


# Upper Wakulla River Wildlife Abundance Trends September 1992 through May 2021

March 2022

Robert E. Deyle


## Executive Summary

This report analyzes long-term trends in the abundance of 24 species surveyed by park staff and volunteers from September 1992 through May 2021. Trend graphs and statistical analyses are included for each of the 24 species, as well as discussions of other factors that may explain the observed trends. The report also analyses trends for three shorter time periods defined by significant perturbations to the upper Wakulla River ecosystem: (1) invasion of the exotic hydrilla spurred by excess nitrogen in the spring (1992-2000), (2) the hydrilla management period (2000-2012) when mechanical harvesting and herbicides were aggressively used to combat the invasive exotic plant, and (3) the post-hydrilla management period (2012-2021) following the cessation of herbicide treatment in 2013.

Aggregate wildlife abundance, measured as total numbers of individual animals counted per survey both for all 24 species and for the six year-round resident species, decreased significantly over the 29.5 years of this monitoring project. Five species increased in abundance over this period, 14 decreased, and five exhibited no statistically significant long-term trend. Aggregate wildlife abundance and nine species increased in abundance during the hydrilla invasion, probably because of increased food supply. During the hydrilla management period, aggregate wildlife abundance decreased as did 12 species, most likely because of the disruptions of mechanical harvesting, the loss of total plant biomass, and/or the decrease of some native submerged aquatic plants resulting from herbicide treatments. During the post-hydrilla management period, aggregate wildlife abundance for all 24 species continued to decrease. However, aggregate abundance for the six year-round resident species (American alligator, anhinga, common gallinule, green heron, pied-billed grebe, and yellow-crowned night heron) increased significantly. Four species continued to decrease while three others began to decline after increasing or remaining stable during the preceding period. However, 10 species increased during this period including four of the six year-round residents. Five species that increased during the post-hydrilla management period had decreased during the preceding period.

Multivariate analysis of trends for selected species between 2012 and 2021 provided several new insights:

- The recent increasing trend for the American alligator remains statistically significant after controlling for river stage, air temperature, and cloud cover. Alligator counts are higher when river stage is lower, temperature is higher, and cloud cover is less.
- While cooter turtles exhibit no significant recent trend, like the alligator they are observed more frequently when river stage is lower, temperature is higher, and cloud cover is less.
- The recent decreasing trend for the wood duck remains significant when controlling for river stage and air temperature. Their counts are higher when river stage is lower and when temperatures are warmer, reflecting their seasonal abundance pattern.
- Pied-billed grebe which exhibited no significant trend during this period are more prevalent when temperatures are lower reflecting the seasonal influx of winter migrants.
- Common gallinule are more prevalent when temperatures are lower reflecting the seasonal influx of winter migrants. They also are observed more frequently when river stage is lower. While they exhibit a significant decreasing trend during this period, that trend is no longer significant when the time period is shifted to that beginning with the onset of weekly monitoring on November 10, 2012. Date remains insignificant in a multivariate regression model that includes river stage, air temperature, and cloud cover.

Notable changes observed since 2018 include the following:

- The number of species with statistically significant increasing trends in counts per survey since 2012 increased from seven to nine with the addition of green heron, limpkin, and tricolored heron and the shift of the pied-billed grebe from increasing to no trend.

- While the cattle egret's post-2012 trend is negative as a result of shifting their nesting colony from the river boat tour route to the second mile of the river, the trend since 2015 has been a significant increase.
- Period-of-record (1992-2021) rates of decline decreased by more than 0.05 count per day for three species (common gallinule, American alligator, and anhinga) and increased for one (American coot).
- The period-of-record rate of increase rose for three species (double-crested cormorant, white ibis, and hooded merganser) but declined for two others (pied-billed grebe and cattle egret).
- Three species were substantially less abundant in winter and spring 2021 than at the same time in 2020: anhinga, common gallinule, and pied-billed grebe.
- Both double-crested cormorants and anhinga have been observed eating crayfish during summer 2021. This may reflect a decline in fish populations.

The upper Wakulla River ecosystem may still be adjusting to previous perturbations with the cessation of herbicide treatments in 2012 and the cessation of the hydrilla invasion as a result of reduced nitrogen discharges and increased manatee grazing. The primary productivity base of the ecosystem appears to have attained a fairly stable mix of bare sediments (36%), algal mats (28%), and vascular SAV (36%). This may be leading to a shift from a predominantly SAV-based to a more detrital-based food web. Species that can and/or do feed primarily or substantially on crayfish, which are detrital feeders, continue to exhibit stable or increasing trends: hooded merganser, yellow-crowned night-heron, pied-billed grebe, white ibis, American alligator (juveniles). Species that feed predominantly on SAV, including common gallinule, American coot, and manatee, are declining. Those that depend more heavily on medium to large fish also appear to be in decline: osprey, great blue heron, and anhinga. These generalizations are complicated, however, by other phenomena including vagaries of winter migration (American coot, common gallinule, hooded merganser) and summer nesting (cattle egret, double-crested cormorant). Other recent trends in the ecosystem, i.e. declining river stage coupled with increasing river flow and periodic salinity spikes, will likely lead to further changes in the ecosystem and in the abundance and diversity of animal species observed along the river boat tour route on the upper river.

## Introduction

Park staff and volunteers have monitored the abundance of 35 species of animals along the 2-mile river boat tour route in Wakulla Springs State Park over 29.5 years (monthly by park staff from September 1992 through October 2012 and weekly by volunteers since November 2012).[1] This report analyzes data for 24 of those species excluding several that occur in very small numbers.[2] It extends the analysis prepared in 2019 by analyzing data collected from January 2019 through May 2021. The report analyzes long-term trends in aggregate wildlife abundance and the abundance of individual species; analyzes trends

[1] Many thanks to the volunteers who spent portions of their Saturday mornings monitoring wildlife during the two and a half years since the last analysis of monitoring data: Doug Alderson, Connie Bersok, Melissa Forehand, Kim Forehand-van der Linde, Lynette Norr, Katy Sparrow, Pat Teaf, and Nico Wienders, and to park biologist, Patty Wilbur, for supporting this continuing initiative, tracking down squirrely data, and providing personal observations to supplement the raw numbers. Special thanks to Bob Thompson who organized and managed the volunteer monitoring initiative until his "retirement" in 2018, for his encouragement, support, and straight-shooting feedback on my several forays into new ways of looking at the data and for driving the boat after the COVID pandemic led to uncoupling the survey from the regular river tours. Thanks also to park volunteer coordinator, Jackie Turner, for her support in coordinating the monitoring program following Bob Thompson's retirement as volunteer monitoring program manager. I am solely accountable for the final product, subject to Patty Wilbur's review and approval.

[2] See Appendix A: Copy of Current Survey Form. Species counted but not analyzed here because of very low counts include Florida softshell turtle, snake (any), American bittern, least bittern, lesser scaup, bufflehead, red-shouldered hawk, bald eagle, spotted sandpiper, barred owl, and kingfisher. We dropped the American wigeon and black-crowned night-heron from the survey in 2018 and added the bufflehead. The last wigeon counted was in December 2014, while bufflehead have been routinely listed as "another species observed" in the comment section.

for three shorter time periods defined by significant perturbations to the upper Wakulla River ecosystem; and examines possible explanations for the observed trends drawing on available scientific literature and documented changes to the river ecosystem.

This report uses two approaches to analyze long-term wildlife abundance:

- animal counts for each survey for 1992-2021 for statistical analysis of trends
- annual mean or annual seasonal monthly mean animal counts for 1994-2020 for visual analysis of patterns.[3]

The counts per survey approach offers the greatest statistical power for testing the significance of apparent trends,[4] but the high variance among individual surveys makes it difficult to visually detect temporal patterns. Therefore, the analyses of aggregate wildlife abundance and individual species in Appendix E include graphs of annual mean or annual seasonal monthly mean animal counts. Where species abundance is strongly seasonal, i.e. individuals are entirely absent or nearly so for several months, statistical trend analysis is conducted only for the months when the species is predominantly present. Table 1 lists the different seasonal abundance patterns exhibited by monitored species.

**Table 1. Wakulla Wildlife Seasonal Abundance Patterns**

| Abundance Pattern | Species |
|---|---|
| Year-round breeder (YB) | American alligator, anhinga, common gallinule,* cooter turtle, green heron, pied-billed grebe,* wood duck, yellow-crowned night-heron |
| Year-round occasional breeder (YOB) | Double-crested cormorant,** great blue heron, great egret,** little blue heron** |
| Year-round non-breeder (YNB) | Snowy egret, tricolored heron |
| Winter migrant (WM) | American coot, American wigeon, blue-winged teal, hooded merganser |
| Summer breeder (SB) | Cattle egret,** osprey |
| Winter peak non-breeder (WP) | Manatee, white ibis |
| Occasional visitor (OV) | Limpkin, purple gallinule |

*Year-round breeding populations probably supplemented by winter migrants.
**These species often nest in colonies downriver from the tour boat survey route and occasionally along the tour boat route as well.

This report also includes analysis of trends during three periods defined by several significant perturbations to the upper Wakulla River ecosystem: 1992-2000; 2000-2012; and 2012-2021.[5]

[3] Annual means were calculated for each month and then averaged for the year beginning in 1994 because of incomplete data in 1992 and 1993. Annual seasonal monthly means were calculated for the months when an individual species is most commonly observed, e.g. the months in residence for winter migrants.
[4] Larger numbers of observations (N) provide greater statistical power in ordinary least squares regression, i.e. they decrease the likelihood of concluding that no relationship exists when in fact one does. Regression analyses of counts per survey data, where the number of observations is 500+ for most species, offer greater statistical power than the analyses of long-term annual means employed in the 2017 report which were for 20 years, i.e. N=20. The results from means analyses are conservative, i.e. more likely to understate than overstate apparently significant trends. Note, however, that the explanatory power ($R^2$) of animal count trends is generally lower than that of trends based on annual means. Reducing the data to annual means removes much of the variance among individual observations thereby “smoothing” the data and increasing the power of time as a predictor of abundance.
[5] This summary is drawn principally from Bryan (2020b), Savery (2005), and Van Dyke (2019).

- Hydrilla Invasion (1992-2000): This nine-year period encompasses the time prior to and during the invasion of the exotic plant, *Hydrilla verticillata,* and the first three years of efforts to control it. Hydrilla roots in the sediments, grows to and spreads over the surface, forming mats that shade out most of the native submerged aquatic vegetation (SAV) and interfere with tour boat operation. The abrasive stems with their whorled leaves also pose a nuisance to swimmers.

  Hydrilla was first observed near the boat dock in April 1997. By December of that year, it had spread downriver to the first turn, approximately one quarter mile past the boat dock. During 1998 it invaded the spring basin, the swimming area, and the area behind the spring. In 1998, the state park initiated efforts to remove hydrilla by hand pulling and applied the aquatic plant herbicide Aquathol in granular form in the swimming area. The herbicide proved ineffective, and, despite removing some 260,000 kg during that year, the hydrilla continued to spread down river. Intensive mechanical harvesting was implemented along with hand pulling in 1999 and 2000 to clear the swimming area and boat tour routes. Nevertheless, the hydrilla continued to expand downriver past the first turn and began to occupy large areas in the middle and on the west side of the river. It also infested the spring to a depth of 60 feet obscuring features on the glass bottom boat tour. In 2000 the hydrilla spread further, going beyond the tour boat turnaround one mile from the boat dock and continuing another mile down the river.

- Hydrilla Management (2000-2012): This 13-year period comprises the time when the park intensified efforts to remove the hydrilla. Mechanical harvesting supplemented by hand pulling continued through 2001 by which time approximately 2,000,000 kg had been removed (see Appendix B) but with no success in stemming the invasion. In addition, park staff observed what Jess Van Dyke (2019, p. 1) describes as "unacceptable . . . by-catch of juvenile fish and macroinvertebrates." He quotes park biologist Scott Savery as saying that "each succeeding time we harvest, there are less snails and crawfish."

  In 2002, the state park resorted to treating the upper river by applying liquid Aquathol across the spring basin.[6] Liquid Aquathol was applied during most of the ensuing 11 years (see Appendix C). The initial treatment succeeded in killing back the stems of 70 to 80 percent of the hydrilla (Van Dyke, 2019). However, several of the native SAV species also succumbed and recovered to differing degrees after each treatment. The rapid hydrilla die-off led to a surge in river flow that scoured the bottom sediments of the upper river and likely caused additional loss of native SAV. The hydrilla recovered to some extent each year, necessitating regular treatments. Native SAV species also recovered, some more readily than others, resulting in changes to the species composition of the SAV community. Algae[7] recovered most quickly and began to dominate some areas of the upper river. Crayfish kills also occurred after the initial treatment in 2002 and to a lesser extent in 2008 (Bryan, 2020b). Experiments conducted by the Florida Department of Environmental Protection in 2005 indicated that the initial crayfish die-off may have been caused by dissolved oxygen depletion from the decomposing plants rather than a direct toxic effect from the herbicide (FDEP, 2005). During this time, manatee began to graze the hydrilla in increasing numbers. Manatee were first observed in the park in 1997 and appeared periodically in small numbers until 2003. Also, during this time, total nitrogen discharges from City of Tallahassee wastewater management facilities to the aquifer that feeds Wakulla Spring began to decline culminating in a 73 percent drop between 2011 and 2012 as major improvements to the T.P. Smith

[6] Aquathol is a brand name for endothall, a pesticide registered for use in aquatic ecosystems by the Florida Fish and Wildlife Commission (UF IFAS, 2019). While considered "safe," it is not risk free and does have documented deleterious effects on an array of aquatic organisms (Pesticide Action Network, 2019).

[7] The term "algae" as used here also includes the so-called "blue-green algae," which actually are bacteria (cyanobacteria) that lack a nucleus. The dominant "algae" that formed dense mats during this period include the cyanobacterium *Lyngbya*, the green alga *Spirogyra*, and the yellow-green alga *Vaucheria*.

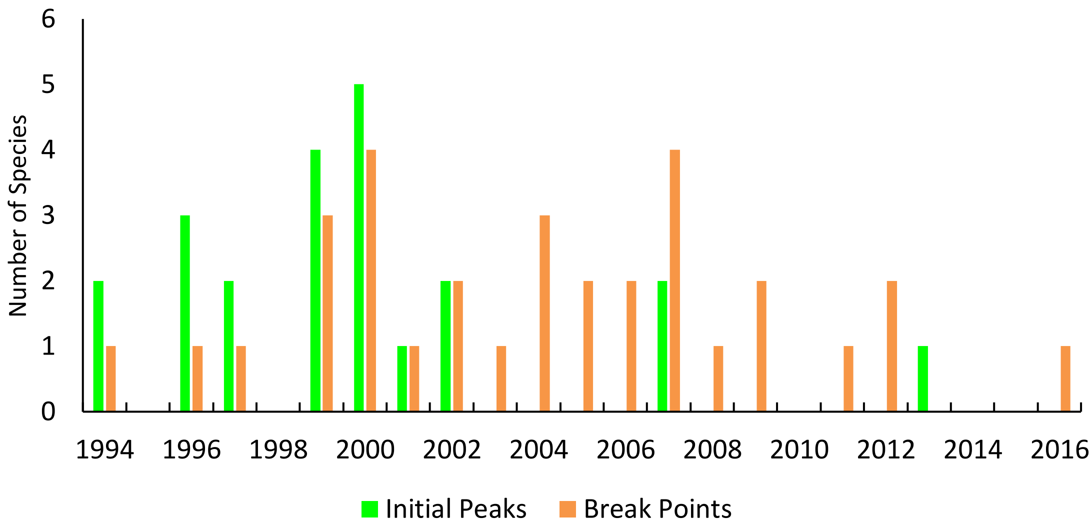
wastewater treatment plant went online (see Appendix D, Figure D-1). These changes were reflected in a decline in nitrate-nitrogen levels at the spring, which levelled off at about 0.41 mg/L in 2014 (see Figure D-2).

The year 2000 was chosen as the break point between this perturbation period and the hydrilla invasion rather than 1998 when hydrilla control efforts first began because of the large number of species that exhibit peaks and/or initial break points in their abundance patterns in 1999 and 2000 (see Figure 1).[8] This pattern may reflect a lagged effect of the initial perturbations.

- Post Hydrilla Management (2012-2021): This nine-year period is defined by three change factors that occurred in 2012:
    - cessation of herbicide treatment of hydrilla: the last treatment was in May 2012;
    - substantial reduction in nitrate-nitrogen loading to the spring following completion of the upgrades to the Tallahassee wastewater treatment plant in November 2012; and
    - the November 2012 shift from monthly wildlife surveying by staff to weekly surveying by volunteers.

