A TIMESERIES ANALYSIS OF FLORIDA COASTAL BIRD POPULATIONS AND RAINFALL

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ABSTRACT

Wading bird and shorebird vitality and populations are used by scientists as a barometer of an ecosystem and response to changes. We will look at the population sample of Florida shorebirds and wading birds deemed "Imperiled" by U.S. Fish and Wildlife Services from 1966 to 2019 in relation to average rainfall to forecast the population decline 10 years into the future.

INTRODUCTION

Wading birds and shorebirds are considered bellwethers of ecological health and climate change. Water managers and scientists closely monitor their nesting activity every year. A 2019 report showed that nesting was down nearly 30% from 2018 (Cook 2020). According to the U.S. Fish and Wildlife Service, their populations are declining across North American, possibly due loss of breeding, migration, and wintering habitats, and disturbance and exploitation. We will look at the impact of cyclical hydrological events, specifically increased precipitation has on declining populations in Florida over the period of 1966 through 2019.

The earth is warming, and so is Florida. Florida's average temperature has increased more than one degree Fahrenheit during the last century. Increased temperatures increased evaporation, which increases humidity, which increases the frequency and volume of precipitation. Increased temperatures also lead to rising sea levels due to increased precipitation and the melting of polar ice caps. This will lead to major loss of habitat expected to impact wading birds and shorebirds, both resident and migratory (What Climate Change Means for Florida 2016). A one-foot increase in sea-level could erode up to 200 ft of Florida coastline, jeopardizing the primary and protected habitat of wading and shorebirds (Tatiana Borisova 2008). Shorebirds and wading birds are highly vulnerable to the changing climate and will need swift conservation and policy enactment to prevent population collapse (al. 2014)

Because shorebirds and wading birds have evolved into ecologically variated subgroups, some species will be able to adapt, but scientists believe "species that are on the edge of their physiological range, that depend strongly on synchronizing life history events with environmental cues, or that have limited dispersal capability likely will be the most affected. Habitat fragmentation and urban development will complicate the ability of some animals to find new habitat," (Pearlstine 2009)

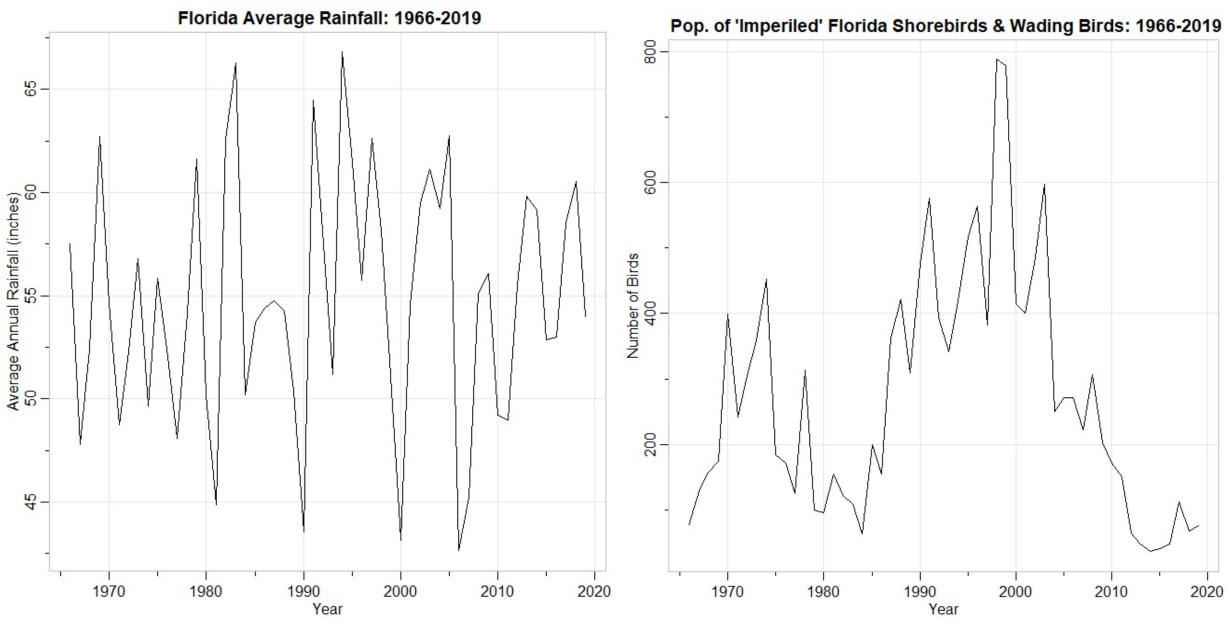
Energetic costs of breeding, egg laying, feeding the young are relative to cycle initiated by temperature, precipitation, and availability of food sources cue migration and breeding and disrupts egg-laying. Similarly, a change in timing of seasonal heavy precipitation, or overall increase in precipitation can impact clutch success and parental viability (Carey 2009). These cyclical disruptions also create conflict for resources between migratory and resident birds that respond to hydrologic cues to find food and nest (Pearlstine 2009).

