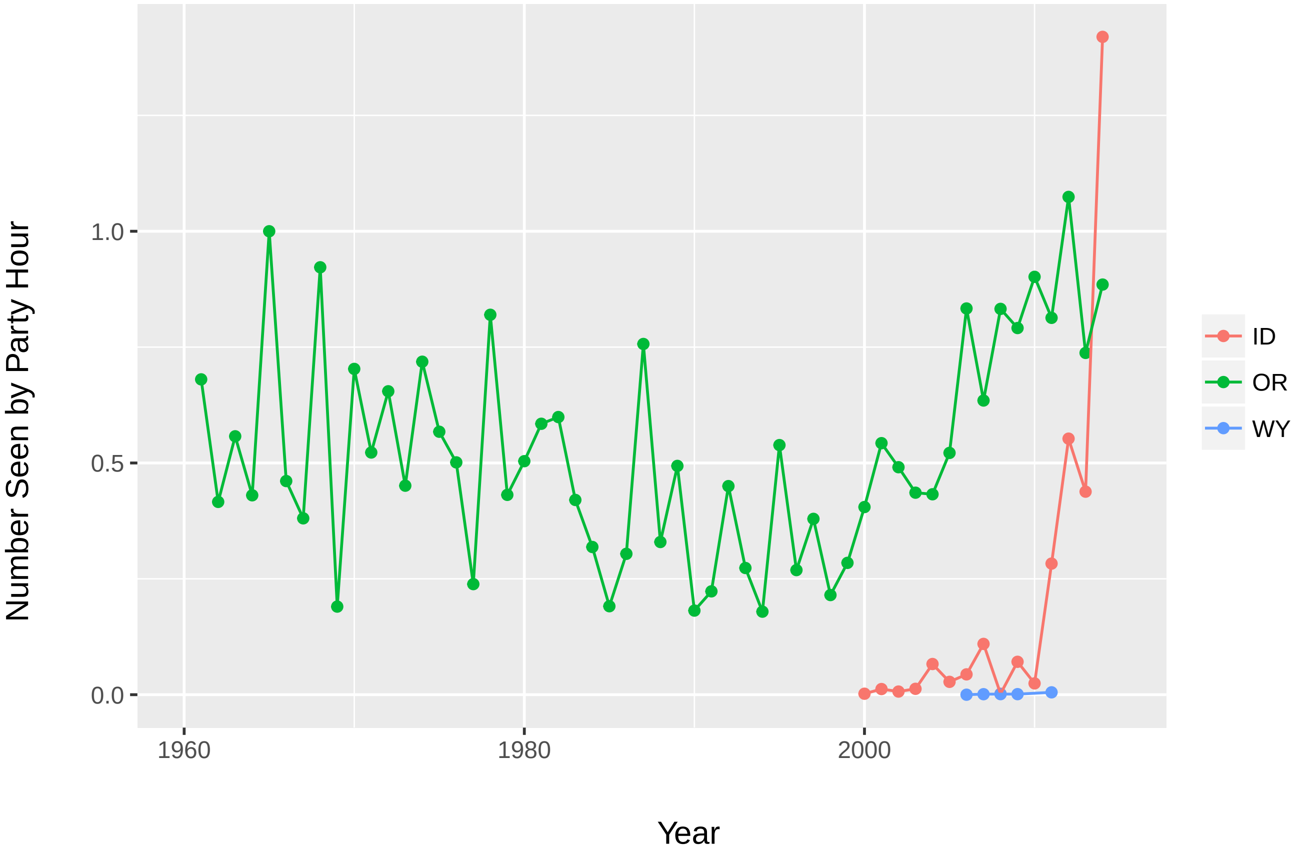


Figure 186: Lesser Goldfinch abundance trends and area correlations across 2nd (northern US) latitudinal tier, CBC data.

CBC data show that in the third latitudinal tier, the three states with CBC records of Lesser Goldfinches have weak to moderate positive correlations with each other (Fig. 187).



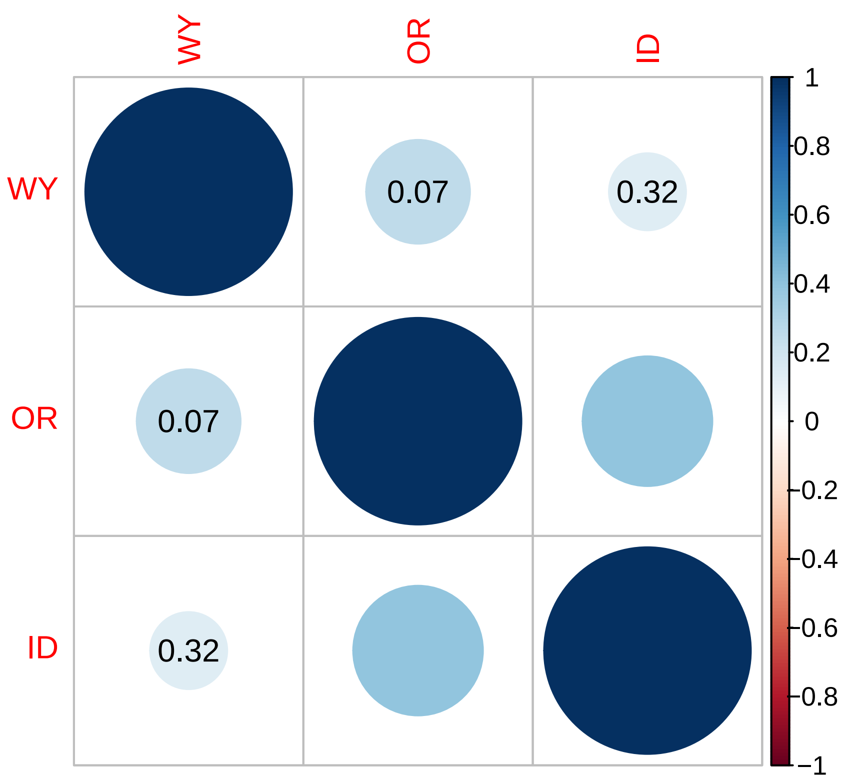


Figure 187: Lesser Goldfinch abundance trends and area correlations across 3rd (mid US) latitudinal tier, CBC data.

CBC data show that in the southernmost latitudinal tier, different states consistently show different winter abundances of Lesser Goldfinch. The different states show weak negative to strong positive correlations with each other (Fig. 188).

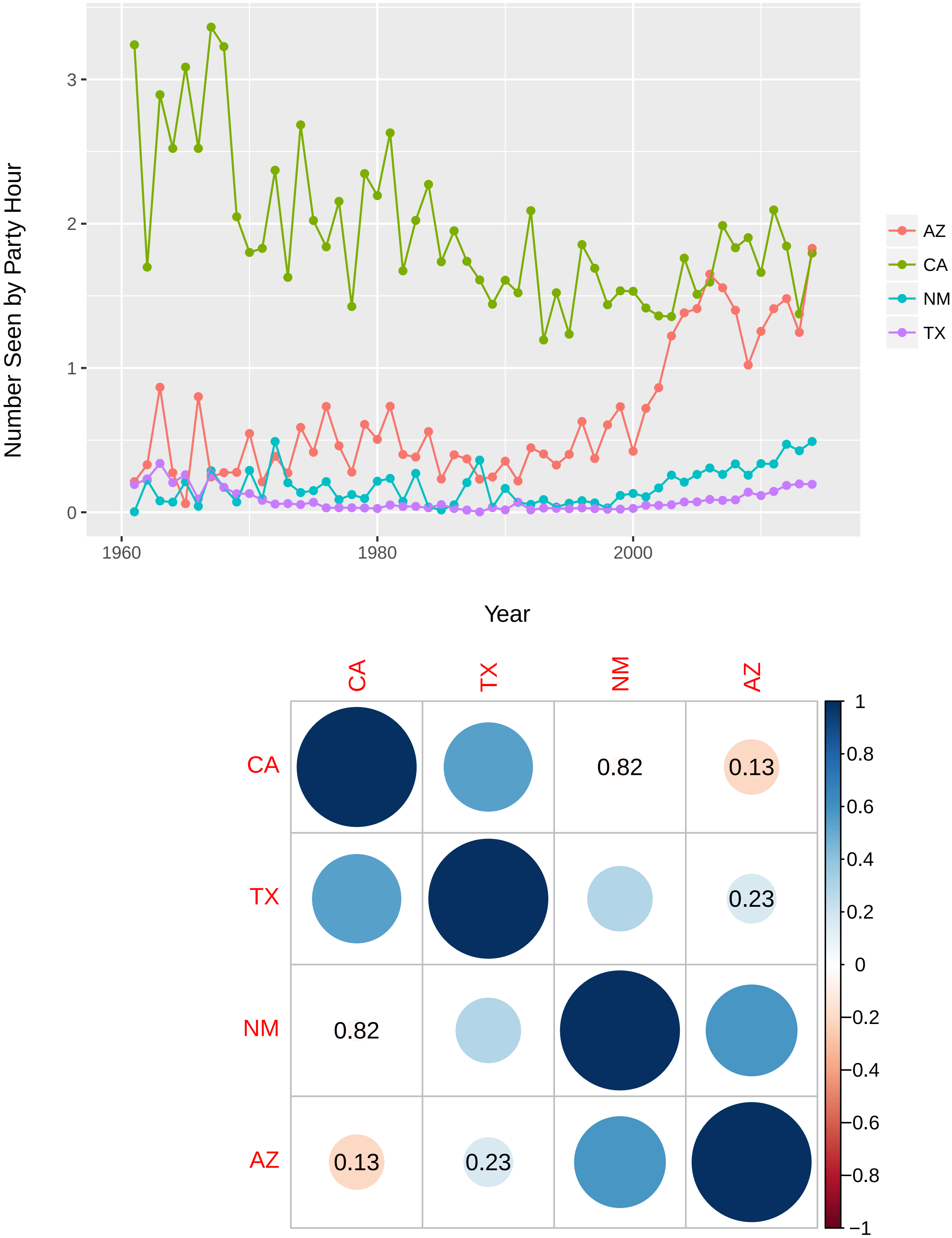


Figure 188: Lesser Goldfinch abundance trends and area correlations across 4th (southern US) latitudinal tier, CBC data.

CBC data show that in the third longitudinal tier, different states consistently show different winter abundances of Lesser Goldfinch. Texas shows a strong negative correlation with Mexico, while the other areas show weak to moderate positive correlations with each other (Fig. 189).

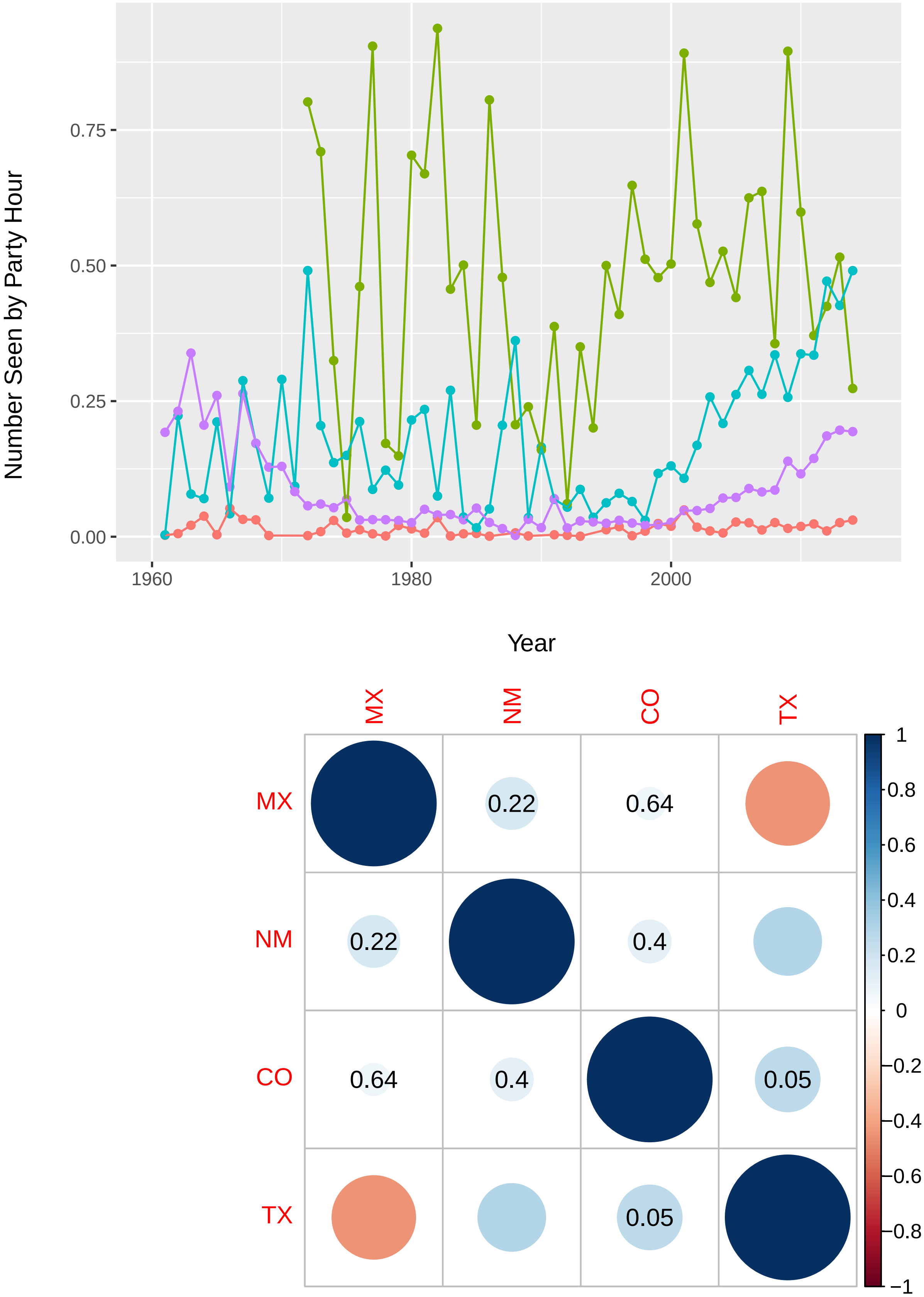


Figure 189: Lesser Goldfinch abundance trends and area correlations across 3rd (Rocky Mountains) longitudinal tier, CBC data.

CBC data show that in the fourth longitudinal tier, different states consistently show different winter abundances of Lesser Goldfinch, and different states show alternations in rises and falls in abundance. California shows a strong negative correlation with Mexico, and Oregon shows a weak positive correlation with California (Fig. 190).

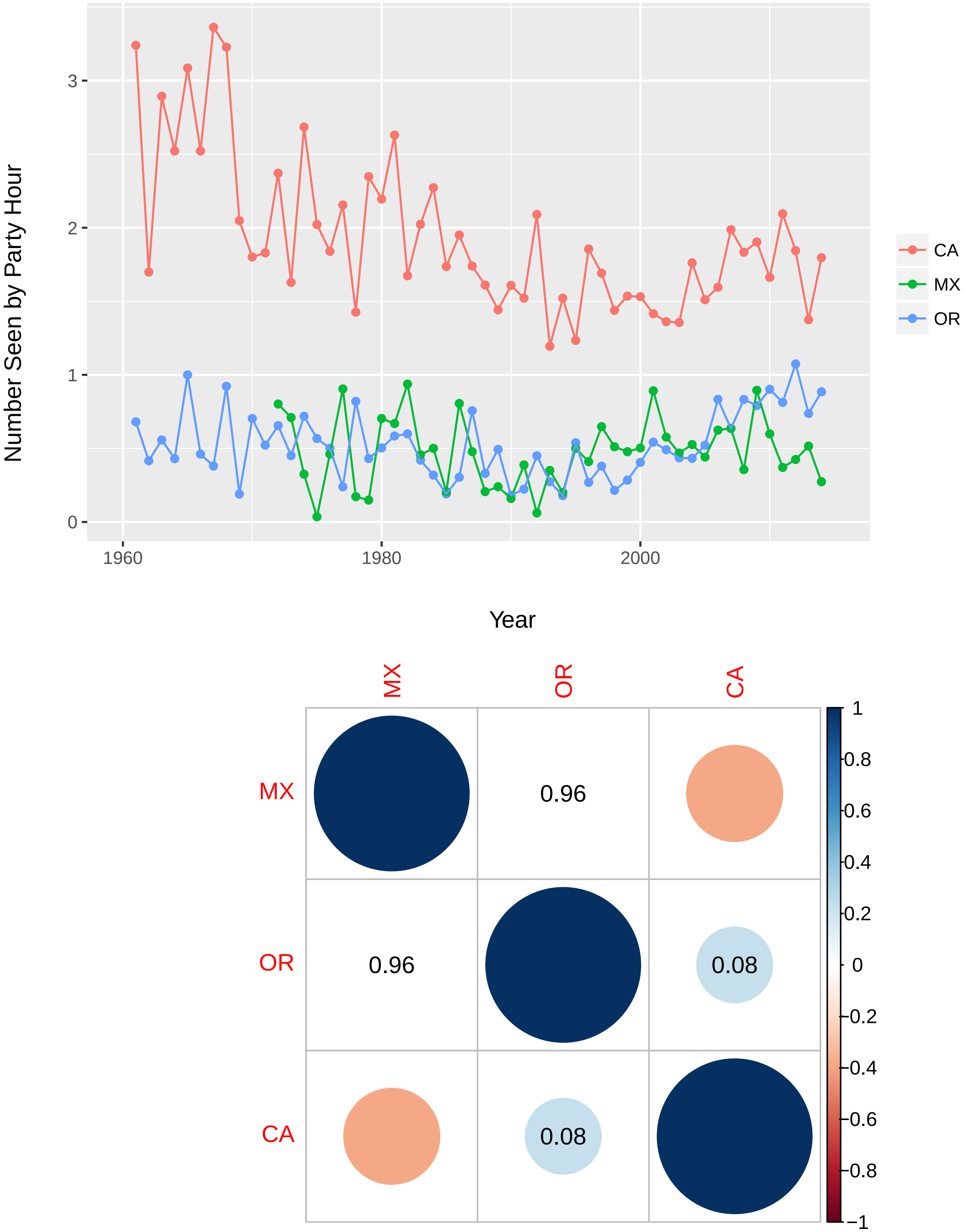


Figure 190: Lesser Goldfinch abundance trends and area correlations across 4th (Pacific) longitudinal tier, CBC data.

eBird Analyses

Across the second latitudinal tier, daily eBird records show few correlations between different areas and between different years (Fig. 191).

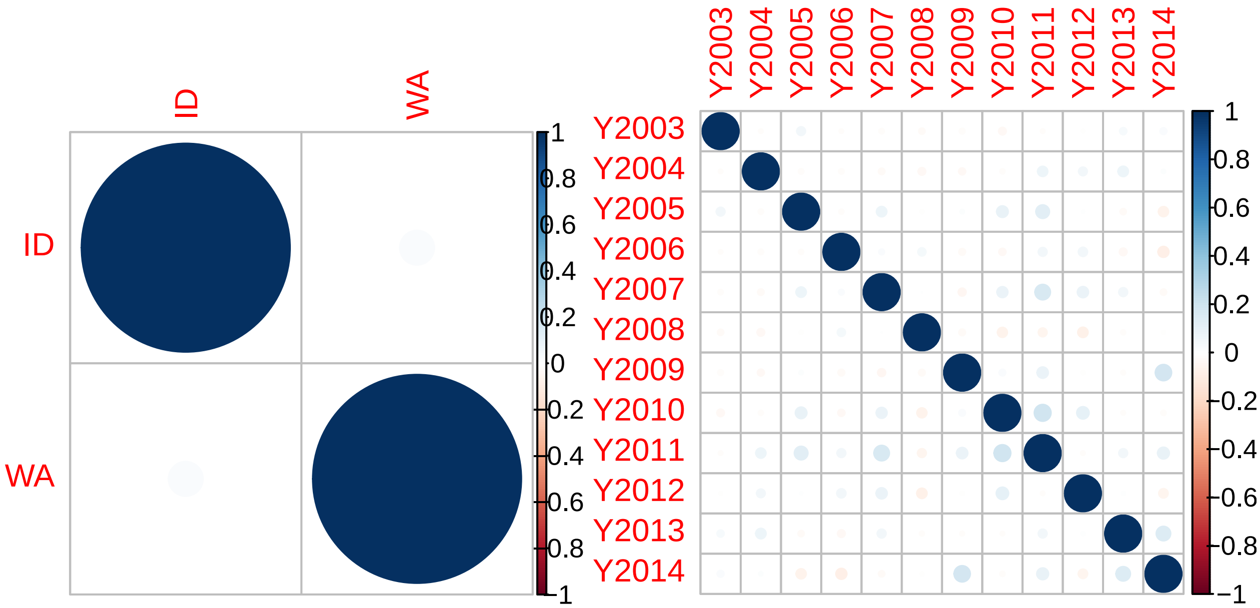


Figure 191: Correlations of Lesser Goldfinch invasion pattern between individual areas and between years for the 2nd (northern US) latitudinal tier, eBird data.