The cessation of Aquathol treatment should have ended the cycle of SAV injury and recovery as well as any toxic effects on animal species. The substantial reduction in nitrate-nitrogen inflow to the spring may have contributed to the apparent inability of the hydrilla to recover from heavy manatee grazing. The shift to weekly wildlife monitoring likely resulted in a more robust data base, reducing the influence of factors that vary from one survey date to another including air temperature, precipitation, cloud cover, surveyor aptitude, distractions during the boat tour, etc.

**Figure 1. Initial Peaks and Break Points in Annual Mean Abundance of 23 Monitored Animal Species: 1994-2016[9]**




[8] "Peaks" tabulated in Figure 1 (green bars) comprise the year in which a given species attained its peak mean number of counts per survey over the period 1994 through 2016. Thus, for example, the annual mean abundances of five species reached their peaks (maximums) in 2000. "Break points" tabulated in Figure 1 (orange bars) constitute years after which the annual mean number of counts per survey of a species dropped off substantially based on a visual assessment of the plot of that species's annual mean counts per survey. Species with gradual fluctuations in mean annual counts exhibit no break points, while others may exhibit multiple break points over the survey period. 2016 is the last year displayed because that is the last year in which a peak or break point occurred.

[9] The manatee is excluded from this chart because it was not surveyed routinely until 2007.

The next sections present trend analyses for aggregate wildlife abundance and individual species abundance plus trends for the several analysis periods. These are followed by a summary of findings. Detailed results for aggregate wildlife abundance and each species are presented in Appendix E. Those include bar graphs of monthly means over the entire period of record for each species and graphs of counts per survey and means versus time for the various time periods. Trend lines and associated statistics (model fit - prob(F); model explanatory power - R-squared or $R^2$; and slope) are included in counts-per-survey plots where simple ordinary least-squares regression analysis yields a linear model significant at the 95% level or better (prob(F) $\leq 0.05$).[10]

Aggregate Wildlife Abundance Trends

Changes in the aggregate numbers of individual animals counted per survey can serve as an indicator of shifts in the relative biological productivity of the upper river ecosystem. In previous analyses of the survey data we have analyzed the total numbers counted  per survey for all 24 species analyzed. However, aggregate trends revealed by this means may be confounded by variables outside the Wakulla River ecosystem for species that are not year-round residents. For example, the abundance of winter migrants will reflect both carrying capacity of the Wakulla River and factors that influence summer breeding success as well as migration timing and destination. As detailed in Appendix E, research has revealed that some species are not migrating as far south as in the past, likely because of changing climate. Other species, such as white ibis, migrate regionally, nesting elsewhere during the summer and returning to the river in fall and winter.

So as to minimize the confounding that may be caused by external factors, this analysis also includes an assessment of aggregate trends for all but one of the year-round resident breeders listed in Table 1: American alligator, anhinga, common gallinule, green heron, pied-billed grebe, wood duck, yellow-crowned night-heron. Cooter turtles are excluded because counts are substantially influenced by water visibility depth for which we do not have a reliable statistical control. Data are only analyzed for the summer breeding season, i.e. the months of April through July, to avoid the confounding by in-migration of common gallinule and pied-billed grebes in late summer.

Figures 2 and 3 illustrate variation over the period of record in the relative numbers of the most prevalent monitored animal species included in these two measures of aggregate abundance tabulated as annual means. Figure 2 reveals a shift in dominant species from the 1999 peak to the post-hydrilla management period beginning in 2012. Two winter migrants, American coot and American wigeon, along with the common gallinule, dominated total species counts in 1999. By 2020, the most prevalent species included white ibis, common gallinule, and American alligator. Figure 2 also shows that wigeon have completely disappeared from the upper Wakulla River, while alligators and common gallinule have decreased, and hooded merganser, pied-billed grebe, and white ibis have increased.

Figure 3 demonstrates that the principal drivers of aggregate abundance of year-round resident breeding species have been more consistent, comprising common gallinule, American alligator, and anhinga throughout the period of record. Wood duck, however, recently have been supplanted by pied-billed grebes.

[10] See Appendix E for descriptions of these statistics.

**Figure 2. Total Annual Mean Animal Counts for Most Prevalent Species 1994-2020**

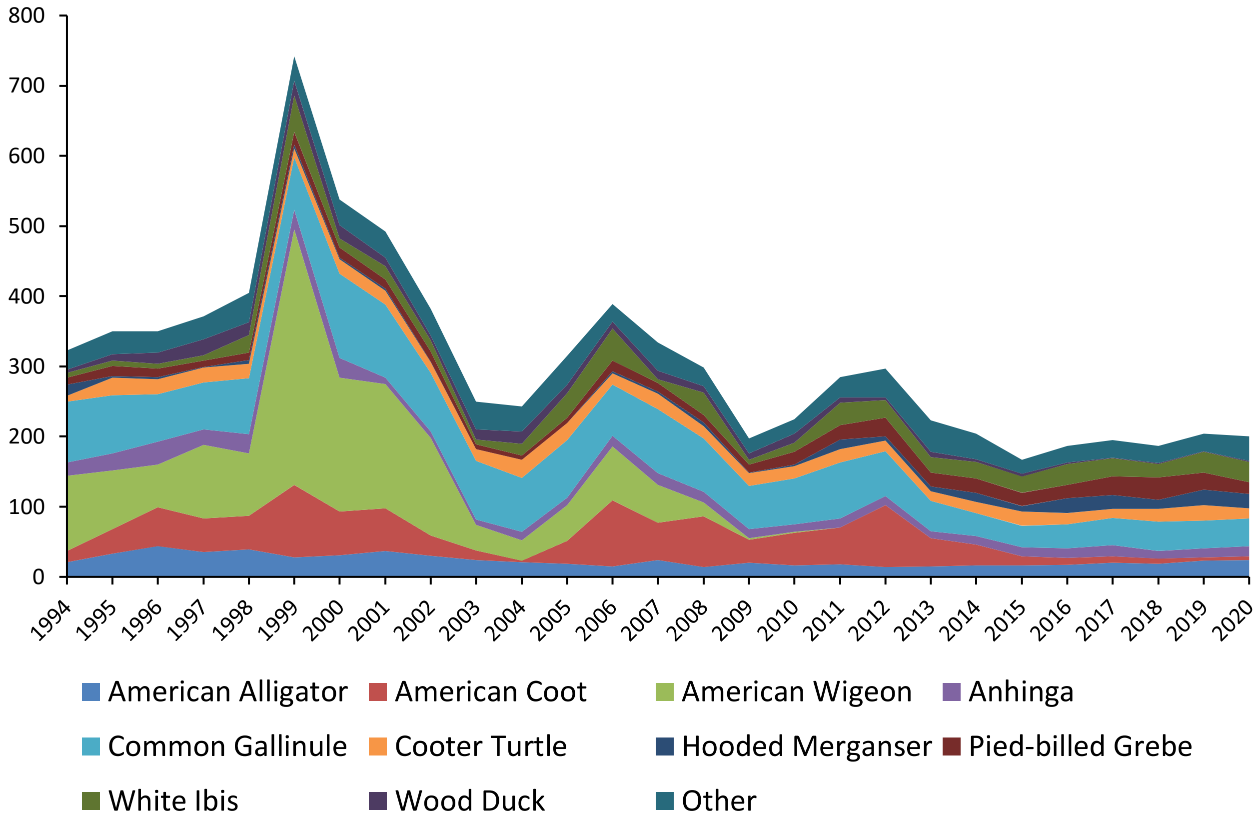



**Figure 3. Total Annual Mean Animal Counts for Year-Round Resident Breeders 1994-2020**

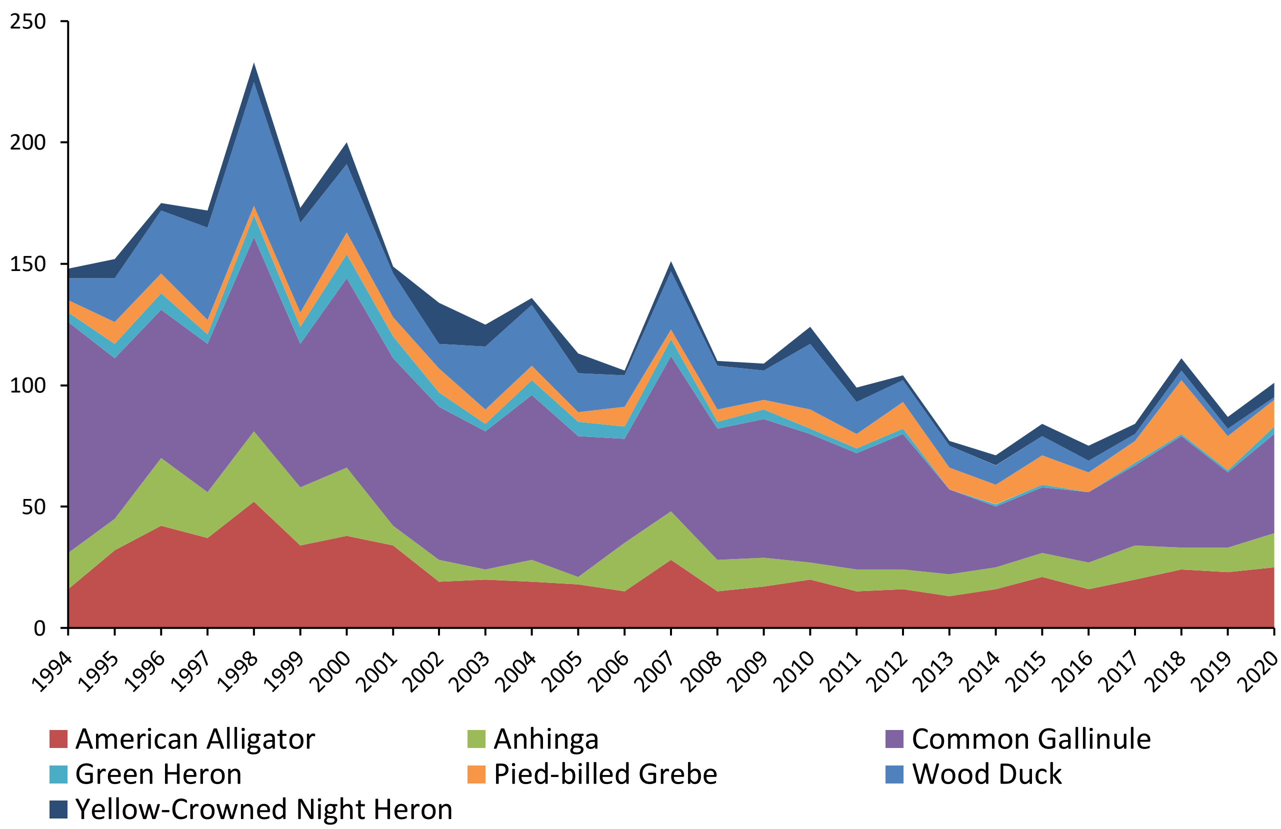


Table 2, and Figures 4 and 5, reveal statistically significant declines in aggregate wildlife abundance for the period of record using both metrics. As shown in Figure 4, total animal counts per survey for all 24 species on the upper Wakulla River exhibit a significant (better than 99.99% level) decreasing abundance trend of -0.0277 animals counted per day or 10.10 counts per year over the period of record, 9/1/92 – 5/29/21. Survey date explains 22.9% of the observed variation in counts per survey. Figure 5 shows that total animal counts per survey during the months of April through July for the seven year-round resident breeders on the upper Wakulla River also exhibit a significant (better than 99.99% level) decreasing abundance trend. However, the rate of decrease is slower: -0.0097 animals counted per day or 3.53 counts per year over the period of record, 4/5/93 – 5/29/21. Survey date explains a much greater percentage of the observed variation in counts per survey – 44.81% – most likely reflecting the much lesser influence of factors outside the river ecosystem for these species.

**Table 2. Wakulla Wildlife Aggregate Abundance Trends**

| **Time Interval Statistics** | **Total All Species Abundance (counts per survey)** | **Total Abundance of Selected Year-Round Resident Breeders:* April-July (counts per survey)** |
|---|---|---|
| **Period of Record (1992/1993-2021)** | | |
| Prob(F) | < 0.0001 | <0.0001 |
| Slope | -0.0277 | -0.0097 |
| R-squared | 0.229 | 0.448 |
| **Hydrilla Invasion (1992-2000)** | | |
| Prob(F) | 0.0350 | 0.0075 |
| Slope | 0.7895 | 0.0245 |
| R-squared | 0.059 | 0.427 |
| **Hydrilla Mgmt (2000-2012)** | | |
| Prob(F) | 0.0006 | <0.0001 |
| Slope | -1.7593 | -0.0152 |
| R-squared | 0.076 | 0.348 |
| **Post-Hydrilla Mgmt (2012-2021)** | | |
| Prob(F) | 0.0014 | 0.0001 |
| Slope | -0.0117 | 0.0071 |
| R-squared | 0.019 | 0.081 |

**Figure 4. Total Counts per Survey 24 Species, 1992-2021**

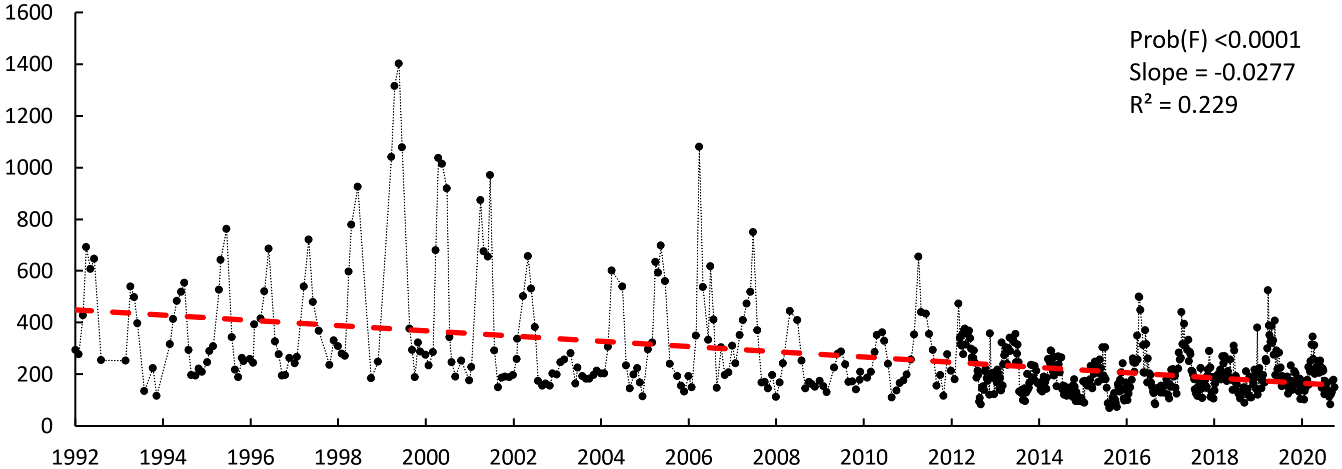
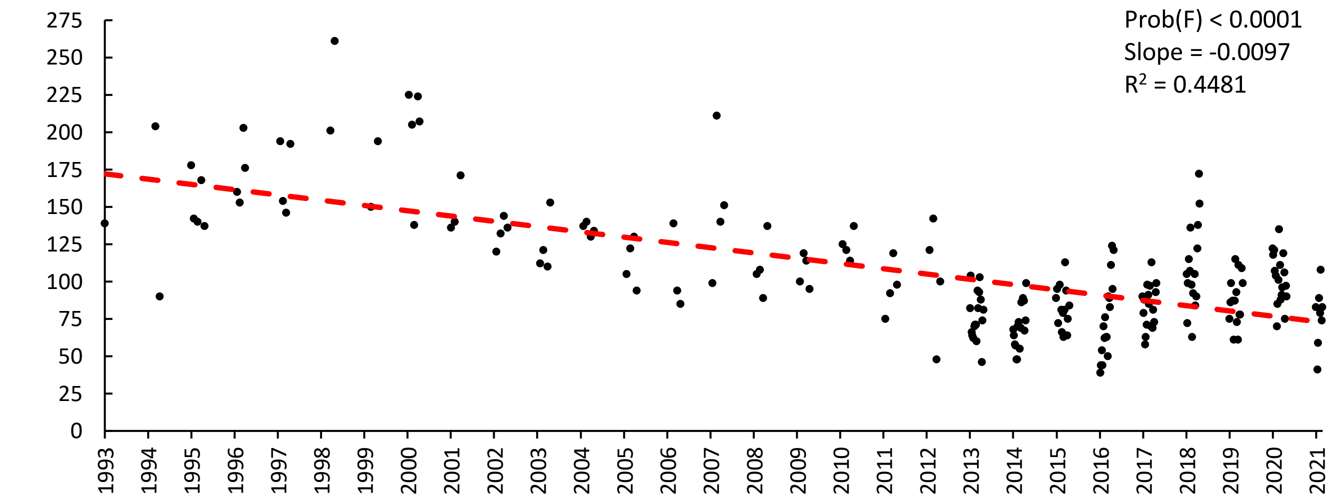



**Figure 5. Total Counts per Survey Year-Round Resident Breeders, April - July 1993-2021**




American alligator, anhinga, common gallinule, green heron, pied-billed grebe, wood duck, yellow-crowned night-heron

As shown in Table 2, regression analyses reveal significant increases in aggregate wildlife abundance during the hydrilla invasion period, 1992-2000, for both measures, followed by significant decreases during the hydrilla management period, 2000-2012.[11] The two measures diverge for the post-hydrilla management period, 2012-2021: the trend for all 24 animals analyzed is significant at the 99.86% level and negative (slope = -0.0117) while the trend for the seven year-round resident breeders is significant at the 99.99% level but positive (slope = 0.0071. Once again the year-round breeder model explains more of the observed variation (8.1%) than the model for all 24 species (1.9%). However, survey date does not explain a great deal of the observed variation for either measure of aggregate abundance suggesting that other variables are at work.