MODEL SPECIFICATION

DATA

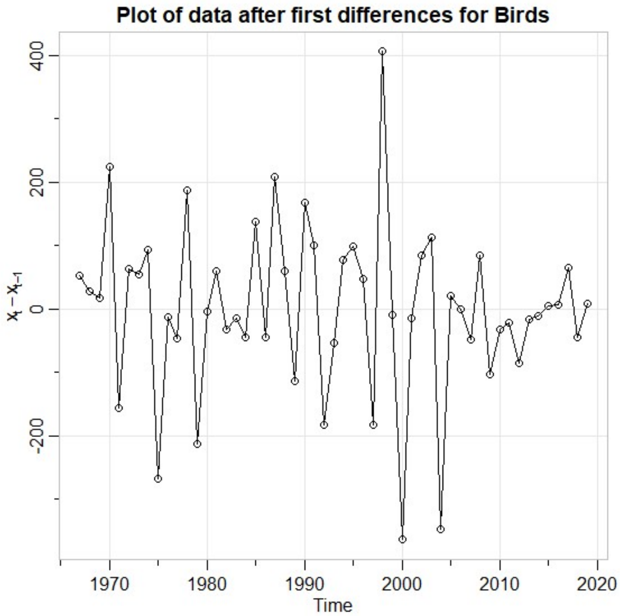
Data were compiled from the USGS Breeding Bird Survey (North American Breeding Bird Survey 1966-2019) and the FSU Climate Center (Florida statewide averaged precipitation data (in inches). n.d.). Rainfall was formatted from monthly to yearly. The USGS BBS survey was revised to include only birds listed as Imperiled by U.S. FWS.

