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Special Graduation Project

Changes in bird populations at the Santa Inés Agroecological farm, Zamorano University, Honduras

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Abstract

The study aimed to identify bird species with temporal trends, evaluate the relationship between these trends and climate variability, and determine differences between resident and migratory birds. For 7 years, ornithologist Oliver Komar counted birds at Zamorano University's agroecological farm. Time series decomposition and regression analysis were applied to identify temporal trends for 88 bird species. Subsequently, regression and contingency table analysis were employed to examine the relationships between migratory and resident bird species with temperature and precipitation. Temporal trends were significant for 51 species (58%), with 41 (47%) declining and 10 (11%) increasing. The magnitude of declines averaged 59% while increases averaged 155%. Temperature had a negative effect on 18 species (20%) and a positive effect on six (7%). Precipitation negatively affected 10 bird species (11%) and positively two (2%). Temporal declines were proportionally more frequent for residents, but the magnitude of the declines was greater for migrants. Temperature was more negatively correlated with migrants. Differences between migrants and residents with respect to precipitation were inconclusive. In conclusion, (1) more bird species are declining than are increasing on the farm, which will eventually erode biodiversity; (2) as biodiversity declines the farm will become more vulnerable to climate change, agricultural pests, and invasive species. Furthermore, (3) the ecosystem services provided by migratory birds are diminishing. Recommendations include using non-parametric methods and different time scales to analyze the effects of climate change on birds, investigating the relationships between feeding guilds and other factors that affect birds, and developing a biodiversity conservation plan for the farm.

Keywords: Agroecology, climate variability, ornithology, precipitation, temperature

Resumen

El estudio buscó identificar tendencias en el tiempo de la presencia de aves y su relación con el clima. Durante siete años, el ornitólogo Oliver Komar realizó conteos de aves en la finca agroecológica de la Universidad Zamorano. Se realizaron análisis de series temporales y regresiones para identificar tendencias en 88 especies. Después se realizaron tablas de contingencia para evaluar las diferencias entre especies residentes y migratorias considerando el efecto de la temperatura y precipitación. Las tendencias temporales fueron significativas para 51 especies (58%), 41 (47%) en declive y 10 (11%) en aumento. La magnitud de los cambios poblacionales promedió un declive de 59% y aumento de 155%. La temperatura afectó negativamente a 18 especies (20%) y positivamente a seis (7%). La precipitación impactó negativamente a 10 especies (11%) y positivamente a dos (2%). Las tendencias en declive fueron más frecuentes en residentes, pero los declives fueron más marcados en migratorias. La temperatura mostró una mayor correlación negativa en las especies migratorias, mientras que las diferencias respecto a la precipitación no fueron concluyentes. En conclusión: (1) más especies están en declive que en aumento, lo que contribuirá a la erosión de la biodiversidad; (2) la finca será más vulnerable a cambios climáticos, plagas y especies invasoras; y (3) los servicios ecosistémicos de aves migratorias están disminuyendo. Se recomienda usar métodos no paramétricos en diferentes escalas de tiempo para analizar impactos climáticos, investigar las relaciones entre gremios alimenticios y otros factores que pueden afectar la presencia de las aves, y desarrollar un plan de conservación de biodiversidad en la finca.

Palabras clave: Agroecología, ornitología, precipitación, temperatura, variabilidad climática

Introduction

In environmental ecology, biodiversity plays a crucial role in maintaining equilibrium and environmental health. Globally, the alteration of natural environments in cultivated areas is generally causing an important decrease in biodiversity (Chazal & Rounsevell, 2009; Gao et al., 2024). The primary factor adversely affecting the trend of bird species is agricultural intensification (Rigal et al., 2023). Estimates suggest that in the coming years, agricultural intensification could either directly or indirectly contribute to 70% of the loss of terrestrial biodiversity (Herrando et al., 2016; Secretariat of the Convention on Biological Diversity, 2014). The loss of biodiversity can have negative effects on regional sustainability and economic development, with serious consequences for the well-being of human communities that depend on ecosystemic services to survive. Specific data on biodiversity and population trends is needed to understand the natural mechanisms of ecosystems, effectively manage the regions under examination and the ecological benefits they provide.

Climate change exacerbates changes in land use leading to a global decline in biodiversity (Chen & Khanna, 2024). Two climatic variables primarily affect bird populations: temperature and precipitation (Ferger et al., 2014). Agroecology emerged as an alternative production method that replicates ecological features and uses agricultural principles in a way that does not adversely affect environmental quality and adapts to climate change (Bernard & Lux, 2017). Since agroecology simulates a natural ecological environment, its function relies on biodiversity to thrive.

An important aspect to consider in biodiversity are birds, among the most thoroughly studied taxonomic groups (Fink et al., 2020). Researchers have utilized birds as indicators to evaluate the health of ecosystems (Gregory & van Strien, 2010; Stoltefaut et al., 2024). In North America, bird populations have been declining due to land use change and climate change (Rosenberg et al., 2019). Monitoring species is critical for understanding the state of an ecosystem and species conservation; it requires regular data for a considerable number of years (Neate-Clegg et al., 2020).

The Agroecological Farm's data in eBird shows the detection of 199 bird species, with a recorded diversity ranging from 122 to 147 species in any given year (eBird, 2024). Previous studies have provided key information about the agroecological farm at Zamorano University. The study compared two agricultural systems and the results showed that 84 species of birds were found in the intensive agricultural section and 121 species in the agroecological component. This suggests that the diversity of bird species on the agroecological farm is higher than that on the intensive agricultural unit (Melgar, 2017). Despite introducing some tree species, another study on the farm about monitoring trees reveals that the majority are native (Benítez & Denisse, 2016). It is healthy in the ecosystem to have native species already adapted to the zone. Even though the agroecological farm is believed to have a low impact on the environment, there has been a notable local decline in butterfly diversity (Bautista, 2023; Calderón, 2020).

The purpose of this study is to identify population trends in the avifauna of Zamorano University's agroecological farm over 7 years of monitoring. The study´s objectives included the following: a) identify individual bird species exhibiting temporal trends, b) evaluate the relationship between observed trends and climate variability, and c) determine differences in trends between resident and migratory bird communities.

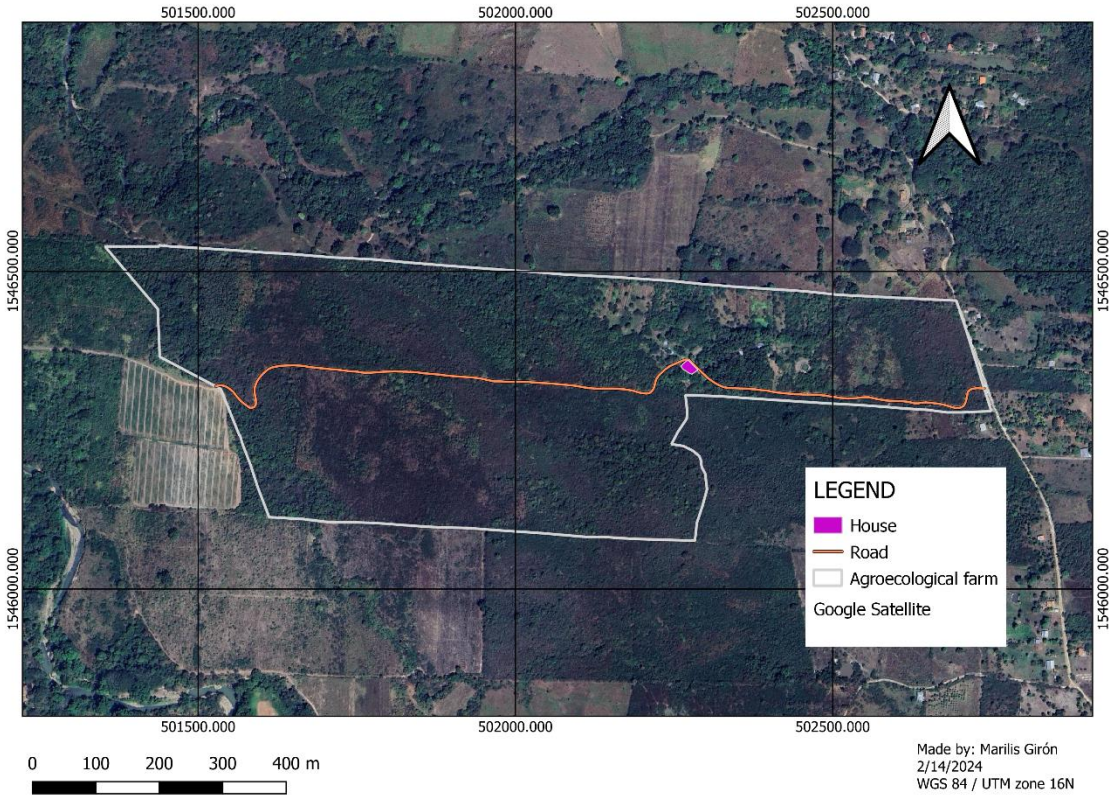
Methodology

Research Area

The agroecological farm is a 40-hectare section of the campus of the Pan-American Agricultural School (Zamorano University) in the Yegüare Valley, San Antonio de Oriente, Francisco Morazán, Honduras (Figure 1). In addition to cultivating corn, beans, yucca, and plantains, the agroecological farm also has three cattle that are part of a silvopastoral system. The production serves as a demonstration to educate students and local farmers about sustainable agriculture.

Figure 1

Agroecological farm map



Research Design

This ongoing work was part of a field activity performed as a part of the Learning by Doing module for second-year university students, led by the ornithology expert, Dr. Oliver Komar. The transect used follows a road across the agroecological farm (length 1338 m). Bird counts were conducted regularly for the past 7 years, except from early 2020 to early 2021 due to the COVID-19 pandemic. During the observation periods, climate conditions were noted, revealing virtually no precipitation and winds below the Beaufort scale level 4, typically 1 or 2, providing ideal conditions for bird observations.

A database of the different bird monitoring activities for the Santa Ines agroecological farm is stored on the Cornell Lab of Ornithology citizen-science platform, "eBird" including approximately two morning bird counts per month on a fixed route. For the present analysis, this data was transferred to an Excel® worksheet, then rearranged into monthly average counts.

The selected climate station *Zorrales* was used to collect the precipitation and temperature data, as it possessed the most complete dataset recorded during the study period. It is located 3 km from the study area and has the coordinates of Latitude 14.001943 °N, and Longitude -86.997244 °E. Climate data were rearranged into total monthly precipitation (from the preceding month) (December 2015 to March 2024) and average monthly temperature (January 2016- to April 2024).

To assure that species have sufficient data to be analyzed, only those that were present for at least 10% of the research time were included. The study assigned observed potential for 76 months of resident bird presence and 42 months of migratory bird presence. As a result, during the study, bird species were examined if they were present for more than 4 months for migratory species or more than 7 months for resident species.