These results suggest an increase in the overall biological productivity of the upper Wakulla River ecosystem accompanying the hydrilla invasion (1992-2000), likely fueled in part by high levels of nitrate-nitrogen[12] and enhanced floating aquatic vegetation habitat that probably favored the American wigeon,

[11] See Appendix E for trend graphs for each of the measures of aggregate abundance for the three perturbation periods.

[12] Nitrate-nitrite and total nitrogen data from the spring indicate that levels increased in the mid-1980s, were fairly constant through the 1990s, and began to decrease in 2001 (Gilbert, 2012).

American coot, common gallinule, and other species that fed on the aquatic organisms supported by the hydrilla habitat. This was followed by a steep decline during the early years of intensive hydrilla management (2000-2004) consistent with by-catch losses from mechanical harvesting and drastic changes in the native SAV community that began with the hydrilla invasion and have been manifest in the aftermath of the herbicide treatments in the post-hydrilla management period (2012-2021). *Sagittaria kurziana* (springtape), which had been the dominant native SAV species, proved to be very sensitive to the herbicide, while the other submerged aquatic grass, *Vallisneria americana* (American eelgrass), was able to recover more quickly. *Najas guadalupensis* (southern naiad) took over large areas for a time (Savery, 2005; Van Dyke, 2019), and *Chara sp.* (muskgrass) recovered well. Large areas of the bottom sediments were colonized by algae during the annual fluxes in SAV accompanying the herbicide treatments (Savery, 2005), but extensive areas of the main channel were reduced to bare sediments and shells due to the scouring that followed the initial hydrilla die back (Van Dyke, 2019). Quarterly SAV sampling conducted by volunteers and park staff since 2013 have documented the persistence of these conditions (Thompson, 2020).

Long-Term Species Abundance Trends

Table 3 and Figure 6 present long-term species abundance trends based on animal counts per survey for the full period of record (September 1992 through May 2021). These are represented as annual rates of change based on the slopes of the regression models for each species with significant trends using the following classifications:

**Increasing Abundance:** linear regression model is statistically significant (prob(F) ≤ 0.05) and slope is positive.

**Decreasing Abundance**: linear regression model is statistically significant (prob(F) ≤ 0.05) and slope is negative.

**No Significant Trend**: linear regression model is not statistically significant (prob(F) > 0.05).

The explanatory power of significant trends is classified as follows: weak: $R^2 < 0.20$; moderate: $R^2 \geq 0.20$ and $R^2 < 0.50$; and strong: $R^2 \geq 0.50$.

Species are listed in Table 3 as well as in Figure 6 in order of increasing abundance. Table 3 also presents trends previously reported for the period September 1992 through December 2018.

Fourteen of the 24 species analyzed (58 percent) exhibited statistically significant decreasing trends over the study period, while only five experienced significant increases and five remained unchanged. The American wigeon, common gallinule, and American coot experienced the most rapid rates of decline, displayed in Table 3 and Figure 6. The hooded merganser exhibited the most rapid rate of increase.

The most substantial change in these trends compared to the 1992-2018 trends reported in 2019 is the shift of the double-crested cormorant from no significant trend to a positive trend. This change likely reflects the continued annual nesting by cormorants in a rookery approximately two miles downstream from the spring within the park. For quite a few species, e.g. blue-winged teal, the trend changed by a few one hundredths because there was no substantial change over the past two years and thus the slope of the regression model flattened out some. For three species, the rate of decline decreased by 0.05 or more count per year - common gallinule, American alligator, and anhinga. For only one species did the rate of decline grow by more than 0.05 count per year – the American coot. The rate of increase grew by 0.05 or more count per year for three others – cormorant, white ibis, and hooded merganser, while it decreased by 0.05 or more for pied-billed grebe and cattle egret.

Analysis of Abundance Trends by Species and Current Status

Table 4 presents individual wildlife species abundance trends based on counts per survey for the full period of record, September 1992 through May 2021, and for the three perturbation periods, 1992-2000, 2000-2012, and 2012-2021, employing the same classification scheme as Table 3.

Trend results are presented for seasonal counts per survey for six species with strong seasonal abundance patterns (see monthly means in Appendix E): American coot, American wigeon, blue-winged teal, cattle egret, hooded merganser, and osprey. The American coot is a winter migrant mostly present November through March. The American wigeon is a winter migrant whose annual winter monthly mean (November - February) dropped to 0 in 2012-2013. Blue-winged teal are winter migrants most prevalent between September and March. Cattle egrets are summer breeders most prevalent in May through August and virtually absent the remainder of the year. The hooded merganser is a winter migrant with peak abundance during November through February. The osprey is a spring-summer breeder (January-August) whose monthly means for the period of record drop to 0 for the months of September through December.

**Table 3. Summary of Long-Term Trends in Wildlife Species Abundance 1992-2021**

| Abundance Trend | Species | Annual Rate of Change (Counts per Year) | |
|---|---|---|---|
| | | 09/01/92 – 12/29/18 | 09/01/92 – 05/29/21 |
| Decreasing | †American wigeon* | -6.60 | -17.37 |
| | Common gallinule** | -2.92 | -2.56 |
| | †American coot** | -1.46 | -3.58 |
| | Wood duck** | -0.59 | -0.61 |
| | American alligator* | -0.72 | -0.48 |
| | Anhinga* | -0.50 | -0.42 |
| | †Blue-winged teal* | -0.31 | -0.29 |
| | Cooter turtle* | -0.28 | -0.27 |
| | Green heron** | -0.18 | -0.16 |
| | Limpkin** | -0.17 | -0.14 |
| | †Osprey** | -0.12 | -0.10 |
| | Snowy egret* | -0.08 | -0.08 |
| | Tricolored heron* | -0.08 | -0.06 |
| | Purple gallinule* | -0.05 | -0.03 |
| | | | |
| No significant trend | Great blue heron | 0.00 | 0.00 |
| | Great egret | 0.00 | 0.00 |
| | Little blue heron | 0.00 | 0.00 |
| | Manatee | 0.00 | 0.00 |
| | Yellow-crowned night-heron | 0.00 | 0.00 |
| | | | |
| Increasing | Double-crested cormorant* | 0.00 | 0.11 |
| | Pied-billed grebe* | 0.59 | 0.47 |
| | †Cattle egret* | 0.86 | 0.54 |
| | White ibis* | 0.55 | 0.60 |
| | †Hooded merganser* | 1.84 | 2.02 |

†Trends based on seasonal survey counts rather than annual survey counts.

* $R^2 < 20$; ** $R^2 \geq 20$ and $< 50$; *** $R^2 \geq 50$

**Figure 6. Species Annual Rates of Change in Abundance 1992-2021**

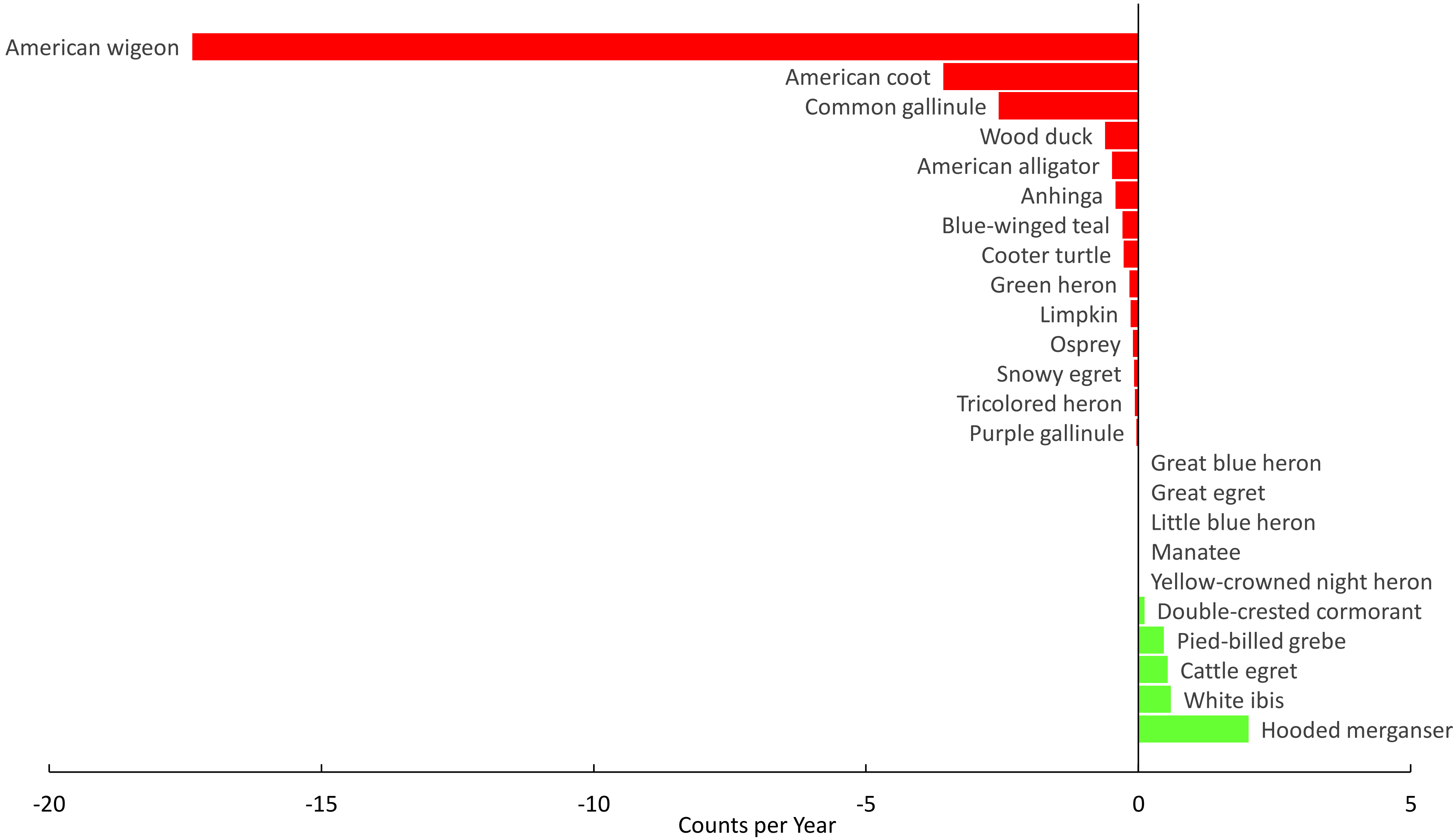


**Table 4. Wildlife Abundance Trends and Current Status by Species**

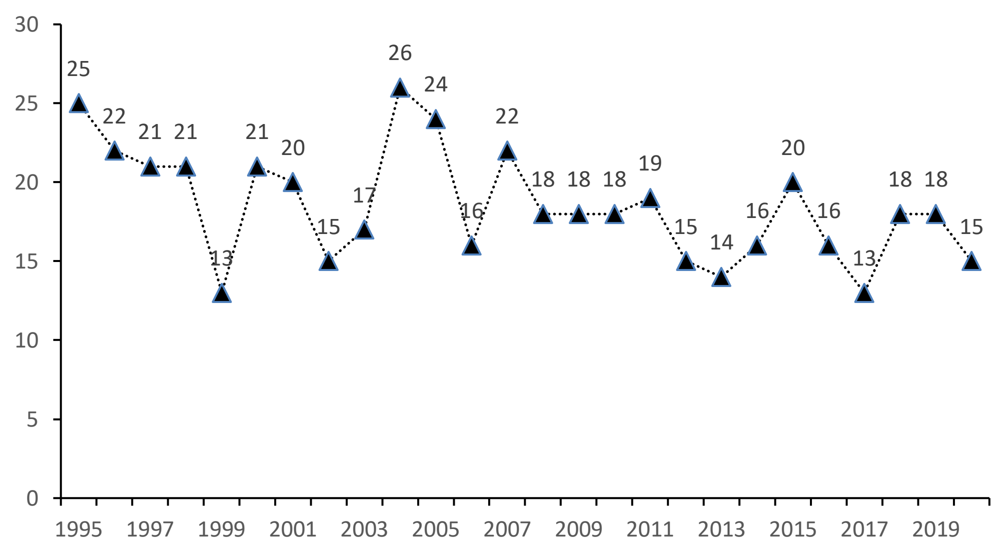
| Species | Seasonal Distribution | Long-Term Counts per Survey (1992-2021) | Hydrilla Invasion Counts per Survey (1992-2000) | Hydrilla Management Counts per Survey (2000-2012) | Post-Hydrilla Management Counts per Survey (2012-2021) | Current Apparent Status |
|---|---|---|---|---|---|---|
| American alligator | YB | Decreasing* | No Trend | Decreasing** | Increasing* | Long-term decrease; recovering since 2012 |
| †American coot | WM Nov-Mar | Decreasing** | Increasing*** | No Trend | Decreasing*** | Continuing long-term decrease |
| †American wigeon | WM Nov-Feb | Decreasing*** | Increasing** | Decreasing*** | Decreasing* | None observed since 2014 |
| Anhinga | YB | Decreasing* | No Trend | No Trend | Increasing* | Increase since 2012; decline began Nov 2020 |
| †Blue-winged teal | WM Sep-Mar | Decreasing* | No Trend | Decreasing* | No trend | Long-term decrease; occasional since 2012 |
| †Cattle egret | SB May-Aug | Increasing* | No Trend | Increasing* | Increasing** | Decrease since 2012 but increasing trend since relocation of nesting colony |
| Common gallinule | YB†† | Decreasing** | No Trend | Decreasing* | Decreasing* | Continuing long-term decline |
| Cooter turtle | YB | Decreasing* | No Trend | No Trend | No Trend | Modest long-term decrease; high variability |
| Double-crested cormorant | YB†† | Increasing* | No Trend | Decreasing* | Increasing* | Small numbers; recent increases in nesting along second mile below tour boat turnaround |
| Great blue heron | YOB†† | No Trend | No Trend | No Trend | Decreasing* | Small numbers; recent decrease |
| Great egret | YOB | No Trend | No Trend | No Trend | Increasing* | Small numbers; recent increase |
| Green heron | YB | Decreasing** | Increasing* | Decreasing* | Increasing* | Recent increasing trend due to nesting on tour route |
| †Hooded merganser | WM Nov-Feb | Increasing* | †No Trend | Increasing** | Increasing* | Continuing long-term increase; some flux |
| Limpkin | OV | Decreasing** | Decreasing** | No trend | Increasing* | Occasional with a cluster of visits in 2020 |
| Little blue heron | YOB | No Trend | Increasing* | No Trend | No Trend | No recent trend |
| Manatee | WP Oct-Feb | No Trend | No data | Increasing** | Decreasing* | Decreasing after 2012-13 and 2013-14 peaks |
| †Osprey | SB Feb-Jul | Decreasing** | Increasing* | Decreasing* | Decreasing* | Small numbers; continuing long-term decline |
| Pied-billed grebe | YB†† | Increasing* | Decreasing* | Increasing* | No Trend | Positive trend no longer significant |
| Purple gallinule | OV | Decreasing* | Increasing* | Decreasing* | No Trend | Small numbers; none observed since 2013 |
| Snowy egret | YNB | Decreasing* | No Trend | Decreasing* | No Trend | Small numbers; stable after long-term decline |
| Tricolored heron | YNB | Decreasing* | Increasing* | Decreasing* | Increasing* | Recent higher counts yielded positive trend |
| White ibis | WP Jul-Mar | Increasing* | Increasing* | No Trend | No Trend | Stable after increase during hydrilla invasion |
| Wood duck | YB | Decreasing** | Increasing* | Decreasing* | Decreasing* | Continuing long-term decline |
| Yellow-crowned night-heron | YB | No Trend | No Trend | Decreasing* | Increasing* | Increasing after decline during hydrilla management period |

† Trends based on seasonal survey counts rather than annual survey counts.
††Year-round breeding populations probably supplemented by winter migrants.
*$R^2 < 20$; **$R^2 \geq 20$ and $< 50$; ***$R^2 \geq 50$

**Cooter turtles**, which include both the Suwannee cooter (*Pseudemys concinna suwanniensis*) and the coastal plain cooter (*Pseudemys floridana floridana*), have exhibited a long-term decline in abundance but no significant trends during any of the perturbation periods. The remaining species are described in the following sections for the three perturbation periods. Cooters are year-round breeders that primarily eat submerged aquatic vegetation, especially *Vallisneria spp.*, *Naias spp.*, *Sagittaria kurziana*, and *Ceratophyllum demersum* (Krysko et al., 2019). These are all taxa that were affected by the Aquathol treatment of the hydrilla. Quarterly SAV surveys begun in 2013 have recorded almost no *Naias spp.* in the upper river along the tour route. *Sagittaria kurziana* was very sensitive to the herbicide and likely does not occur at the same densities in the main river channel now given the broad expanses of bare sediment but it is the most prevalent SAV species now. *Vallisneria americana* was more resistant to the herbicide. Some was transplanted around the spring bowl and near the boat dock in 2004 (Van Dyke, 2019). *Ceratophyllum demersum* was a relatively minor component of the river SAV community and is now virtually absent.