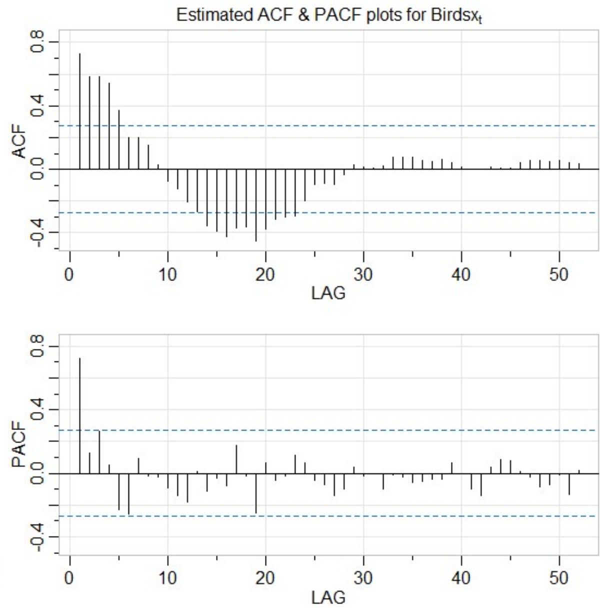
TABLE 1



DATA ANALYSIS

TABLE 2

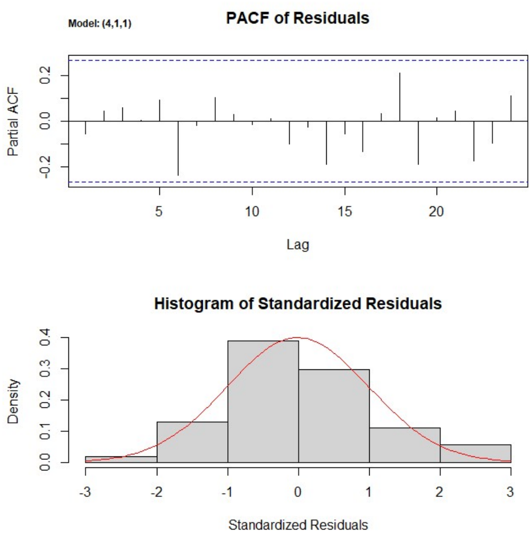


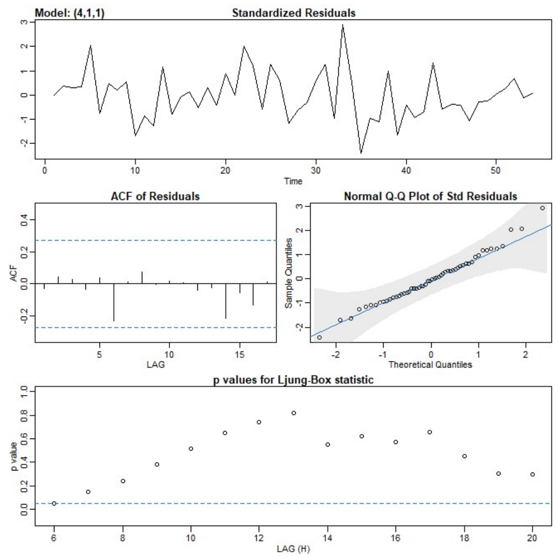


The data were nonstationary, so we construct plots of x_t vs. t and the estimated ACF to determine if the time series data is stationary. After reviewing the plots and Estimated ACF & PCF, we determine that the data have no seasonality. The ACF tails to zero after 5 lags and the PACF tails towards zero 1 lag. We will look at ARIMA with differencing.

FITTING AND DIAGNOSTICS

ARIMA(4,1,1)





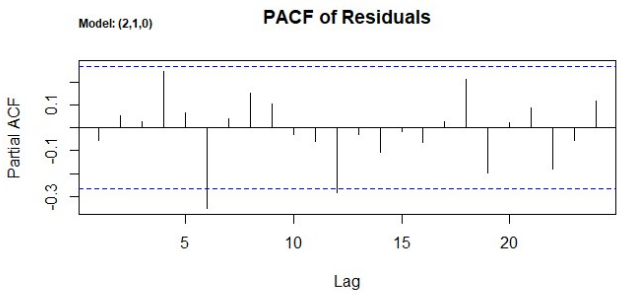
- Ljung-Box-Pierce test does not indicate any significant groups of autocorrelations
- ACF & PACF plots do not exhibit any significant values
- There are a few standardized residuals outside of the -1.96 and 1.96 range, but still < 3
- The normality assumption appears to be satisfied
- The hypothesis test for ϕ_1 = 0, ϕ_2 = 0 , ϕ_3 = 0 , ϕ_4 = 0 and θ_1 = 0 results in

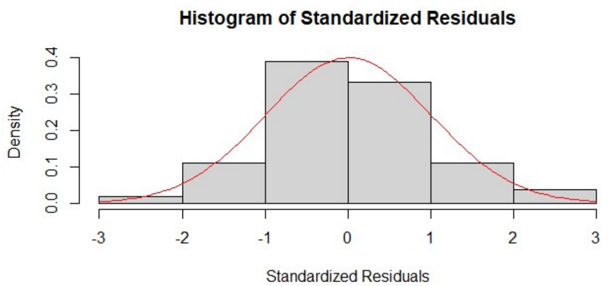
```
$ttable
         Estimate      SE t.value p.value
ar1       -0.0828  0.3099 -0.2672  0.7905
ar2       -0.1712  0.1645 -1.0409  0.3033
ar3        0.0821  0.1631  0.5031  0.6172
ar4        0.2817  0.1321  2.1329  0.0382
ma1       -0.2898  0.3065 -0.9454  0.3493
constant   1.3317 12.5707  0.1059  0.9161
```