Across the third latitudinal tier, daily eBird records show a moderate positive correlation between Idaho and Oregon, and weak to moderate positive correlations between different years (Fig. 192).

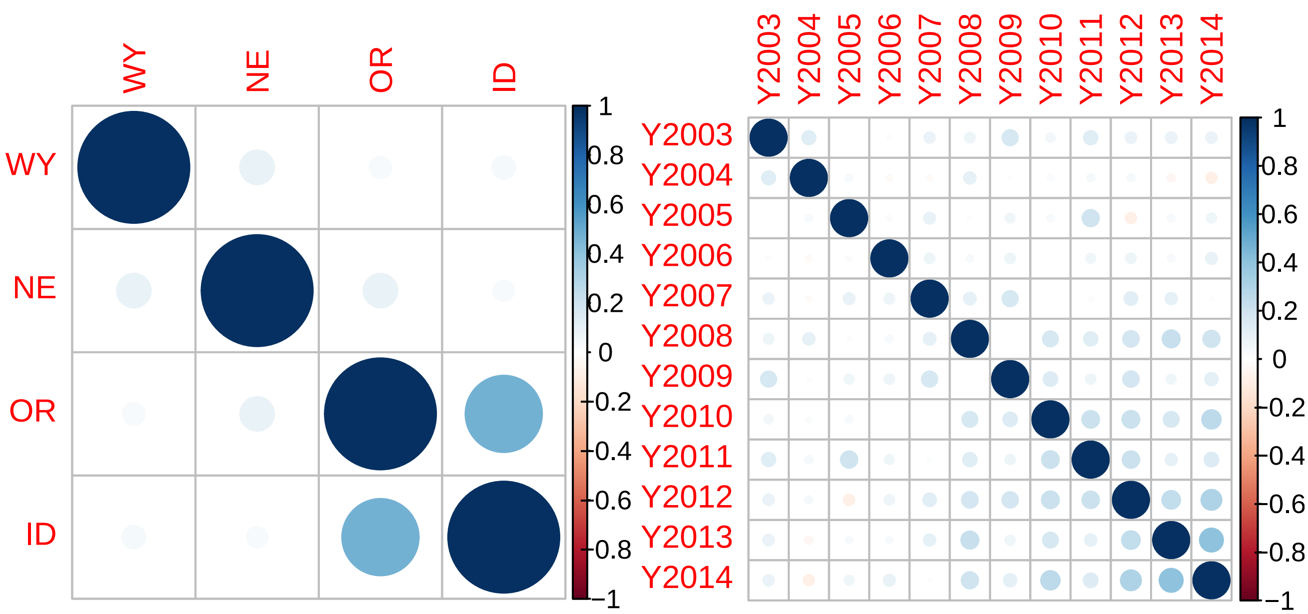


Figure 192: Correlations of Lesser Goldfinch invasion pattern between individual areas and between years for the 3rd (mid US) latitudinal tier, eBird data.

Across the southernmost latitudinal tier, daily eBird records show strong positive correlations between different areas, and weak to strong positive correlations between different years, with the strongest positive correlations between years that are six years apart (Fig. 193).

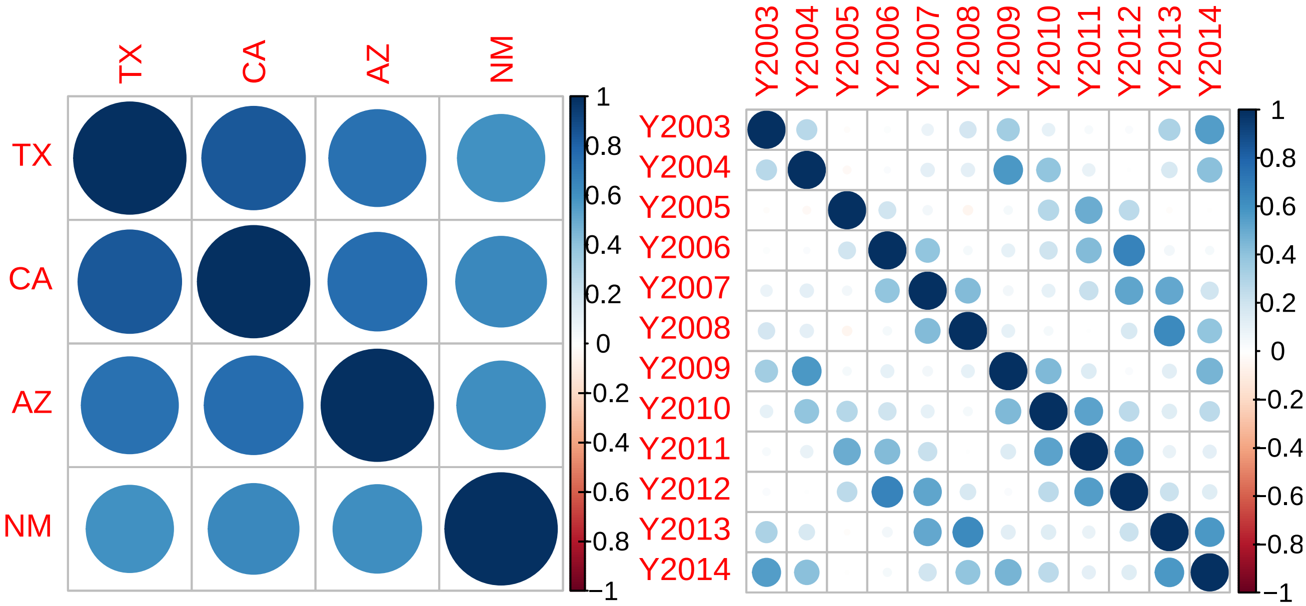


Figure 193: Correlations of Lesser Goldfinch invasion pattern between individual areas and between years for the 4th (southern US) latitudinal tier, eBird data.

Across the third longitudinal tier, daily eBird records show moderate to strong positive correlations between different areas, and weak to strong positive correlations between different years (Fig. 194).

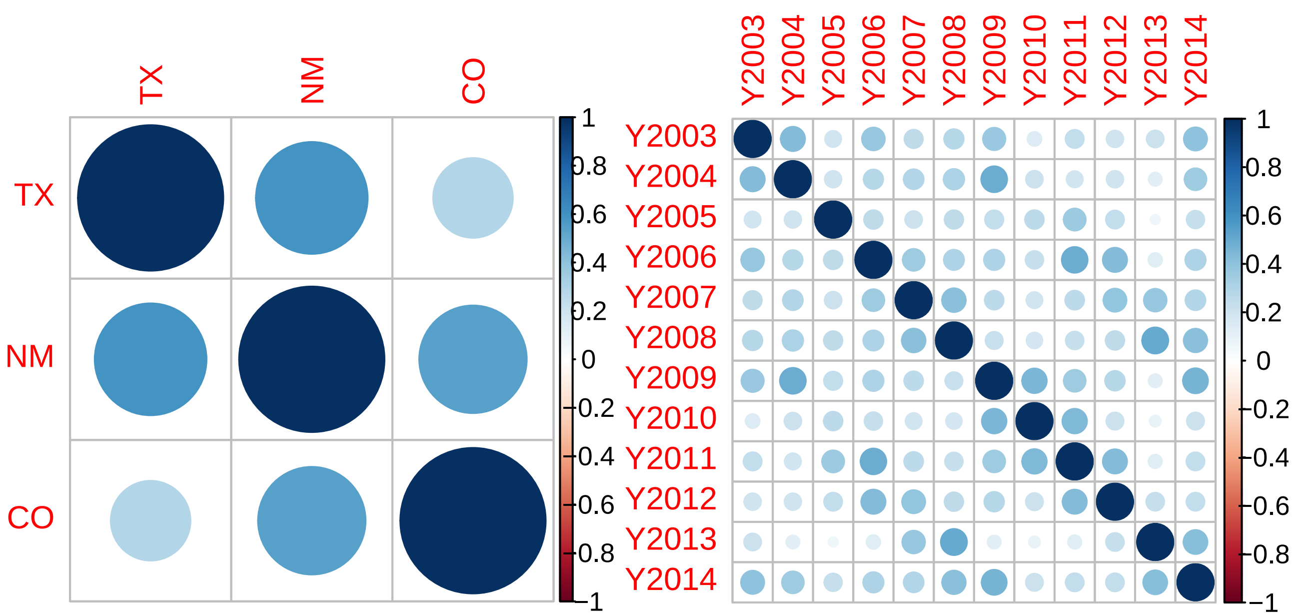


Figure 194: Correlations of Lesser Goldfinch invasion pattern between individual areas and between years for the 3rd (Rocky Mountains) longitudinal tier, eBird data.

Across the fourht longitudinal tier, daily eBird records show strong positive correlations between different areas, and weak to strong positive correlations between different years, with the strongest positive correlations between years that are six years apart (Fig. 195).

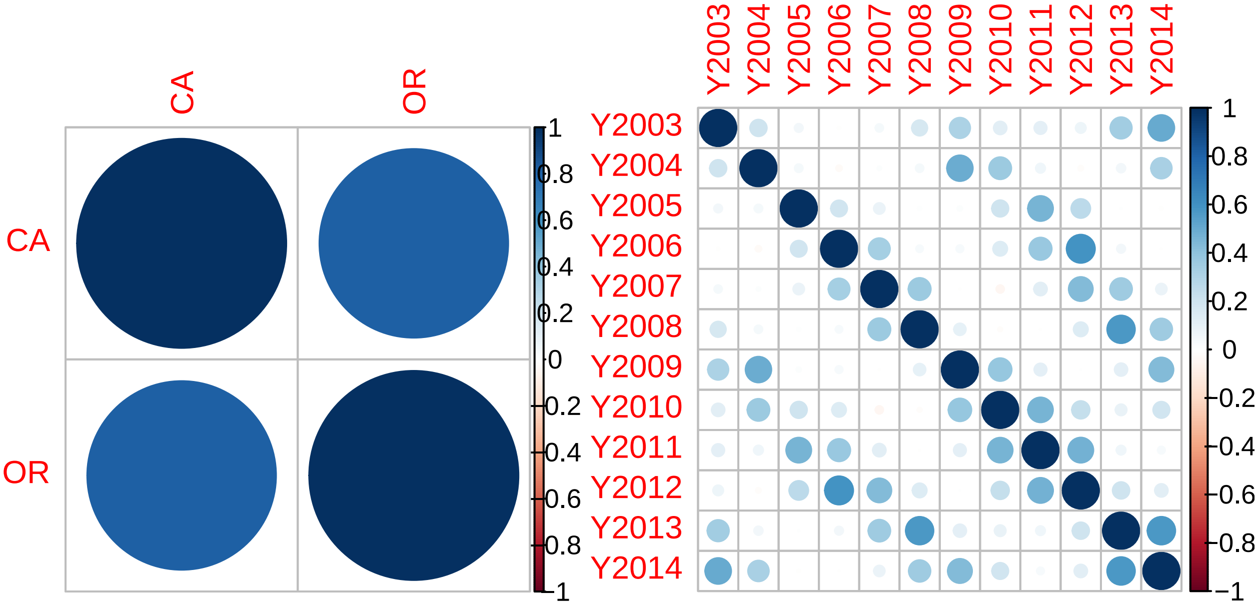


Figure 195: Correlations of Lesser Goldfinch invasion pattern between individual areas and between years for the 4th (Pacific) longitudinal tier, eBird data.

Pine Siskin

CBC Analyses

Christmas Bird Count data since 1960 show that the highest numbers of Pine Siskins are recorded across southern Canada, and the northern and western United States (Fig. 196).

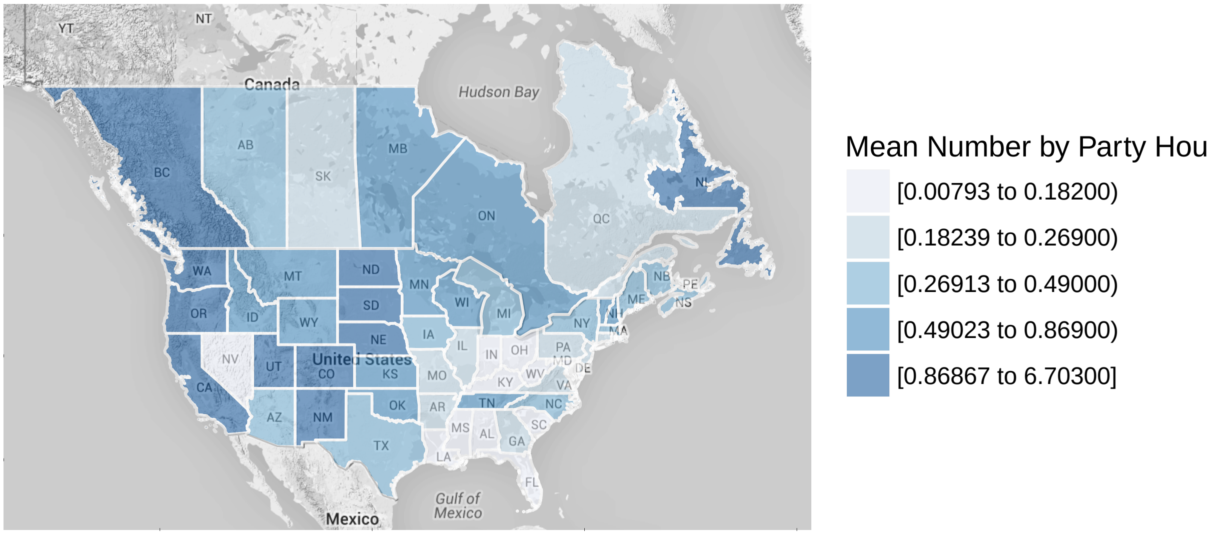


Figure 196: Pine Siskin abundance by area, CBC data.

Christmas Bird Count data since 1960 show that the highest variation in Pine Siskin numbers occurs in the eastern and southern United States, and also a few Canadian provinces (Fig. 197).

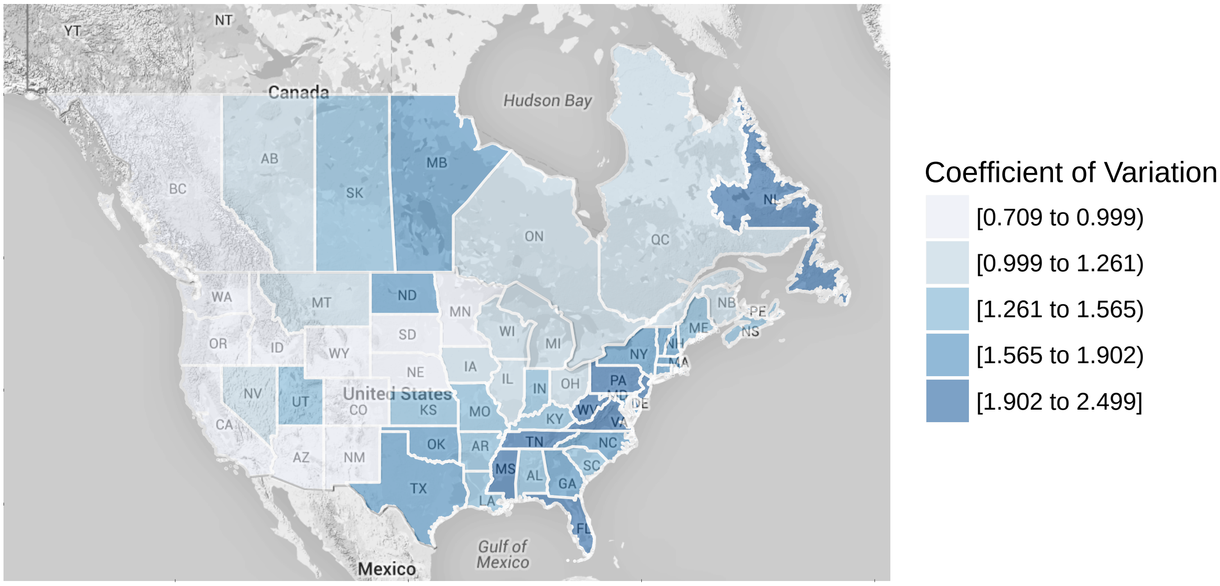


Figure 197: Coefficient of variation for Pine Siskin abundance by area, CBC data.

Along the northernmost latitudinal tier, CBC data show some rises and falls in abundance that are similarly timed in different areas. There are weak to strong positive correlations and weak negative correlations between different areas (Fig. 198).

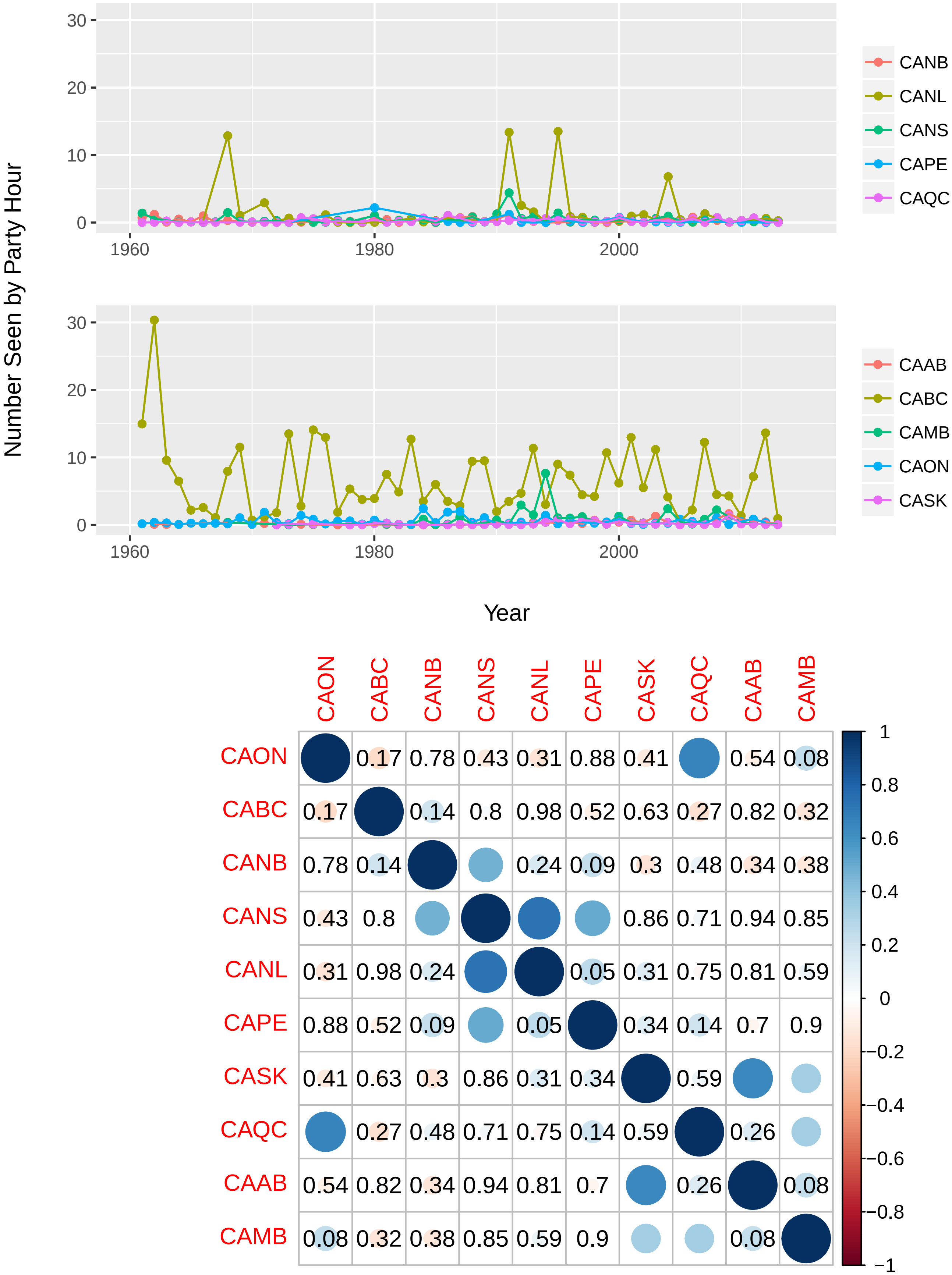


Figure 198: Pine Siskin abundance trends and area correlations across 1st (Canadian) latitudinal tier, CBC data.