High variation in cooter counts between surveys likely reflects the effects of air temperature and cloud cover on basking behavior, the effects of varying river stage elevation on available basking sites, and the effects of varying water visibility depth on observing turtles in the water. Multivariate analysis of data for the period November 10, 2012, through May 29, 2021, confirms the absence of a significant trend during the post-hydrilla management period. It also indicates that cooter turtles, like the American alligator, are more abundant when river stage is lower (more basking sites), air temperature is warmer, and the weather is clear or has some clouds. The high variation between surveys also may explain the absence of significant trends during any of the ecosystem perturbation periods. Nonetheless, a graph of annual means reveals a steep one-year drop in 1999 at the onset of mechanical hydrilla harvesting and steep drops in 2002 and 2006 (see Figure 7). The 2002 drop coincides with the initial Aquathol treatment in April of that year which resulted in substantial collateral loss of native SAV both from the herbicide and scouring of the river bottom. Annual mean abundance had recovered by 2004 but dropped steeply again in 2006 when the April herbicide treatment resulted in the second highest concentration recorded during that period (see Appendix C).

**Figure 7. Cooter Turtle Annual Mean Abundance 1995-2020**

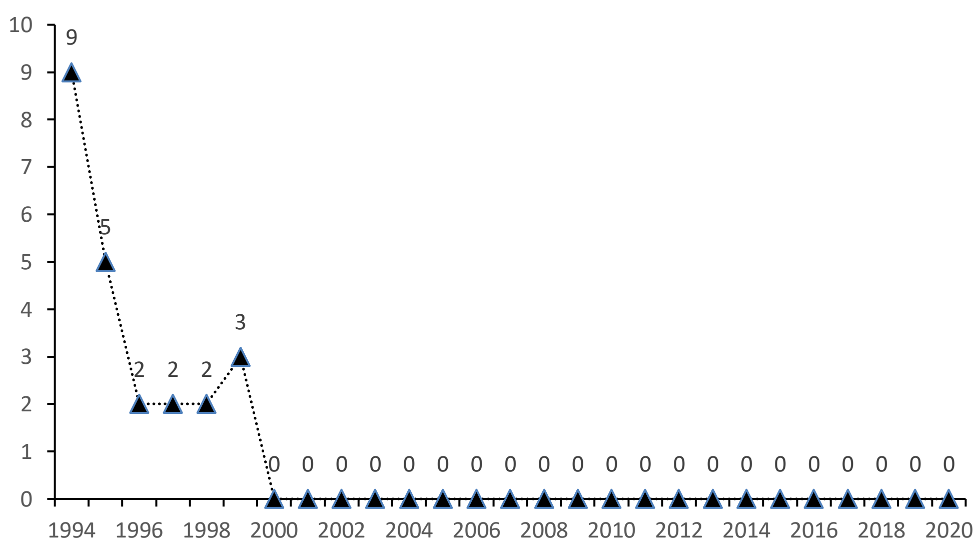



*Hydrilla Invasion Period (1994-2000)*

Most of the species analyzed during the hydrilla invasion period exhibited no significant trends. <u>Two species decreased in abundance during this time</u>, the limpkin and pied-billed grebe. As shown in Figure 8, the **limpkin** began to decline in 1994 following high water levels due to higher-than-normal rainfall and two tropical storms: Alberto and Beryl. Annual means dropped to zero in 2000 and have remained so ever since with occasional sightings for a few days or weeks at a time. Dana Bryan (2020a) suggests that the limpkin's demise was due to drowning of the eggs of the native apple snail (*Pomacea paludosa*) which is the limpkin's primary food source. He also has hypothesized (personal communication, October 10, 2020) that their initial recovery was hampered by the dense hydrilla infestation "filling the water column and preventing the snails from surfacing to breathe." While research is scarce on apple snail diet, Drizd (2011) reports that *P. paludosa* will graze periphyton on the leaves of hydrilla. Sharfstein and Steinman (2001) documented that they consume *Utricularia*, a submersed species that has been found in the spring and river. Monette et al. (2015) report that *P. paludosa* occupies American eelgrass (*Vallisneria americana*) habitat. Baker et al. (2010) report that the invasive apple snail (*P. insularum*) eats *Hydrilla*, as well as *Vallisneria americana*, and several other submersed and emergent species found in the upper Wakulla River including *Chara sp., Najas guadalupensis, Sagittaria latifolia,* and *Ceratophyllum demersum*. Efforts to rejuvenate the apple snail population through reintroduction have been largely unsuccessful. Bryan suggests that "predation on apple snails, especially when they . . . [are] young and small, might be so great that they have never been able to overcome that predation pressure to build their former populations" (personal communication, October 9, 2020). Alligators, soft-shell turtles, redear sunfish, and white ibis also prey on apple snails (Darby et al., 1997; Sharfstein and Steinman, 2001). The collateral loss of many of the native SAV species following the herbicide treatments for hydrilla also may have limited their rebound. *Utricularia sp*., *Chara sp., Najas guadalupensis,* and *Ceratophyllum demersum* have essentially disappeared except for a few small patches along the Sally Ward run.

The **pied-billed grebe** is a year-round breeding resident whose numbers are augmented by winter migrants from September through March. Despite a significant long-term trend of increasing abundance over the period of record, the grebe experienced a significant decrease at the outset during the hydrilla invasion period (see Appendix E). This may have been due to interference by the floating hydrilla mat with the grebe's ability to dive for the small fish and crustaceans, especially crayfish, upon which it

**Figure 8. Limpkin Annual Mean Abundance 1994-2020**



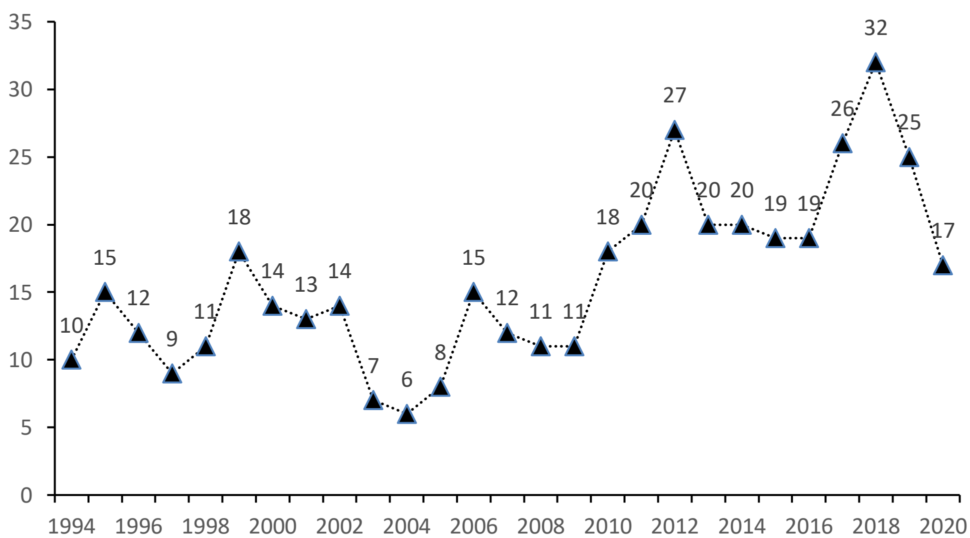

primarily feeds (The Cornell Lab of Ornithology, 2019; personal observation[13]). Trends in counts per survey turned around during the hydrilla management period resulting in a significant increase. However,

[13] I served as a regular volunteer river boat tour guide between April 2013 and July 2018, and September 2019 through February 2020, typically conducting three to four tours per day, one day a week. I also participated in the park's August 2016 survey of the upper three miles of the river and have conducted monitoring surveys of the upper river.

annual means show a decline between 2000 and 2004 during the intensive mechanical harvesting and herbicide treatment of the hydrilla (see Figure 9). By-catch from the mechanical harvesting and the crayfish kill following the initial April 2002 Aquathol treatment may have contributed to this decline. Annual means generally increased after 2004 with a couple of plateaus. They declined and levelled off after 2011-12 but then turned sharply upward in 2017 and 2018 indicating a possible improvement in the local ecosystem that may benefit this species, but then fell again in 2019 and 2020. The counts-per-survey abundance trend had shown a significant positive trend through 2018, but with the addition of the 2019-2021 data, the trend is no longer significant. In a multivariate model of data between November 10, 2012, through May 29, 2021, the trend remains statistically non-significant after controlling for air temperature, river stage, and cloud cover (see Table 5). Only air temperature is significantly correlated with abundance, exhibiting an inverse relationship likely reflecting the annual influx of winter migrants. Long-term abundance patterns may reflect other factors. La Sorte and Thompson (2009) documented a southward shift in the grebe's winter range between 1975 and 2004 which may be continuing. The North American Breeding Bird Survey conducted by the U.S. Geological Survey (Sauer et al., 2020) indicates that pied-billed grebe breeding populations in eastern North American states and provinces from which they likely migrate to Florida generally declined over the period 1993-2019 at rates ranging from -0.23 to -1.09 percent per year. Thus the long-term increasing trends for the period of record shown in Table 5 may be largely due to larger resident breeding populations rather than increases in the numbers of winter migrants.

<u>Nine species exhibited significant increases during the hydrilla invasion period</u>: American coot and American wigeon, both of which are winter migrants; the green heron, which is a year-round resident breeder; the little blue heron, a year-round resident and occasional breeder; the osprey, which is a seasonal breeder; the purple gallinule, which is an occasional visitor; the tricolored heron, which is a nonbreeding year-round resident; the white ibis, which is a year-round nonbreeder that congregates at Wakulla during the non-breeding season; and the wood duck, which is a year round breeding resident (see seasonal patterns in Appendix E).

**Figure 9. Pied-Billed Grebe Annual Mean Abundance 1994-2020**




The **American wigeon** winter monthly mean more than doubled between 1998-99 and 1999-2000 from 318 to 701, dropped to 450+ for the next two winters and then proceeded to decline to single digits by 2009-10 and zero from 2012-13 through 2016-17 (see Figure 10). The wigeon was dropped from the survey in 2018. Van Dyke (2019) suggests that the wigeon population increased because the hydrilla provided ideal habitat for these winter-migrant dabbling ducks, which primarily feed on plants during the

**Table 5. Pied-billed Grebe Abundance Trends – Annual, Summer, and Winter***

| Season | Statistics | Period of record 1992-2021 | Hydrilla Invasion 1992-2000 | Hydrilla Management 2000-2012 | Post-Hydrilla Management 2012-2021 |
|---|---|---|---|---|---|
| Annual | Prob(F) | <0.0001 | 0.0037 | <0.0001 | 0.4632 |
| | Slope | 0.0013 | -0.0042 | 0.0028 | n/s |
| | R-squared | 0.070 | 0.108 | 0.124 | n/s |
| Summer (April-August) | Prob(F) | <0.0001 | 0.2863 | 0.8614 | 0.0087 |
| | Slope | 0.0009 | n/s | n/s | 0.0018 |
| | R-squared | 0.087 | n/s | n/s | 0.039 |
| Winter (September-March) | Prob(F) | <0.0001 | 0.0241 | <0.0001 | 0.6988 |
| | Slope | 0.0017 | -0.0041 | 0.0041 | n/s |
| | R-squared | 0.140 | 0.106 | 0.263 | n/s |

* Statistically significant increasing trend slopes appear in green font; significant decreasing trend slopes in red.

non-breeding season (The Cornell Lab of Ornithology, 2019). This is plausible, but migrant bird distributions in any given winter also may be affected by summer breeding success, weather during migration, and food availability along the migration route, which can result in inter-annual fluctuations. The wigeon's long-term decline after 2005-06 may have resulted in part from the net decrease in SAV biomass that resulted from the herbicide treatments and accompanying impacts. However, analysis of Christmas Bird Count (CBC) circles[14] between 1975 and 2004 indicates that the southern boundary of the wigeon's winter range began to shift northward during that time (La Sorte and Thompson, 2007) consistent with the expected effects of climate change (Notaro et al., 2016). The summer breeding range of the wigeon also has shifted north since the mid-1980s (Mini et al., 2014). The North American Breeding Bird Survey conducted by the U.S. Geological Survey (Sauer et al., 2017) indicates that American wigeon breeding populations in eastern North America exhibited a statistically significant long-term decline between 1966 and 2015 of -3.64 percent per year and a significant decline of -1.99 percent per year over the more recent period 2005-2015. It seems likely, therefore, that the trends we have experienced at Wakulla are the result of some combination of range and breeding population shifts along with changes to the upper Wakulla River ecosystem.

The hydrilla invasion period increase of the predominantly herbivorous **American coot** (The Cornell Lab of Ornithology, 2019), also may have been in response to the rising abundance of hydrilla. The coot increased during this period but subsequently dropped precipitously mid-way through the intensive hydrilla management period, recovered to a maximum winter monthly mean of 217 in the winter of 2006-07, declined, then rallied again to a secondary peak winter monthly mean of 152 in 2011-12, and then dropped off again after the winter of 2012-2013 (see Figure 11). The resulting net long-term decline appears unrelated to the ecosystem disturbances at Wakulla Spring. Substantial inter-annual variations may be due to factors other than conditions at the spring. The long-term decline is consistent with documented decreases in breeding populations in most of the areas from which it probably migrates in the Midwest and eastern North America (Sauer et al., 2017; 2020) and a northward shifting of its winter range (La Sorte and Thompson, 2007).

[14] The Audubon Christmas bird count surveys are conducted within 24-km (15-mile) diameter circles for a period of one day during a two-week period centered approximately on 25 December.