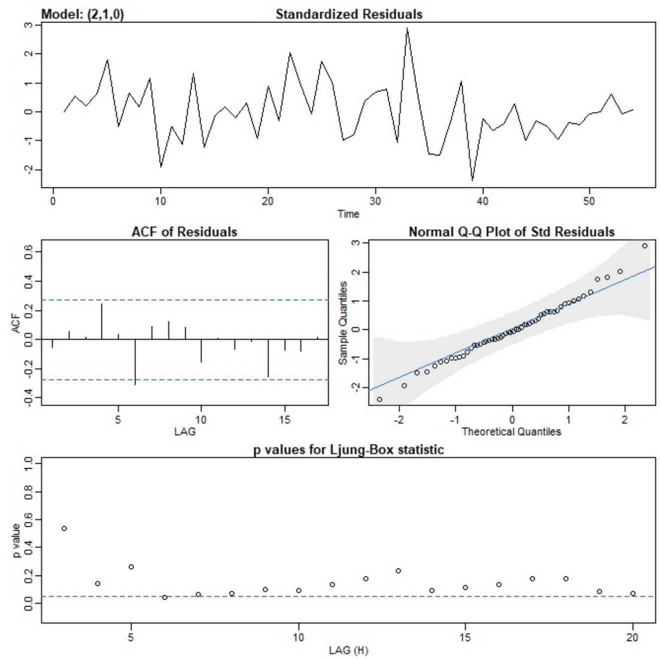
- Because the p-values are very large, there is not sufficient evidence to indicate that $\phi_n \neq 0$ and $\theta_n \neq 0$

Because some p-values are greater than 0.05, this model is not a good candidate

ARIMA(2,1,0





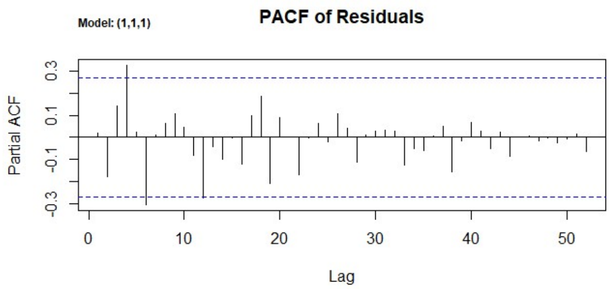


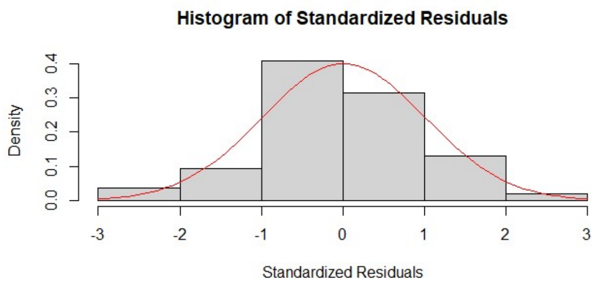
- Ljung-Box-Pierce indicates a few borderline groups of autocorrelations
- ACF & PACF exhibit some significant values
- There are a few standardized residuals outside of the -1.96 and 1.96 range, but still < 3
- The normality assumption appears to be satisfied
- The hypothesis test for ϕ_1 = 0, ϕ_2 = 0 and θ_1 = 0 results in

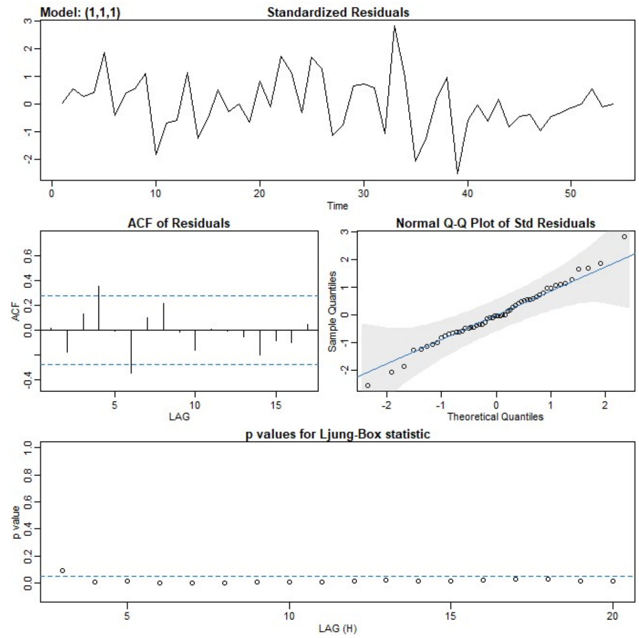
```
$degrees_of_freedom
[1] 48

$ttable
      Estimate     SE t.value p.value
ar1    -0.3220 0.1289 -2.4986  0.0159
ar2    -0.3587 0.1275 -2.8131  0.0071
trend  -0.4709 9.7868 -0.0481  0.9618
rain1  -0.0536 2.6066 -0.0206  0.9837
rain2  -0.4637 0.3475 -1.3344  0.1884
```