Along the second latitudinal tier, CBC data show rises and falls in abundance that are mostly similarly timed in different areas. There are weak to strong positive correlations between most areas (Fig. 199).

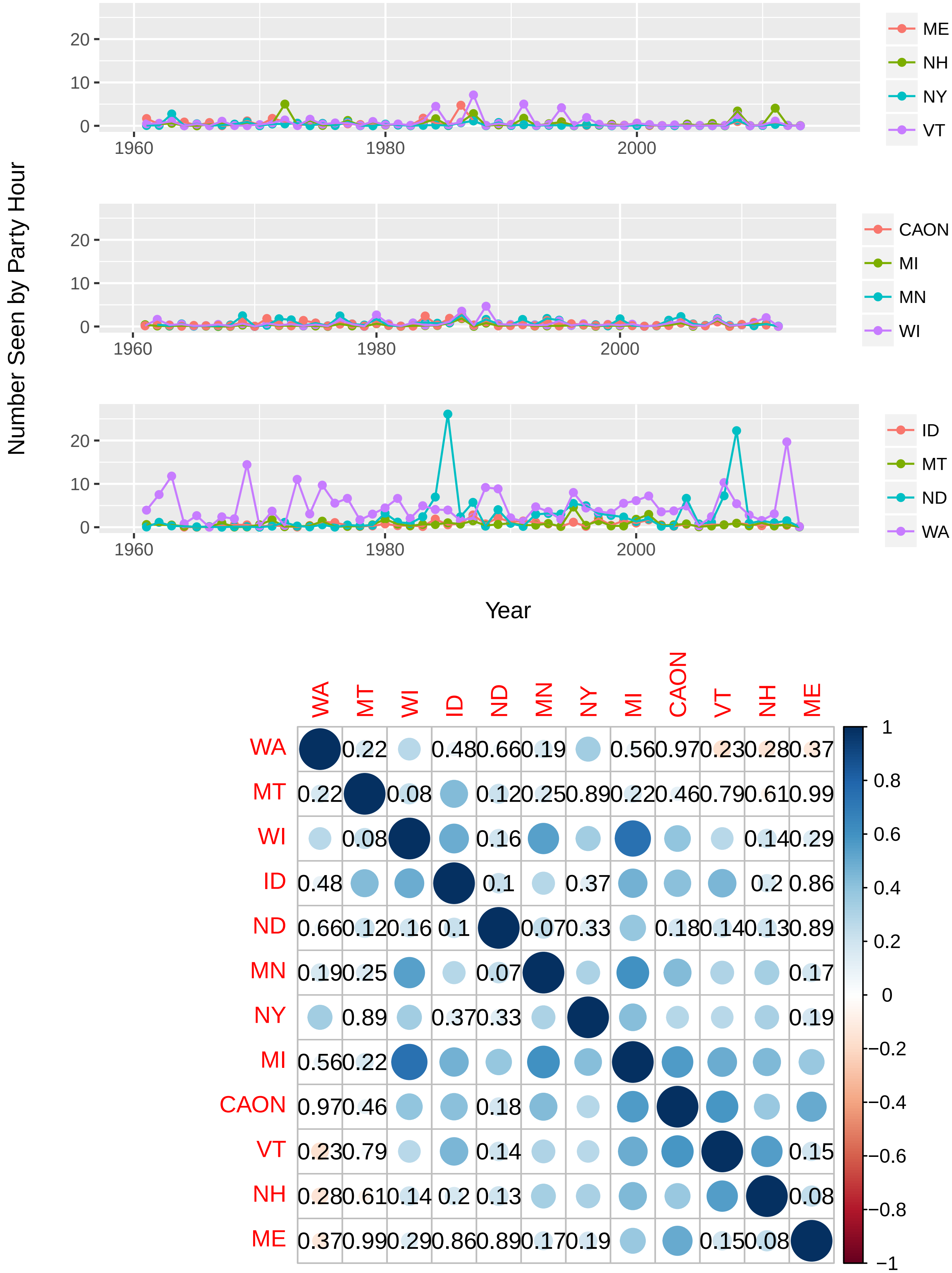


Figure 199: Pine Siskin abundance trends and area correlations across 2nd (northern US) latitudinal tier, CBC data.

Along the third latitudinal tier, CBC data show rises and falls in abundance that are mostly similarly timed in different areas. There are weak to strong positive correlations between most areas (Fig. 200).

Figure 200: Pine Siskin abundance trends and area correlations across 3rd (mid US) latitudinal tier, CBC data.

Along the southernmost latitudinal tier, CBC data show rises and falls in abundance that are mostly similarly timed in different areas. There are weak to strong positive correlations between most areas (Fig. 201).

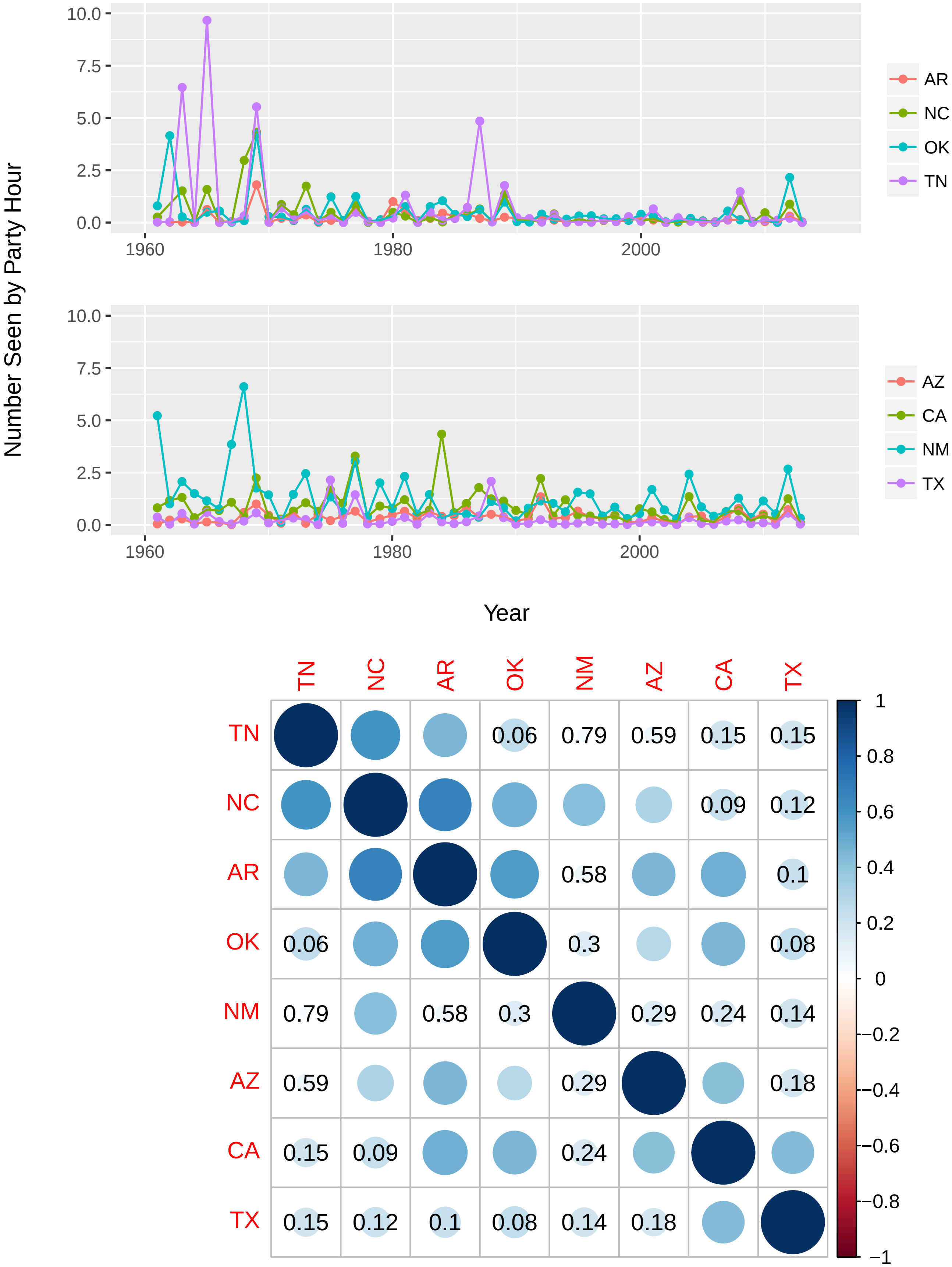


Figure 201: Pine Siskin abundance trends and area correlations across 4th (southern US) latitudinal tier, CBC data.

Along the easternmost longitudinal tier, CBC data show many rises and falls in abundance that are similarly timed in different areas, with consistently lower abundances recorded in southern areas. There are many weak to strong positive correlations between different areas (Fig. 202).

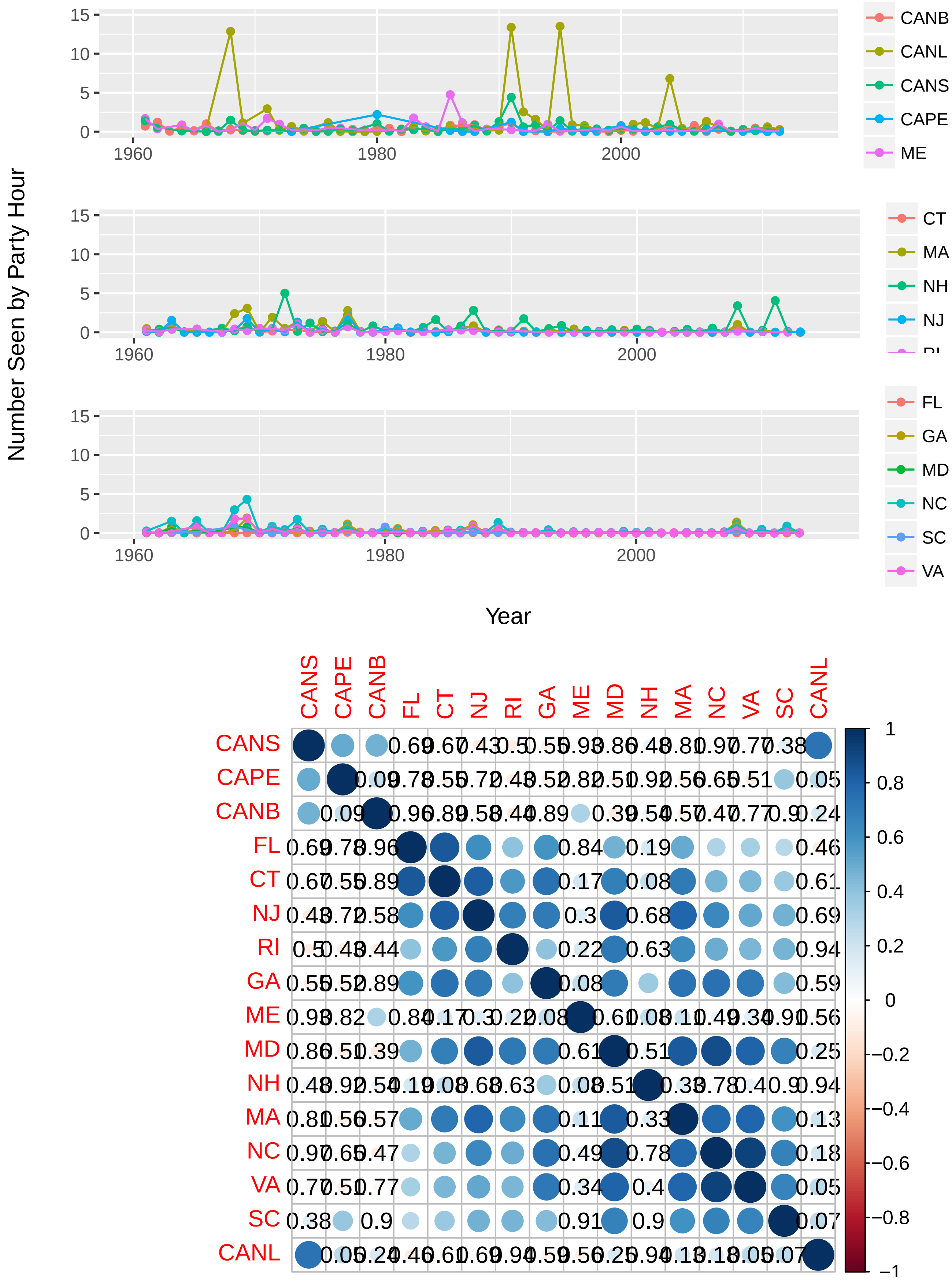


Figure 202: Pine Siskin abundance trends and area correlations across 1st (Atlantic) longitudinal tier, CBC data.

Along the second longitudinal tier, CBC data show rises and falls in abundance that are mostly similarly timed in different areas, with consistently lower abundances recorded in southern areas. There are moderate to strong positive correlations between most areas (Fig. 203).

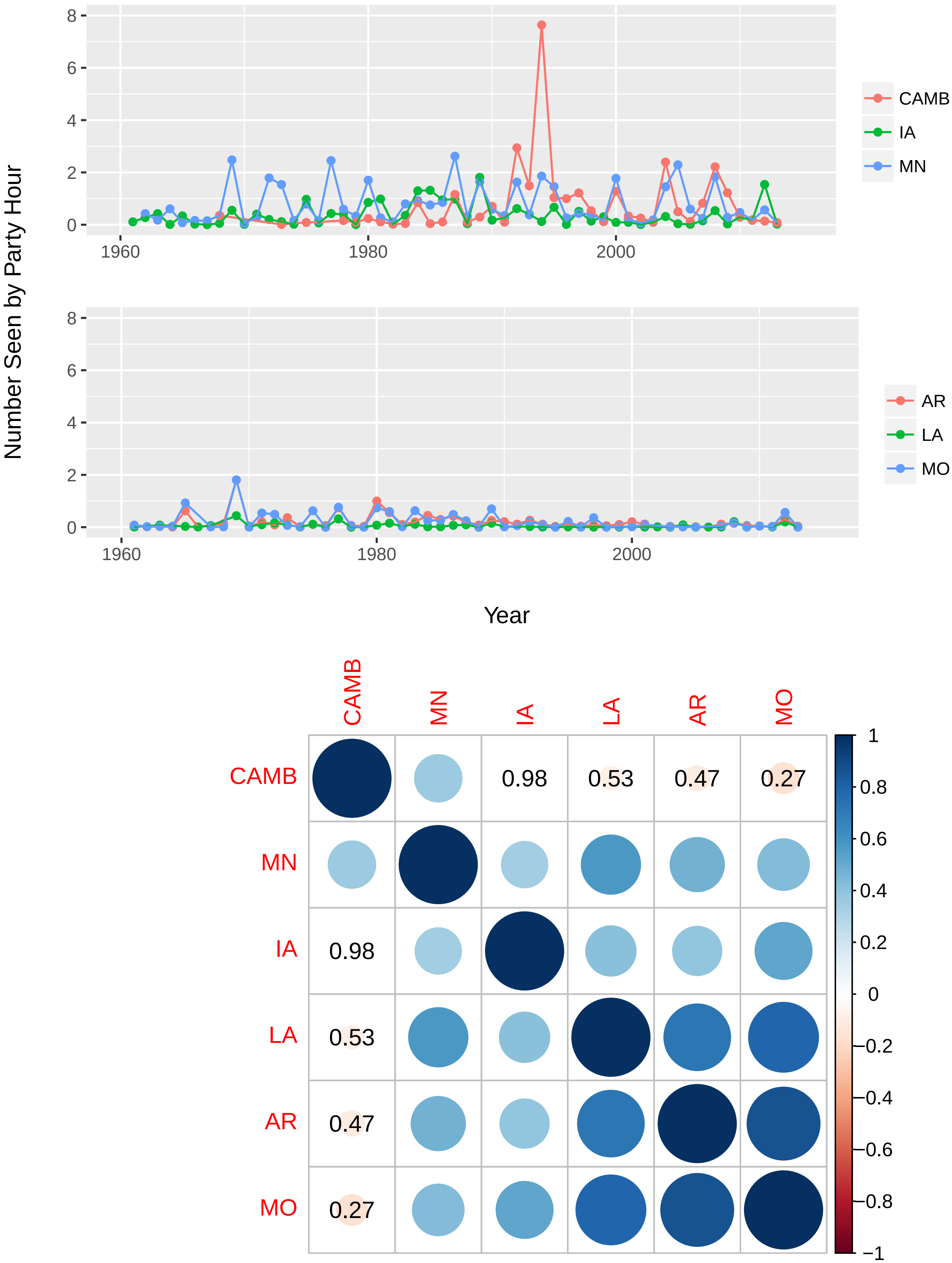


Figure 203: Pine Siskin abundance trends and area correlations across 2nd (midwest) longitudinal tier, CBC data.

Along the third longitudinal tier, CBC data show rises and falls in abundance that are mostly differently timed in different areas. There are several weak correlations between different areas, with a moderately strong positve correlation between Saskatchewan and Montana (Fig. 204).