**Figure 10. American Wigeon Winter Monthly Mean Abundance 1993-2017**

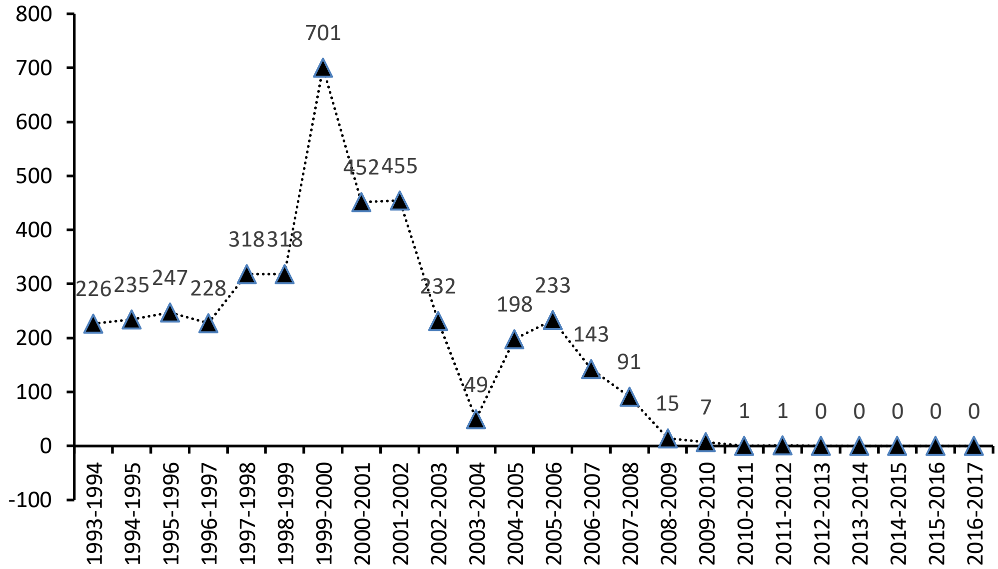
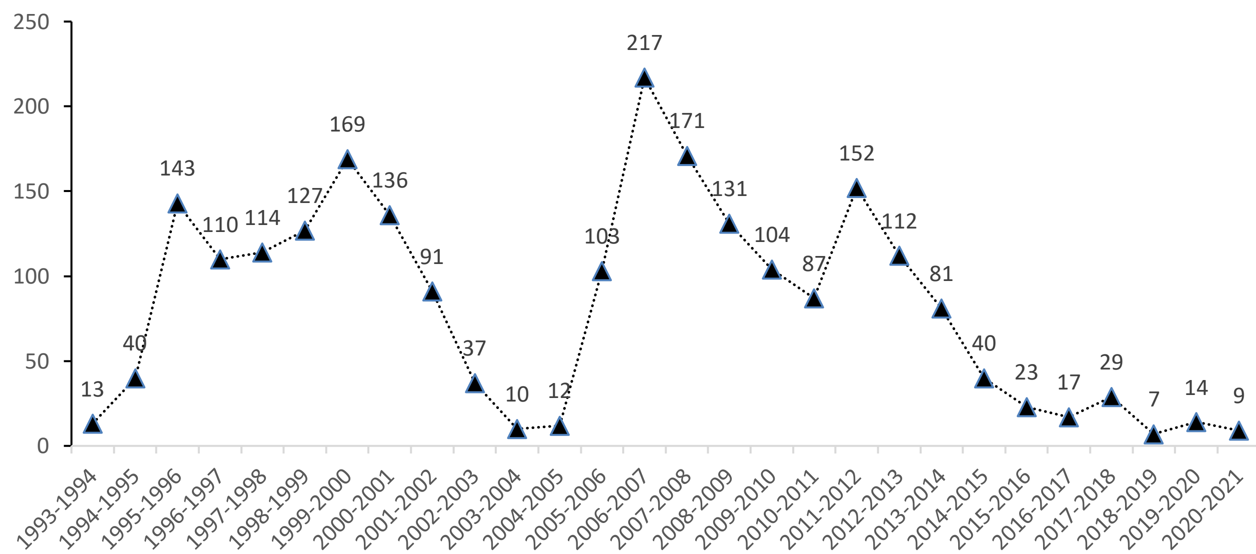
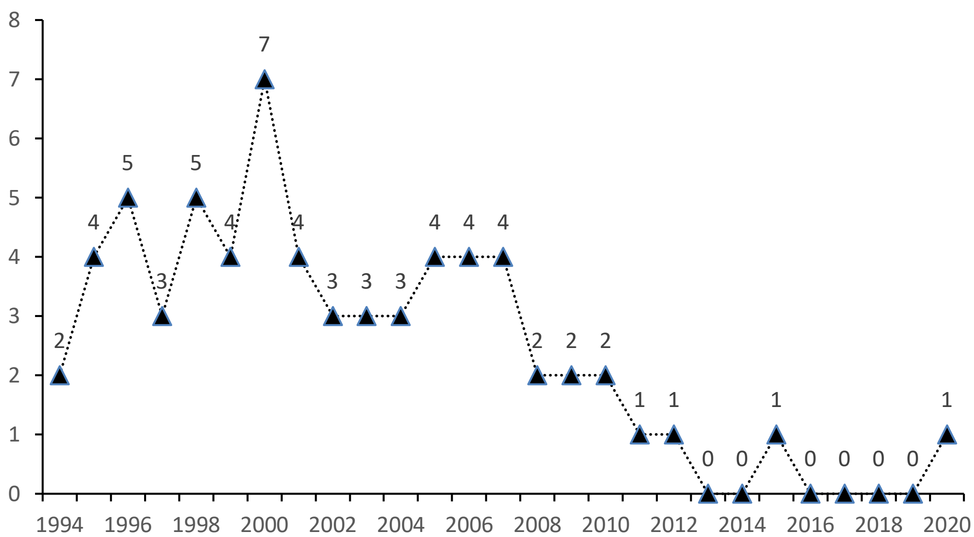



**Figure 11. American Coot Winter Monthly Mean Abundance 1994-2021**




The **green heron** has experienced a significant long-term decrease in abundance measured as counts per survey. Numbers for the green heron are generally small throughout the period of record with annual means ranging from zero to seven between 1994 and 2020 (see Figure 12). This may reflect relatively large feeding and/or breeding territories. After an initial increase during the hydrilla invasion period, the species declined significantly during the hydrilla management period, a pattern that is manifest in both counts per survey and annual mean counts per survey (see Appendix E). As of 2018, the green heron had not recovered, exhibiting no significant trend in counts per survey during the post-hydrilla management period. Nesting along the river boat tour route in 2020 shifted the trend, however, yielding a significant increase in counts per survey for the period January 2012 through May 2021. Annual mean counts per survey bottomed out in 2013 with annual means of zero thereafter except in 2015 and 2020 when it increased to one. The green heron eats mostly small fish as well as some macroinvertebrates, amphibians, reptiles, and small mammals (The Cornell Lab of Ornithology, 2019). With such a diverse diet, its decline may be a result of an overall decrease in the biological productivity of the upper river ecosystem.

**Figure 12. Green Heron Annual Mean Abundance 1994-2020**




The **little blue heron** exhibits no significant long-term abundance trend, but it did increase significantly during the hydrilla invasion period. No significant trends in counts per survey have been manifest since then. The little blue is often a solitary feeder with a diverse diet including insects, shrimp, amphibians, and fish (Florida Fish and Wildlife Conservation Commission, 2003). It has bred in nesting colonies along the second mile of the upper Wakulla River periodically since 1989, as documented by the park's summer full-river wildlife surveys, most recently nesting there since 2016 (see Figure 13). Annual means peaked in 2000 and 2001 followed by declines from 2002 through 2004 (see Figure 14). It is possible that the little blue benefitted from the expansion of the hydrilla and then experienced a setback after the initial intensive mechanical and chemical control efforts greatly reduced the hydrilla cover as well as the animals that inhabited it. Annual means peaked again in 2007 and 2011 but returned to pre-2000 levels in 2012.

**Figure 13. Little Blue Heron Summer River Survey, Park Section, 1989-2020**

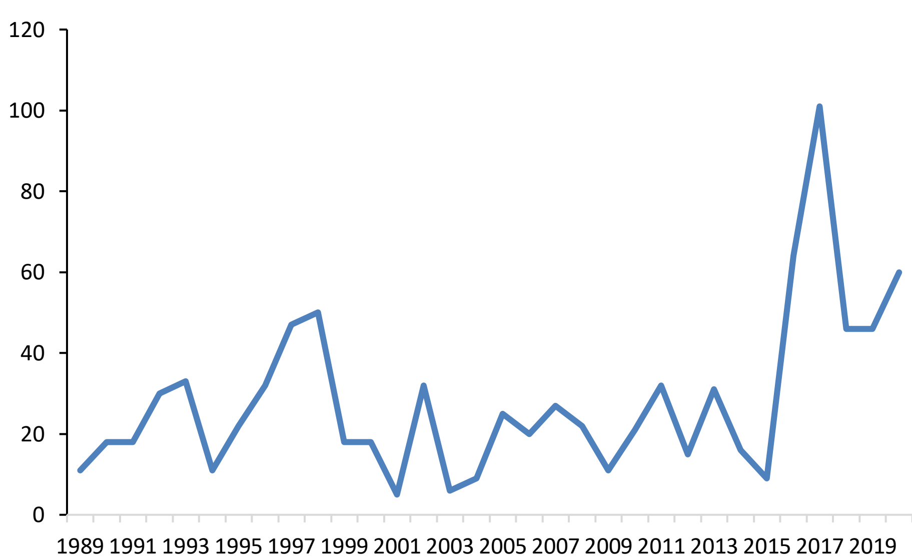
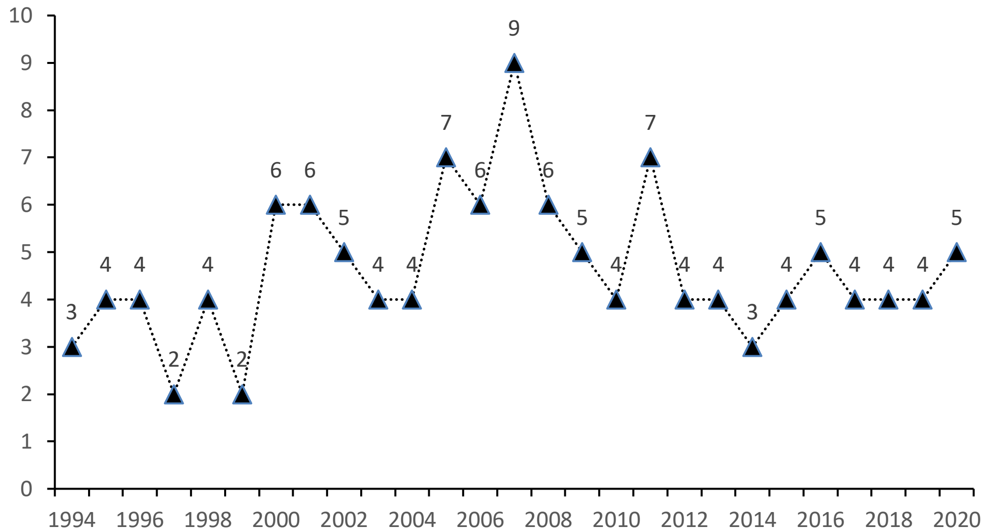


**Figure 14. Little Blue Heron Annual Mean Abundance 1994-2020**




Although listed as a year-round occupant of North Florida, **ospreys** are present on the upper Wakulla River in small numbers, most commonly during the breeding season (February - July) when the monthly means over the period of record (1992-2020) have been two or three (see Appendix E). Monthly means have been zero between September and December. The osprey exhibits significant decreasing trends over the long-term and during the hydrilla management and post-hydrilla management periods, but it also experienced a significant increase in abundance during the hydrilla invasion period. Breeding monthly means peaked at six in 2000, then declined to a plateau of two by 2010 and to one by 2016 (see Figure 15). As many as four or five active nests have been observed along the river boat tour route in the past (Bob Thompson, personal communication) with others further down the river including one about 0.25 mile below the tour boat turn around (personal observation). Three active nests circa 2015 have given way to one or none for the past six years (personal observation corroborated by Patty Wilbur). With an exclusive fish diet high on the food pyramid, the osprey's decline may be indicative of the apparent long-term decrease in biological productivity reflected in the period of record declines of the aggregate measures of wildlife abundance. A loss of fish in the size classes it typically consumes – six to twelve inches (The Cornell Lab or Ornithology, 2019) – may also be a factor, perhaps due in part to the by-catch of juvenile fish during mechanical hydrilla harvesting and/or the dramatic shifts in the SAV community following the herbicide treatments of the early 2000s.[15]

**Purple gallinules** have always been rare along the river boat tour route on the upper Wakulla River (see Appendix E) with only four survey counts greater than four over the 29.5-year period of record (five observed on 7/28/98; six on 8/31/98; and nine on 7/5/96 and 6/8/13). Annual means have ranged from zero to two and have been zero every year since 2002, with the exception of 2007, when the mean was one (see Figure 16). While purple gallinules eat a wide variety of aquatic plants, including hydrilla, as well as insects, they prefer marsh habitats with floating aquatic vegetation (The Cornel Lab of Ornithology, 2019). Although the purple gallinule exhibits a significant long-term trend of decreasing abundance, it did experience a significant increase during the hydrilla invasion period, followed by a significant decrease during the hydrilla management period. It is plausible that the hydrilla mats provided

[15] Unfortunately, no baseline data on fish or other aquatic vertebrates and invertebrates exist for the upper one mile of the Wakulla River so we can only speculate that the by-catch of juvenile fish and invertebrates from the mechanical harvesting and/or the dramatic fluxes in the SAV community may have been accompanied by other changes throughout the food web that contributed to the observed declines in species that are principally or exclusively fish eaters including anhinga, double-crested cormorant, osprey. FDEP's stream condition index (SCI) monitoring site is located two miles downriver from the spring (Florida Springs Institute, 2014). The SCI evaluates the abundance and diversity of macroinvertebrates.

attractive habitat, and that the mechanical and herbicide management of the hydrilla led to their subsequent decline, including no observations between May 2002 and February 2007.

**Figure 15. Osprey Breeding Season Monthly Mean Abundance Feb-Jul 1994-2020**

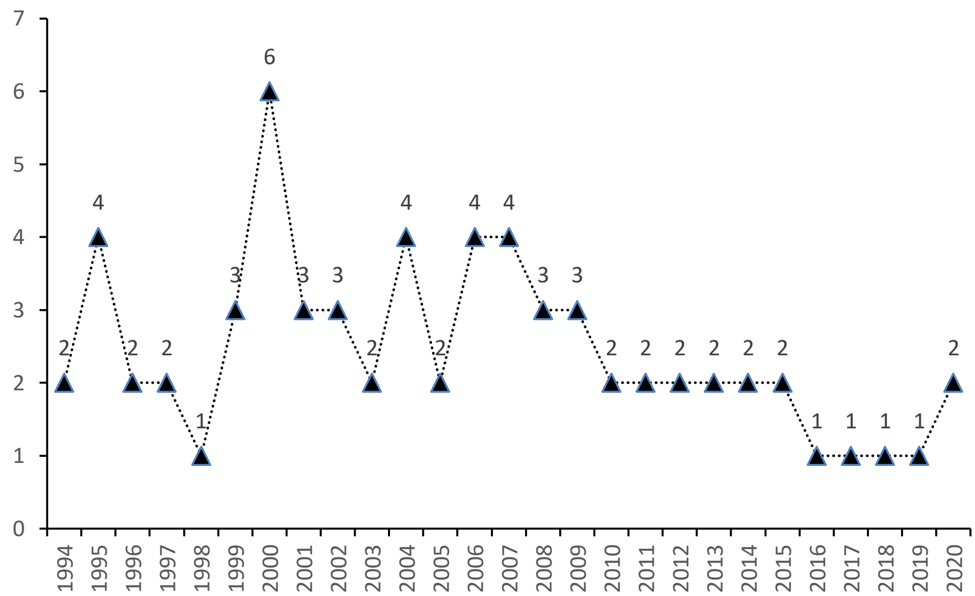
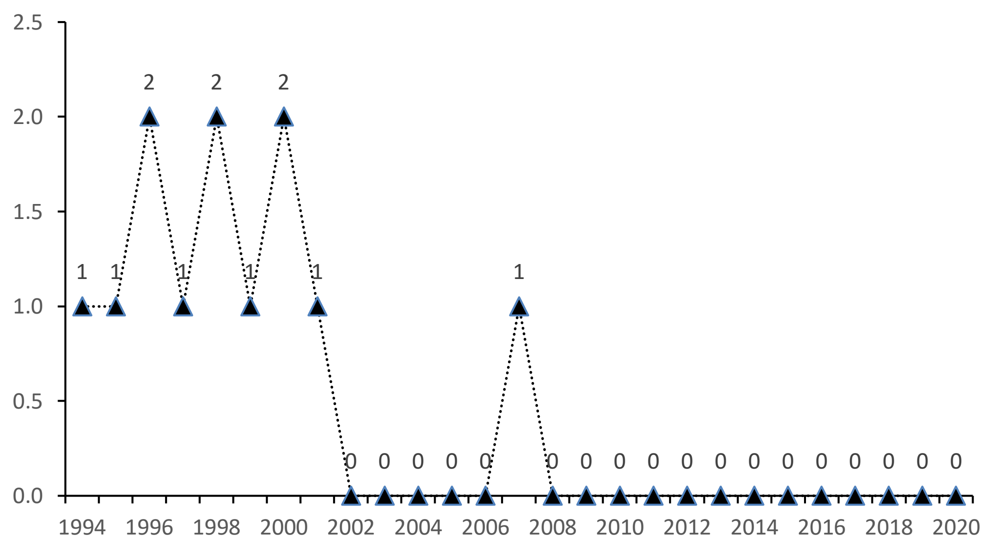
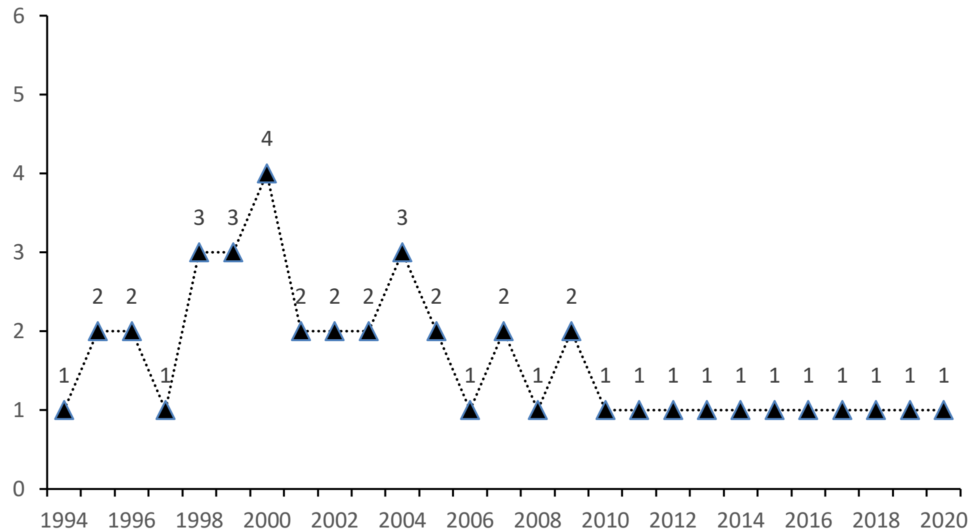