- Because some p-values are greater than 0.05, this model is not a good candidate

ARIMA(1,1,1)





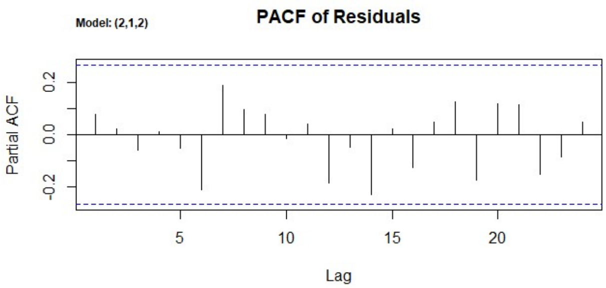


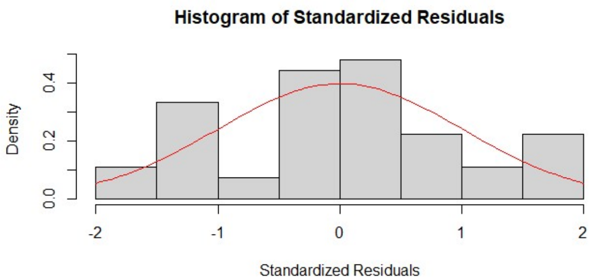
- Ljung-Box-Pierce indicates groups of autocorrelations
- ACF & PACF exhibit some significant values
- There are a few standardized residuals outside of the -1.96 and 1.96 range, but still < 3
- The normality assumption appears to be satisfied, though slightly skewed
- The hypothesis test for ϕ_1 = 0and and θ_1 = 0 results in

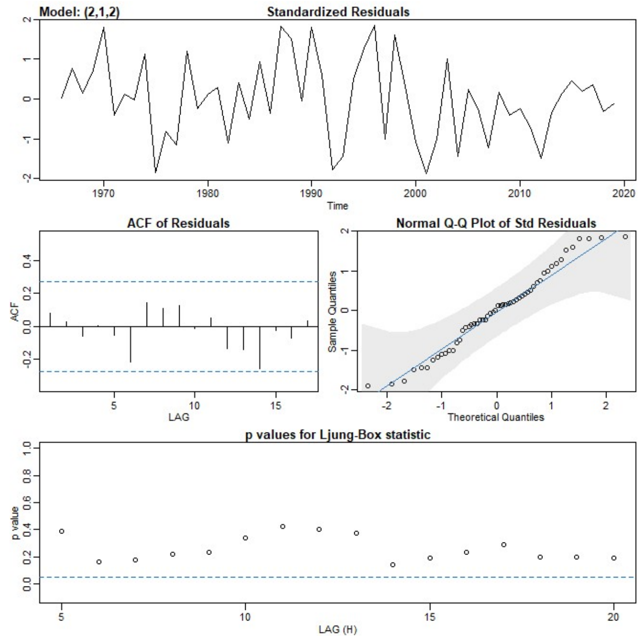
```
$ttable
      Estimate     SE t.value p.value
ar1     0.1402 0.2479  0.5658  0.5742
ma1    -0.5162 0.1981 -2.6052  0.0122
trend  -0.9117 9.6392 -0.0946  0.9250
rain1   0.3684 2.4119  0.1528  0.8792
rain2  -0.3634 0.3527 -1.0304  0.3080
```

- Because the p-values are very large, there is not sufficient evidence to indicate that $\phi_1 \neq 0$
- Because some p-values are greater than 0.05, this model is not a good candidate

ARIMA(2,1,2)