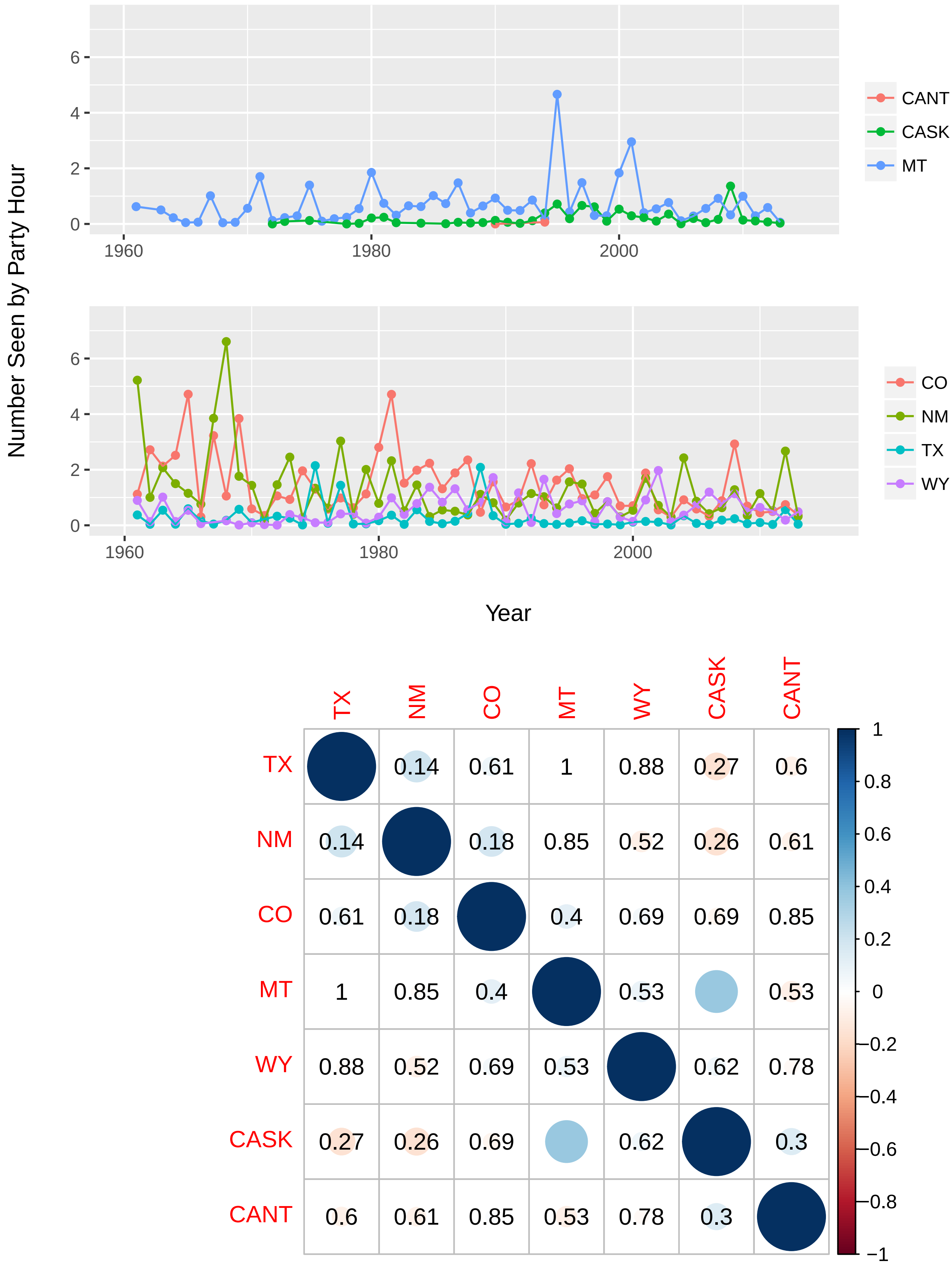


Figure 204: Pine Siskin abundance trends and area correlations across 3rd (Rocky Mountains) longitudinal tier, CBC data.

Along the westernmost longitudinal tier, CBC data show rises and falls in abundance that are similarly timed in some areas and alternating in others. There are many weak to strong positive correlations and a few weak negative correlations between different areas (Fig. 205).

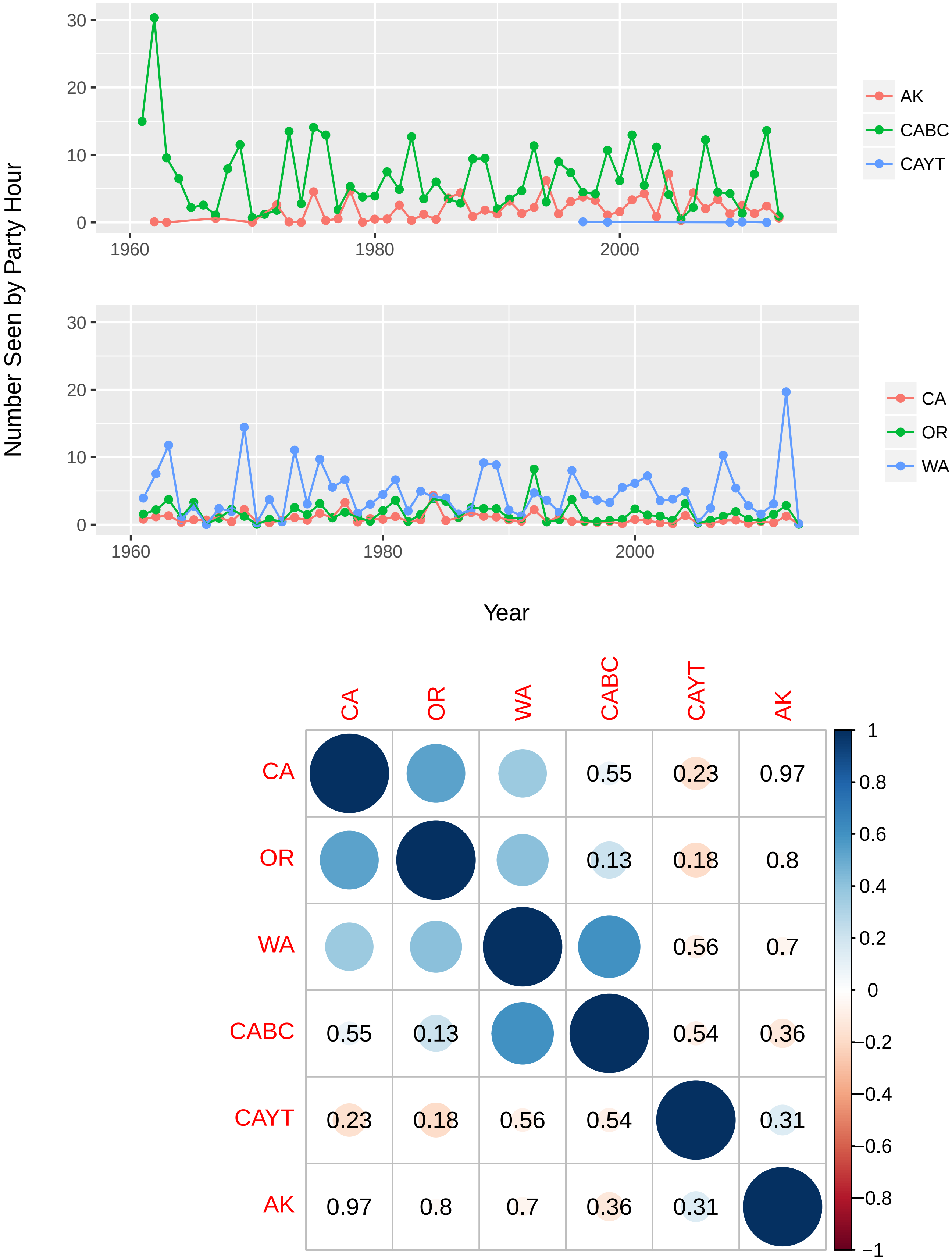


Figure 205: Pine Siskin abundance trends and area correlations across 4th (Pacific) longitudinal tier, CBC data.

eBird Analyses

Along the 1st latitudinal tier, eBird data show weak to strong positive correlations between many different areas. There are many weak to strong positive correlations and a few weak negative correlations between different years (Fig. 206).

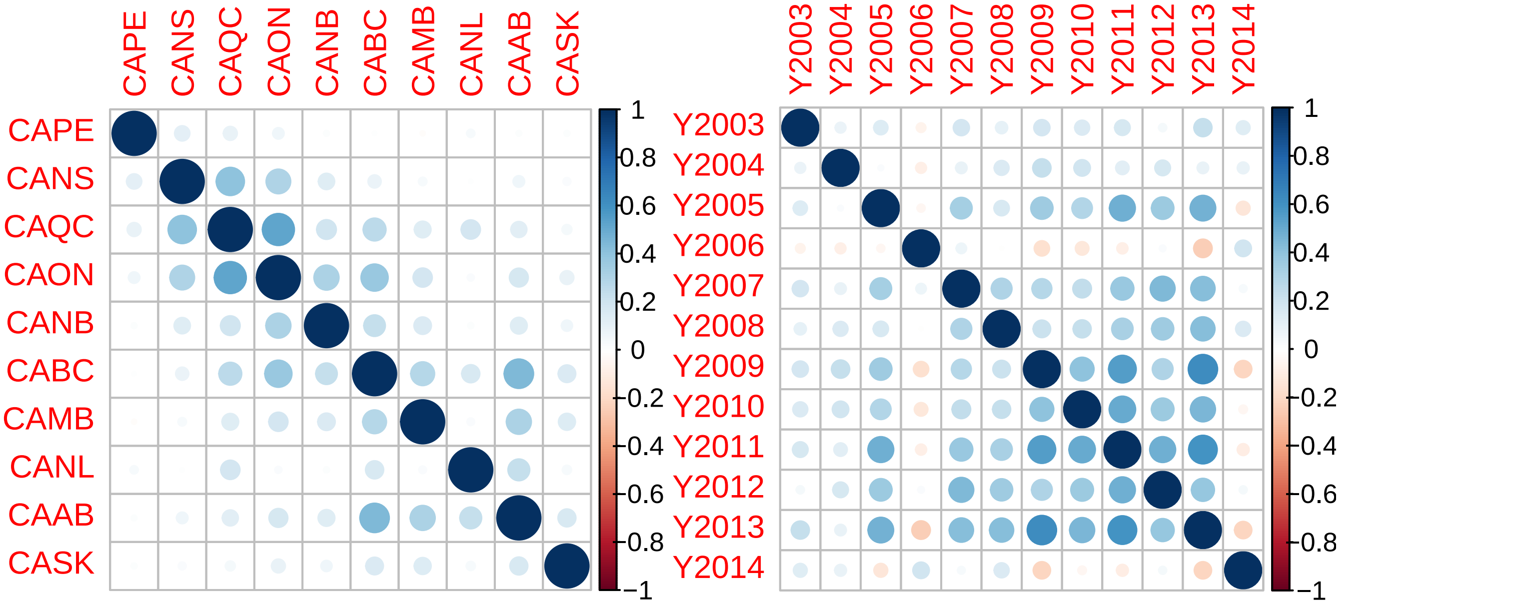


Figure 206: Correlations of Pine Siskin invasion pattern between individual areas and between years for the 1st (Canadian) latitudinal tier, eBird data.

Along the second latitudinal tier, eBird data show weak to strong positive correlations between most different areas. Lesser Goldfinch records in different years show weak to strong positive and negative correlations with each other (Fig. 207).

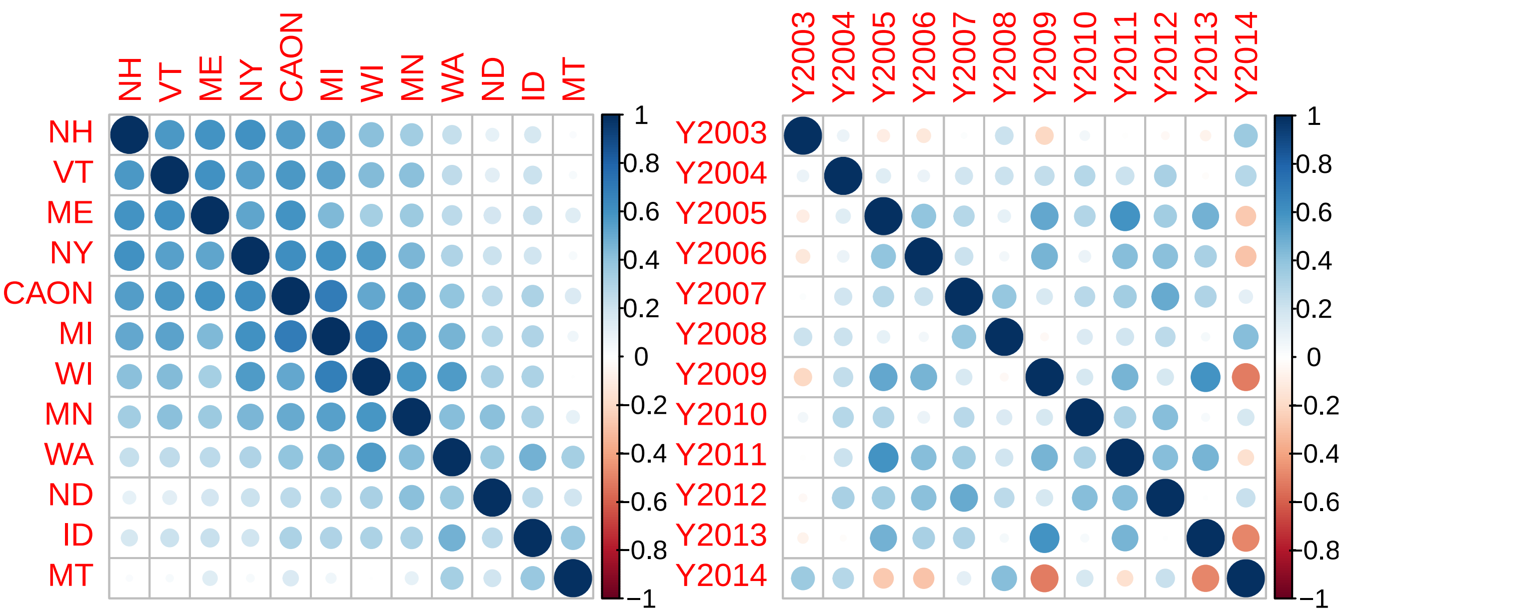


Figure 207: Correlations of Pine Siskin invasion pattern between individual areas and between years for the 2nd (northern US) latitudinal tier, eBird data.

Along the third latitudinal tier, eBird data show weak to strong positive correlations between most different areas. Recent years alternate between weak to strong positive correlations and weak to moderate negative correlations between years (Fig. 208).

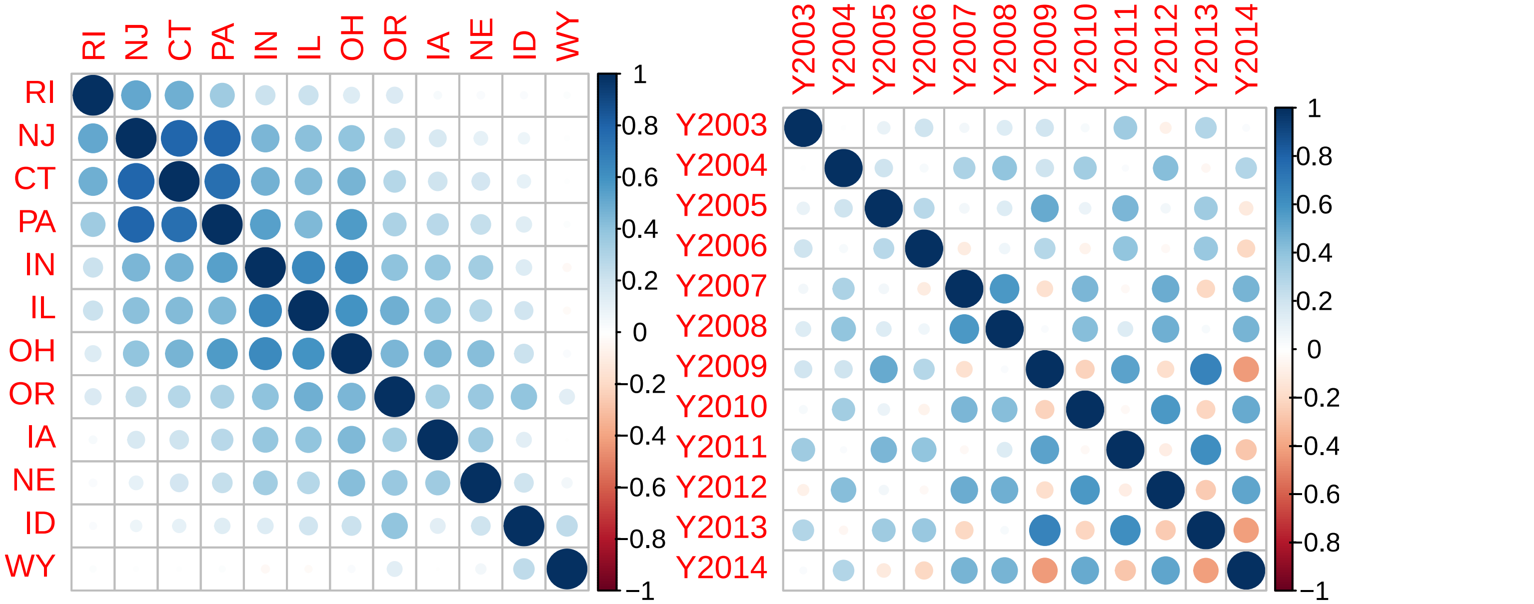


Figure 208: Correlations of Pine Siskin invasion pattern between individual areas and between years for the 3rd (mid US) latitudinal tier, eBird data.

Along the southernmost latitudinal tier, eBird data show weak to strong positive correlations between all different areas. Recent years alternate between weak to strong positive correlations and weak to moderate negative correlations between years (Fig. 209).

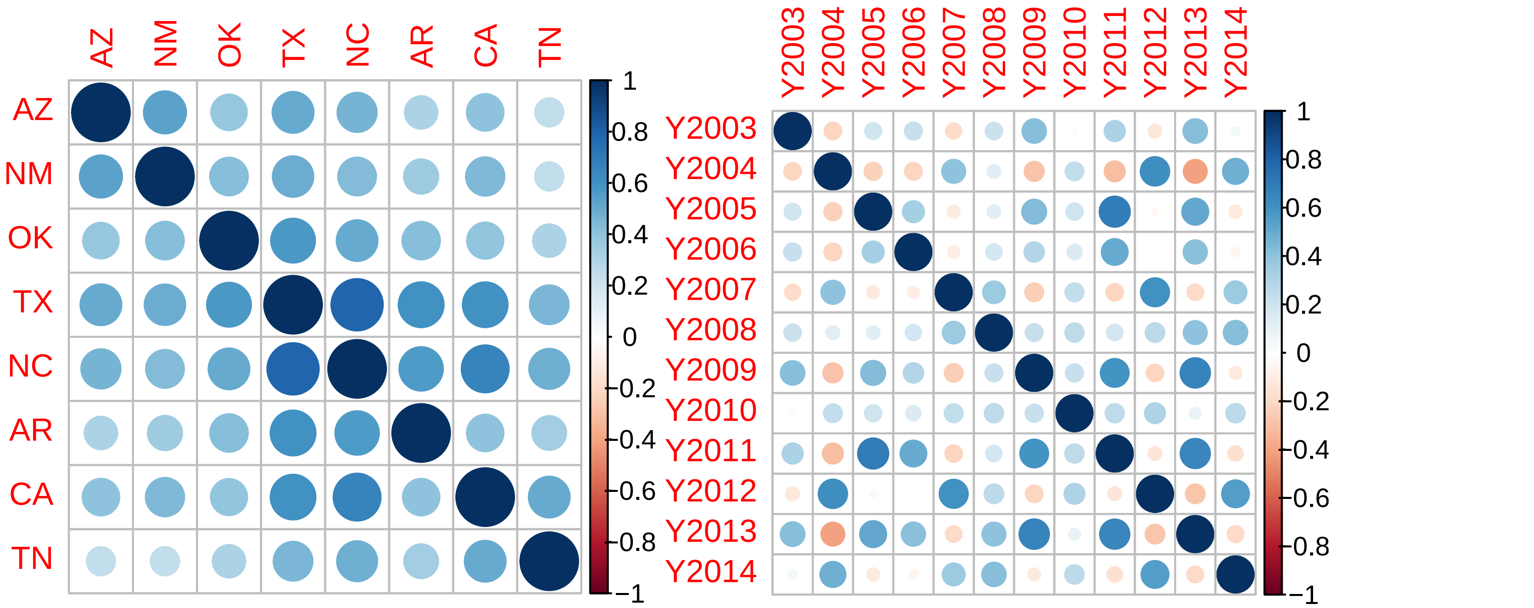


Figure 209: Correlations of Pine Siskin invasion pattern between individual areas and between years for the 4th (southern US) latitudinal tier, eBird data.

Along the easternmost longitudinal tier, eBird data show weak to strong positive correlations between many different areas, especially those in the middle of the longitude. Recent years alternate between strong positive correlations and weak to moderate negative correlations between years (Fig. 210).