**Figure 16. Purple Gallinule Annual Mean Abundance 1994-2020**




The **tricolored heron**, while more common than the purple gallinule, also is present in small numbers with annual means ranging from one to four, peaking in 2000 and stable at one since 2010 (see Figure 17). This species, which has experienced a significant long-term trend of decreasing abundance, exhibits a significant increase in abundance during the hydrilla invasion followed by a significant decreasing trend during the hydrilla management period and then a modest rebound in the post-hydrilla management period raised up by higher counts per survey in 2018 through 2021. Frederick (2013) reports that the tricolored heron feeds almost exclusively on small fish and tends to feed alone or at the edge of mixed flocks. Its rise and fall in abundance may reflect increased food availability associated with the expanding hydrilla mats and a subsequent decline resulting from the mechanical harvesting by-catch of juvenile fish and, perhaps, reduced fish habitat associated with decreases in the overall SAV community following herbicide treatment. However, Florida breeding populations of tricolored herons have exhibited a declining trend of -1.27 percent per year during much of the period of record from 1993-2019 (Sauer et al., 2020) as well as during the most recent 10-year period analyzed, 2005-2015 (-1.73 percent per year as reported by Sauer et al., 2017). Thus the Wakulla declines may be associated, at least in part, with a larger-scale shift in regional metapopulation.[16]

**Figure 17. Tricolored Heron Annual Mean Abundance 1994-2020**




Based on year-round counts per survey, the **white ibis** has experienced a long-term increasing trend in abundance spurred by a significant increase during the hydrilla invasion period (see Table 6). However, no significant trends in counts per survey are exhibited during the hydrilla management period or the post-management period,

Ibis migrate regionally and their site allegiance can be low for both breeding and roosting habitat (Heath et al., 2009). During summer months (April - June), counts are low on the upper Wakulla River, often comprising mostly immature birds (personal observation) while adults are presumably nesting in colonies elsewhere. Adults and immatures congregate in much larger numbers during the non-breeding season starting in July and peaking from October through February (see Figure 18).

Separate analysis of trends for the summer and winter seasons reveals some different patterns (see Table 6). There is no significant long-term trend for summer season abundance but increasing trends during the hydrilla invasion and post-hydrilla management periods. Winter abundance does exhibit a significant long-term positive trend as well as positive trends during the hydrilla invasion and post-hydrilla management periods.

Annual mean counts per survey initially peaked in 1999 during the hydrilla invasion and then declined sharply through 2003 during the use of mechanical harvesting and the initial Aquathol treatments (see Figure 18). White ibis eat primarily insects and crustaceans, especially crayfish (Wikipedia, 2019), therefore, the 2002 crayfish kill may have contributed to this decline. Annual mean counts per survey peaked again in 2006, fluctuated widely until 2011, and since then have varied less extensively. Some of this variation may be due to other factors affecting the species's choice of nonbreeding-season roosting sites.

[16] "A metapopulation is a group of populations that are separated by space but consist of the same species. These spatially separated populations interact as individual members move from one population to another" (https://study.com/academy/lesson/metapopulation-definition-theory-examples.html).

**Table 6. White Ibis Abundance Trends – Annual, Summer Breeding, and Winter Non-breeding**

| Season | Statistics | Period of record 1992-2021 | Hydrilla Invasion 1992-2000 | Hydrilla Management 2000-2012 | Post-Hydrilla Management 2012-2021 |
|---|---|---|---|---|---|
| Year-round | Prob(F) | <0.0001 | 0.0133 | 0.2018 | 0.0810 |
| | Slope | 0.0016 | 0.0065 | n/s | n/s |
| | R-squared | 0.027 | 0.080 | n/s | n/s |
| Summer (April-June) | Prob(F) | 0.2409 | 0.0296 | 0.0853 | 0.0151 |
| | Slope | n/s | 0.0030 | n/s | 0.0008 |
| | R-squared | n/s | 0.263 | n/s | 0.054 |
| Winter (July-March) | Prob(F) | <0.0001 | 0.0169 | 0.2783 | 0.0377 |
| | Slope | 0.0022 | 0.0075 | n/s | 0.0033 |
| | R-squared | 0.048 | 0.096 | n/s | 0.014 |

**Figure 18. White Ibis Monthly Means 1992-2020**

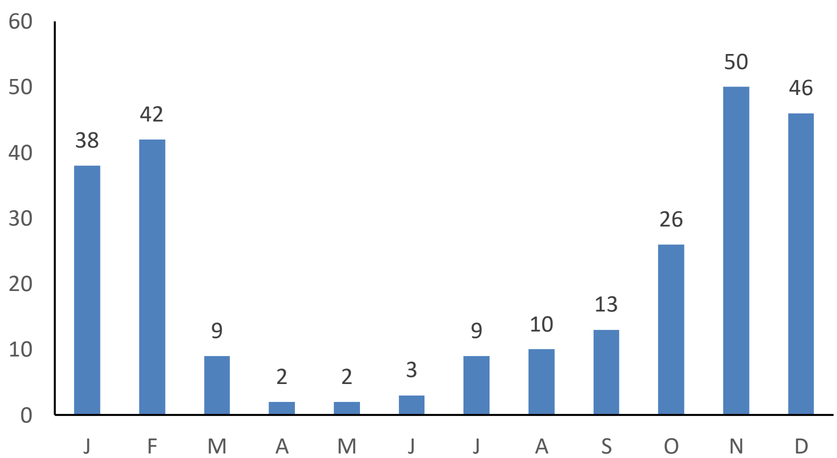
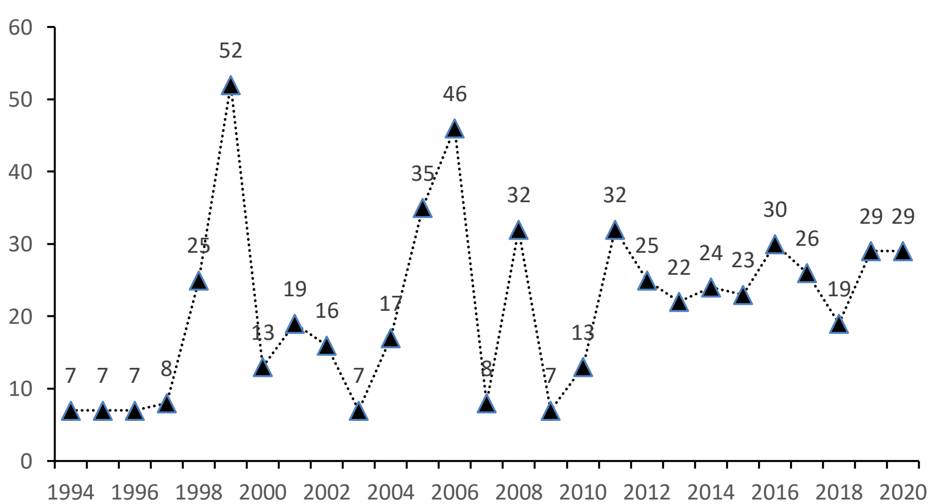


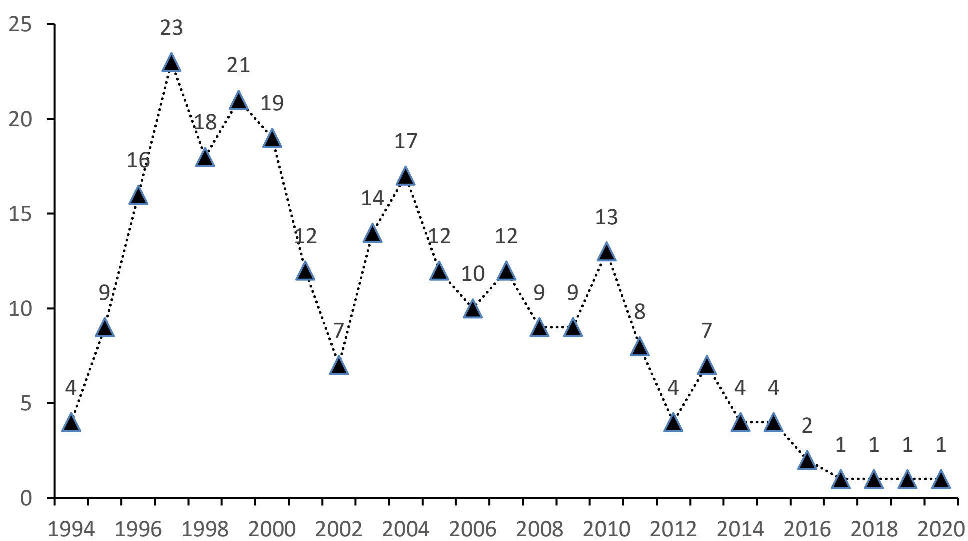

**Figure 19. White Ibis Annual Mean Abundance 1994-2020**



**Wood duck** are year-round breeders with much higher counts during the apparent breeding season of April through September (see Appendix E). Like the American wigeon and osprey, the wood duck experienced a significant long-term decrease on the upper Wakulla River yet began with a significant increasing trend during the hydrilla invasion period. This was followed by significant decreasing trends in both the hydrilla management period and the post-hydrilla management period. Annual mean counts per survey peaked between 1997 and 1999, declined steeply to 2002, rebounded to 2004, and then generally declined to very low values in 2016 through 2020 (see Figure 20). Multivariate analysis of the recent trend in counts per survey, between November 10, 2012, through May 29, 2021, reveals that the trend remains statistically significant after controlling for temperature and river stage (see Appendix E).

Wood ducks are omnivores that feed on a wide variety of both aquatic and terrestrial plants and insects and other arthropods (The Cornel Lab or Ornithology, 2019). Their peak between 1997 and 1999 may have been a result of increased food supply provided by the expanding hydrilla. Their subsequent decline may have been a result of the combined loss of aquatic plants and macroinvertebrates that accompanied the intense mechanical harvesting efforts and further losses with the large-scale reductions in hydrilla biomass caused by the Aquathol treatments. Their decline also may reflect a larger scale regional decrease. The most recent USGS Breeding Bird Survey (Sauer et al., 2020) records a long-term decreasing trend of –3.34% per year in Florida between 1993 and 2019, possibly due to decreasing forested wetland habitat.

**Figure 20. Wood Duck Annual Mean Abundance 1994-2020**

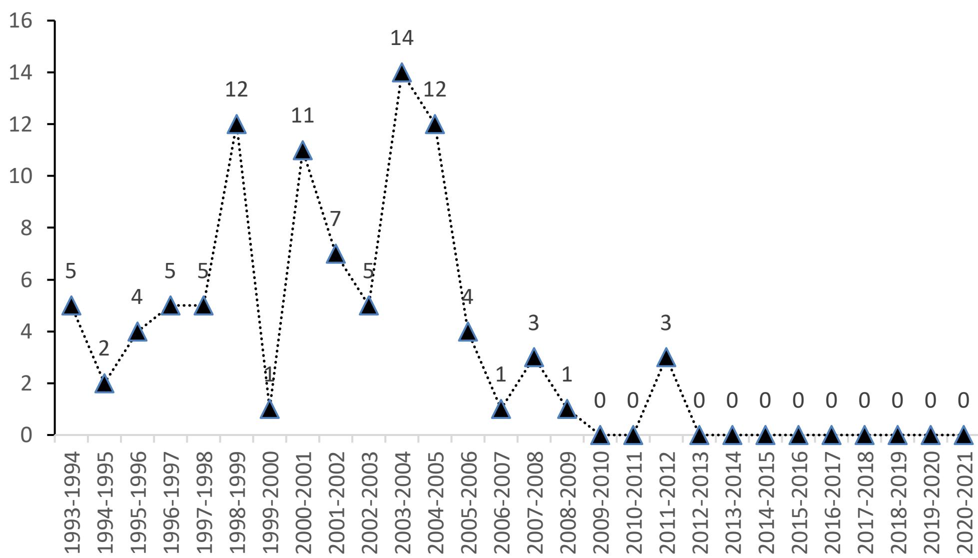



*Hydrilla Management Period (2000-2012)*

As shown in Table 4, <u>twelve wildlife species experienced statistically significant declines during the period of intensive efforts to control the invasive hydrilla</u>: American alligator, American wigeon, blue-winged teal, common gallinule, double-crested cormorant, green heron, osprey, purple gallinule, snowy egret, tricolored heron, wood duck, and yellow-crowned night-heron. The American wigeon, blue-winged teal, common gallinule, purple gallinule, and wood duck are all predominantly herbivorous omnivores, with the teal feeding mainly on aquatic plant seeds (Rohwer et al., 2002). The dramatic changes in the SAV community may have contributed to their population declines. As noted above, this seems plausible for the **American wigeon**, **purple gallinule**, **and wood duck** which increased as the hydrilla proliferated, however other external factors may also have contributed to the long-term declines of the wigeon and wood duck on the upper Wakulla River.

Seasonal counts per survey of the winter migrant **blue-winged teal** show a statistically significant long-term decrease but no significant trend during the post-hydrilla management period (see Appendix E). This species migrates through this area on its way to and from south Florida and Central and South America (Rohwer et al., 2002). Highest monthly means occur in October, but we have recorded individuals in every month except May, June, and July. Winter monthly means exhibited several large amplitude swings between the winters of 1997-98 and 2005-06 (see Figure 21). They ranged from three to zero after 2005-06 and have been zero since 2012-13. However, their long-term decline on the upper Wakulla River is consistent with the USGS breeding bird census (Sauer et al., 2020) which shows decreases in all the Midwest, Mid-Atlantic, and Northeast states and Canadian provinces between 1993 and 2019.

**Figure 21. Blue-Winged Teal Winter Monthly Mean Abundance Sep-Mar 1993-2021**




The **common gallinule** is another predominantly surface-feeding herbivore that is a year-round breeder on the upper Wakulla River, with winter populations apparently increased by migrants from the north. The species attained a peak in annual means in 2000 at the end of the hydrilla invasion period (see Figure 22), but that increase was not sufficient to generate a statistically significant positive trend in counts per survey for annual counts per survey or for seasonal counts during summer or winter (see Table 6). It experienced significant decreasing trends during the hydrilla management period beginning in 2001, one year prior to the first large-scale liquid herbicide treatment, perhaps due to the disturbance of the hydrilla surface mat by mechanical harvesting. Figure 22 shows that the decline in annual means continued to 2015, three years after the last liquid herbicide treatment, after which a rebound appeared to begin. However, annual mean counts have plateaued since 2017. As shown in Table 6, during the post-hydrilla management period the trends in annual and winter counts per survey are decreasing, while the trend for summer counts per survey is positive and significant.

In a multivariate model controlling for river stage, air temperature, and cloud cover, the annual negative trend in counts per survey is no longer statistically significant. Higher abundance is associated with lower river stage (birds may be more visible), lower air temperature (reflecting annual arrival of winter migrants), and more cloud cover (also perhaps a reflection of higher numbers during winter). The decline in total SAV biomass resulting from the herbicide treatment and associated impacts, including the ascendance of blue-green algae which offer low food value, are plausible contributing causes for this species's decline. Table 6 suggests that a decline in winter migrants may be contributing to the decline in annual counts per survey since 2000. Common gallinule that winter in Florida migrate from Ontario, the upper Midwest, New England, and the Mid-Atlantic states (Stevenson and Anderson, 1994). Sauer et al. (2020) report an annual rate of decline of -4.26 percent in breeding populations between 1993 and 2019 in New England and the Mid-Atlantic states. The 1993-2019 trend in Florida breeding populations also is negative: a decrease of 1.78 percent per year. It is not clear what may be behind the increases in summer counts per survey since 2012.