Table 1

Analyzed species

No.	Scientific name	Common name
1	*Colinus cristatus*	Crested Bobwhite
2	*Patagioenas flavirostris*	Red-billed pigeon
3	*Columbina inca*	Inca Dove
4	*Columbina passerina*	Common Ground Dove
5	*Columbina talpacoti*	Ruddy Ground Dove
6	*Leptotila verreauxi*	White-tipped Dove
7	*Zenaida asiatica*	White-winged Dove
8	*Crotophaga sulcirostris*	Groove-billed Ani
9	*Morococcyx erythropygus*	Lesser Ground-Cuckoo
10	*Piaya cayana*	Squirrel Cuckoo
11	*Archilochus colubris*	Ruby-throated Hummingbird
12	*Cynanthus canivetii*	Canivet's Emerald
13	*Amazilia rutila*	Cinnamon Hummingbird
14	*Bubulcus ibis*	Western Cattle Egret
15	*Coragyps atratus*	Black Vulture
16	*Cathartes aura*	Turkey Vulture
17	*Pandion haliaetus*	Osprey
18	*Buteogallus anthracinus*	Common Black Hawk
19	*Rupornis magnirostris*	Roadside Hawk
20	*Buteo brachyurus*	Short-tailed Hawk
21	*Glaucidium brasilianum*	Ferruginous Pygmy-Owl
22	*Eumomota superciliosa*	Turquoise-browed Motmot
23	*Melanerpes formicivorus*	Acorn Woodpecker
24	*Melanerpes aurifrons*	Golden-fronted Woodpecker
25	*Herpetotheres cachinnans*	Laughing Falcon
26	*Caracara plancus*	Crested Caracara
27	*Amazona albifrons*	White-fronted Parrot
28	*Eupsittula canicularis*	Orange-fronted Parakeet
29	*Thamnophilus doliatus*	Barred Antshrike
30	*Tityra semifasciata*	Masked Tityra
31	*Pachyramphus aglaiae*	Rose-throated Becard
32	*Tolmomyias sulphurescens*	Yellow-olive Flatbill
33	*Camptostoma imberbe*	Northern Beardless-Tyrannulet
34	*Empidonax minimus*	Least Flycatcher
35	*Myiarchus tuberculifer*	Dusky-capped Flycatcher
36	*Myiarchus nuttingi*	Nutting's Flycatcher
37	*Myiarchus crinitus*	Great Crested Flycatcher
38	*Myiarchus tyrannulus*	Brown-crested Flycatcher
39	*Pitangus sulphuratus*	Great Kiskadee
40	*Megarynchus pitangua*	Boat-billed Flycatcher
41	*Myiozetetes similis*	Social Flycatcher
42	*Tyrannus melancholicus*	Tropical Kingbird
43	*Tyrannus verticalis*	Western Kingbird
44	*Tyrannus forficatus*	Scissor-tailed Flycatcher
45	*Cyclarhis gujanensis*	Rufous-browed Peppershrike
46	*Vireo flavifrons*	Yellow-throated Vireo
47	*Calocitta formosa*	White-throated Magpie-Jay
48	*Tachycineta thalassina*	Violet-green Swallow
49	*Stelgidopteryx serripennis*	Northern Rough-winged Swallow

No.	Scientific name	Common name
50	*Hirundo rustica*	Barn Swallow
51	*Polioptila albiloris*	White-lored Gnatcatcher
52	*Troglodytes rufociliatus*	Rufous-naped Wren
53	*Cantorchilus modestus*	Cabanis's Wren
54	*Dumetella carolinensis*	Gray Catbird
55	*Turdus grayi*	Clay-colored Thrush
56	*Euphonia affinis*	Scrub Euphonia
57	*Spinus psaltria*	Lesser Goldfinch
58	*Peucaea ruficauda*	Stripe-headed Sparrow
59	*Icteria virens*	Yellow-breasted Chat
60	*Amblycercus holosericeus*	Yellow-billed Cacique
61	*Icterus spurius*	Orchard Oriole
62	*Icterus pustulatus*	Streak-backed Oriole
63	*Icterus pectoralis*	Spot-breasted Oriole
64	*Icterus gularis*	Altamira Oriole
65	*Icterus galbula*	Baltimore Oriole
66	*Molothrus aeneus*	Bronzed Cowbird
67	*Dives dives*	Melodious Blackbird
68	*Quiscalus mexicanus*	Great-tailed Grackle
69	*Seiurus aurocapilla*	Ovenbird
70	*Leiothlypis peregrina*	Tennessee Warbler
71	*Geothlypis tolmiei*	MacGillivray's Warbler
72	*Geothlypis trichas*	Common Yellowthroat
73	*Setophaga citrina*	Hooded Warbler
74	*Setophaga ruticilla*	American Redstart
75	*Setophaga magnolia*	Magnolia Warbler
76	*Setophaga petechia*	Yellow Warbler
77	*Setophaga pensylvanica*	Chestnut-sided Warbler
78	*Basileuterus delattrii*	Chestnut-capped Warbler
79	*Piranga rubra*	Summer Tanager
80	*Piranga ludoviciana*	Western Tanager
81	*Pheucticus ludovicianus*	Rose-breasted Grosbeak
82	*Passerina caerulea*	Blue Grosbeak
83	*Passerina cyanea*	Indigo Bunting
84	*Passerina ciris*	Painted Bunting
85	*Spiza americana*	Dickcissel
86	*Volatinia jacarina*	Blue-black Grassquit
87	*Saltator atriceps*	Black-headed Saltator
88	*Saltator grandis*	Cinnamon-bellied Saltator

Statistical Analysis

The species data were processed using a time series decomposition, combining an additive model and a trend plus seasonal model. Linear regression analysis was used to find temporal trends by plotting the decomposed fits of each species, which were based on average monthly counts, against the months of bird observations. Linear regression was used to calculate population changes for each of the 88 species.

To calculate the magnitude of population change over time, graphs for each species and their trendlines were examined. The magnitude of change was obtained by subtracting the initial value from the final value on the trendline. This difference was then divided by the initial value and multiplied by 100 to express as a percentage, as in Equation 1. Values indicating a decline of > 100%, were recorded as a 100% decline, as this reflected that the trendline reached a negative value, which is not biologically possible when counting individuals.

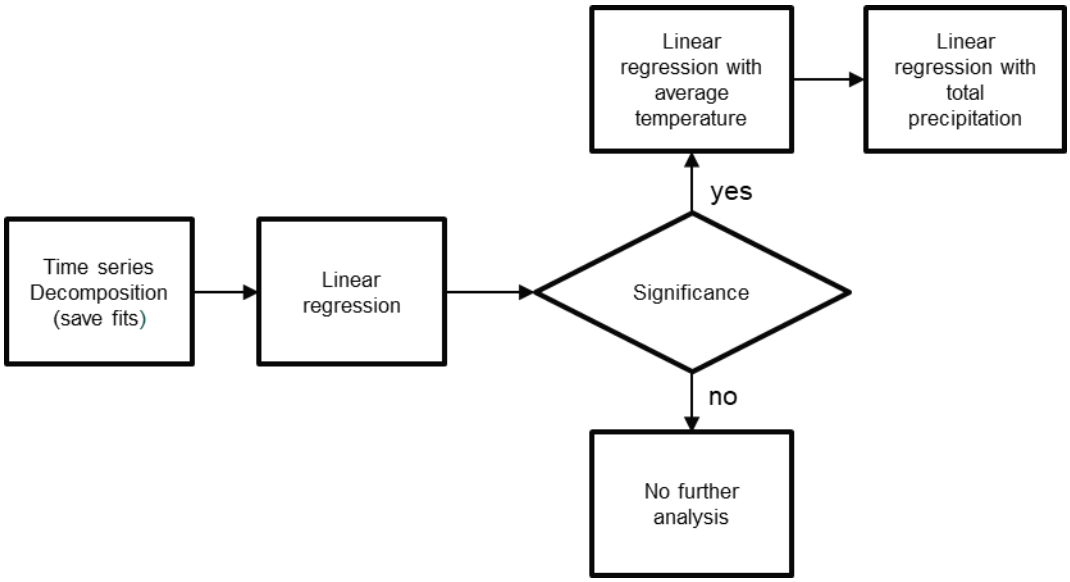
$$\%\ change = \frac{initial\ count - final\ count}{inital\ count} \times 100 \quad [1]$$

The species that showed significant temporal trends (P < 0.10) were used to perform regression analysis with the predictor variables of time in months, total precipitation per month (the previous month) and average temperature per month (Figure 2). It was determined that precipitation would be one month prior due to effects on food availability like insect activity. The effects of rainfall on an ecosystem are often observed sometime after the rain falls. This delay happens because the ecosystem's response to hydration isn't immediate.

If the P value is significant (P < 0.10), indicates an increase or decrease in the population; species which did not present significant temporal trends were considered to have maintained stable populations over the study period. Then a classification between resident and migratory birds, each species exhibited a linear regression with time, temperature, and precipitation. The list of bird species and occurrence, whether migratory, resident or transitory (Dubón et al., 2024). The Minitab® statistical software (version 22.1.0.0) was used for the decomposition processes and regression analysis (Cadieux et al., 2022). A chi-square test was made to detect differences on migratory and resident birds in terms of temporal trends, relationship with precipitation and temperature. The JASP® software was used to run on a three by two test (JASP team, 2022).

Figure 2

Steps for statistics with bird species



Results and Discussion

Trends Over Time

Of the 88 species analyzed, 51 (58%) showed significant trends (Table 2); declines were detected in 41 species (47%) whereas 37 (42%) were stable (Appendix A) and 10 (11%) increased. Examples of species with significant declines include the resident Dusky-capped Flycatcher *Myiarchus tuberculifer* ($P < 0.001$, $R^2 = 0.48$, Figure 3) and the migrant Yellow Warbler *Setophaga petechia* ($P = 0.002$, $R^2 = 0.09$, Figure 4). On the other hand, 10 species show increases. Examples of species with increments are the resident insectivore Cabanis's Wren *Cantorchilus modestus* ($P < 0.001$, $R^2 = 0.32$, Figure 5) and the migratory insectivore-frugivore Western Tanager *Piranga ludoviciana* ($P = 0.061$, $R^2 = 0.03$, Figure 6). Factors that could explain rapid changes in bird populations include food availability, feeding guild, competition, predation, climate change, extreme conditions, or anthropogenic activities such as agriculture and urbanization.

Bird species showed different degrees of population change over time. On average species showed an increase of 155% and a decrease of 59%. According to the species' diets (Table 2), 36 species were insectivorous, of which 29 (33%) declined and seven (8%) increased. A study in El Salvador found that 15 out of the 22 declining bird species were insectivorous (Komar O. et al., 2009). Despite the different time frames, insectivore abundance changes remain relevant due to historical and continuing declines in this guild caused by agricultural practices and loss of habitat (Eggleton, 2020). While 41 (47%) species in the present study declined over just 7 years, a long-term analysis of North American bird populations revealed declines in 57% of bird species analyzed for the period 1970 to 2017 (Rosenberg et al., 2019). Clearly, bird populations have been decreasing over many decades, and at least in the Honduras study site, are still declining.

Table 2

Bird species with significant linear trends, abundance regressed against time (months)