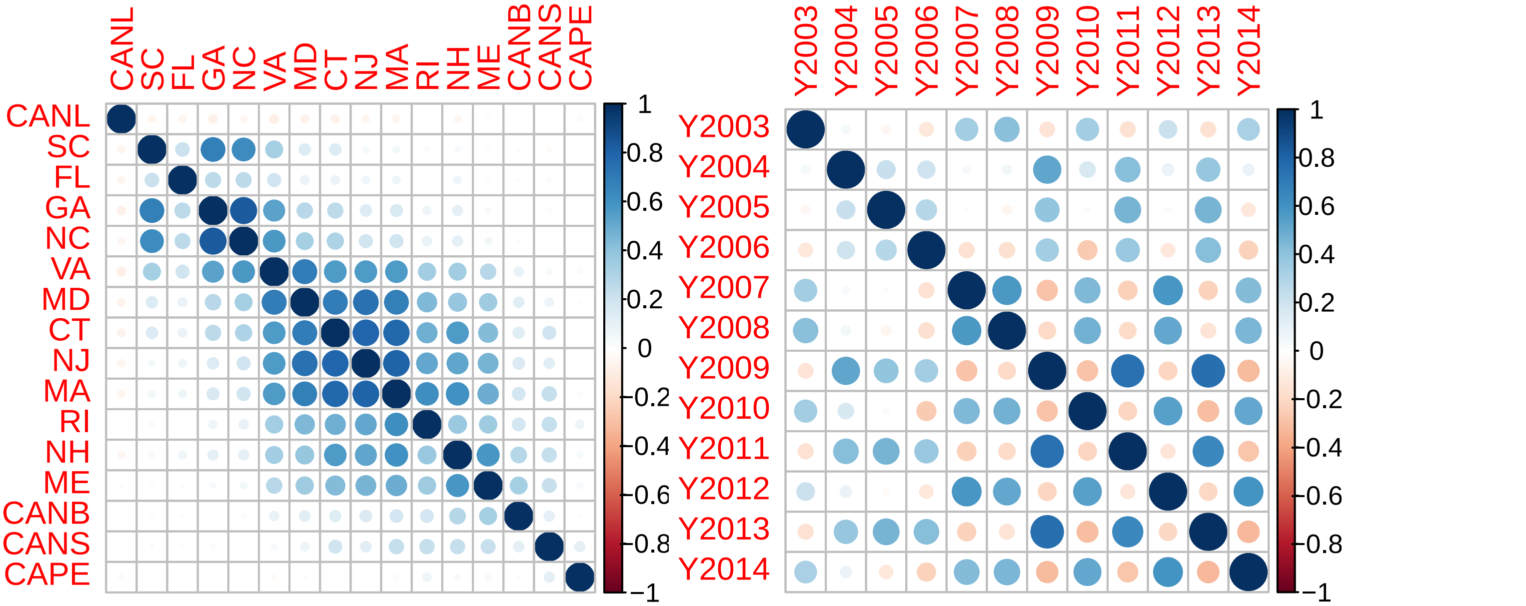


Figure 210: Correlations of Pine Siskin invasion pattern between individual areas and between years for the 1st (Atlantic) longitudinal tier, eBird data.

Along the 2nd longitudinal tier, eBird data show weak to strong positive correlations between most different areas, and mostly weak to strong positive correlations between years. There is some alternation in strong positive correlations between years (Fig. 211).

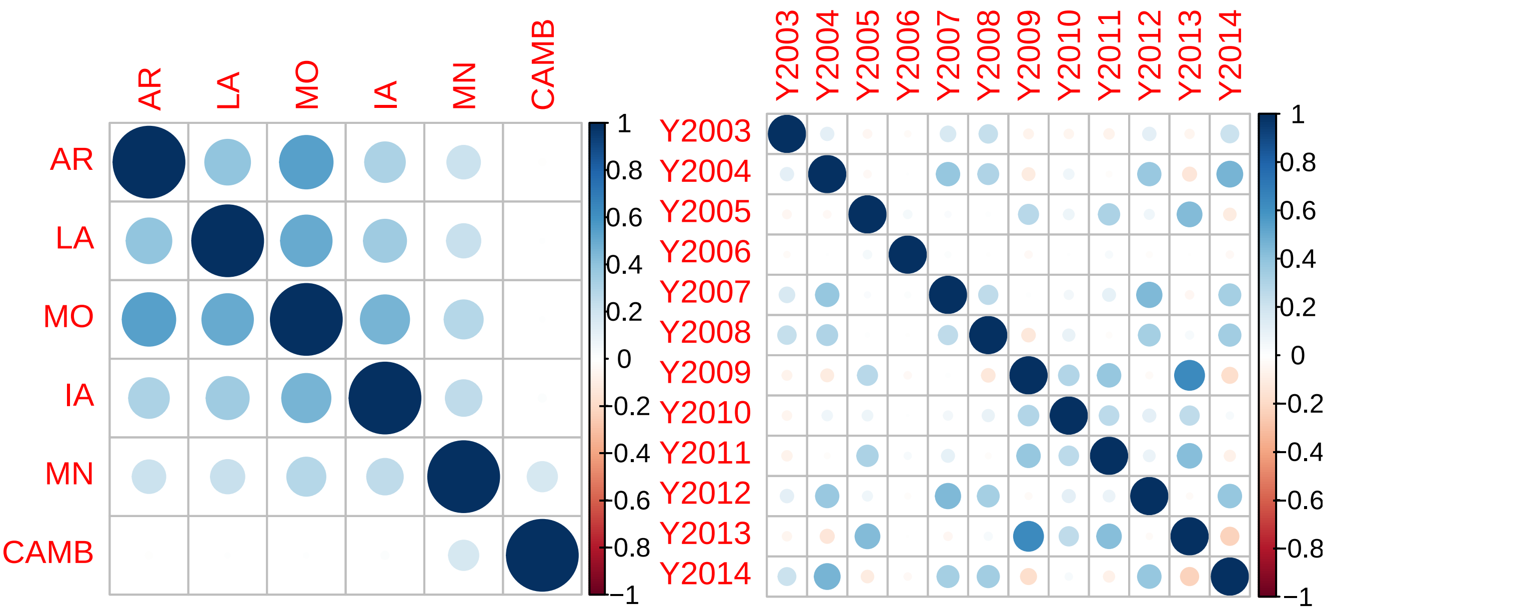


Figure 211: Correlations of Pine Siskin invasion pattern between individual areas and between years for the 2nd (midwest) longitudinal tier, eBird data.

Along the 3rd longitudinal tier, eBird data show weak to strong positive correlations between many different areas, and weak to strong positive and negative correlations between years. There is some alternation in positive and negative correlations between years (Fig. 212).

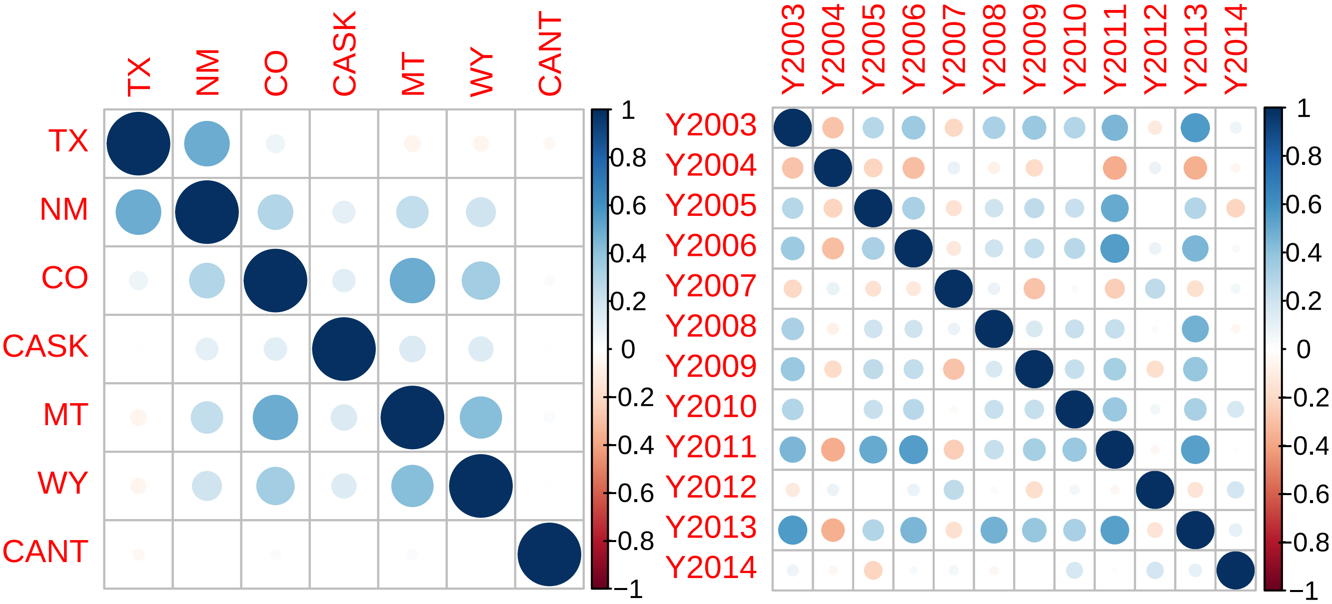


Figure 212: Correlations of Pine Siskin invasion pattern between individual areas and between years for the 3rd (Rocky Mountains) longitudinal tier, eBird data.

Along the westernmost longitudinal tier, eBird data show mostly strong positive correlations between different areas, and some alternation in positive and negative correlations between years (Fig. 213).

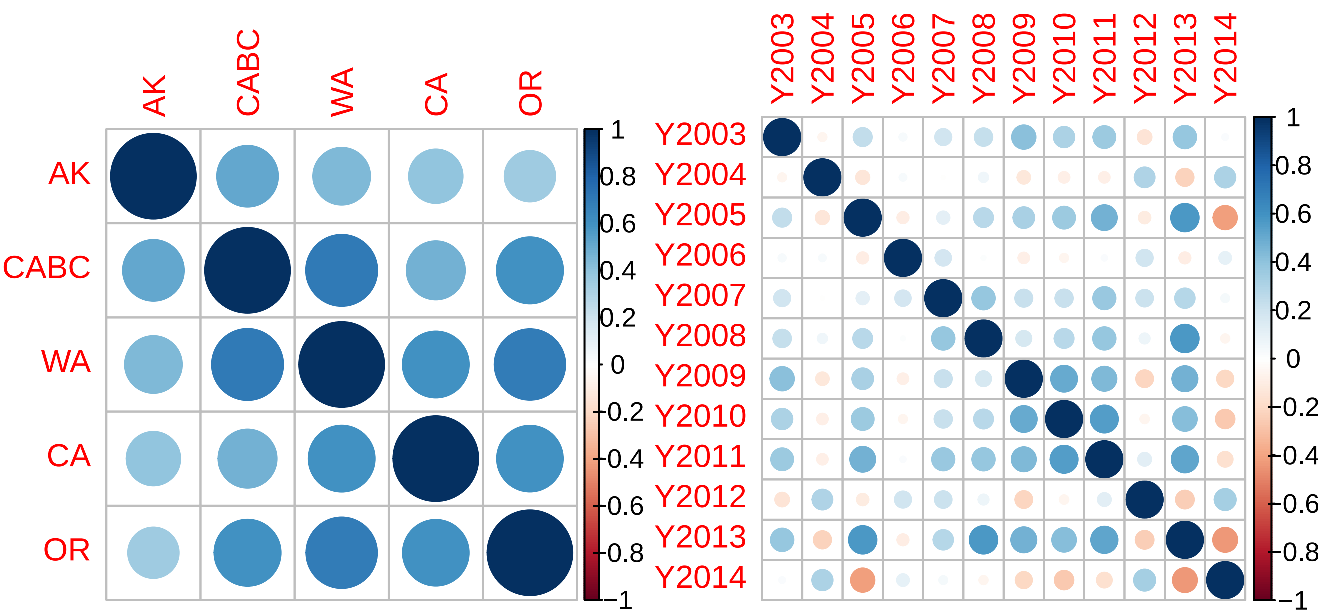


Figure 213: Correlations of Pine Siskin invasion pattern between individual areas and between years for the 4th (Pacific) longitudinal tier, eBird data.

Interspecies Comparisons

CBC Analyses

Along the northernmost latitudinal tier, CBC data show weak to strong positive correlations and weak negative correlations between most species. Due to lack of CBC records, I removed the Lesser Goldfinch from analyses (Fig. 214).

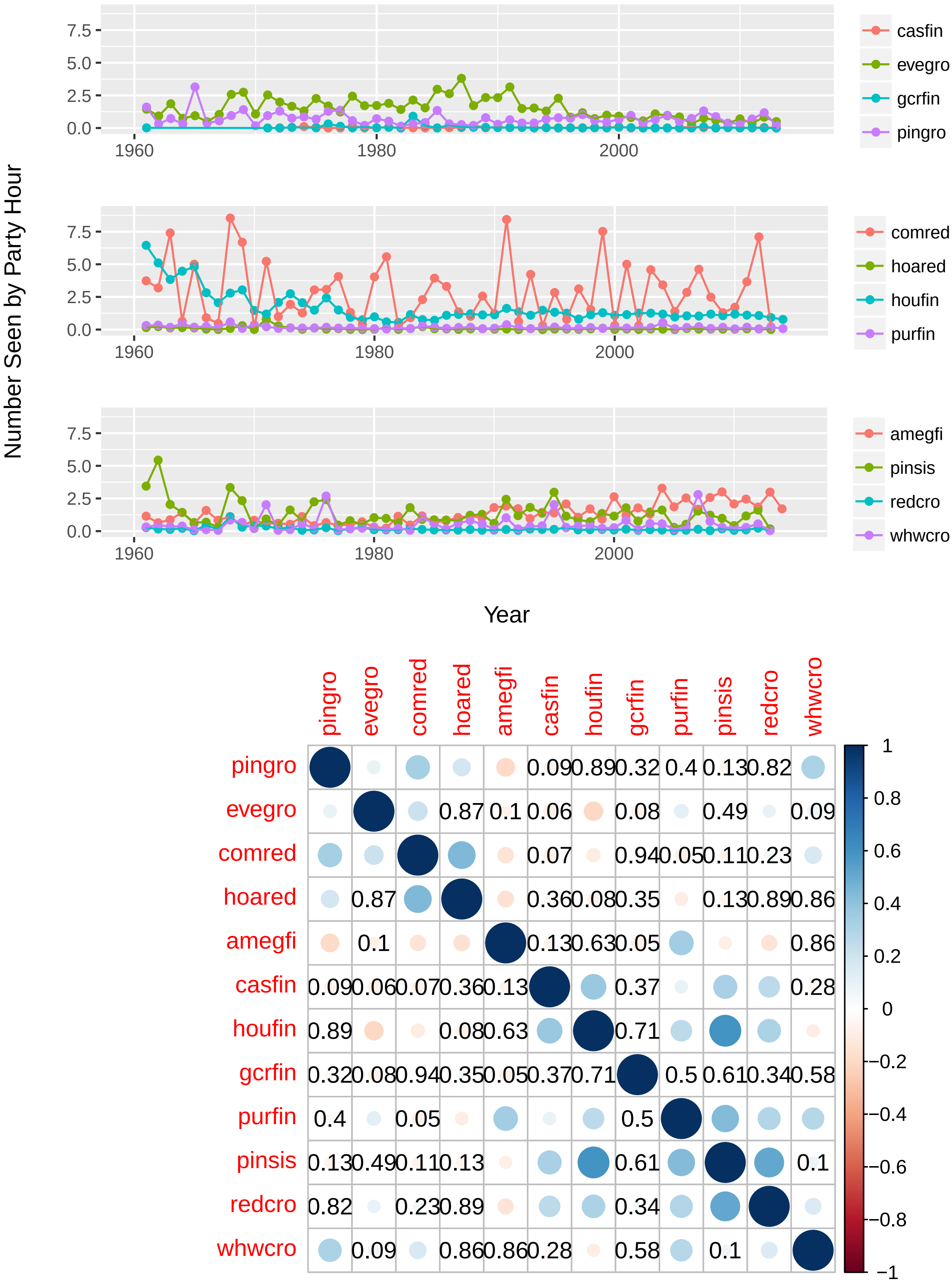


Figure 214: Species abundance trends and correlations across 1st (Canadian) latitudinal tier, CBC data.

Along the second latitudinal tier, CBC data show weak to moderate positive and negative correlations between most species (Fig. 215).

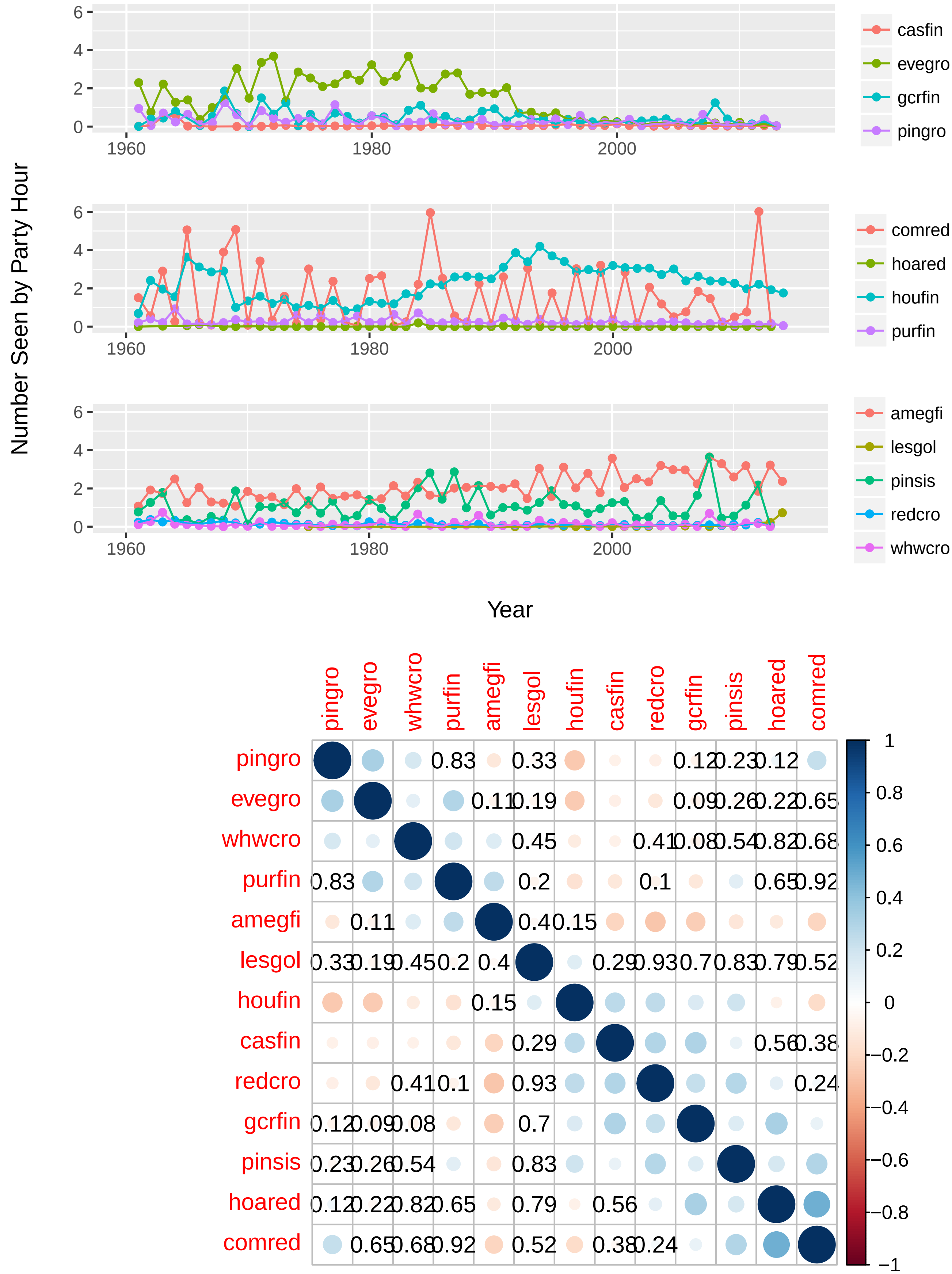


Figure 215: Species abundance trends and correlations across 2nd (Northern US) latitudinal tier, CBC data.