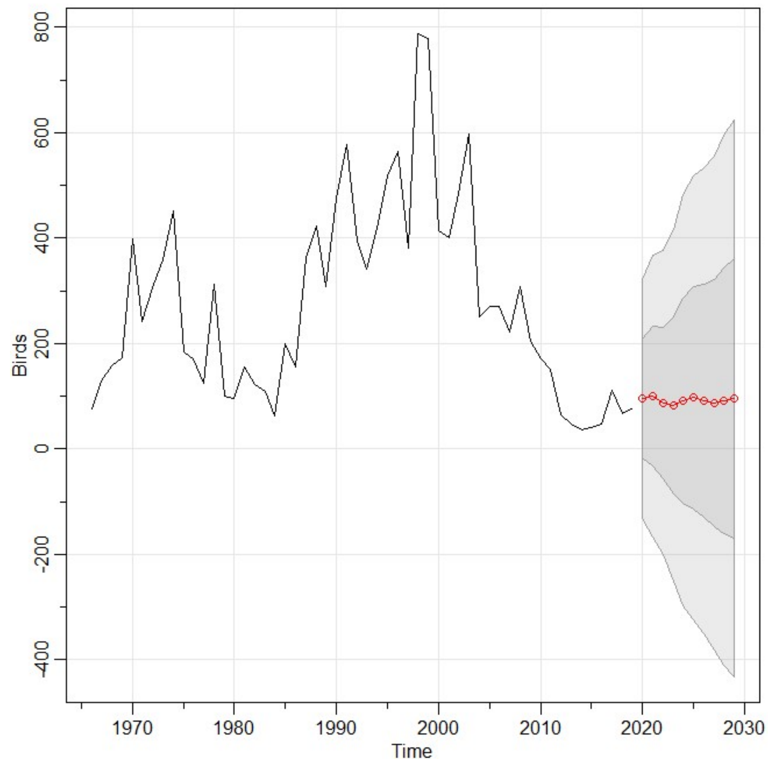

```
$ttable
      Estimate      SE  t.value p.value
ar1     0.2478  0.0994   2.4937  0.0163
ar2    -0.7334  0.1019  -7.1942  0.0000
ma1    -0.8082  0.0741 -10.9123  0.0000
ma2     1.0000  0.0953  10.4909  0.0000
trend  -0.5442 10.8444  -0.0502  0.9602
rain1   1.2978  2.2518   0.5763  0.5672
rain2  -0.8193  0.2436  -3.3641  0.0016
```

- Ljung-Box-Pierce test does not indicate any significant groups of autocorrelations
- ACF & PACF plots do not exhibit any significant values
- There are a few standardized residuals outside of the -1.96 and 1.96 range, but still < 3
- The hypothesis test for ϕ_1 = 0, ϕ_2 = 0 and θ_1 = 0 , θ_2 = 0 results in

```
$ttable
      Estimate     SE t.value p.value
ar1     0.1402 0.2479  0.5658  0.5742
ma1    -0.5162 0.1981 -2.6052  0.0122
trend  -0.9117 9.6392 -0.0946  0.9250
rain1   0.3684 2.4119  0.1528  0.8792
rain2  -0.3634 0.3527 -1.0304  0.3080
```

- Because the p-values are small, there is sufficient evidence to indicate that $\phi_1 \neq 0$, $\phi_2 \neq 0$ and $\theta_1 \neq 0$, $\theta_2 \neq 0$
- Even though 1st order(Rain) is not a good pvalue(less than .05) we still keep it because 2nd order is (.0016) and because it's quadratic.
- This is not an ideal model, but it’s the best, so we will use this to forecast 10 years.

FORECASTING



We had some troubles with modeling, which perhaps is why the forecasting graph is not connected. However, we were able to forecast the combined wading bird and shorebird population 10 years:

2020-2029: 95.23162, 100.18151, 87.20184, 82.54575, 92.10266, 97.26784, 91.43549, 87.49334, 91.87662, 95.88481

If this is correct, then the bird population is dramatically decreasing, which is already indicated by the current time series.

DISCUSSION

There was some issue with modeling that I think could be focused on the regression model and the data.

We attempted to center the average of rainfall, which was probably unnecessary. We probably should average the yearly population of birds to address the centering issues instead. Or perhaps instead of using the average annual rainfall for the entire state, we should only look at total annual rainfall for coastal counties. Another model could only include extreme weather events that coincide with nesting and nestling season.

Problems with the BBS data could be attributed to the survey variation by migration route, possibly explaining large variations between species during certain years. Other factors impact shorebirds, like pollution from oil spills.