No.	Species	Occurrence	Diet	R^2	F	P	Trend	Δ
1	*Colinus cristatus*	R	I, G	2%	2.87	0.093	d	32%
2	*Patagioenas flavirostris*	R	F	3%	3.8	0.054	d	48%
3	*Columbina inca*	R	G	5%	6.55	0.012	d	17%
4	*Columbina passerina*	R	G	3%	4.35	0.04	d	43%
5	*Zenaida asiatica*	R	G, F	13%	15.91	< 0.001	d	40%
6	*Crotophaga sulcirostris*	R	I	14%	16.72	< 0.001	d	36%
7	*Morococcyx erythropygus*	R	I	41%	71.17	< 0.001	d	70%
8	*Piaya cayana*	R	I	4%	4.69	0.033	i	39%
9	*Cynanthus canivetii*	R	N	43%	74.63	< 0.001	d	100%
10	*Amazilia rutila*	R	N	3%	3.64	0.059	d	28%
11	*Bubulcus ibis*	R	I	17%	21.97	< 0.001	d	73%
12	*Pandion haliaetus*	M	C	49%	96.25	< 0.001	d	108%
13	*Rupornis magnirostris*	R	C	26%	36.01	< 0.001	d	77%
14	*Glaucidium brasilianum*	R	C, I	7%	8.61	0.004	i	109%
15	*Eumomota superciliosa*	R	I, F	12%	14.18	< 0.001	d	49%
16	*Melanerpes aurifrons*	R	I, F	5%	6.08	0.015	d	32%
17	*Herpetotheres cachinnans*	R	C	9%	11.2	0.001	d	53%
18	*Caracara plancus*	R	C	4%	5.44	0.022	d	35%
19	*Amazona albifrons*	R	F	22%	29.33	< 0.001	i	263%
20	*Eupsittula canicularis*	R	F	25%	34.25	< 0.001	d	68%
21	*Tityra semifasciata*	R	F, I	29%	41.82	< 0.001	i	422%
22	*Camptostoma imberbe*	R	I	21%	26.85	< 0.001	d	62%
23	*Myiarchus tuberculifer*	R	I	48%	94.09	< 0.001	d	63%
24	*Myiarchus tyrannulus*	R	I	9%	11.04	0.001	d	63%
25	*Pitangus sulphuratus*	R	I, F	36%	56.48	< 0.001	d	52%
26	*Megarynchus pitangua*	R	I, F	23%	30.02	< 0.001	d	36%
27	*Myiozetetes similis*	R	I, F	10%	12.16	0.001	d	28%
28	*Tyrannus melancholicus*	R	I, F	13%	16.36	< 0.001	d	76%
29	*Tyrannus forficatus*	M	I, F	23%	29.8	< 0.001	d	100%
30	*Cyclarhis gujanensis*	R	I	53%	110.93	< 0.001	d	72%
31	*Calocitta formosa*	R	I, C	8%	9.03	0.003	i	74%
32	*Tachycineta thalassina*	M	I	88%	736.31	< 0.001	d	100%
33	*Polioptila albiloris*	R	I	12%	14.01	< 0.001	d	28%
34	*Cantorchilus modestus*	R	I	32%	46.88	< 0.001	i	280%
35	*Euphonia affinis*	R	F	3%	3.94	0.05	i	27%
36	*Spinus psaltria*	R	G, I	67%	197.93	< 0.001	d	93%
37	*Peucaea ruficauda*	R	G, I	9%	11.23	0.001	d	52%
38	*Amblycercus holosericeus*	R	I	12%	14.91	< 0.001	d	68%
39	*Icterus spurius*	M	I, N	36%	55.84	< 0.001	d	100%
40	*Icterus pectoralis*	R	I, N	31%	45.2	< 0.001	d	66%
41	*Molothrus aeneus*	R	G	7%	8.09	0.005	i	92%
42	*Dives dives*	R	I	34%	51.47	< 0.001	d	34%
43	*Quiscalus mexicanus*	R	I	21%	26.58	< 0.001	i	69%
44	*Geothlypis trichas*	M	I	33%	49.82	< 0.001	d	100%
45	*Setophaga magnolia*	M	I	4%	5.45	0.022	d	51%
46	*Setophaga petechia*	M	I	9%	10.58	0.002	d	60%
47	*Setophaga pensylvanica*	M	I	52%	109.51	< 0.001	d	62%
48	*Piranga ludoviciana*	M	I, F	3%	3.59	0.061	i	177%
49	*Passerina caerulea*	R	G	32%	48.06	< 0.001	d	77%

No.	Species	Occurrence	Diet	R^2	F	P	Trend	Δ
50	*Volatinia jacarina*	R	G, I	9%	10.22	0.002	d	33%
51	*Saltator grandis*	R	I, F	6%	6.84	0.01	d	36%

Note. R= resident; M= migratory; C= carnivore; I=insectivore; F= frugivore; G= granivore; i=increase; d= decrease; N/A= not apply

Figure 3

Linear regression results for Myiarchus tuberculifer on month

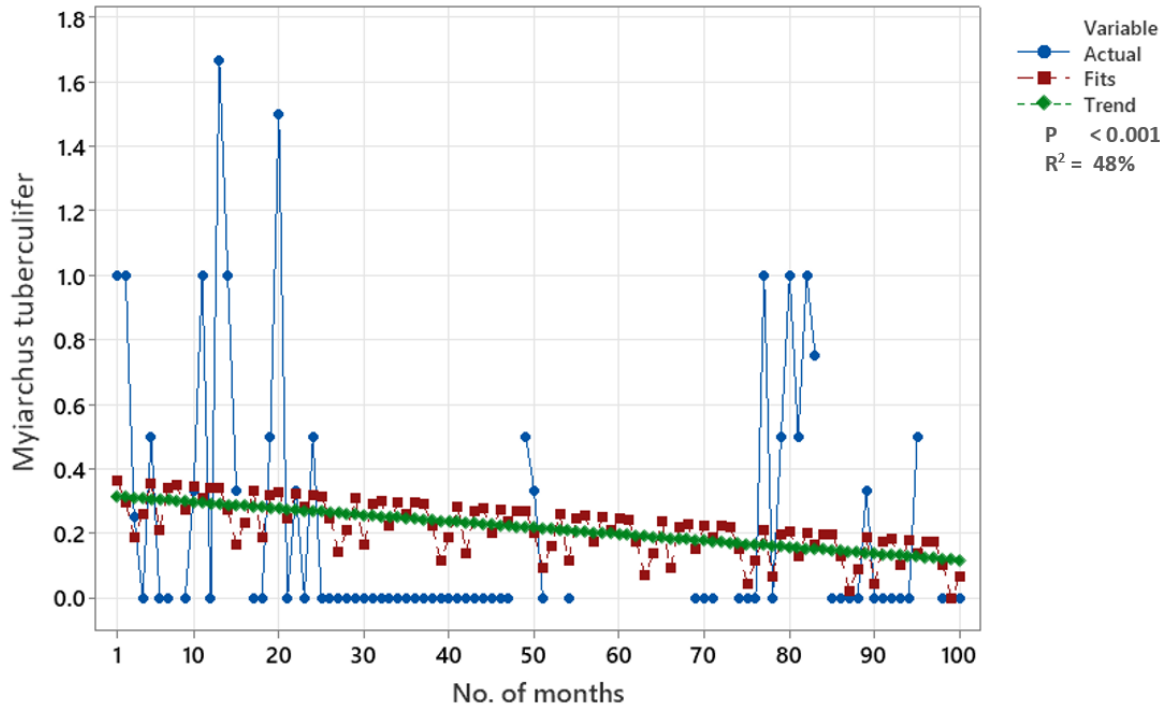


Figure 4

Linear regression results for Setophaga petechia on month

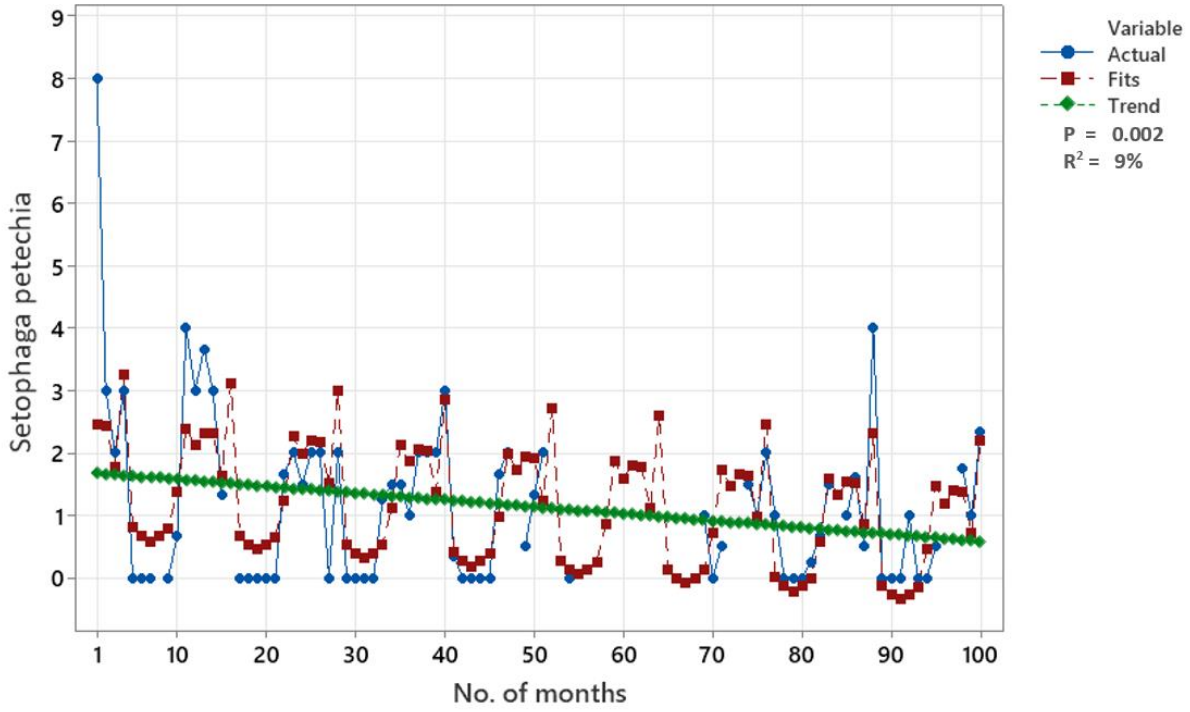


Figure 5

Time series decomposition plot of Cantorchilus modestus

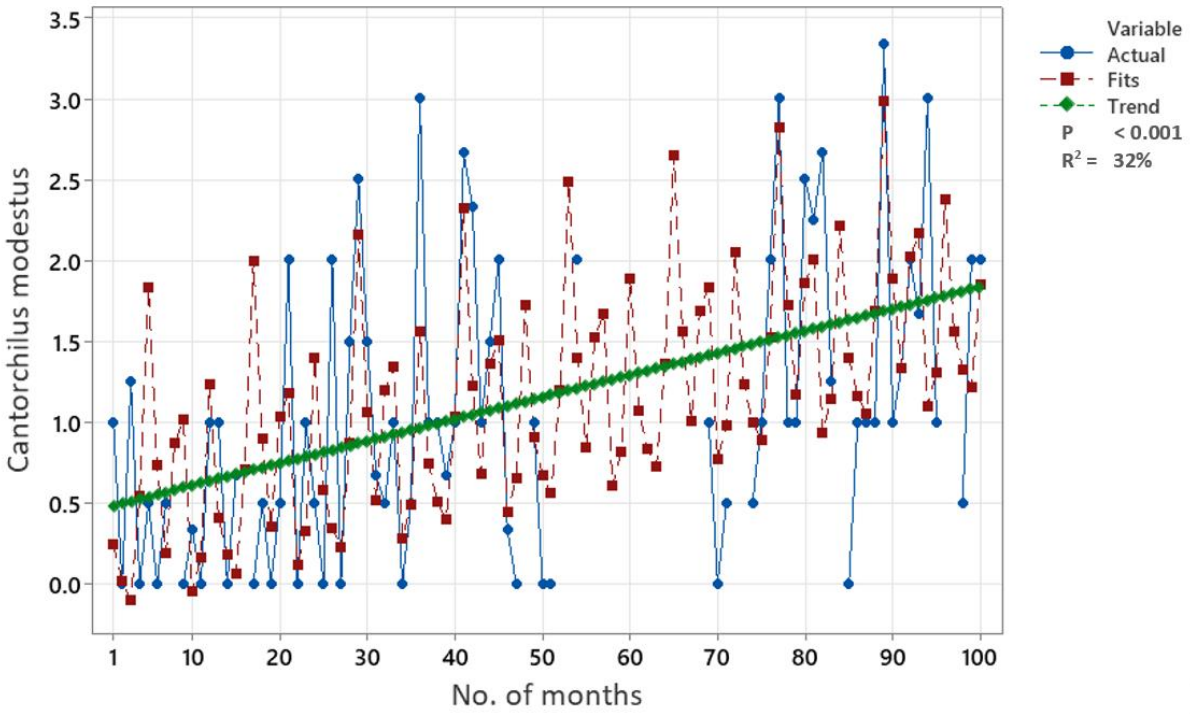
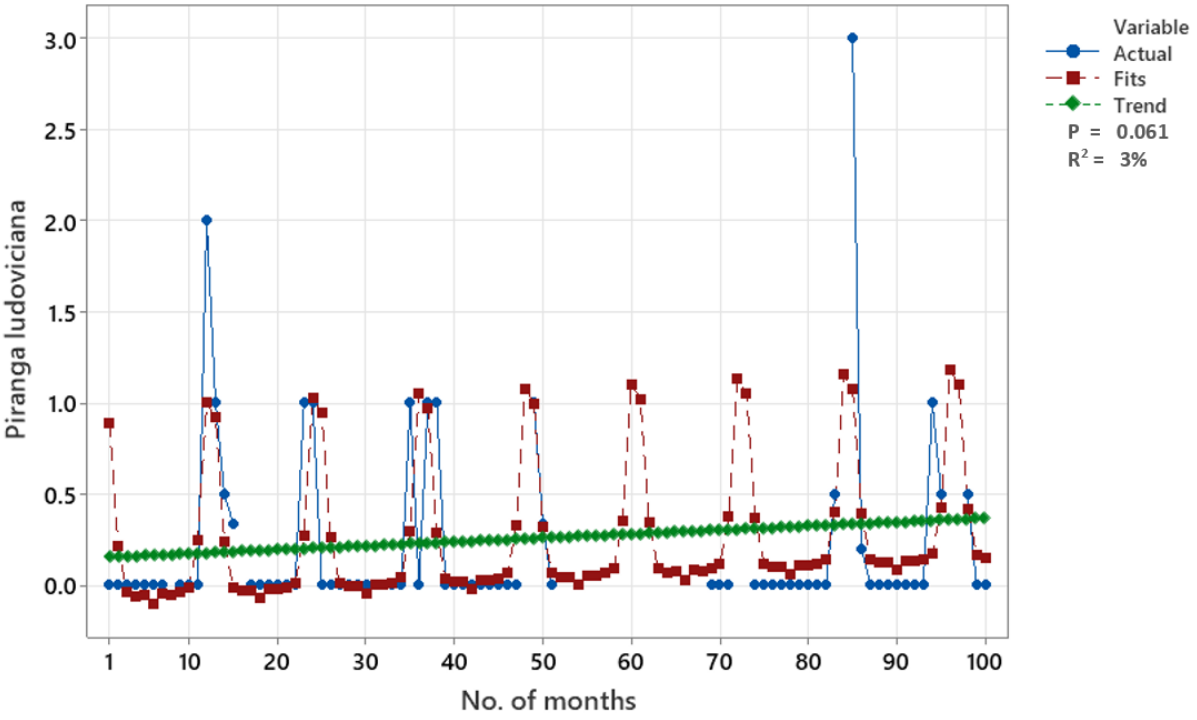