Along the third latitudinal tier, CBC data show weak to strong positive and negative correlations between most species (Fig. 216).

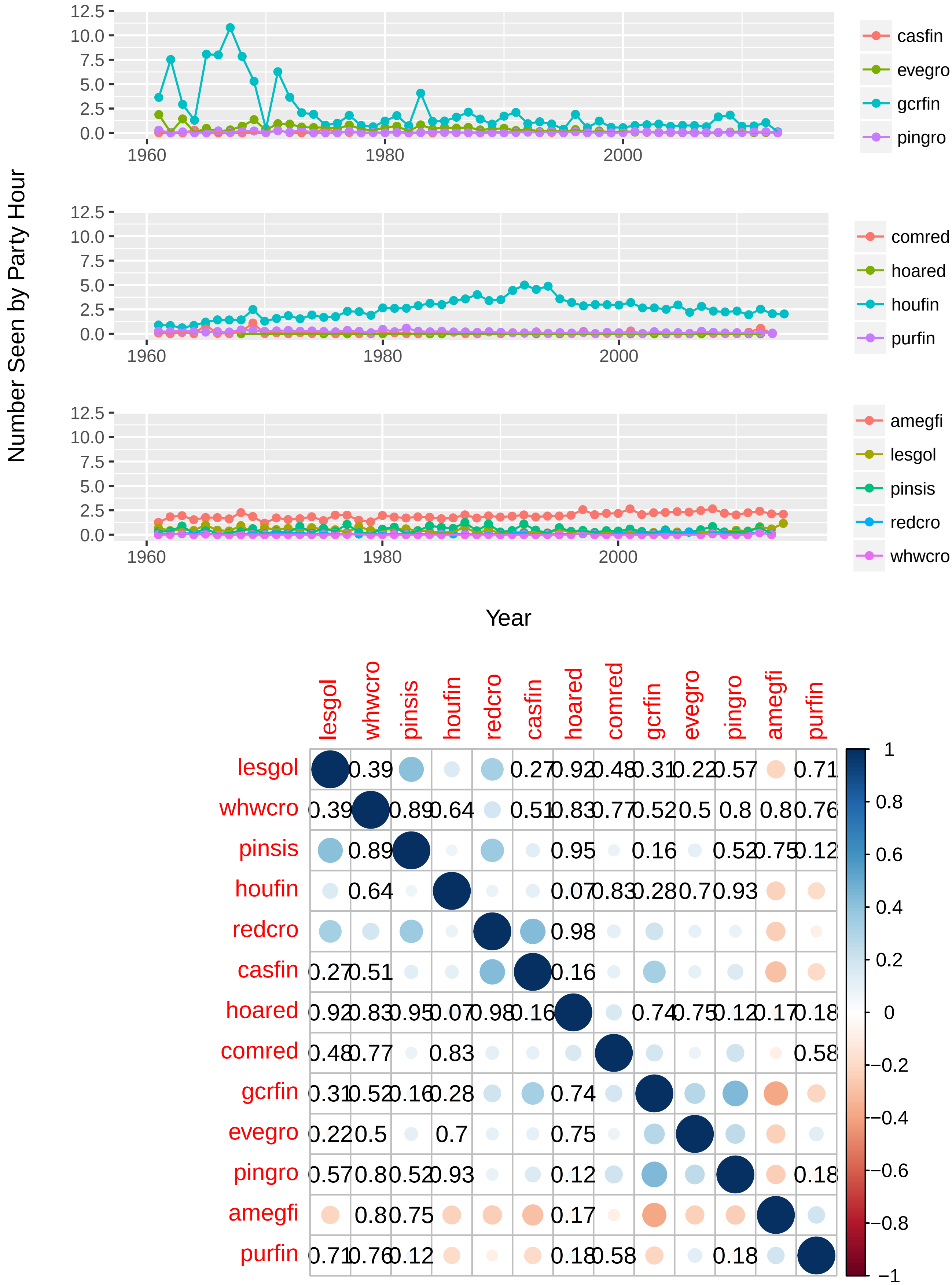


Figure 216: Species abundance trends and correlations across 3rd (Mid US) latitudinal tier, CBC data.

Along the southernmost latitudinal tier, CBC data show weak to strong positive and negative correlations between most species. Due to lack of CBC records in ths latitude, I removed the Hoary Redpoll from analyses (Fig. 217).

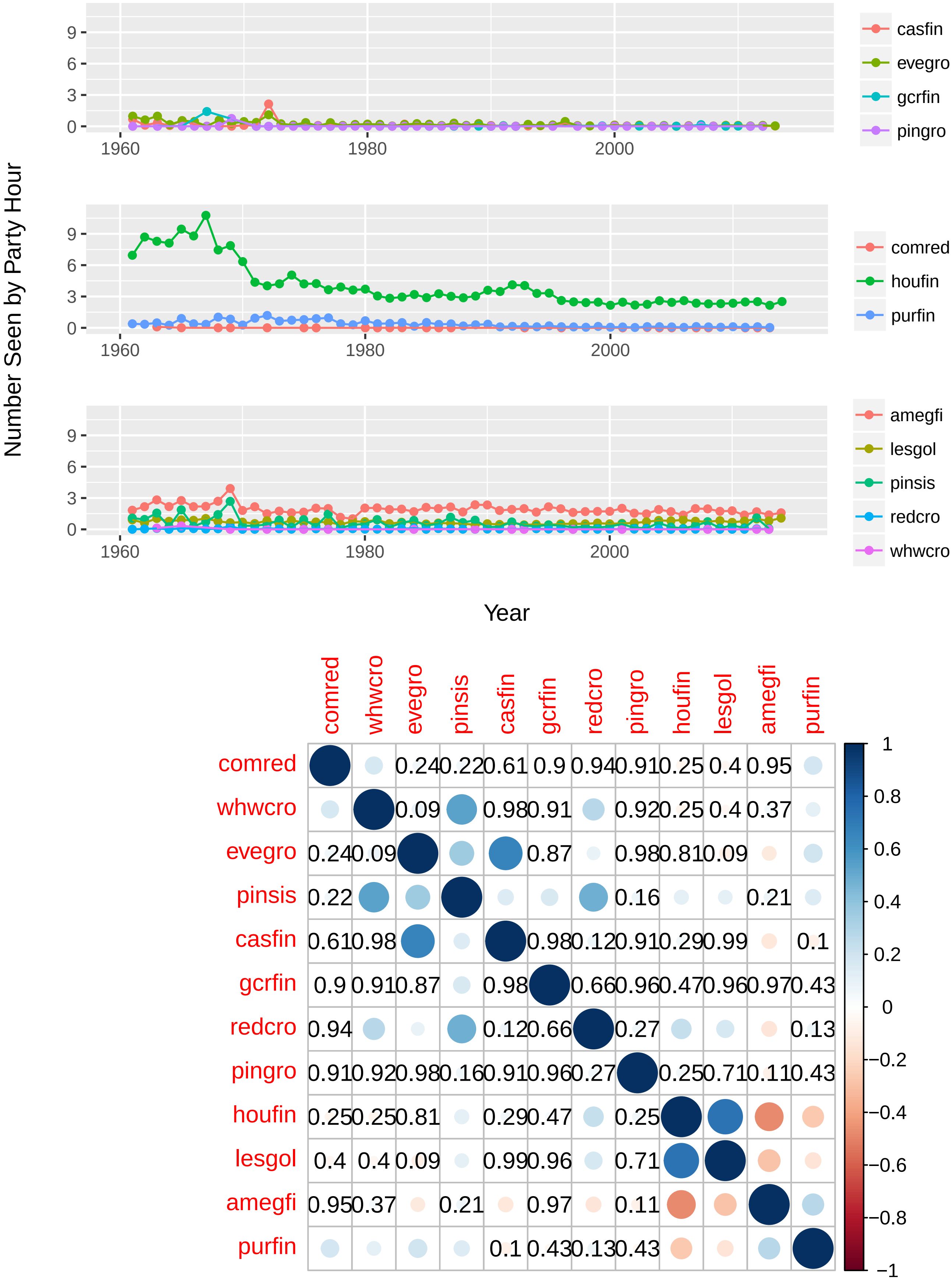


Figure 217: Species abundance trends and correlations across 4th (Southern US) latitudinal tier, CBC data.

Along the easternmost longitudinal tier, CBC data show weak to strong positive correlations and several weak negative correlations between most species (Fig. 218).

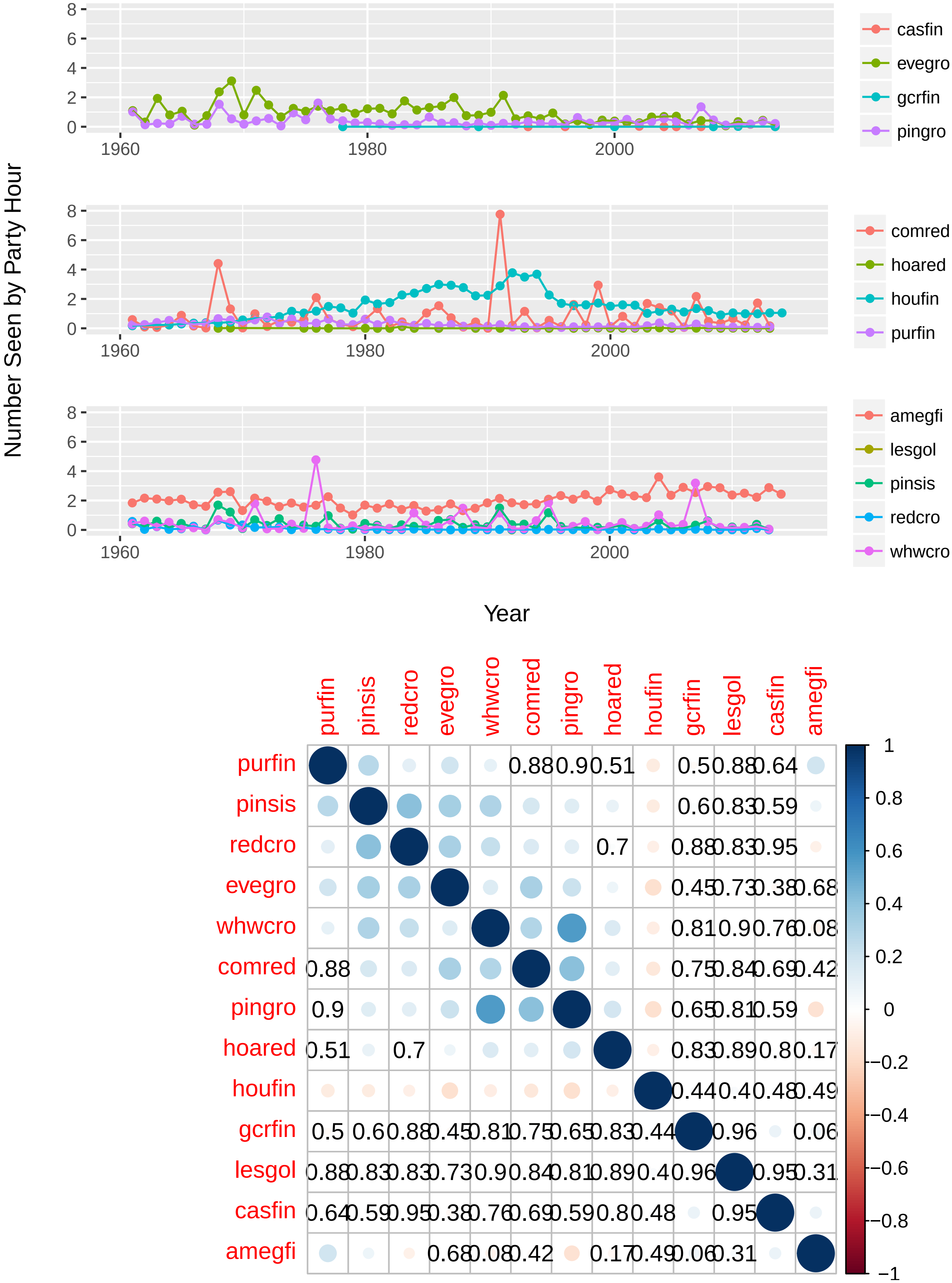


Figure 218: Species abundance trends and correlations across 1st (Atlantic) longitudinal tier, CBC data.

Along the second longitudinal tier, CBC data show weak to strong positive and negative correlations between most species, with strong negative correlations between the American Goldfinch and the Hoary Redpoll, Common Redpoll, Evening Grosbeak, Pine Grosbeak, and White-winged Crossbill (Fig. 219).

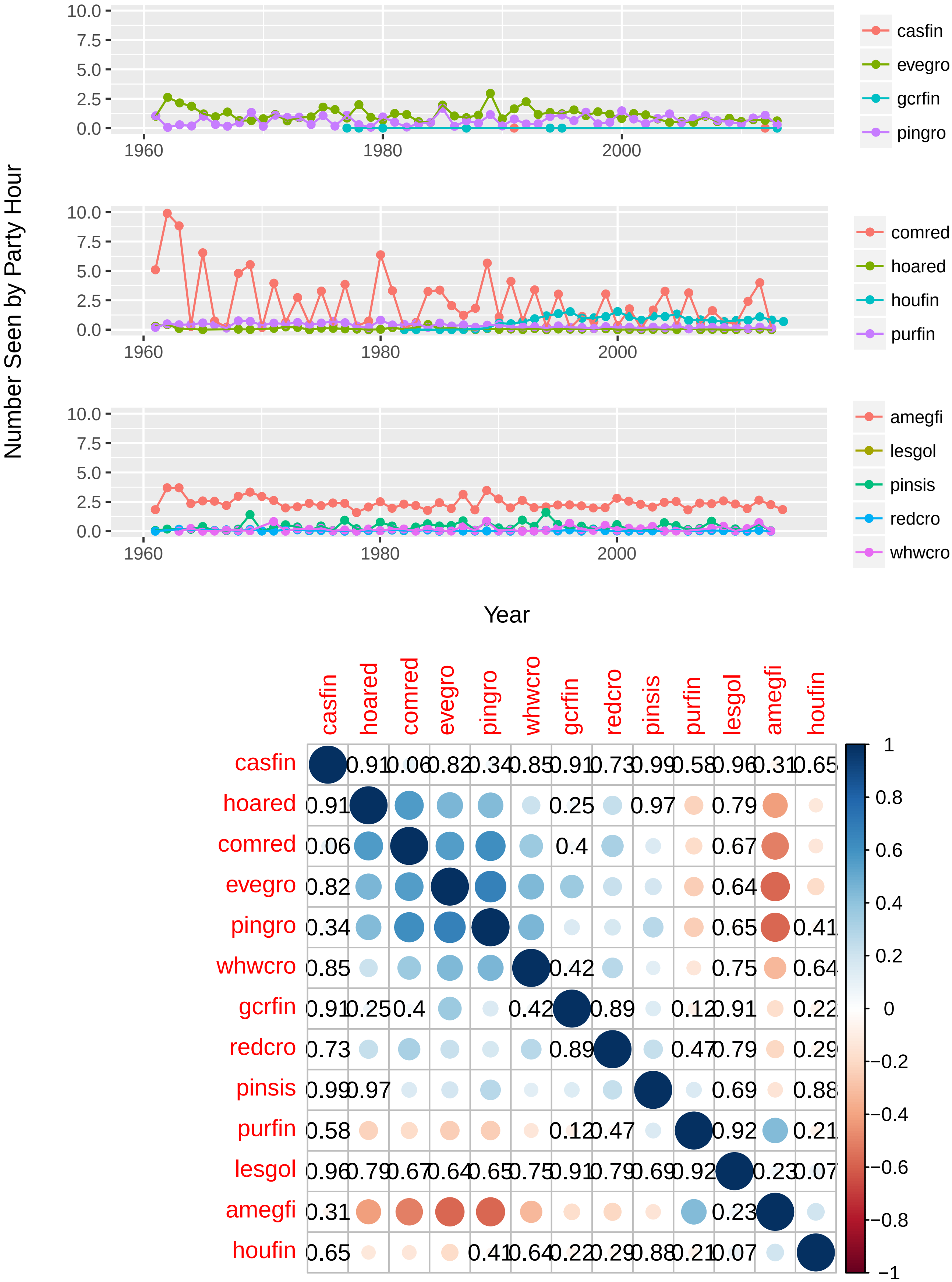


Figure 219: Species abundance trends and correlations across 2nd (Midwest) longitudinal tier, CBC data.

Along the third longitudinal tier, CBC data show weak to strong positive and negative correlations between most species (Fig. 220).

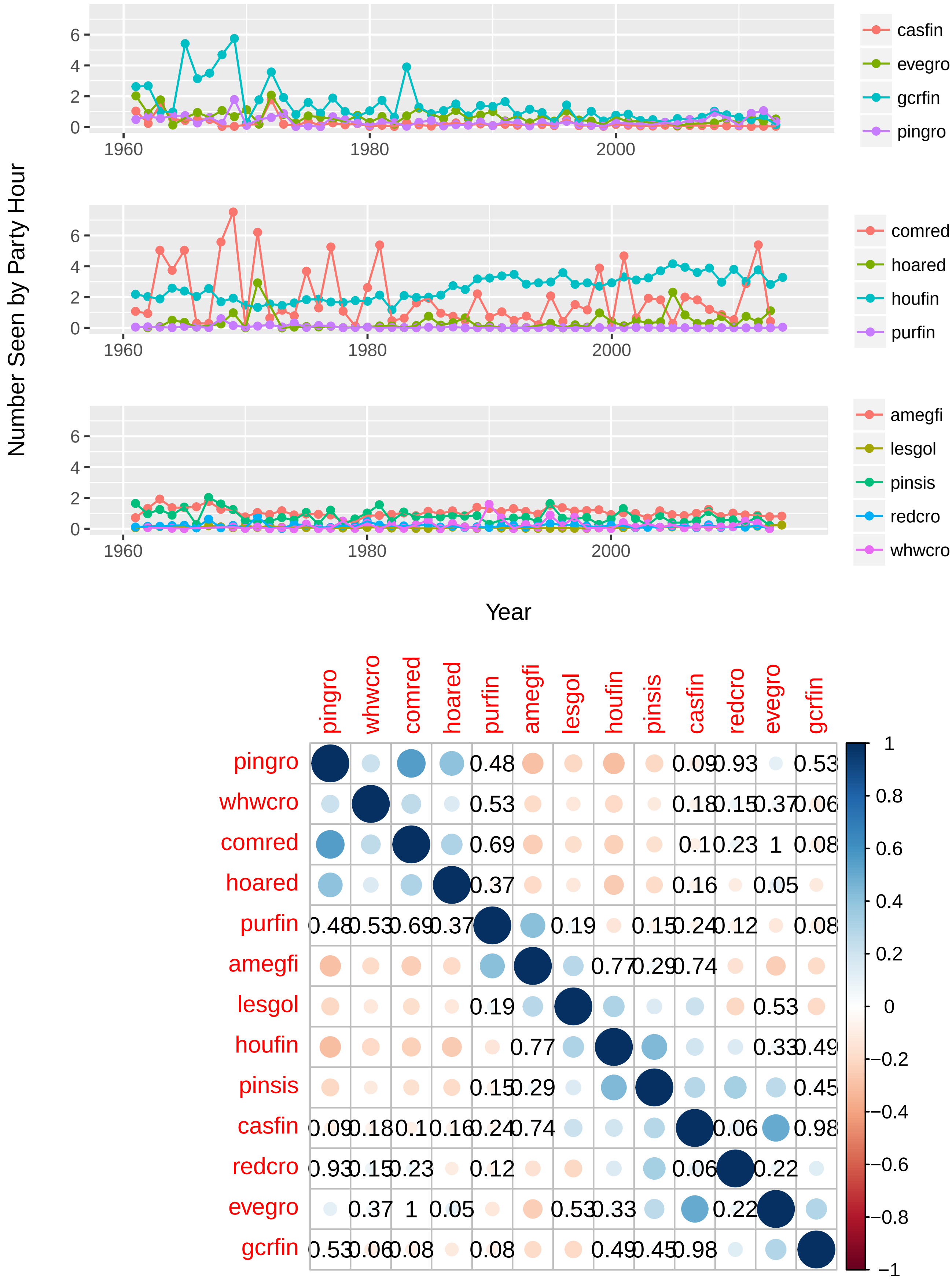


Figure 220: Species abundance trends and correlations across 3rd (Rocky Mountain) longitudinal tier, CBC data.