**Figure 22. Common Gallinule Annual Mean Abundance 1994-2020**

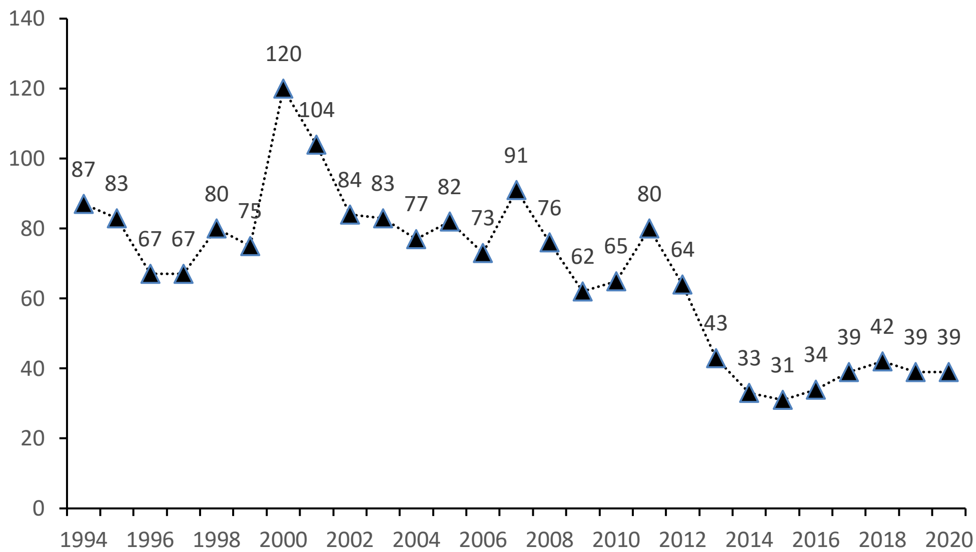



**Table 7. Common Gallinule Abundance Trends – Annual, Summer, and Winter**

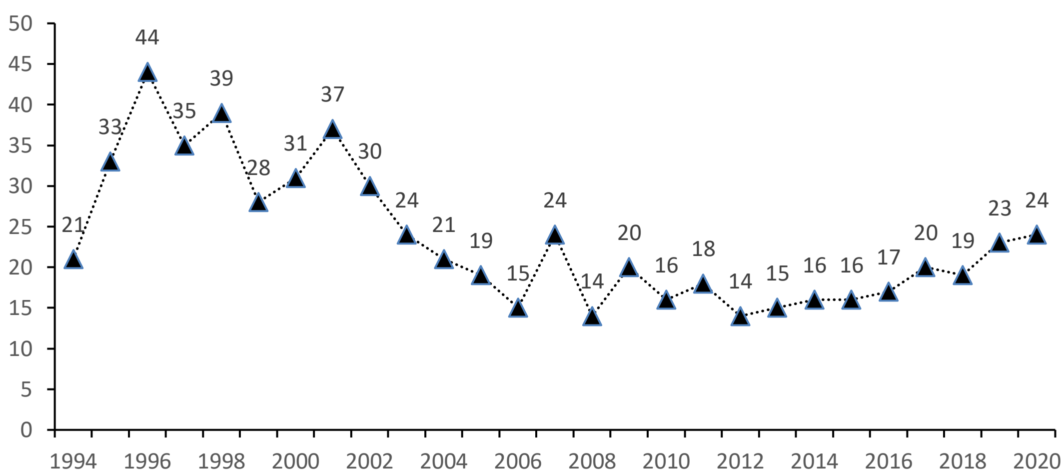
| Season | Statistics | Period of record 1992-2021 | Hydrilla Invasion 1992-2000 | Hydrilla Management 2000-2012 | Post-Hydrilla Management 2012-2021 |
|---|---|---|---|---|---|
| Annual | Prob(F) | < 0.0001 | 0.4291 | <0.0001 | 0.0417 |
| | Slope | -0.0070 | n/s | -0.0081 | -0.0015 |
| | R-squared | 0.407 | n/s | 0.116 | 0.010 |
| Summer (May-August) | Prob(F) | <0.0001 | 0.4565 | 0.0236 | 0.0271 |
| | Slope | -0.0052 | n/s | -0.0049 | 0.0027 |
| | R-squared | 0.351 | n/s | 0.098 | 0.034 |
| Winter (September-April) | Prob(F) | <0.0001 | 0.2848 | <0.0001 | 0.0001 |
| | Slope | -0.0076 | n/s | -0.0104 | -0.0035 |
| | R-squared | 0.441 | n/s | 0.172 | 0.051 |

<u>The other seven species that exhibited the onset of significant decreases in abundance during the hydrilla management treatment period are primarily carnivorous</u>: American alligator, double-crested cormorant, green heron, osprey, snowy egret, tricolored heron, and yellow-crowned night-heron. The **green heron** and **tricolored heron** are discussed above.

As a top predator in the aquatic food web, the **American alligator**'s abundance may be indicative of aggregate changes in the biological productivity of the ecosystem (Gabrey, 2010; Mazzotti et al., 2009). Alligator annual mean abundance began a protracted decline in 2002 at the onset of intensive Aquathol treatment following fluctuating levels during the preceding hydrilla invasion period (see Figure 23). Its abundance numbers turned around beginning in 2013, yielding a significant increasing trend in counts per survey since 2012, a possible indication of increasing biological productivity. Multivariate analysis of counts per survey between November 10, 2012, through May 29, 2021, reveals that the alligator post-hydrilla management trend remains statistically significant after controlling for air temperature, river stage, and cloud cover. That analysis also reveals that alligator counts are higher when river stage is lower (more basking areas), air temperature is warmer, and the weather is clear or has some clouds. Another possible explanation for the recent increases in alligator counts is the choice of nesting locations by female alligators. Three females began nesting along the tour boat route sometime after 2013 (personal observation) resulting in higher counts when young are visible. No formal data are available on when that began, and other accounts indicate that young alligators have been observed along the tour route in previous years (Wakulla Springs Archive, 2004). Nevertheless, we began splitting alligator survey counts into two size classes as of April 2018 to provide some control for juveniles inflating the count: less than three feet and greater than or equal to three feet (see Appendix A).

The **double-crested cormorant**, which feeds predominantly on fish (The Cornell Lab of Ornithology, 2019), is a year-round resident of the upper Wakulla River that has bred in colonies in the second mile of the river below the spring every year since at least 1989, with the possible exception of 2014, as documented by the park's summer full-river wildlife surveys (see Figure 24).[17] The cormorant had exhibited no significant long-term trend in counts per survey for the period of record through 2018. However, with the addition of data for January 2019 through May 2021, a significant positive trend has emerged (see Appendix E). The cormorant experienced a significant decrease during the hydrilla management period followed by a significant increase in abundance during the post-hydrilla management period. The recent increase in abundance is evident from the annual means shown in Figure 25 and may reflect the larger nesting rookery that year. Cormorants have been observed eating crayfish during summer and fall 2021 for the first time which may reflect declining fish populations.

**Figure 23. American Alligator Annual Mean Abundance 1994-2020**




[17] Park staff and volunteers have conducted a synoptic survey of wildlife along the entire length of the Wakulla River twice each year since 1989: once in winter (late January or early February) and once in summer (late July or early August). Three teams conduct the survey simultaneously, one on each of three river segments: spring to "upper bridge" (CR 365); upper bridge to "lower bridge" (US 98); and lower bridge to St. Marks River confluence.

**Figure 24: Double-Crested Cormorant Count Summer River Survey, Park Section, 1989-2020**

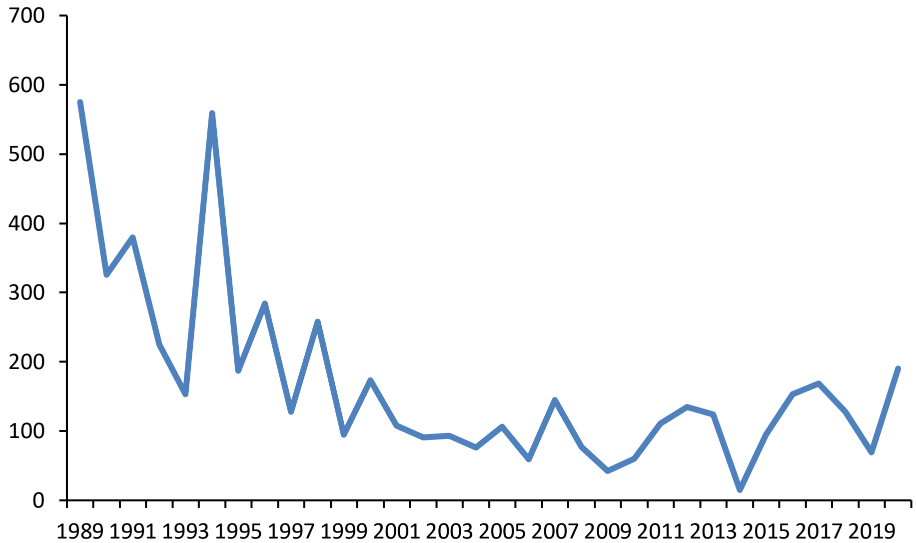
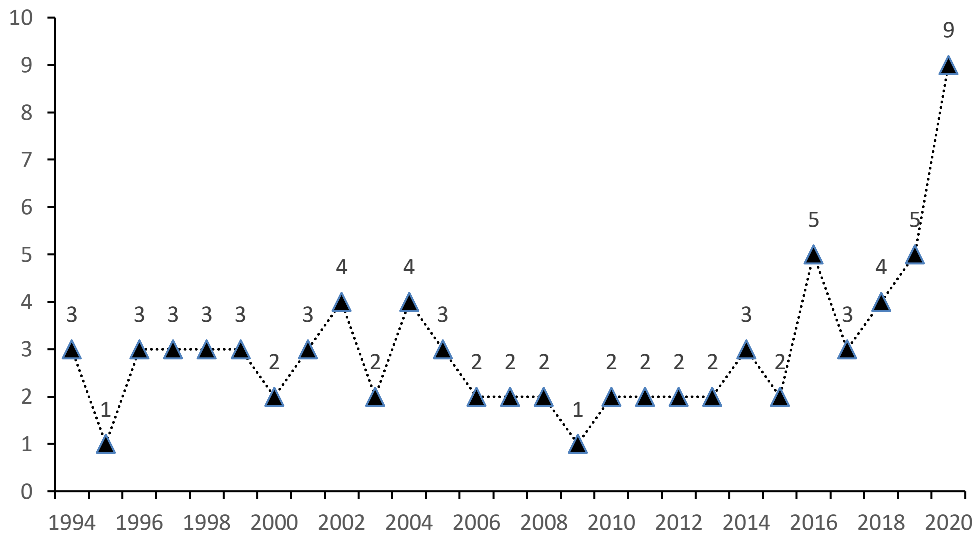
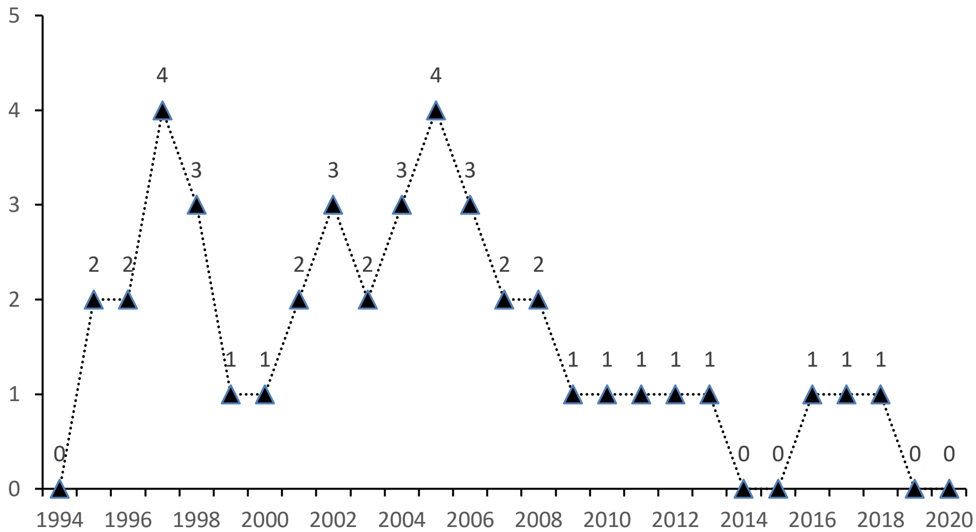



**Figure 25. Double-Crested Cormorant Annual Mean Abundance 1994-2020**




The **snowy egret** exhibited a significant long-term decrease in counts per survey as well as a significant decreasing trend during the hydrilla management period (see Appendix E). The decline began in 2005, midway through that period, after high variability earlier in the period of record as illustrated by the annual means displayed in Figure 26. The snowy egret levelled off at an annual mean of one in 2009 with dips to zero in 2014 and 2015 and 2019 and 2020. The snowy eats mostly small fish as well as some macroinvertebrates, amphibians, reptiles, and small mammals (The Cornell Lab of Ornithology, 2019). The by-catch of juvenile fish and invertebrates from the mechanical harvesting and/or the dramatic fluxes in the SAV community may have been accompanied by other changes throughout the food web that contributed to the observed decline in this species. However, numbers for snowy egret are generally small throughout the period of record with annual means ranging from zero to four between 1994 and 2020. Thus, some of the observed changes over time may be artifacts of random fluctuations in these small populations and where individuals choose to be.

**Figure 26. Snowy Egret Annual Mean Abundance 1994-2020**




The **yellow-crowned night-heron** is a summer breeder present in small numbers (monthly means of one to three) during the non-breeding season (July - March) with peak counts (monthly means of five to eight) during the breeding season (April - June). Most individuals migrate to south Florida or beyond in the winter (Watts, 2011). They feed primarily on crustaceans (The Cornell Lab of Ornithology, 2019) – mostly crayfish on the upper Wakulla River (personal observation). The species exhibits no significant long-term trend in counts per survey over the period of record, 1992-2021 (see Appendix E), however, a significant decrease in abundance during the hydrilla management period was followed by a significant increase during the post-hydrilla management period. No clear signals emerge from the count-per-survey data as to likely causes of these shifts. Contrary to what might be expected, night-heron counts spiked to 20 and 25 between April and June 2002 coincident with the crayfish kill that resulted from the initial Aquathol treatment. They spiked again at 19 in May 2003, and 22 in May 2010. Annual mean counts show a peak in 2002, a three-year low from 2005-2007, a smaller peak in 2010-11, and a steady increase since 2012 (see Figure 27). Because yellow-crowned night-herons feed mostly at night, count fluctuations may in part reflect nest locations where they are most likely to be seen during the breeding season, especially juveniles. Some nesting sites along the river boat tour route are used every year, while others are used irregularly (personal observation).

Four species exhibited significant increases in abundance during the hydrilla management period: cattle egret, hooded merganser, manatee, and pied-billed grebe. The **pied-billed grebe** is discussed above. As shown in Table 4, the **cattle egret** has experienced a long-term increasing trend (see Appendix E) that has been driven by breeding behavior. It feeds in pastures and fields and therefore is generally only seen on the river during the breeding season. As shown in Figure 28, it has nested in varying numbers along the upper river on and off since the early 1990s, peaking in 2020. It nested in colonies along the river boat tour route from 2012 through 2014; in other years, the nesting colony has been along the second mile of the river below the river boat tour turnaround. Breeding season monthly means were zero to three from 1994 to 2011 (see Figure 29) despite large nesting colonies along the second mile of the river. The egrets then established breeding colonies on the upper river in 2012, 2013, and 2014 which pulled the long-term trend up with breeding season monthly means of 45 to 59. The high counts in 2012 account for the significant increasing trend in counts per survey during the hydrilla management period. The cattle egrets relocated their colony to the downriver site in 2015 yielding a net decrease in counts per survey for the post-hydrilla management period. However, since 2015, summer monthly means (see Figure 29) and counts per survey (see Appendix E) have increased coincident with expansion of the downriver colony.