Figure 6

Time series Decomposition plot of Piranga ludoviciana



Relation of Bird Abundance to Climate Variables

The average monthly temperature shows a lot of variability because of seasonal changes (Figure 7). Temperature at the study site, regressed against time, showed no significant trend (P = 0.375; R^2 = 0) although the trend line appeared to increase (Figure 8). Using the monthly average temperature as a predictor variable of avian species abundance (Table 3), the analysis revealed that 18 (20%) species have a negative relationship, while six (7%) have a positive relationship, and 27 (31%) of bird species have no relationship with respect to temperature (Appendix B). Temperature had a negative effect on the resident Western Cattle Egret *Bubulcus ibis* (P = 0.001, R^2 = 0.16, Figure 9) and the migrant Western Tanager *Piranga ludoviciana* (P < 0.001, R^2 = 0.18, Figure 10); for these species, an increase in temperature appears to lead to decreases in population. A few residents, such as *Cantorchilus modestus* (Figure 11), exhibited a positive relationship, while none of the migrants did.

Temperature is one of the most determinant climate variables affecting species distributions (Devictor et al., 2008; Thuiller et al., 2004). It could be one of many factors that could explain changes in bird populations. One study revealed that global warming affected 46% of migratory species by moving their distribution in northward range expansions for a period of 26 years (Hitch & Leberg, 2007). Warming influences migrants to leave earlier, and bird species tend to lay eggs even sooner than before (Li et al., 2022). This may explain why some show a negative relationship: birds are nesting earlier than before, and distances in migration are increasing. Over time, a species' susceptibility to temperature changes depends on its ability to adapt. When temperature extremes occur, temperature influences species declines and increases, in a non-linear fashion (Chen & Khanna, 2024).

Figure 7

Monthly average temperature (2016-2024)

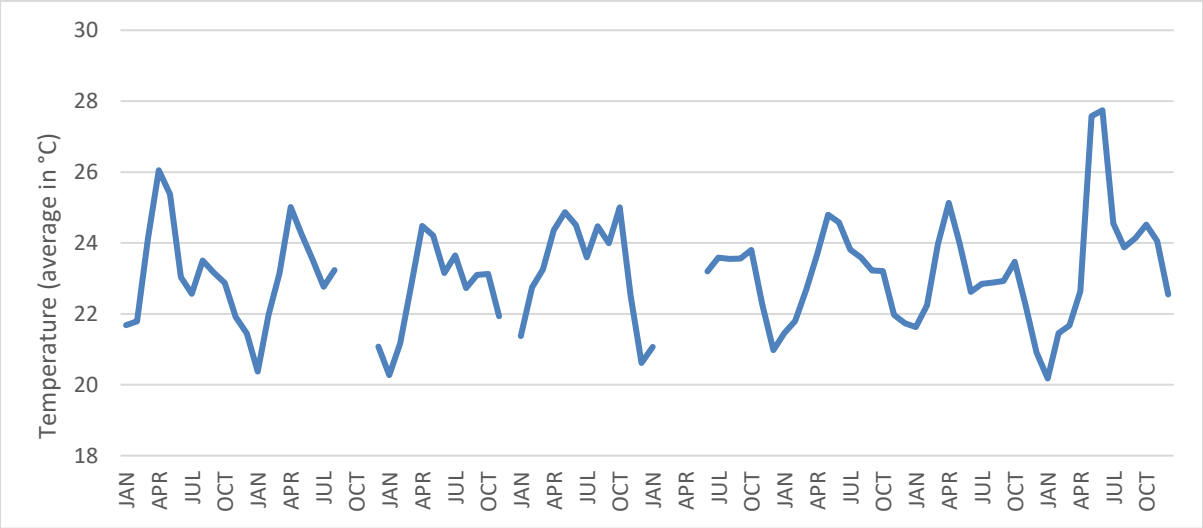


Figure 8

Regression of temperature

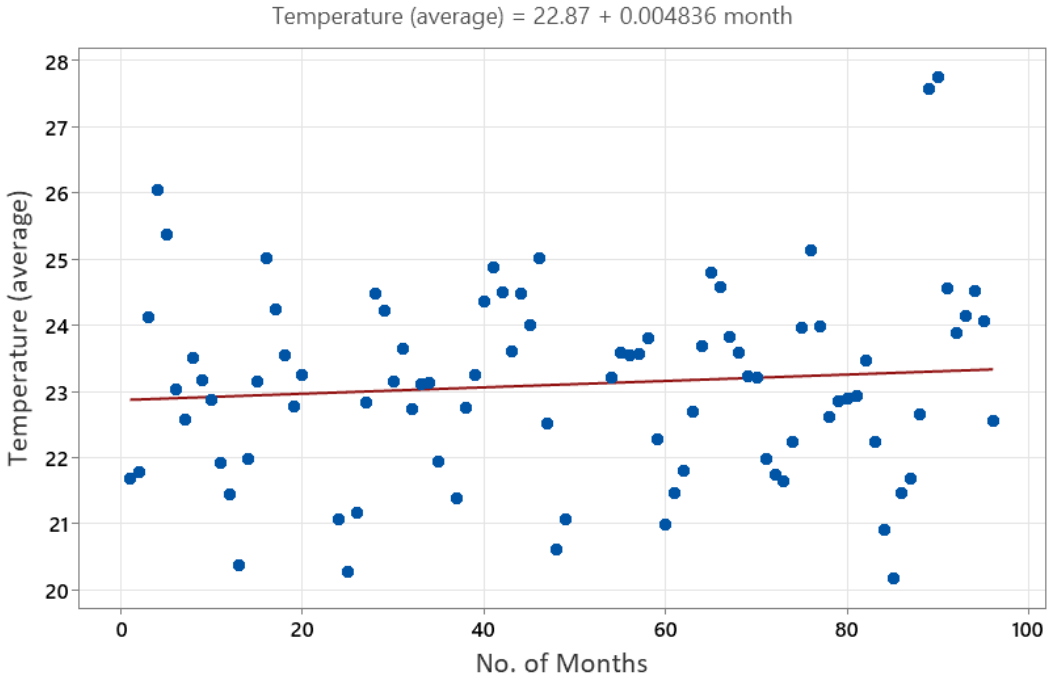


Table 3

Bird species with significant linear trends, abundance regressed against temperature

No.	Species	R^2	F	P	Trend	Occurrence
1	*Colinus cristatus*	7%	6.25	0.015	+	R
2	*Patagioenas flavirostris*	5%	4.13	0.046	-	R
3	*Columbina passerina*	8%	6.82	0.011	-	R
4	*Piaya cayana*	3%	2.99	0.088	+	R
5	*Cynanthus canivetii*	4%	3.49	0.066	-	R
6	*Amazilia rutila*	6%	5.51	0.022	-	R
7	*Bubulcus ibis*	16%	13.16	0.001	-	R
8	*Glaucidium brasilianum*	10%	8.14	0.006	-	R
9	*Caracara plancus*	6%	4.91	0.03	-	R
10	*Eupsittula canicularis*	4%	3.64	0.061	-	R
11	*Tityra semifasciata*	4%	3.7	0.059	+	R
12	*Myiarchus tuberculifer*	4%	3.74	0.058	-	R
13	*Myiarchus tyrannulus*	3%	3.15	0.08	-	R
14	*Myiozetetes similis*	5%	4.68	0.034	-	R
15	*Tyrannus forficatus*	3%	3.34	0.072	-	M
16	*Tachycineta thalassina*	6%	4.98	0.029	-	M
17	*Cantorchilus modestus*	13%	10.85	0.002	+	R
18	*Spinus psaltria*	7%	5.85	0.018	-	R
19	*Molothrus aeneus*	3%	3.24	0.077	+	R
20	*Geothlypis trichas*	16%	13.7	< 0.001	-	M
21	*Setophaga magnolia*	13%	11.29	0.001	-	M
22	*Setophaga petechia*	12%	8.5	0.005	-	R
23	*Piranga ludoviciana*	18%	15.85	< 0.001	-	M