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APPENDIX

R Code

```
library(readxl)

Annual_Imperiled_bird_count <- read_excel("C:/Users/buhrd/OneDrive - DePaul University (1)/School/MAT 512
(Forecast)/Final Project/Annual Imperiled bird count.xlsx")

#View(Annual_Imperiled_bird_count)

annual_average_rainfall_ <- read_excel("C:/Users/buhrd/OneDrive - DePaul University (1)/School/MAT 512
(Forecast)/Final Project/annual average rainfall .xlsx")

#View(annual_average_rainfall_)


Birdz <-Annual_Imperiled_bird_count
Birds <- ts(Birdz$Value, start=1966)
x <- as.numeric(Birds)

rain <- annual_average_rainfall_
rain <- ts(annual_average_rainfall_$Annualrain, start=1966)
rainx <- as.numeric(rain)

library(astsa)

dev.new(width=8, height=6)
tsplot(Birds,ylab="Number of Birds", xlab="Year", type="l", main=" Pop. of 'Imperiled' Florida Shorebirds & Wading Birds:
1966-2019")

dev.new(width=8, height=6)
tsplot(rain,ylab="Average Annual Rainfall (inches)", xlab="Year", type="l", main=" Florida Average Rainfall: 1966-2019")

#---Birds ACF

# ACF and PACF of x_t
dev.new(width=8, height=6)
acf2(Birds, max.lag=52, main=expression(paste("Estimated ACF & PACF plots for Birds", x[t])))

# Examine the first differences
diffx <- diff(Birds, differences=1)
dev.new(width=8, height=6)
tsplot(diffx, ylab=expression(x[t]-x[t-1]), type="o", main="Plot of data after first differences for Birds")


# ACF and PACF of x_t - x_t-1
#dev.new(width=8, height=6)
#acf2(diffx, max.lag=52, main="Estimated ACF & PACF plots for differencings")


#--------
# ACF and PACF of x_t Birds
dev.new(width=8, height=6)
acf2(x, max.lag=53, main="Estimated ACF & PACF of Birds data")

# Plot of (1-B)(1-B^12)*x_t
```

```
dev.new(width=8, height=6)
tsplot((diff(x,lag=1, differences=12)), ylab=expression((1-B)(1-B^1)*x[t]), xlab="Year", type="o",
main=expression(paste("Plot ofBirds ", (1-B)(1-B^12)*x[t])))

# ACF and PACF of (1-B)(1-B^12)*x_t
dev.new(width=8, height=6)
acf2(diff(diff(Birds, differences=1)), max.lag=12, main=expression(paste("Est. ACF & PACF for ", (1-B)(1-B^12)*x[t], "
data")))

 #....................

trend = time(Birds);
rain1 = rain - mean(rain);
rain2 = rain1^2
fit = lm(Birds~trend +rain1+rain2)
acf2(resid(fit), 52)
sarima(Birds, 2,1,0, xreg=cbind(trend, rain1, rain2))

source("examine.mod.R")
dev.new(width=8, height=6)
mod.fit.210<- sarima(as.numeric(Birds), p=2,d=1,q=0, xreg=cbind(trend, rain1, rain2))
mod.fit.210
examine.mod(mod.fit.210,2,1,0)

dev.new(width=8, height=6)
mod.fit.312<- sarima(Birds, p=3,d=1,q=2, xreg=cbind(trend, rain1, rain2))
mod.fit.312
examine.mod(mod.fit.312,3,1,2)

dev.new(width=8, height=6)
mod.fit.212<- sarima(Birds, p=2,d=1,q=2, xreg=cbind(trend, rain1, rain2))
mod.fit.212
examine.mod(mod.fit.212,2,1,2 )
#this one

dev.new(width=8, height=6)
mod.fit.111<- sarima(x, p=1,d=1,q=1,xreg=cbind(trend, rain1, rain2))
mod.fit.111
examine.mod(mod.fit.111,1,1,1,lag.max=52)

# Forecasts 30 time periods into the future
dev.new(width=8, height=6)
forecast <- sarima.for(Birds, n.ahead=10, p=2, d=1, q=2,plot.all=TRUE)
forecast

pred.mod <- Birds - ts(mod.fit.212$fit$residuals, start=1966)

dev.new(width=8, height=6)
tsplot(Birds, ylab="Number of Threatened birds in Florida in relation to rain", xlab="Year", type="o", main="Bird Data")
lines(pred.mod, col="red", type="o", pch=17)
legend("topright", legend=c("Observed", "Forecast"), lty=c("solid", "solid"), col=c("black", "red"), pch=c(1, 17), bty="n")
```