Along the westernmost longitudinal tier, CBC data show weak to strong positive and negative correlations between most species (Fig. 221).

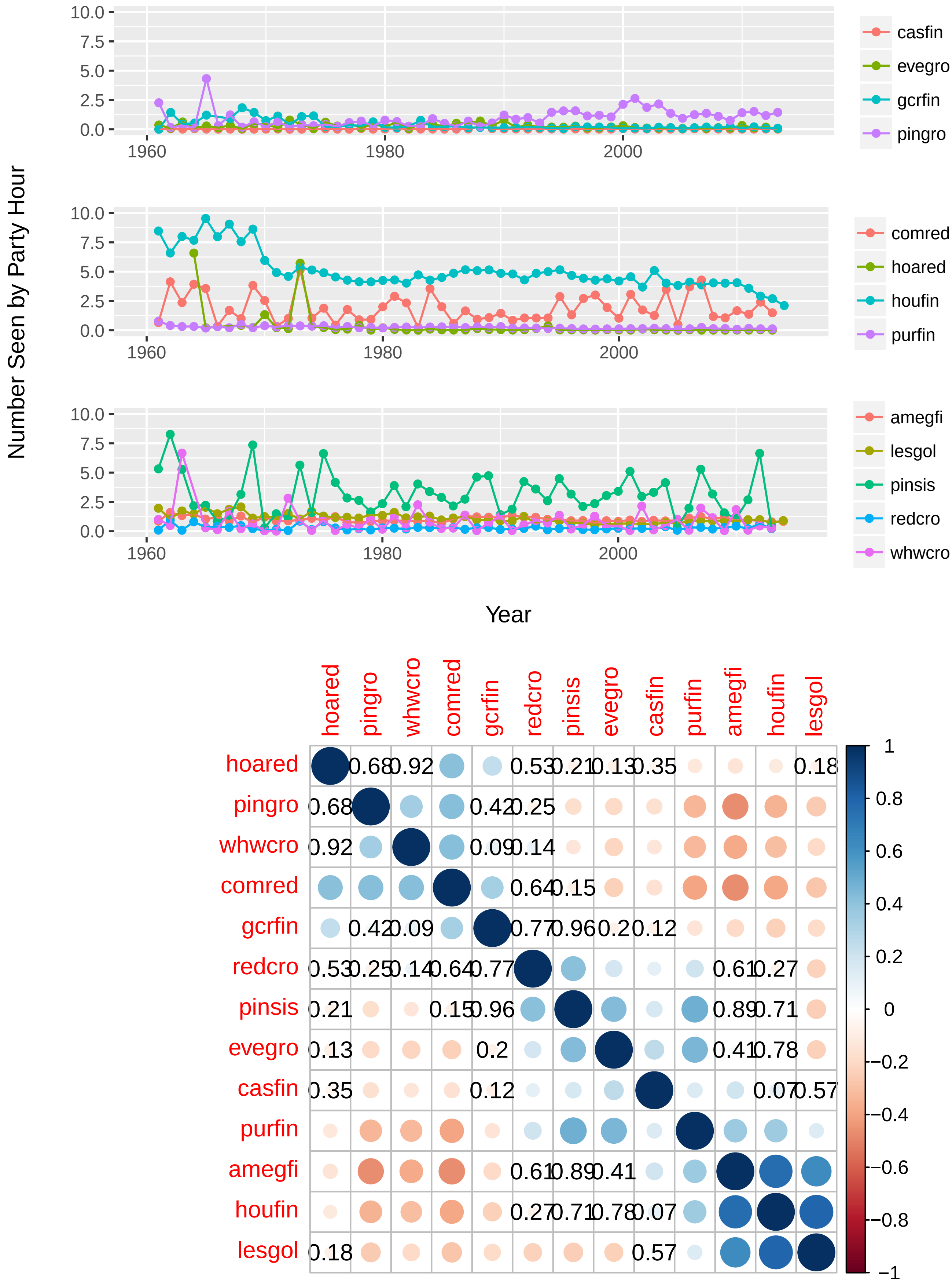


Figure 221: Species abundance trends and correlations across 4th (Pacific) longitudinal tier, CBC data.

eBird Analyses

Along the northernmost latitudinal tier, eBird data show weak to strong positive correlations between most species (Fig. 222).

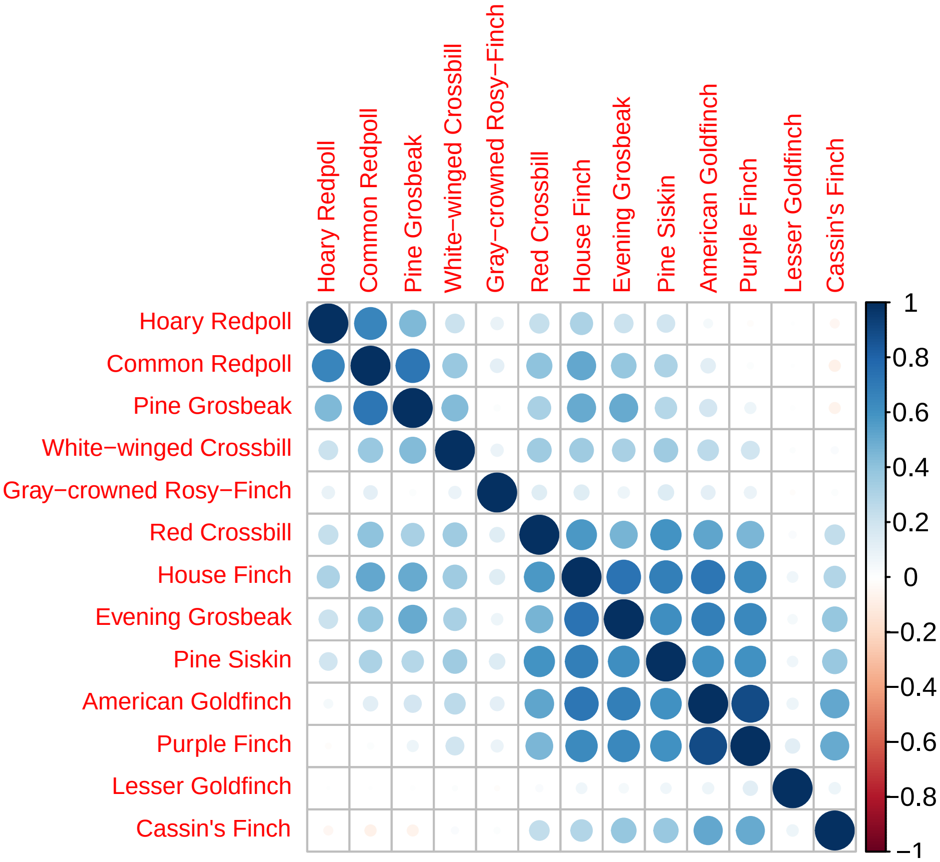


Figure 222: Correlations of daily abundance trends between species in the 1st (Canadian) latitudinal tier, eBird data.

Along the second latitudinal tier, eBird data show weak to strong positive correlations between most species (Fig. 223).

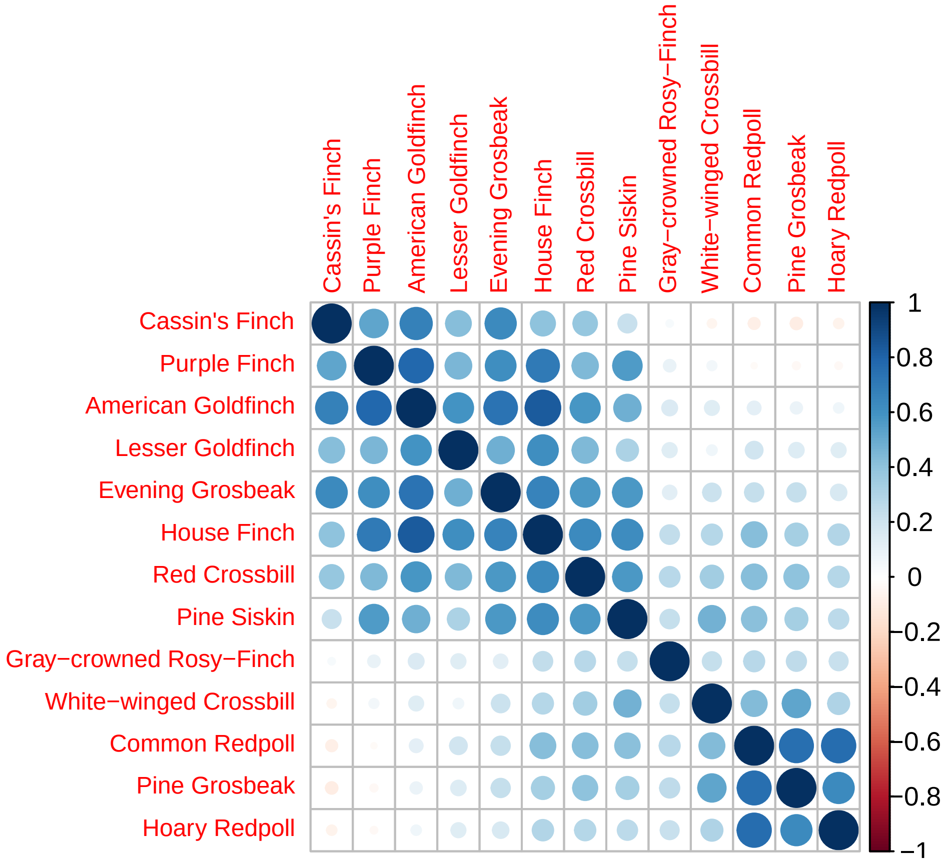


Figure 223: Correlations of daily abundance trends between species in the 2nd (Northern US) latitudinal tier, eBird data.

Along the third latitudinal tier, eBird data show weak to strong positive correlations between most species, with the strongest correlation between the Purple Finch and the Pine Siskin (Fig. 224).

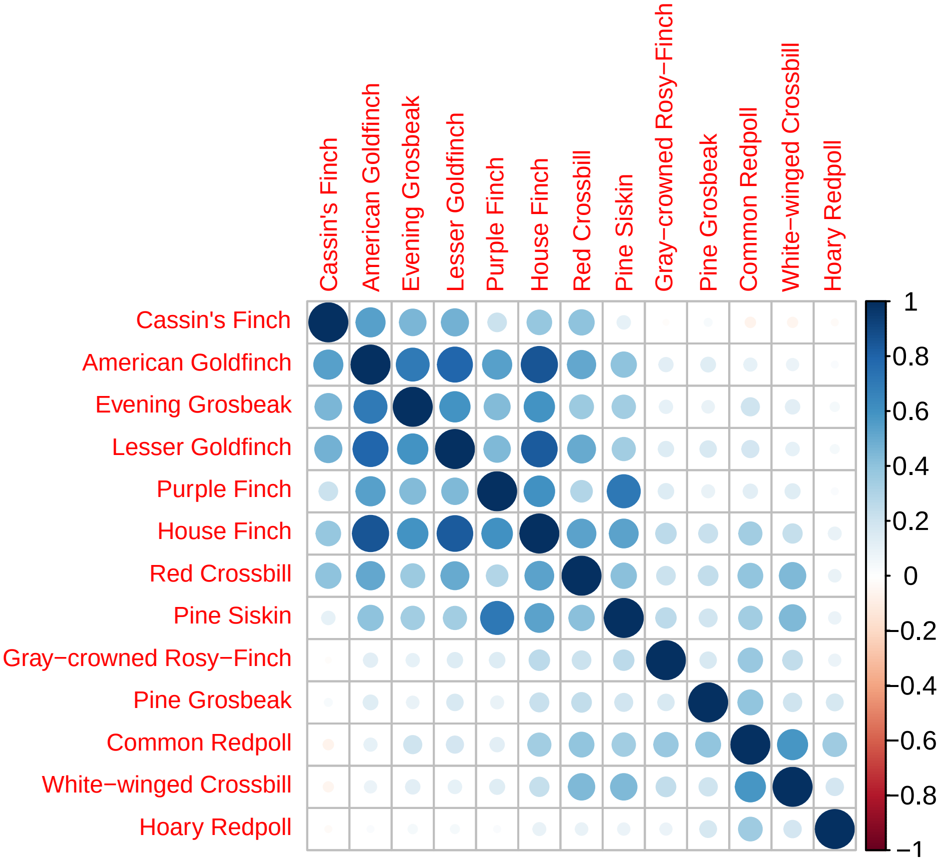


Figure 224: Correlations of daily abundance trends between species in the 3rd (Mid US) latitudinal tier, eBird data.

Along the southernmost latitudinal tier, eBird data show weak to strong positive correlations between most species, with the strongest correlations between the Purple Finch, Evening Grosbeak, Pine Siskin, Lesser Goldfinch, Red Crossbill, and Cassin's Finch (Fig. 225).

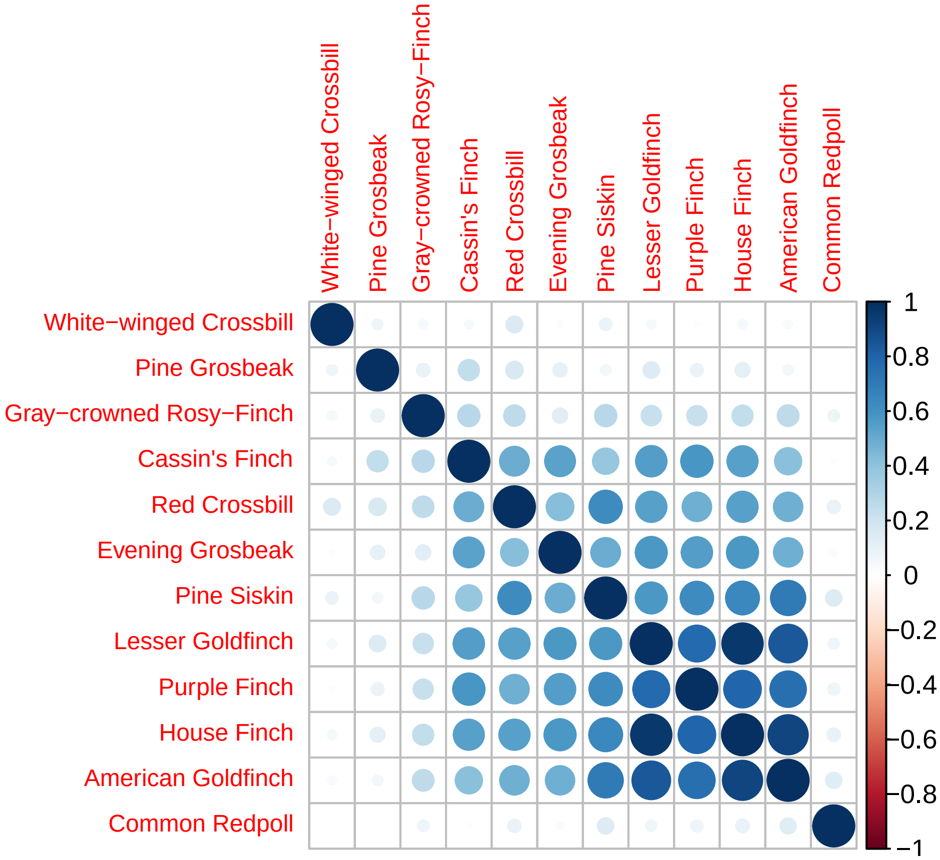


Figure 225: Correlations of daily abundance trends between species in the 4th (Southern US) latitudinal tier, eBird data.

Along the easternmost longitudinal tier, eBird data show weak to strong positive correlations between most species, with the strongest correlations between the Purple Finch and the Pine Grosbeak, and between the Common Redpoll, the Pine Grosbeak, and the two crossbill species an (Fig. 226).

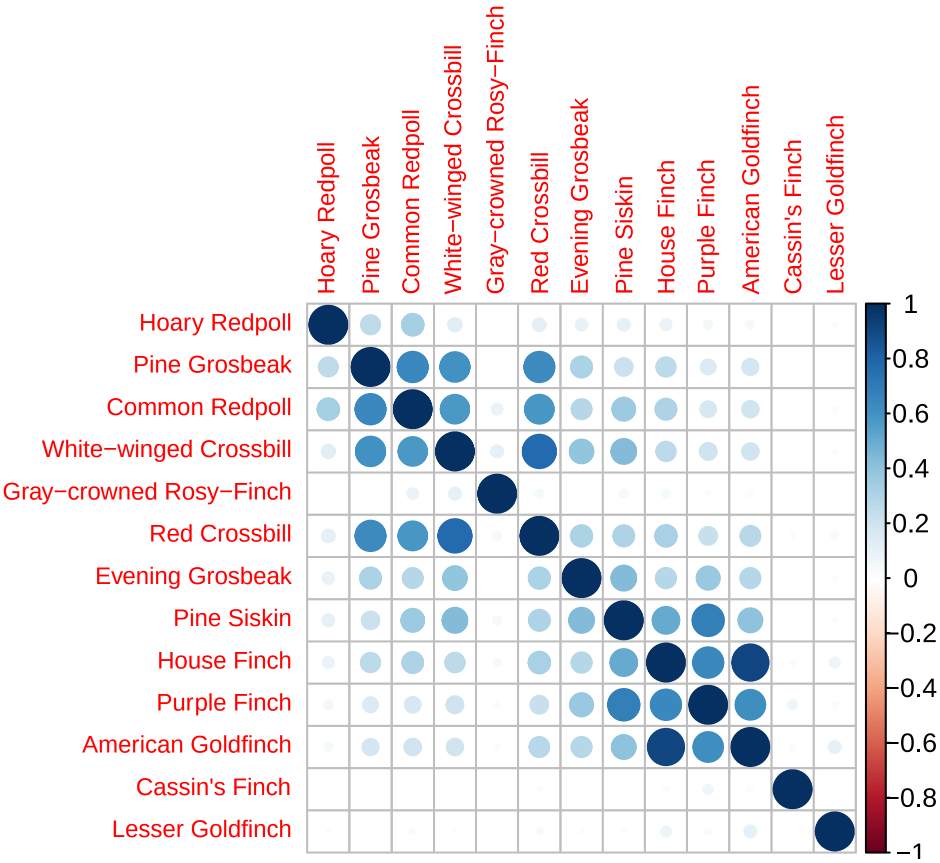


Figure 226: Correlations of daily abundance trends between species in the 1st (Atlantic) longitudinal tier, eBird data.

Along the second longitudinal tier, eBird data show weak to strong positive correlations between most species (Fig. 227).