No.	Species	R^2	F	P	Trend	Occurrence
24	*Saltator grandis*	13%	10.86	0.002	+	R

Note. += positive; - = negative; s= stable; M= Migratory; R= Resident

Figure 9

Linear regression of Bubulcus ibis over temperature

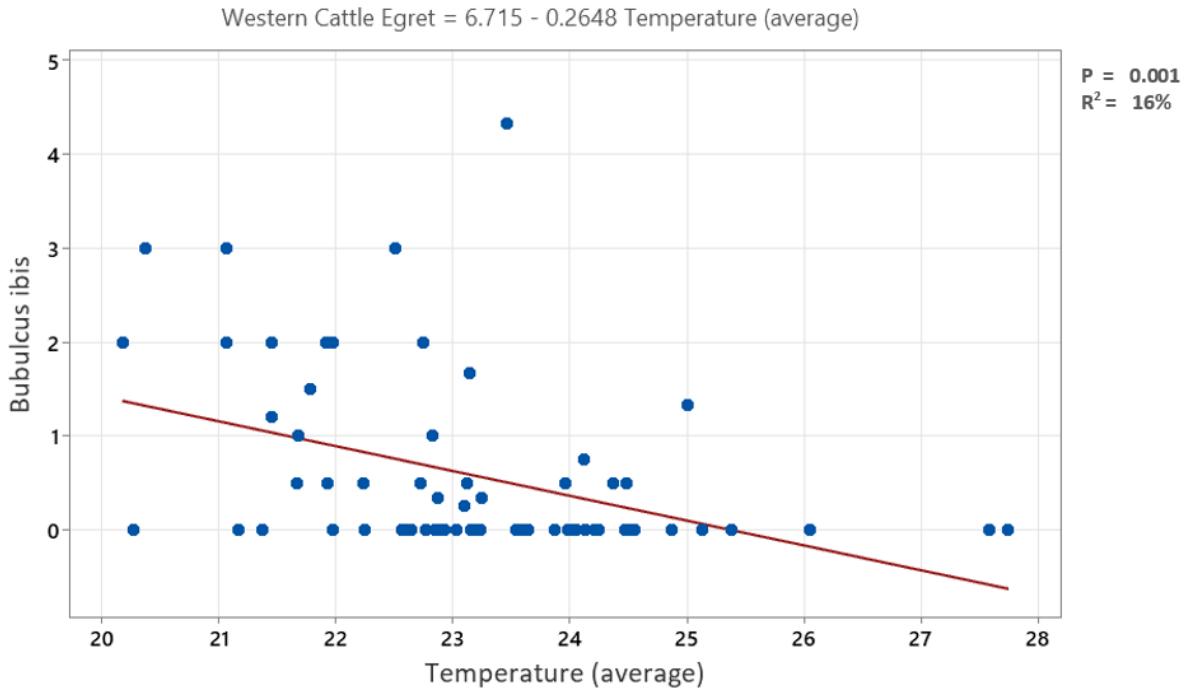


Figure 10

Linear regression results for Piranga ludoviciana on temperature

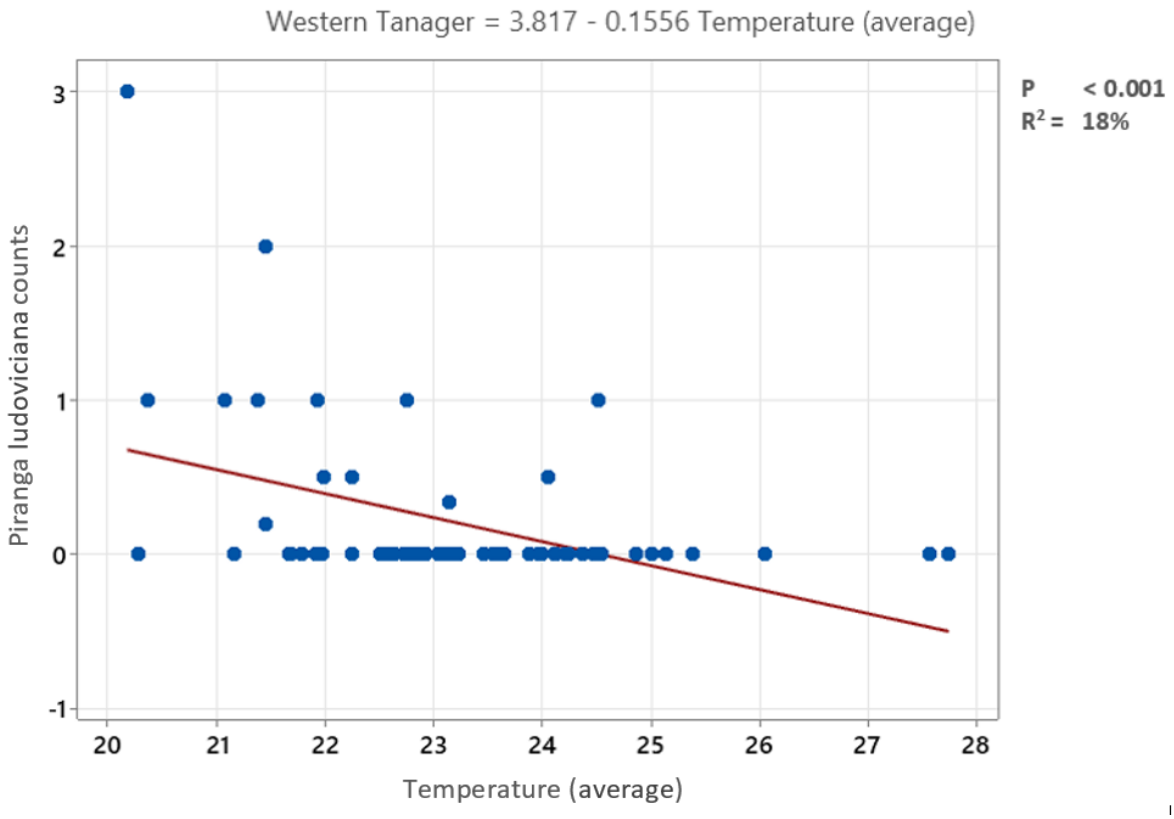
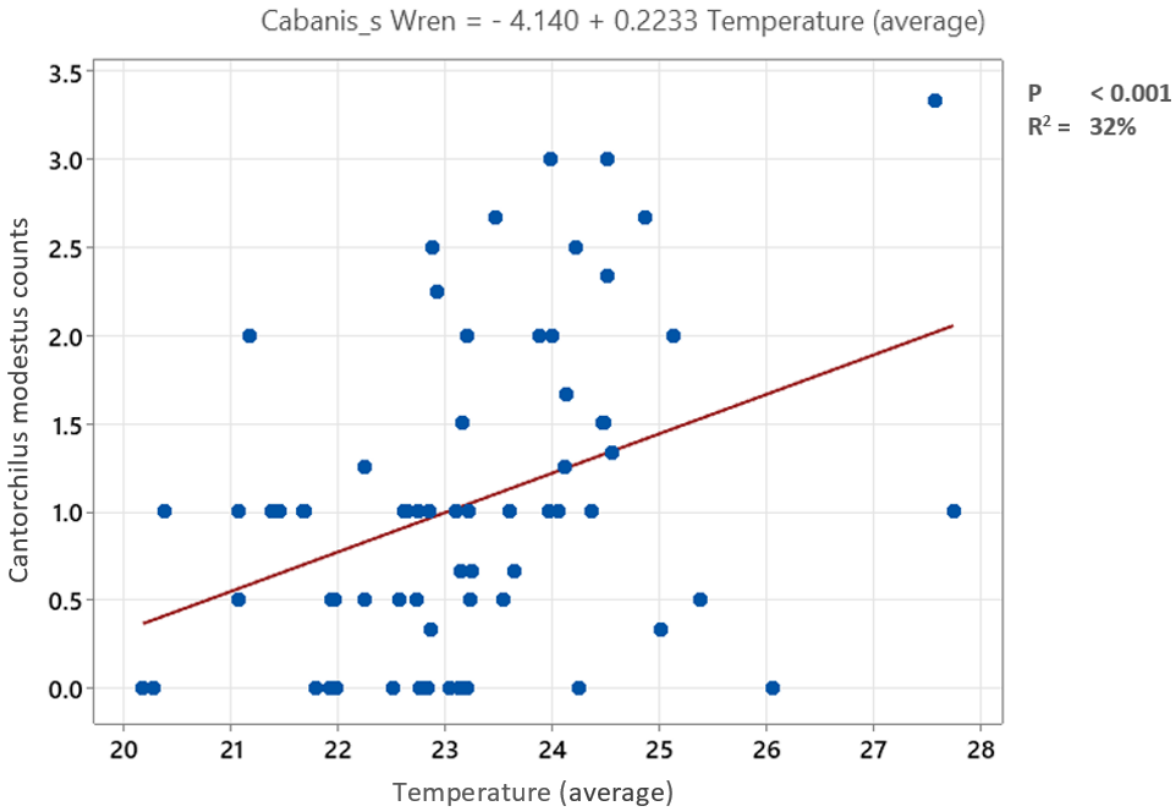


Figure 11

Linear regression results for Cantorchilus modestus on temperature



The precipitation (Figure 12) did not exhibit a significant temporal trend (P = 0.319, R^2 = 0%). However, it appeared to increase slightly over time (Figure 13). As a predictor variable, this had a relationship with bird species, which had 10 (11%) with negative, and a positive relationship of two (2%) species (Table 4). Few species have a positive relationship, like the insectivore-frugivore resident Turquoise-browed Motmot *Eumomota superciliosa* (P = 0.007, R^2 = 0.09, Figure 14), or the majority that have a negative relationship, like the insectivore resident, Brown-crested Flycatcher *Myiarchus tyrannulus* (P = 0.001, R^2 = 0.13, Figure 15).

Meanwhile, precipitation showed no effect in 39 (44%) species analyzed (Table 4, Appendix C). Changes in precipitation analysis methods can enhance the study of their impact on bird species. Other studies used precipitation at different times, such as the previous semester or year, because it

gives vegetation a gradual change effect (Faaborg et al., 1984). Precipitation affects vegetation by determining how much water is available and its effects are seen over time. So dense abundant vegetation and fruit is supported by higher rainfall, while sparse, plants that tolerate drought thrive by lower rainfall. Rainfall changes vegetation, which in turn impacts birds by influencing their habitats, food sources, and nesting locations. This results in changes to bird populations and the diversity of bird species (Ferger et al., 2014).

A study showed that precipitation in dry regions (≤ 5 mm average daily precipitation) improves bird populations, but an increase in precipitation in humid ecosystems (≥ 5 mm average daily precipitation) decreases populations (Chen & Khanna, 2024). The agroecological farm, located in a secondary tropical dry forest with an annual mean precipitation of 1,100 mm, receives 3 mm of average daily precipitation, thereby qualifying as a dry region. Different from the results, an increase of bird abundance was expected since precipitation is slightly rising over time.

Figure 12

Sum of monthly precipitation (2015-2024)

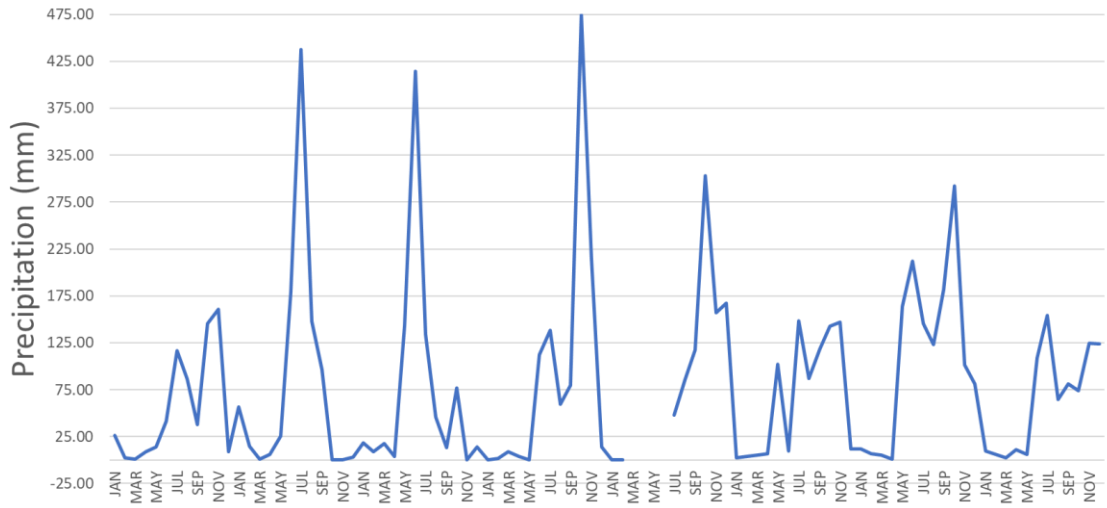


Figure 13

Regression of precipitation

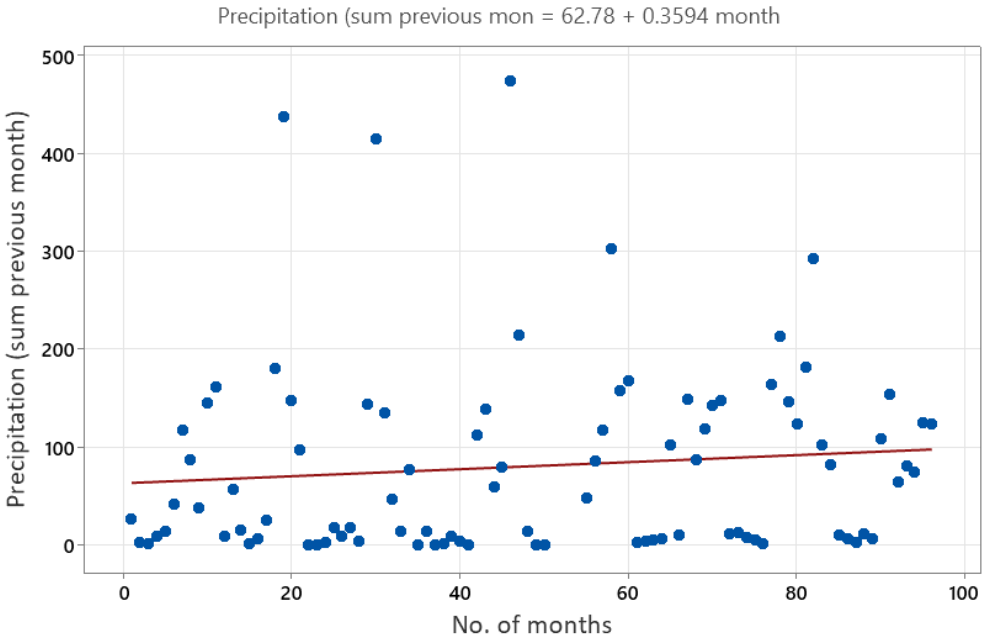


Table 4

Bird species with significant linear trends, abundance regressed against precipitation

No.	Species	Ocurrence	R^2	F	P	trend
1	*Columbina passerina*	R	8%	6.99	0.01	+
2	*Glaucidium brasilianum*	R	6%	5.18	0.026	-
3	*Eumomota superciliosa*	R	9%	7.72	0.007	+
4	*Caracara plancus*	R	3%	3.37	0.071	-
5	*Myiarchus tyrannulus*	R	13%	11.58	0.001	-
6	*Tyrannus melancholicus*	R	4%	3.9	0.052	-
7	*Euphonia affinis*	R	6%	5.83	0.018	-
8	*Amblycercus holosericeus*	R	4%	3.88	0.053	-
9	*Geothlypis trichas*	M	4%	4.19	0.045	-
10	*Setophaga magnolia*	M	12%	10.72	0.002	-
11	*Setophaga petechia*	R	7%	6.41	0.014	-
12	*Piranga ludoviciana*	M	5%	4.8	0.032	-

Note. += positive; - = negative

Figure 14

Linear regression results for Eumomota superciliosa on precipitation

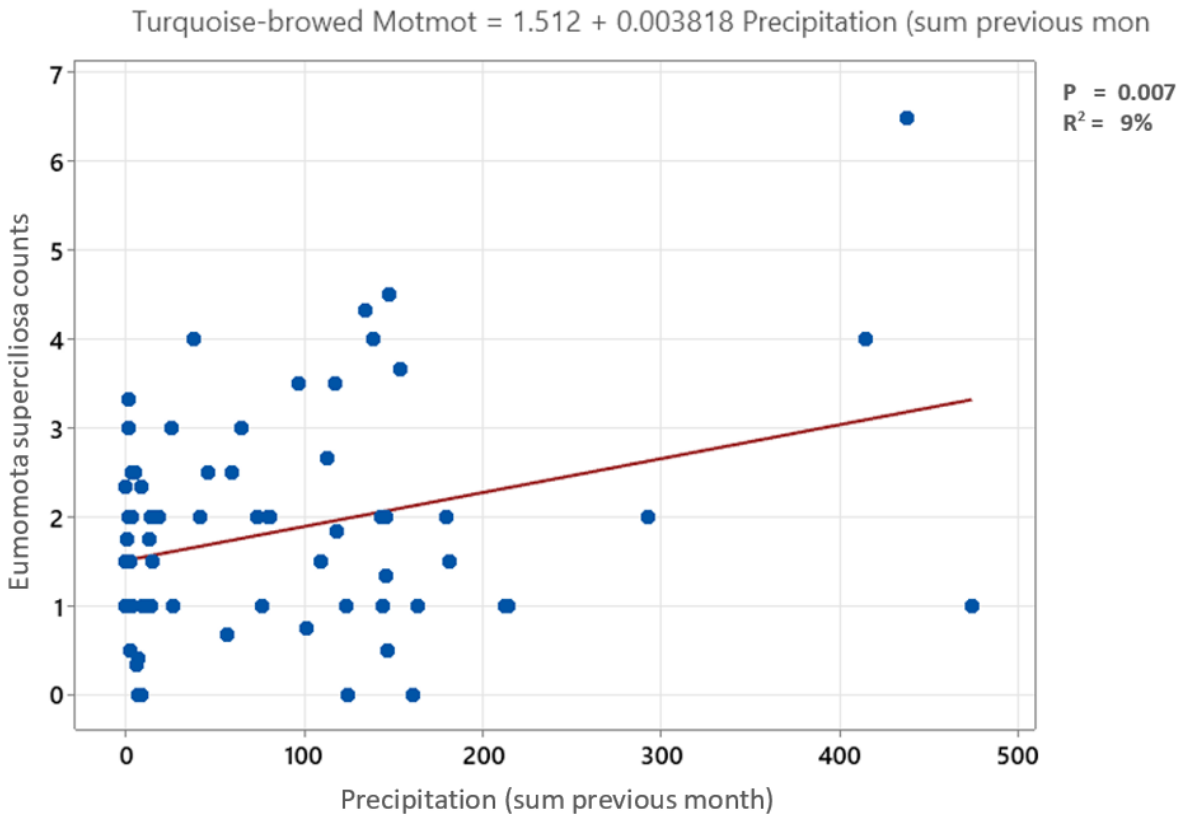
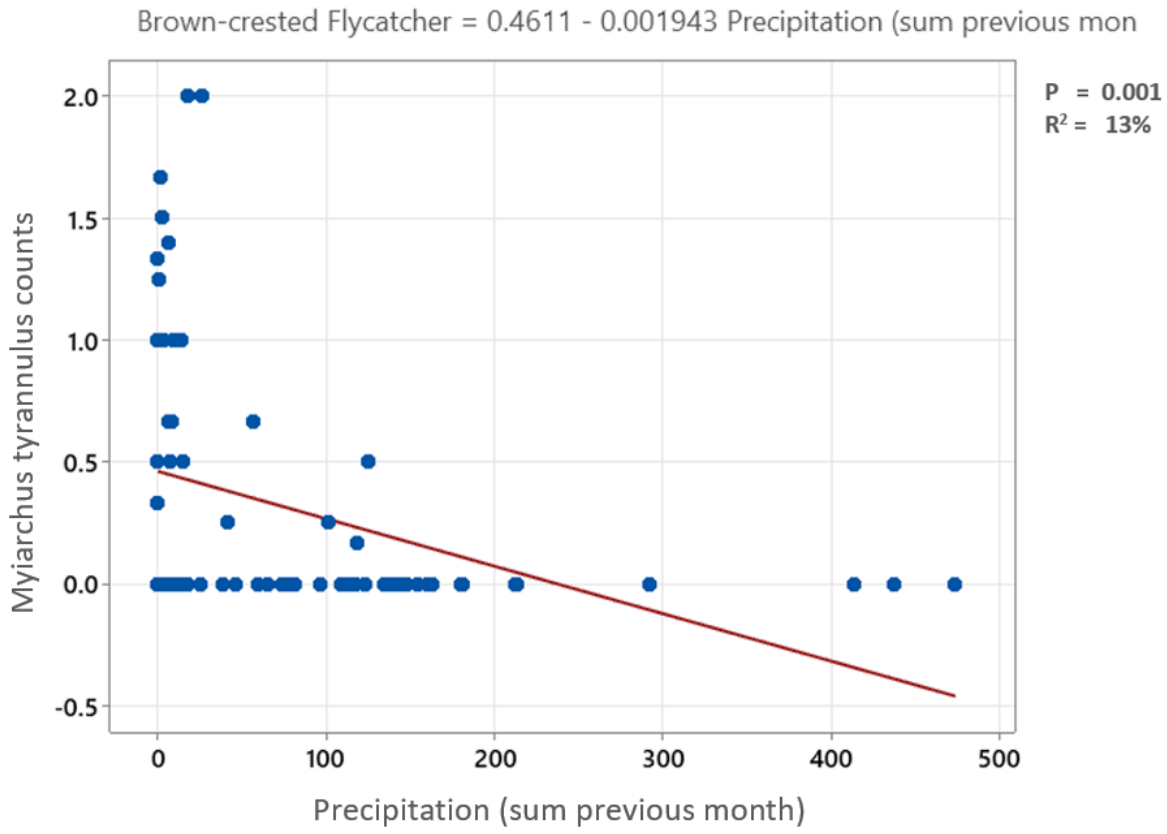


Figure 15

Linear regression results for Myiarchus tyrannulus on precipitation



Migratory and Resident Birds

From the 88 species of birds analyzed (Table 2), 60 (68%) were resident and 28 (32%) were migratory. Temporal trends in abundance were detected in 42 (70%) resident species and in nine (32%) migratory species. Resident birds showed declines in 33 (55%) species and increases in nine (15%) species. While migratory species showed decline in eight (29%) species and increase in one (4%). A chi-square test indicated a significant difference between the temporal trends of these two groups (P = 0.003). However, the average magnitude of population decline was 53% for resident birds and 85% for migratory birds. The average population increase was 153% for resident birds and 177% for migratory birds (Table 2).

As expected, population changes of residents are different from migrants. Compared to migrants, resident species show a greater proportion of declines over time. This could be due to local stressors that impact the populations of resident species, more than migrants, such as hunting, loss of habitat, increased predation, or disease. Conditions on the agroecological farm could cause these negative effects. On the other hand, the magnitude of changes in the population of migratory birds was, on average, greater than that of resident species, possibly because of their ability to relocate, their adaptation to a highly mobile lifestyle, or due to causes that are external to the farm during the breeding season and transit times.

With respect to temperature, six resident species and zero migratory species exhibited a positive relationship, while 12 resident species and six migratory species showed a negative relationship (Table 5, Table 6). No relationship was found for 24 resident species and three migratory species (Appendix D, Appendix E). A much higher proportion of migrants, 67%, were negatively affected by temperature, while only 29% of residents showed this pattern. The two groups apparently respond differently to temperature (chi-square test, P = 0.077).

For precipitation, two resident species and no migratory species showed a positive relationship, while four migratory and six resident species showing a negative relationship (Table 5, Table 6). Additionally, five migratory and 34 resident birds showed no relationship with precipitation. The proportion of migrants negatively correlated with precipitation (44%) was higher than the proportion of residents (14%), but the difference was not statistically significant (chi-square test, P = 0.106).

Differences were expected between the two occurrence groups due to their behaviors of residency and migration (Schaefer et al., 2008). Temperature may impact migratory and resident species differently altering their competitive interactions (Ahola et al., 2007), or in the case of migrants, influencing departure dates in the early spring. For example, global warming is known to move migration dates earlier in the year, which should cause migrant abundance to decline before

the warmest months of the year in Honduras. This could lead to more negative correlation with temperature for migrants, matching the observed results. Based on results from Puerto Rico (Faaborg et al., 1984), residents were expected to respond more positively to rainfall than migrants. This relationship may have occurred in Honduras, but only two resident species responded positively (and zero migrants) and the difference was not statistically significant.

Table 5

Migrant species with significant linear trends, abundance regressed against climate variables

No.	Species	Temperature	Precipitation	Diet
1	*Tyrannus forficatus*	-	s	I, F
2	*Tachycineta thalassina*	-	s	I
3	*Geothlypis trichas*	-	-	I
4	*Setophaga magnolia*	-	-	I
5	*Setophaga petechia*	-	-	I
6	*Piranga ludoviciana*	-	-	I, F

Note. += positive; -= negative; s=stable; I=insectivore; F= frugivore

Table 6

Resident species with significant linear trends, abundance regressed against climate variables

No.	Species	Temperature	Precipitation	Diet
1	*Colinus cristatus*	+	s	I, G
2	*Patagioenas flavirostris*	-	s	F
3	*Columbina passerina*	-	+	G
4	*Piaya cayana*	+	s	I
5	*Cynanthus canivetii*	-	s	N
6	*Amazilia rutila*	-	s	N
7	*Bubulcus ibis*	-	s	I
8	*Glaucidium brasilianum*	-	-	C, I
9	*Eumomota superciliosa*	s	+	I, F
10	*Caracara plancus*	-	-	C
11	*Eupsittula canicularis*	-	s	F
12	*Tityra semifasciata*	+	s	F, I
13	*Myiarchus tuberculifer*	-	s	I
14	*Myiarchus tyrannulus*	-	-	I
15	*Myiozetetes similis*	-	s	I, F
16	*Tyrannus melancholicus*	s	-	I, F
17	*Cantorchilus modestus*	+	s	I
18	*Euphonia affinis*	s	-	F
19	*Spinus psaltria*	-	s	G, I
20	*Amblycercus holosericeus*	s	-	I
21	*Molothrus aeneus*	+	s	G
22	*Saltator grandis*	+	s	I, F

Note. += positive; -= negative; s=stable; I=insectivore; F= frugivore; C= carnivore; G= granivore; N= nectivore

Conclusions

During the study period, more species declined than increased. If this trend persists, it will eventually erode the biodiversity of the agroecological farm. Biodiversity is a key part of the agroecological farm strategy, which relies on a biodiverse ecosystem to be resilient to climate change, repel invasive species, and prevent losses to agricultural pests.