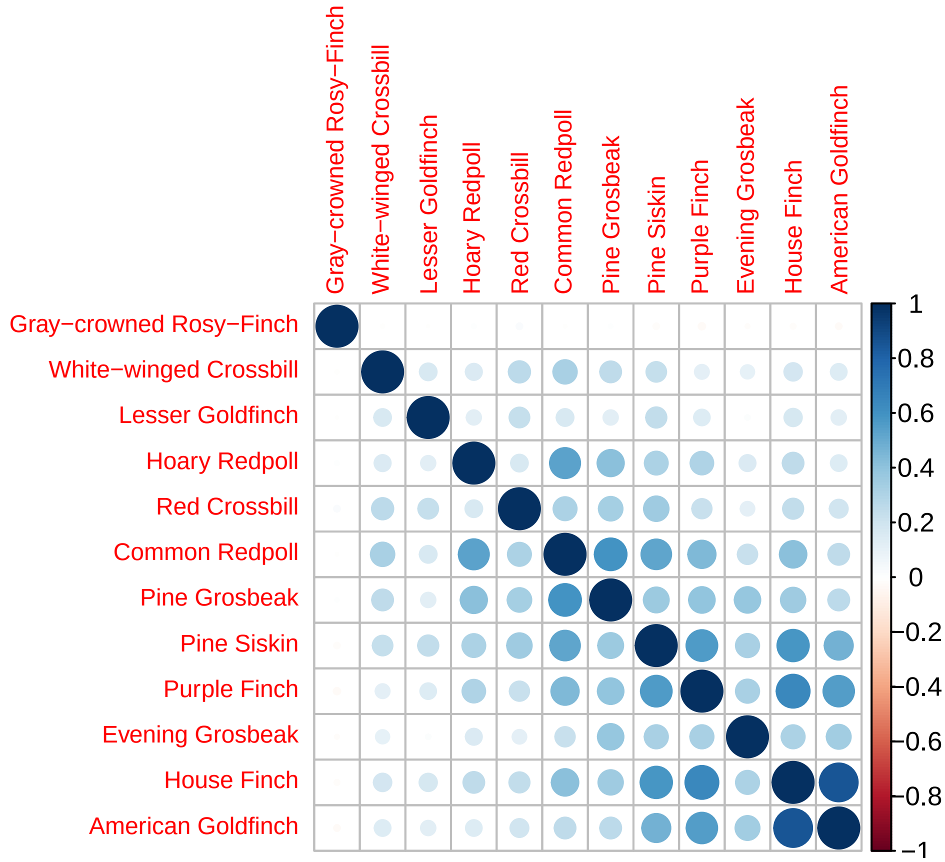


Figure 227: Correlations of daily abundance trends between species in the 2nd (Midwest) longitudinal tier, eBird data.

Along the third longitudinal tier, eBird data show weak to strong positive correlations between most species (Fig. 228).

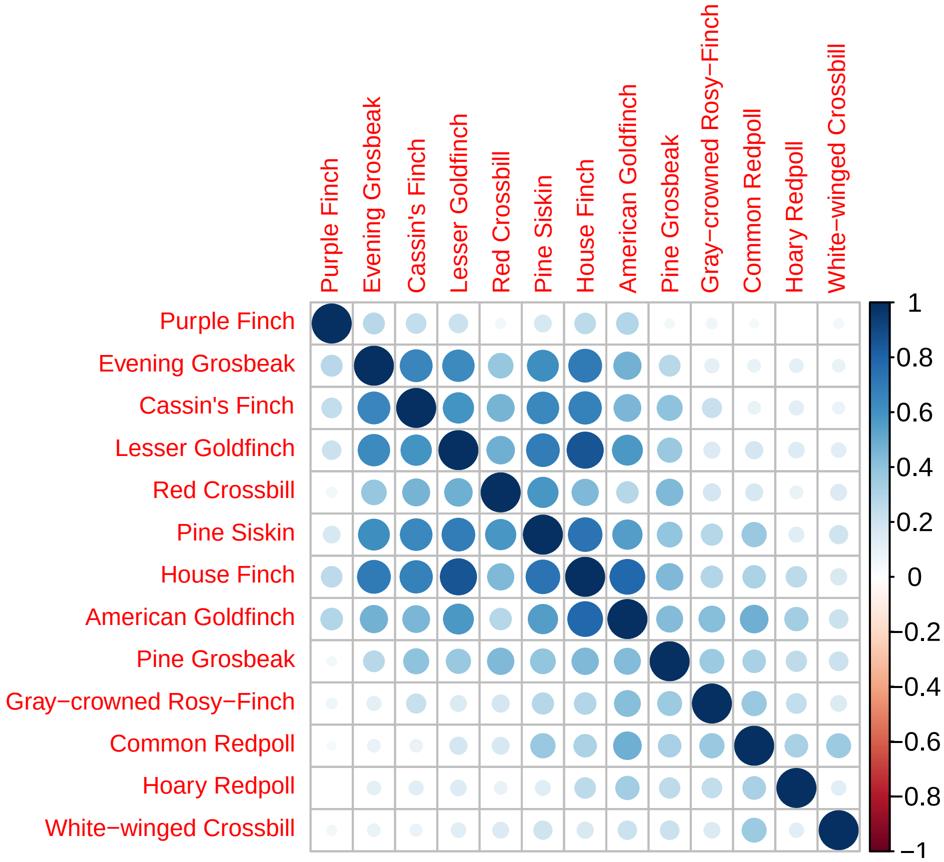


Figure 228: Correlations of daily abundance trends between species in the 3rd (Rocky Mountain) longitudinal tier, eBird data.

Along the westernmost longitudinal tier, eBird data show weak to strong positive correlations between all species (Fig. 229).

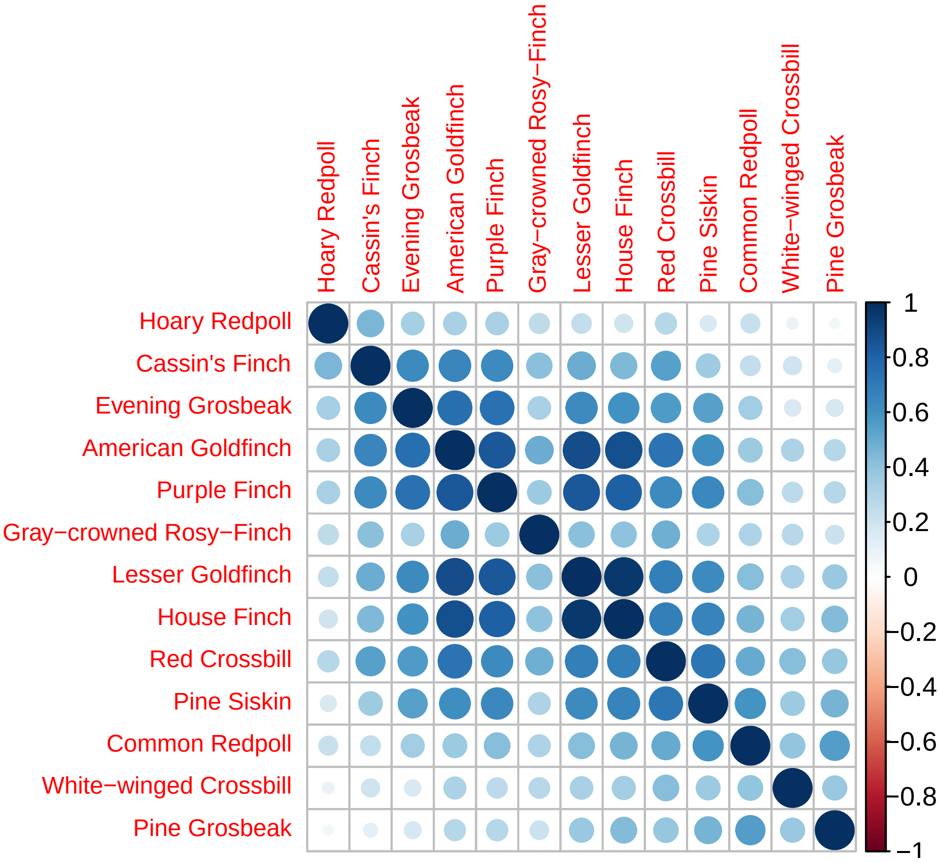


Figure 229: Correlations of daily abundance trends between species in the 4th (Pacific) longitudinal tier, eBird data.

Discussion

Animals show a diversity of responses to periods of low food availability. Some species hibernate or exist in other low-metabolic states to conserve energy during these times. More mobile species, however, often migrate to areas with higher resources. Migration is common in bird species that breed in northern latitudes, especially for insectivorous species whose food supply is invariably low during the winter months (La Sorte et al., 2016). It is thought that over half of North America's roughly 650 breeding bird species exhibit migratory behavior, with an estimated 5 billion individuals flying south each year (The Cornell Lab of Ornithology, 2007; Boreal Songbird Initiative, 2015). Since the timing of food scarcity is roughly consistent year to year in most areas, many migratory bird species travel similar distances with similar timing each year (Wilson, 2009). Although migration is necessary for the survival of species whose food supplies diminish in breeding territories each year, it is tremendously expensive and poses high risks for birds (Alerstam and Lindström, 1990). Therefore, species that feed on food sources available year-round, or can shift their diets to take advantage of available sources, remain in or near breeding grounds. At high latitudes, some birds are able to feed on plant matter or available prey organisms to survive the winter months (Williams and Batzli, 1976).

However, for some species, the availability of wintertime food varies year to year. This pattern is especially true for finches and other seed-eating birds, as seed producing plants vary their production of bumper crops to control predator populations (Smith, 1986). In response to unpredictable changes in resource levels, these birds display facultative migratory behavior, varying the distance, timing, and destinations of migration year to year.

Overall, Christmas Bird Count and eBird records indicate that most North American fringillid species are represented relatively evenly across latitudes during the winter months. Specifically, rises and falls in species abundance are for the most part concurrent in different areas across a latitude. As a result, historic abundance records for each species in US states and Canadian provinces that fall along the same latitudes tend to show positive correlations with each other (e.g. Figs. 5, 22, 29, 67, 73, 84, 93, 117, 124, 151, 159, 169, 178, 193, 201, 207). In contrast, in different areas along longitudes, most species show abundance spikes that either alternate over time (e.g. Figs. 24, 69, 86, 139, 173, 190, 205) or are concurrent but consistently differently sized (e.g. Figs. 8, 25, 104, 121, 203). Abundance records in areas along the same longitude generally only show positive correlations with each other if the areas are close by (e.g. Figs. 7, 18, 24, 68, 71, 76, 79, 88, 97, 103, 126, 146, 172, 179, 183, 195, 202, 210) or never show high abundances of focal species (e.g. Figs. 8, 26, 70, 120, 136, 154, 203). The abundance of all species varies year to year in each area.

Different areas show these patterns more strongly than others. Most species show the strongest positive correlations in historic abundance between the different areas in the latitudes where they typically winter during irruption years and do not breed. For most species that breed in the far northern boreal and subarctic areas, areas across the northern United States (Figs. 4, 22, 29, 73, 83, 91, 117, 124, 151, 159, 169, 177, 199, 207) and mid United States (Figs. 5, 66, 84, 92, 125, 178, 200, 208) show the strongest positive correlations. While some species certainly show similar abundance trends across latitudes more strongly than others, nearly all show at least some adherence to this pattern. Even the most irregular fringillids, the two crossbill species, which are known to nomadically migrate in a series of movements throughout the winter (Adkisson, 1996; Benkman, 2012), indeed sometimes show similarly timed and sized rises in abundance along with stronger positive correlations between different areas across latitudes (Figs. 134, 150, 151). These findings agree with prior studies. Wilson (2012) observed that Purple Finches move primarily shift up and down in latitude, with little east-west movement, during the nonbreeding season. The finding that irruptive species invade in similar numbers across latitudes, combined with the observation of Hochachka et al (1999) that different populations of Common Redpolls move south independently of one another, suggests that there are consistencies in the ways these northern breeding birds respond to food shortages in different years and in different areas. For both crossbill species, which show tremendous variation in the timing of migration, breeding, and molting each year, have similar timing of these events in years with similar levels of food availability in boreal areas (Benkman, 2012). While there are some records from banding recapture data of individuals moving great distances east or west (e.g. Elphick et al., 2001), as a whole irruptive fringillids appear to invade in similar numbers across latitudes as different populations move south with relatively similar timing.

CBC and eBird data show that the winter movements of many species are affected by altitude in addition to latitude. Areas at high elevations often show similar environmental conditions as lower elevation areas located at higher latitudes (Stevens, 1992). In the southern latitudinal tiers of my study, data indicate that many fringillid species in my study winter in higher abundances in mountainous areas, namely the Appalachian Range in the east and the Rocky Mountains in the west. CBC data show that along the third longitudinal tier, which comprises the Rocky Mountain states, abundance spikes tend to be more similar with respect to timing and size in different areas than abundance spikes in the three other longitudinal tiers (e.g. Figs. 9, 23, 118, 128, 134, 138, 200, 204). The Cassin's Finch and the Gray-crowned Rosy-Finch breed at high altitudes in the Rocky Mountains. CBC and eBird records of these two species show the least strong positive correlations between different areas in the same latitudes (Figs. 37, 38, 39, 40, 43, 44, 45, 46, 52, 53, 54, 58, 59), suggesting that altitude is more important in governing their winter movements. During irruption years, these species move to lower altitudes (Hahn, 1996; Macdougal-Shackleton et al., 2000). However, CBC records show that both species show concurrent abundance spikes in some areas at the southern ends of their winter ranges (Figs. 39, 54), as well as some alternation in abundance spikes between southern and northern areas (Figs. 42, 56). This suggests that latitude still plays a role in controlling the species' winter movements. The Cassin's Finch shows these patterns more strongly than the Grey-crowned Rosy-Finch. This finding is not surprising given that the Gray-crowned Rosy-Finch breeds at higher elevations than the Cassin's Finch (Macdougal-Shackleton et al., 2000). To better understand the role of altitude in governing winter movements, especially those of high elevation breeding species such as the Gray-crowned Rosy-Finch as well as the two other species of North American Rosy-Finches, one could study CBC and eBird records at a local scale, comparing abundances between counties or circles at different altitudes.

eBird data indicates that many species irrupt southward in distinct biennial cycles. In many areas, the daily abundance records of certain species show strong positive correlations every other year (e.g. Figs. 74, 76, 108, 124, 125, 126 208, 209, 210, 211). These correlations confirm the results of existing studies, which have observed that southward irruptions of the Common Redpoll, Purple

Finch, Pine Siskin, and presumably the Hoary Redpoll occur every year in response to synchronized seed shortages in key seed producing tree species (Bock and Lepthein, 1976; Kennard, 1977; Larson and Bock, 1986; LeBaron, 1999; Knox and Lowther, 2000). I found that for most species, eBird records show the strongest positive correlations every other year in areas where species regularly winter during irruption years but do not breed. Similar to my findings for correlations between different areas, I found that for most species these were the latitudinal tiers across the northern United States (Figs. 108, 124) and mid United States (Figs. 74, 125, 208). However, some species, most notably the Pine Siskin, show distinct biennial patterns along entire longitudes (Figs. 76, 126, 210, 211). I observed strong positive correlations in eBird daily records for both goldfinch species, with strong positive correlations between every sixth year in tiers of high abundance (Figs. 91, 92, 93, 94, 96, 97, 179, 180, 193, 193). I was unable to discern this pattern in the Christmas Bird Count data. Because goldfinches, especially the Lesser Goldfinch, are more sedentary than the other fringillids in my study (Watt and Willoughby, 2014), investigation of the mechanisms behind these correlations seems worthwhile.

My findings that irruptive finches mostly invade in similar numbers every other year across latitudes are at least somewhat limited by restrictions of the dataset. While the Christmas Bird Count and eBird seek to provide accurate records of bird abundances throughout North America, in reality few counts occur in the northernmost reaches of the continent. As a result, these databases do not adequately report bird abundances in these areas. In some years, CBC records show that the most northerly breeding species, such as the Pine Grobeak and Hoary Redpoll, appear completely absent from all latitudinal and longitudinal tiers (e.g. Figs. 8, 24, 103, 120, 138, 157, 202). In reality, populations are wintering in areas north of monitoring efforts. The strong positive correlations in eBird records for the Pine Siskin between every other year in entire longitudes indicates that this species, which breeds in the far north but has a relatively large winter range, regularly occurs in monitored areas only during irruption years (Dawson, 2014).

While CBC and eBird datasets do not completely represent the historic abundance trends of most irruptive North American species, they encompass the regular areas of occurrence for fringillids that breed farther south. For the most part, the American Goldfinch, House Finch, and Lesser Goldfinch show the highest variation between years in the northern latitudinal tiers, which represent the northern limits of their winter ranges (Figs. 214, 215). In comparison, these species show much more less variation in yearly abundance in the middle and southern areas of my study (Figs. 216, 217). All three species also show at least to some extent alternation in high winter abundance between areas in the north and areas in the south (Figs. 86-89, 172-175, 188). These results indicate that fringillids that breed in temperate zones are also facultative migrants, primarily moving on a north-south basis, and show more significant southward movements every other year. However, they appear to move shorter distances during the nonbreeding season than boreal species, especially in the southern areas of their range.

CBC and eBird data show negative correlations in historic abundance trends between certain northern and southern breeding species. Specifically CBC records of the Common Redpoll, Hoary Redpoll, Pine Grosbeak, Grey-crowned Rosy-Finch, Red Crossbill, and White-winged Crossbill often show negative correlations with those of the American Goldfinch, Lesser Goldfinch, and House Finch (Figs. 214, 215, 216, 219, 220, 221). One potential explanation for these correlations is interspecific competition, as influxes of northern species may reduce food for resident species. However, this reasoning is likely incorrect. Indeed intraspecific competition has been observed in certain species such as the American Goldfinch and Evening Grosbeak with males dominating females in the winter months (Prescott, 1991; McGraw and Middleton, 2009). However, aside from introduced populations of House Finches reducing abundances of Purple Finches in eastern North America (Wooton, 1987), no existing studies describe adverse effects of competition reducing abundances of gregarious North American fringillid species. Instead, a more likely explanation is that species that breed in southern latitudes are less cold-tolerant than their northern breeding relatives, and co-occurrence of species from these two groups of fringillids is limited by the fact that southern species are driven down by cold weather when northern species visit their typical ranges (McGraw and Middleton, 2009). The winter movements of House Finches and the two goldfinch species are likely more governed by temperature than the movements of boreal breeding finches. When House Finches were first introduced into eastern North America, their expansion was initially limited by wet winter conditions, and American Goldfinch populations show the lowest tolerances to cold in the typically warmer areas of their range (McGraw and Middleton, 2009; Badyaev et al., 2012).

Species-wide comparisons in CBC and eBird records also show many strong positive correlations between the abundance trends of several northern breeding species. In many latitudinal and longitudinal tiers, the Common Redpoll shows strong positive correlations with the Hoary Redpoll, and the Pine Siskin, Evening Grosbeak, Purple Finch, and occasionally the Pine Grosbeak show strong positive correlations with each other (Figs. 214, 215, 217-225, 227-229). These observations are consistent with the earlier findings of Bock and Lepthein (1976), whose analysis of CBC data identified synchronized irruptions between a number of irruptive species due to shared food sources.

Overall, irruptive finches have evolved to breed in environments with food supplies that are highly variable between years. However, the regular cycles that drive food shortages in the far north along with responses to these shortages that are consistent between years create patterns in space and time in the seemingly random movements of many species. The adaptability of these species with respect to their movements suggest that in the future, as environmental conditions change, their winter movements may change drastically in response. While I found only limited evidence for this claim, irruptive fringillids are now often wintering farther north than in the past due to artificially high food availability at feeders (Wilson, 1999). Similarly climate change may shorten the southern movements of these species during irruption years, especially for species that are more sensitive to changes in temperature.

To fully understand irruptive fringillid migration, scientists will need to know the numbers of birds wintering in the northernmost areas of the continent, as well as movement records of individuals or groups. While these data will not realistically become available any time soon, much about irruptions can still be learned from existing sources. Around the world, more people are reporting observations to eBird each year. The dataset is becoming increasingly valuable as a tool for studying bird movements and abundance trends (e.g. La Sorte et al., 2016), and future studies have great potential to improve knowledge of still poorly understood aspects of irruptions, such as mortality. Finally, analysis of eBird as well as Christmas Bird Count data at the local level, rather than the statewide approach that I take in this paper, could reveal much about the small-scale movements of irruptive species.

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