Less than half of the species show a relationship with temperature (20% negative and 7% positive). Less than a quarter of species showed a relationship with precipitation (11% negative and 2% positive). Most species showed no relationship with temperature and precipitation, which suggest that most species are adapted to the observed climatic variation. However, if the climate variation reaches extremes, this can alter ecosystem dynamics and make the farm more vulnerable to external and internal influences.

Migratory and resident species showed statistically significant differences in their responses to time and temperature, but not to precipitation. Temporal trends revealed that a higher proportion of resident species were declining compared to migrants, yet the magnitude of population decline was stronger in migratory species. Additionally, a greater number of migratory species showed negative correlations with temperature than resident species, indicating a likely decline in the ecosystem services derived from migratory species on the agroecological farm.

Recommendations

Use non-parametric analysis methods to evaluate trends in bird populations. Some bird counts violate independence assumptions, such as by counting all individuals in flocks and family groups. Also, when birds form mixed species foraging flocks, various species follow one leader, potentially generating bias in population counts. Using only presence or absence data may help eliminate violation of independence assumptions.

Conduct further analyses of the relationship of avian feeding guilds to temperature and precipitation; additional factors that may impact these relationships include food availability, predation or abundance of predators, and human activities such as agriculture and urbanization. Considering these factors may enhance our comprehension of avian ecology and suggest strategies to alleviate further declines. This information should help managers in the farm to provide preventive methods to maintain biodiversity.

Evaluate different variables of precipitation and temperature, such as different temporal scales (seasonal, biannual, annual). These two climate variables are thought to be important to birds because of their influence on vegetation which affects the food availability across different avian alimentary guilds.

Develop a plan for biodiversity conservation focusing on the declining species in the agroecological farm. The plan could consider training personal and managers of the farm in practices focused on conservation. This iniciative will help to mitigate declines not just of bird species but also in the overall biodiversity.

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Appendices

Appendix A

Bird species linear regression over time (months)

No.	Species	R^2	F	P	Trend	Significance
1	*Colinus cristatus*	2%	2.87	0.093	d	significant
2	*Patagioenas flavirostris*	3%	3.8	0.054	d	significant
3	*Columbina inca*	5%	6.55	0.012	d	significant
4	*Columbina passerina*	3%	4.35	0.04	d	significant
5	*Columbina talpacoti*	0%	1.32	0.254	s	not significant
6	*Leptotila verreauxi*	0%	0.98	0.325	s	not significant
7	*Zenaida asiatica*	13%	15.91	< 0.001	d	significant
8	*Crotophaga sulcirostris*	14%	16.72	< 0.001	d	significant
9	*Morococcyx erythropygus*	41%	71.17	0	d	significant
10	*Piaya cayana*	4%	4.69	0.033	i	significant
11	*Archilochus colubris*	0%	0.31	0.579	s	not significant
12	*Cynanthus canivetii*	43%	74.63	0	d	significant
13	*Amazilia rutila*	3%	3.64	0.059	d	significant
14	*Bubulcus ibis*	17%	21.97	< 0.001	d	significant
15	*Coragyps atratus*	0%	0.97	0.326	s	not significant
16	*Cathartes aura*	0%	0.03	0.855	s	not significant
17	*Pandion haliaetus*	49%	96.25	< 0.001	d	significant
18	*Buteogallus anthracinus*	0%	0.0023	0.962	s	not significant
19	*Rupornis magnirostris*	26%	36.01	< 0.001	d	significant
20	*Buteo brachyurus*	7%	1.11	0.296	s	not significant
21	*Glaucidium brasilianum*	12%	8.61	0.004	i	significant
22	*Eumomota superciliosa*	0%	14.18	< 0.001	d	significant
23	*Melanerpes formicivorus*	5%	0.06	0.805	s	not significant
24	*Melanerpes aurifrons*	9%	6.08	0.015	d	significant
25	*Herpetotheres cachinnans*	4%	11.2	0.001	d	significant
26	*Caracara plancus*	22%	5.44	0.022	d	significant
27	*Amazona albifrons*	25%	29.33	< 0.001	i	significant
28	*Eupsittula canicularis*	0%	34.25	< 0.001	d	significant
29	*Thamnophilus doliatus*	29%	1.31	0.254	s	not significant
30	*Tityra semifasciata*	0%	41.82	< 0.001	i	significant
31	*Pachyramphus aglaiae*	0%	0.36	0.55	s	not significant
32	*Tolmomyias sulphurescens*	21%	0.95	0.332	s	not significant
33	*Camptostoma imberbe*	1%	26.85	< 0.001	d	significant
34	*Empidonax minimus*	48%	1.7	0.196	s	not significant
35	*Myiarchus tuberculifer*	0%	94.09	< 0.001	d	significant
36	*Myiarchus nuttingi*	0%	0.2	0.656	s	not significant
37	*Myiarchus crinitus*	9%	0.16	0.692	s	not significant
38	*Myiarchus tyrannulus*	36%	11.04	0.001	d	significant
39	*Pitangus sulphuratus*	23%	56.48	< 0.001	d	significant
40	*Megarynchus pitangua*	10%	30.02	< 0.001	d	significant
41	*Myiozetetes similis*	13%	12.16	0.001	d	significant
42	*Tyrannus melancholicus*	35%	16.36	< 0.001	d	significant
43	*Tyrannus verticalis*	23%	1.35	0.249	s	not significant

No.	Species	R^2	F	P	Trend	Significance
44	*Tyrannus forficatus*	53%	29.8	< 0.001	d	significant
45	*Cyclarhis gujanensis*	1%	110.93	< 0.001	d	significant
46	*Vireo flavifrons*	8%	1.82	0.18	s	not significant
47	*Calocitta formosa*	88%	9.03	0.003	i	significant
48	*Tachycineta thalassina*	0%	736.31	< 0.001	d	significant
49	*Stelgidopteryx serripennis*	0%	0.66	0.417	s	not significant
50	*Hirundo rustica*	12%	0	0.998	s	not significant
51	*Polioptila albiloris*	0%	14.01	< 0.001	d	significant
52	*Campylorhynchus rufinucha*	32%	0.25	0.622	s	not significant
53	*Cantorchilus modestus*	0%	46.88	< 0.001	i	significant
54	*Dumetella carolinensis*	0%	0.68	0.411	s	not significant
55	*Turdus grayi*	3%	0.11	0.738	s	not significant
56	*Euphonia affinis*	67%	3.94	0.05	i	significant
57	*Spinus psaltria*	9%	197.93	< 0.001	d	significant
58	*Peucaea ruficauda*	0%	11.23	0.001	d	significant
59	*Icteria virens*	12%	0.07	0.785	s	not significant
60	*Amblycercus holosericeus*	36%	14.91	< 0.001	d	significant
61	*Icterus spurius*	0%	55.84	< 0.001	d	significant
62	*Icterus pustulatus*	31%	0.12	0.73	s	not significant
63	*Icterus pectoralis*	0%	45.2	< 0.001	d	significant
64	*Icterus gularis*	0%	1.2	0.276	s	not significant
65	*Icterus galbula*	7%	0.17	0.682	s	not significant
66	*Molothrus aeneus*	34%	8.09	0.005	i	significant
67	*Dives dives*	21%	51.47	< 0.001	d	significant
68	*Quiscalus mexicanus*	0%	26.58	< 0.001	i	significant
69	*Seiurus aurocapilla*	0%	1.37	0.244	s	not significant
70	*Leiothlypis peregrina*	1%	0	0.996	s	not significant
71	*Geothlypis tolmiei*	33%	2.18	0.143	s	not significant
72	*Geothlypis trichas*	0%	49.82	< 0.001	d	significant
73	*Setophaga citrina*	0%	0.36	0.55	s	not significant
74	*Setophaga ruticilla*	4%	0.04	0.838	s	not significant
75	*Setophaga magnolia*	9%	5.45	0.022	d	significant
76	*Setophaga petechia*	52%	10.58	0.002	d	significant
77	*Setophaga pensylvanica*	0%	109.51	< 0.001	d	significant
78	*Basileuterus delattrii*	0%	0.63	0.431	s	not significant
79	*Piranga rubra*	3%	0.1	0.755	s	not significant
80	*Piranga ludoviciana*	0%	3.59	0.061	i	significant
81	*Pheucticus ludovicianus*	32%	0.51	0.476	s	not significant
82	*Passerina caerulea*	0%	48.06	< 0.001	d	significant
83	*Passerina cyanea*	87%	0.72	0.399	s	not significant
84	*Passerina ciris*	17%	1.87	0.174	s	not significant
85	*Spiza americana*	9%	1.17	0.282	s	not significant
86	*Volatinia jacarina*	0%	10.22	0.002	d	significant
87	*Saltator atriceps*	6%	0.16	0.69	S	not significant
88	*Saltator grandis*	2%	6.84	0.01	d	significant

Note: i=increase; d= decrease; s=stable

Appendix B

Bird species linear regression over temperature

No.	Species	R^2	F	P	Trend	Significance
1	*Colinus cristatus*	7%	6.25	0.015	+	significant
2	*Patagioenas flavirostris*	5%	4.13	0.046	-	significant
3	*Columbina inca*	0%	0.01	0.933	s	not significant
4	*Columbina passerina*	8%	6.82	0.011	-	significant
5	*Zenaida asiatica*	0%	0.55	0.463	s	not significant
6	*Crotophaga sulcirostris*	0%	0.58	0.45	s	not significant
7	*Morococcyx erythropygus*	0%	0.01	0.932	s	not significant
8	*Piaya cayana*	3%	2.99	0.088	+	significant
9	*Cynanthus canivetii*	4%	3.49	0.066	-	significant
10	*Amazilia rutila*	6%	5.51	0.022	-	significant
11	*Bubulcus ibis*	16%	13.16	0.001	-	significant
12	*Pandion haliaetus*	0%	0.08	0.777	s	not significant
13	*Rupornis magnirostris*	1%	1.34	0.251	s	not significant
14	*Glaucidium brasilianum*	10%	8.14	0.006	-	significant
15	*Eumomota superciliosa*	1%	1.74	0.191	s	not significant
16	*Melanerpes aurifrons*	2%	2.03	0.159	s	not significant
17	*Herpetotheres cachinnans*	0%	0.37	0.543	s	not significant
18	*Caracara plancus*	6%	4.91	0.03	-	significant
19	*Amazona albifrons*	0%	0.3	0.586	s	not significant
20	*Eupsittula canicularis*	4%	3.64	0.061	-	significant
21	*Tityra semifasciata*	4%	3.7	0.059	+	significant
22	*Camptostoma imberbe*	0%	0.14	0.713	s	not significant
23	*Myiarchus tuberculifer*	4%	3.74	0.058	-	significant
24	*Myiarchus tyrannulus*	3%	3.15	0.08	-	significant
25	*Pitangus sulphuratus*	0%	0.66	0.419	s	not significant
26	*Megarynchus pitangua*	2%	2.28	0.136	s	not significant
27	*Myiozetetes similis*	5%	4.68	0.034	-	significant
28	*Tyrannus melancholicus*	0%	0	0.997	s	not significant
29	*Tyrannus forficatus*	3%	3.34	0.072	-	significant
30	*Cyclarhis gujanensis*	0%	0	0.969	s	not significant
31	*Calocitta formosa*	0%	0.01	0.941	s	not significant
32	*Tachycineta thalassina*	6%	4.98	0.029	-	significant
33	*Polioptila albiloris*	0%	1.02	0.315	s	not significant
34	*Cantorchilus modestus*	13%	10.85	0.002	+	significant
35	*Euphonia affinis*	0%	0.05	0.819	s	not significant
36	*Spinus psaltria*	7%	5.85	0.018	-	significant
37	*Peucaea ruficauda*	0%	0	0.997	s	not significant
38	*Amblycercus holosericeus*	0%	1.05	0.309	s	not significant
39	*Icterus spurius*	0%	1.02	0.317	s	not significant
40	*Icterus pectoralis*	0%	0.58	0.45	s	not significant
41	*Molothrus aeneus*	3%	3.24	0.077	+	significant
42	*Dives dives*	0%	0.46	0.498	s	not significant
43	*Quiscalus mexicanus*	0%	0.2	0.656	s	not significant
44	*Geothlypis trichas*	16%	13.7	< 0.001	-	significant
45	*Setophaga magnolia*	13%	11.29	0.001	-	significant
46	*Setophaga petechia*	12%	8.5	0.005	-	significant
47	*Setophaga pensylvanica*	0%	0.17	0.683	s	not significant
48	*Piranga ludoviciana*	18%	15.85	< 0.001	-	significant

No.	Species	R^2	F	P	Trend	Significance
49	*Passerina caerulea*	0%	0.38	0.54	s	not significant
50	*Volatinia jacarina*	0%	1.11	0.295	s	not significant
51	*Saltator grandis*	13%	10.86	0.002	+	significant

No.	Species	R^2	F	P	trend	significance
1	*Colinus cristatus*	1%	1.41	0.239	s	not significant
2	*Patagioenas flavirostris*	0%	0.51	0.476	s	not significant
3	*Columbina inca*	0%	0.47	0.497	s	not significant
4	*Columbina passerina*	8%	6.99	0.01	+	significant
5	*Zenaida asiatica*	0%	0.17	0.684	s	not significant
6	*Crotophaga sulcirostris*	2%	2.68	0.112	s	not significant
7	*Morococcyx erythropygus*	1%	1.67	0.2	s	not significant
8	*Piaya cayana*	1%	1.37	0.246	s	not significant
9	*Cynanthus canivetii*	1%	1.99	0.163	s	not significant
10	*Amazilia rutila*	0%	0.68	0.411	s	not significant
11	*Bubulcus ibis*	0%	0.71	0.403	s	not significant
12	*Pandion haliaetus*	0%	0.2	0.658	s	not significant
13	*Rupornis magnirostris*	0%	0.54	0.465	s	not significant
14	*Glaucidium brasilianum*	6%	5.18	0.026	-	significant
15	*Eumomota superciliosa*	9%	7.72	0.007	+	significant
16	*Melanerpes aurifrons*	0%	0.08	0.779	s	not significant
17	*Herpetotheres cachinnans*	0%	0.11	0.742	s	not significant
18	*Caracara plancus*	3%	3.37	0.071	-	significant
19	*Amazona albifrons*	0%	0.27	0.605	s	not significant
20	*Eupsittula canicularis*	2%	2.78	0.1	s	not significant
21	*Tityra semifasciata*	0%	0.06	0.813	s	not significant
22	*Camptostoma imberbe*	2%	2.76	0.101	s	not significant
23	*Myiarchus tuberculifer*	0%	1.01	0.317	s	not significant
24	*Myiarchus tyrannulus*	13%	11.58	0.001	-	significant
25	*Pitangus sulphuratus*	0%	1.04	0.311	s	not significant
26	*Megarynchus pitangua*	0%	0.02	0.893	s	not significant
27	*Myiozetetes similis*	0%	0.71	0.404	s	not significant
28	*Tyrannus melancholicus*	4%	3.9	0.052	-	significant
29	*Tyrannus forficatus*	1%	1.58	0.213	s	not significant
30	*Cyclarhis gujanensis*	0%	0.73	0.395	s	not significant
31	*Calocitta formosa*	0%	0.12	0.731	s	not significant
32	*Tachycineta thalassina*	0%	1.18	0.282	s	not significant
33	*Polioptila albiloris*	0%	0.66	0.421	s	not significant
34	*Cantorchilus modestus*	0%	0.07	0.795	s	not significant
35	*Euphonia affinis*	6%	5.83	0.018	-	significant
36	*Spinus psaltria*	0%	0.05	0.819	s	not significant
37	*Peucaea ruficauda*	1%	1.37	0.246	s	not significant
38	*Amblycercus holosericeus*	4%	3.88	0.053	-	significant
39	*Icterus spurius*	0%	0.09	0.765	s	not significant

No.	Species	R^2	F	P	trend	significance
40	*Icterus pectoralis*	0%	0.67	0.416	s	not significant
41	*Molothrus aeneus*	0%	0.08	0.773	s	not significant
42	*Dives dives*	0%	0.34	0.561	s	not significant
43	*Quiscalus mexicanus*	2%	2.66	0.108	s	not significant
44	*Geothlypis trichas*	4%	4.19	0.045	-	significant
45	*Setophaga magnolia*	12%	10.72	0.002	-	significant
46	*Setophaga petechia*	7%	6.41	0.014	-	significant
47	*Setophaga pensylvanica*	0%	0.29	0.591	s	not significant
48	*Piranga ludoviciana*	5%	4.8	0.032	-	significant
49	*Passerina caerulea*	0%	0	0.967	s	not significant
50	*Volatinia jacarina*	0%	0.72	0.398	s	not significant
51	*Saltator grandis*	1%	1.41	0.239	s	not significant

Note: += positive; -= negative; s= no relationship

Appendix C

Bird species linear regression over total of previous month precipitation

No.	Species	R^2	F	P	trend	significance
1	*Colinus cristatus*	1%	1.41	0.239	s	not significant
2	*Patagioenas flavirostris*	0%	0.51	0.476	s	not significant
3	*Columbina inca*	0%	0.47	0.497	s	not significant
4	*Columbina passerina*	8%	6.99	0.01	+	significant
5	*Zenaida asiatica*	0%	0.17	0.684	s	not significant
6	*Crotophaga sulcirostris*	2%	2.68	0.112	s	not significant
7	*Morococcyx erythropygus*	1%	1.67	0.2	s	not significant
8	*Piaya cayana*	1%	1.37	0.246	s	not significant
9	*Cynanthus canivetii*	1%	1.99	0.163	s	not significant
10	*Amazilia rutila*	0%	0.68	0.411	s	not significant
11	*Bubulcus ibis*	0%	0.71	0.403	s	not significant
12	*Pandion haliaetus*	0%	0.2	0.658	s	not significant
13	*Rupornis magnirostris*	0%	0.54	0.465	s	not significant
14	*Glaucidium brasilianum*	6%	5.18	0.026	-	significant
15	*Eumomota superciliosa*	9%	7.72	0.007	+	significant
16	*Melanerpes aurifrons*	0%	0.08	0.779	s	not significant
17	*Herpetotheres cachinnans*	0%	0.11	0.742	s	not significant
18	*Caracara plancus*	3%	3.37	0.071	-	significant
19	*Amazona albifrons*	0%	0.27	0.605	s	not significant
20	*Eupsittula canicularis*	2%	2.78	0.1	s	not significant
21	*Tityra semifasciata*	0%	0.06	0.813	s	not significant
22	*Camptostoma imberbe*	2%	2.76	0.101	s	not significant
23	*Myiarchus tuberculifer*	0%	1.01	0.317	s	not significant
24	*Myiarchus tyrannulus*	13%	11.58	0.001	-	significant
25	*Pitangus sulphuratus*	0%	1.04	0.311	s	not significant
26	*Megarynchus pitangua*	0%	0.02	0.893	s	not significant
27	*Myiozetetes similis*	0%	0.71	0.404	s	not significant
28	*Tyrannus melancholicus*	4%	3.9	0.052	-	significant
29	*Tyrannus forficatus*	1%	1.58	0.213	s	not significant
30	*Cyclarhis gujanensis*	0%	0.73	0.395	s	not significant
31	*Calocitta formosa*	0%	0.12	0.731	s	not significant
32	*Tachycineta thalassina*	0%	1.18	0.282	s	not significant
33	*Polioptila albiloris*	0%	0.66	0.421	s	not significant
34	*Cantorchilus modestus*	0%	0.07	0.795	s	not significant
35	*Euphonia affinis*	6%	5.83	0.018	-	significant
36	*Spinus psaltria*	0%	0.05	0.819	s	not significant
37	*Peucaea ruficauda*	1%	1.37	0.246	s	not significant
38	*Amblycercus holosericeus*	4%	3.88	0.053	-	significant
39	*Icterus spurius*	0%	0.09	0.765	s	not significant
40	*Icterus pectoralis*	0%	0.67	0.416	s	not significant
41	*Molothrus aeneus*	0%	0.08	0.773	s	not significant
42	*Dives dives*	0%	0.34	0.561	s	not significant
43	*Quiscalus mexicanus*	2%	2.66	0.108	s	not significant
44	*Geothlypis trichas*	4%	4.19	0.045	-	significant
45	*Setophaga magnolia*	12%	10.72	0.002	-	significant

No.	Species	R^2	F	P	trend	significance
46	*Setophaga petechia*	7%	6.41	0.014	-	significant
47	*Setophaga pensylvanica*	0%	0.29	0.591	s	not significant
48	*Piranga ludoviciana*	5%	4.8	0.032	-	significant
49	*Passerina caerulea*	0%	0	0.967	s	not significant
50	*Volatinia jacarina*	0%	0.72	0.398	s	not significant
51	*Saltator grandis*	1%	1.41	0.239	s	not significant

Note: += positive; -= negative; s= no relationship

Appendix D

Migratory birds regression analysis results over climate variables

No.	Species	Temperature	Precipitation	Diet
1	*Pandion haliaetus*	s	s	C
2	*Tyrannus forficatus*	-	s	I, F
3	*Tachycineta thalassina*	-	s	I
4	*Icterus spurius*	s	s	I, N
5	*Geothlypis trichas*	-	-	I
6	*Setophaga magnolia*	-	-	I
7	*Setophaga petechia*	-	-	I
8	*Setophaga pensylvanica*	s	s	I
9	*Piranga ludoviciana*	-	-	I, F

Note: += positive; -= negative; s= no relationship; C= carnivore; I=insectivore; F= frugivore; N= nectarivore

Appendix E

Resident species linear regression results with climate variables

No.	Species	Temperature	Precipitation	Diet
1	Colinus cristatus	+	s	I, G
2	Patagioenas flavirostris	-	s	F
3	Columbina inca	s	s	G
4	Columbina passerina	-	+	G
5	Zenaida asiatica	s	s	G, F
6	Crotophaga sulcirostris	s	s	I
7	Morococcyx erythropygus	s	s	I
8	Piaya cayana	+	s	I
9	Cynanthus canivetii	-	s	N
10	Amazilia rutila	-	s	N
11	Bubulcus ibis	-	s	I
12	Rupornis magnirostris	s	s	C
13	Glaucidium brasilianum	-	-	C, I
14	Eumomota superciliosa	s	+	I, F
15	Melanerpes aurifrons	s	s	I, F
16	Herpetotheres cachinnans	s	s	C
17	Caracara plancus	-	-	C
18	Amazona albifrons	s	s	F
19	Eupsittula canicularis	-	s	F
20	Tityra semifasciata	+	s	F, I
21	Camptostoma imberbe	s	s	I
22	Myiarchus tuberculifer	-	s	I
23	Myiarchus tyrannulus	-	-	I
24	Pitangus sulphuratus	s	s	I, F
25	Megarynchus pitangua	s	s	I, F
26	Myiozetetes similis	-	s	I, F
27	Tyrannus melancholicus	s	-	I, F
28	Cyclarhis gujanensis	s	s	I
29	Calocitta formosa	s	s	I, C
30	Polioptila albiloris	s	s	I
31	Cantorchilus modestus	+	s	I
32	Euphonia affinis	s	-	F
33	Spinus psaltria	-	s	G, I
34	Peucaea ruficauda	s	s	G, I
35	Amblycercus holosericeus	s	-	I
36	Icterus pectoralis	s	s	I, N
37	Molothrus aeneus	+	s	G
38	Dives dives	s	s	I
39	Quiscalus mexicanus	s	s	I
40	Passerina caerulea	s	s	G
41	Volatinia jacarina	s	s	G, I
42	Saltator grandis	+	s	I, F

Note: += positive; -= negative; s= no relationship; C= carnivore; I=insectivore; F= frugivore; N= nectarivore; G=granivore