**Figure 27. Yellow-Crowned Night-heron Annual Mean Abundance 1994-2020**

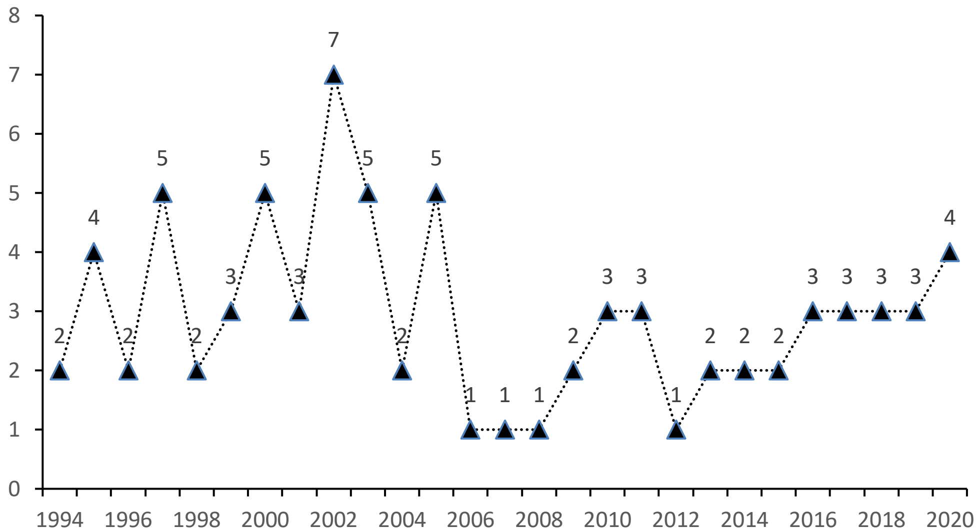
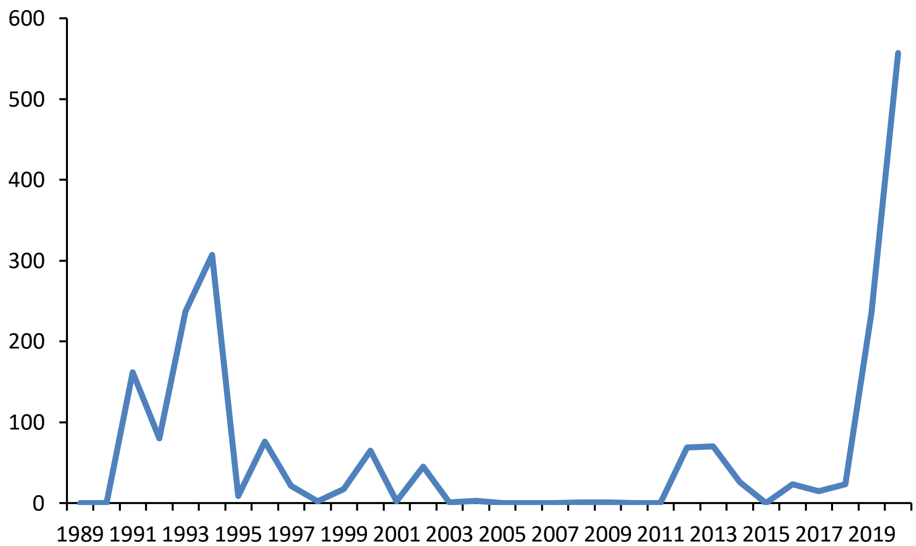
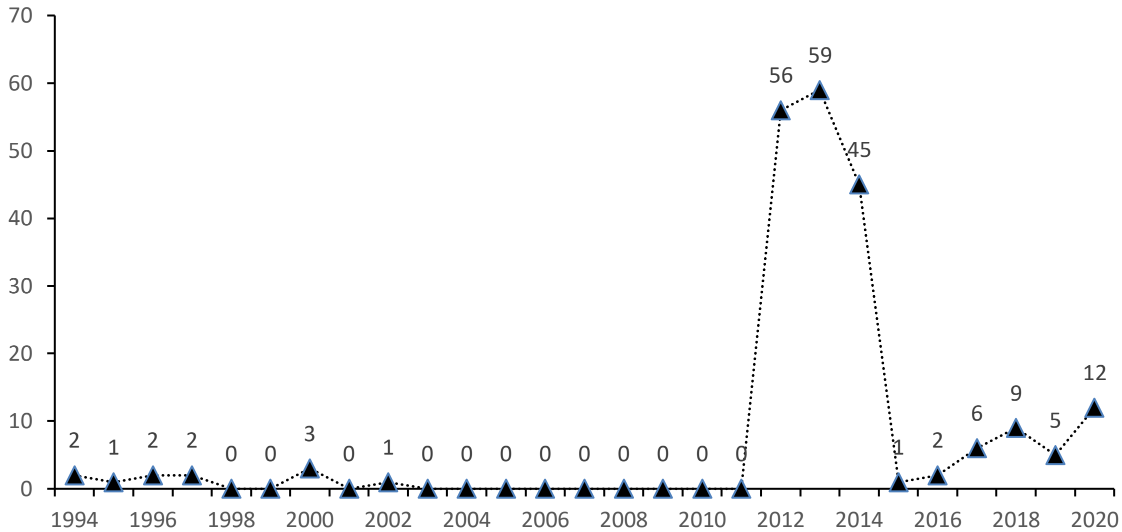



**Figure 28. Cattle Egret Count Summer River Survey, Park Section, 1989-2020**



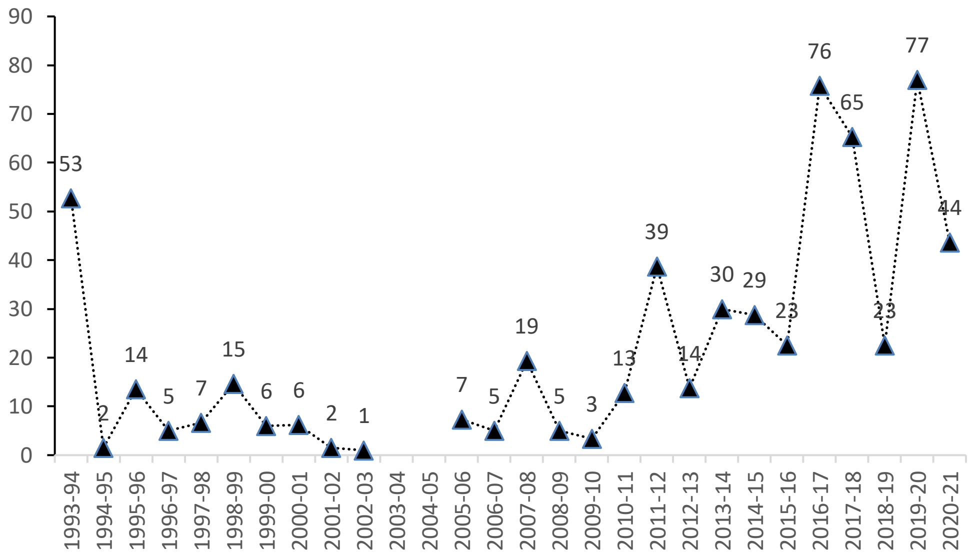

The **hooded merganser** experienced a significant increase in counts per survey over the period of record that was first manifest during the hydrilla management period. The merganser is a winter migrant with a varied diet that includes “small fish, aquatic insects, crustaceans (especially crayfish), amphibians, vegetation, and mollusks” (The Cornel Lab of Ornithology, 2019). On the upper Wakulla River, they are frequently seen eating crayfish (personal observation). Winter monthly means were low for many years after an initial peak in 1993-94, followed by an upswing beginning in 2011-12 and large swings between 2016-17 and 2020-21 (see Figure 30). The increasing trend in winter counts per survey remains statistically significant (better than 99.99% level) despite those swings. Very low winter monthly means of two and one in 2001-02 and 2002-03 may reflect some negative impacts from the most intense hydrilla management initiatives, including the April 2002 initial Aquathol treatment which resulted in a crayfish kill. A second dip in winter monthly means in 2008-09 and 2009-10 (five and three respectively) followed a second smaller crayfish kill after the April 2008 Aquathol treatment. However, the merganser exhibits a statistically significant increasing trend during the hydrilla management period. No local ecosystem changes appear to be related to increases since 2015-16. However, the long-term increasing trend is consistent with increases in summer breeding populations throughout the eastern Canadian provinces and

**Figure 29. Cattle Egret Summer Monthly Mean Abundance, May-Aug, 1994-2020**




in the Midwest, New England, and Mid-Atlantic states between 1993 and 2019 (Sauer et al., 2020) as well as in eastern North America between 2005 and 2015 (Sauer et al., 2017). The increasing trend also is consistent with a southward trend in the centers of abundance and occurrence of wintering populations between 1975 and 2004 (La Sorte and Thompson, 2007).

**Figure 30. Hooded Merganser Winter Monthly Mean Abundance, Nov-Feb, 1993-2021**




As noted above, **manatee** were first observed in the park in 1997 and appeared sporadically in small numbers until 2003, which was the first year for which counts were compiled from the regular wildlife monitoring surveys.[18] They over-wintered at the spring for the first time in 2007-2008. As shown in Figure 31, there was a steady increase in annual monthly means from 2007 to 2012 as more and more manatee travelled to the spring. The influx has been attributed to carrying capacity pressure at Crystal River from which the Wakulla manatee emigrated (P. Wilbur, personal communication). However, Jess Van Dyke (2019) reports that scouring of the river bottom that resulted from the initial hydrilla herbicide

---

[18] Manatee were not included on the survey form until 2007. Data prior to 2007 are likely incomplete. Observations recorded in 2003 and 2005 are from the open-ended "Comments" section at the bottom of the survey form. None were recorded for 2004 or 2006.

treatment in 2002 opened a passageway through shallow water at the park boundary just north of the county route 365 (Shadeville Road) bridge that had previously been largely impassable because of dense hydrilla and/or shallow sediments. Sediments remain largely bare in that area today with sufficient water depth facilitating regular manatee movement into the upper river. Winter monthly means reveal a less acute peak (see Figure 32). These began to increase in winter 2010-11, peaking in 2012-13 and 2013-14, but have since declined. The decline tracks the failure of the hydrilla to recover from manatee grazing over the winter of 2012-13 coupled with the decrease in nitrogen discharges to the spring from the Tallahassee T.P. Smith wastewater treatment plant (see Appendix C). Winter monthly means had plateaued at four to seven animals suggesting that a new carrying capacity may have been reached for this species. However, a seven-year peak occurred in December 2020 likely reflecting a colder early winter than in recent years. Monthly means in December 2020 and January 2021 were greater than those between 2003 and 2020. However, heavy grazing decimated eelgrass (*Vallisneria americana*) beds in and near the spring basin with a steep drop in counts in February and March 2021.

**Figure 31. Manatee Annual Mean Abundance 1994-2020**

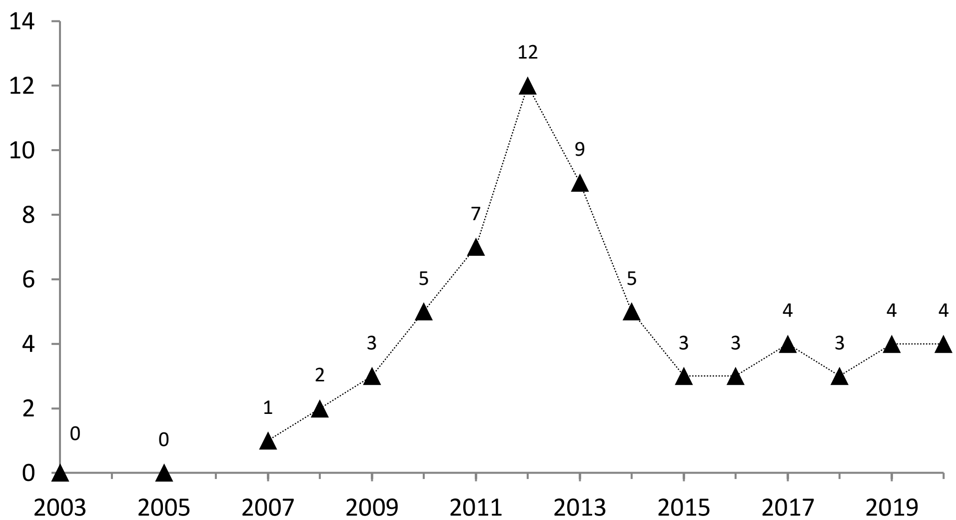
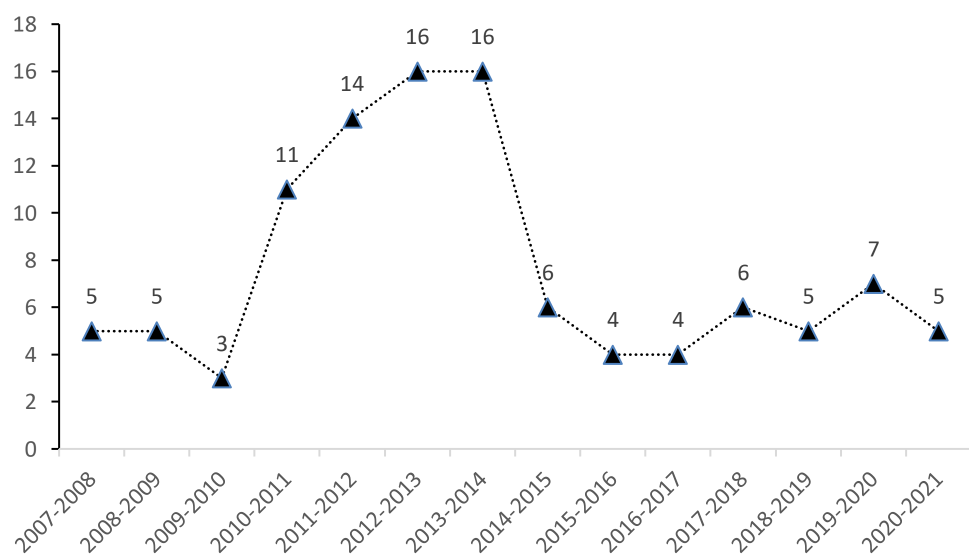



**Figure 32. Manatee Winter Monthly Mean Abundance, Oct-Feb, 2007-2021**



*Post-Hydrilla Management Period (2012-2021)*

Table 4 indicates that <u>ten species have experienced significant increases in counts per survey in the post-hydrilla management period</u>: American alligator, anhinga, cattle egret, double-crested cormorant, great egret, green heron, hooded merganser, limpkin, tricolored heron, and yellow-crowned night-heron. All but the anhinga and great egret are discussed above. **Anhinga** are year-round breeders that almost exclusively eat small to medium-size fish (The Cornel Lab of Ornithology, 2019). Although they exhibited no statistically significant trends during the hydrilla invasion or the hydrilla management period (see Appendix E), their annual mean underwent a steep decline in 2001 during the second year of intense hydrilla mechanical harvesting from which they have not fully recovered (see Figure 33). The by-catch of juvenile fish resulting from mechanical harvesting may have reduced their food supply. It also is possible that the continued down-river expansion of the hydrilla through 2001 may have impeded fishing and compelled them to move elsewhere. Anhinga annual means have oscillated between 10 and 17 since 2004, with periodic dips and peaks, most recently dropping to 11 in 2018. Counts per survey during the post-hydrilla management period exhibit a significant increase although with a very small slope (0.0008 count per survey). This may be an artifact of reduced nesting. Anhinga males are highly territorial during the nesting season (Kearns, 2009). While there were as many as five active nests along the tour route as recently as 2015, there have only been one or two since 2017 (personal observation). With fewer defended nesting territories, breeding season counts would be higher.

A steep decline that began in November 2020 raised concerns among park staff and volunteers. The post-hydrilla management counts per survey data presented in Appendix E show that abundance typically declines each spring, but the 2020-21 decline began earlier. Comparison of monthly means for June through May for 2019-20 and 2020-21 indicates that the most recent seasonal decrease has been much more pronounced than the year before (see Figures 34 and 35). Months colored orange in Figure 35 were 2 or more counts lower in 2020-21 than 2019-20. Months colored green were two or more counts higher. The lower anhinga counts per survey in early 2021 coincided with informal observations of many fewer small and medium size fish by staff and volunteers. In July and August 2021, park staff observed some anhinga eating crayfish (Jackie Turner, personal communication, July 13, 2021). While they are known to eat aquatic crustaceans (Kearns, 2009), doing so is unusual on the upper Wakulla River.

**Great egrets** are present in relatively low numbers with annual means between one and six and individual counts as high as 14 to 24 (see Figure 36). Like the great blue heron, they consume a variety of prey including fish, reptiles, amphibians, invertebrates, small mammals, and other birds (The Cornell Lab of Ornithology, 2019). Great egrets have nested along the upper river on occasion, most recently in 2009 and 2010 (personal communication Bob Thompson), and along the second mile of the river in association with cattle egrets and little blue herons (personal observation 6/25/20). Annual mean abundance peaked in 2000 then began to decline with the onset of mechanical hydrilla management. A brief rally between 2005 and 2007 was followed by a steady decline to annual means of one to zero from 2011 on. However, as shown in Table 4, analysis of count-per-survey data yields no significant trends over the period of record or during the hydrilla invasion or hydrilla management period. A significant trend of increasing abundance during the post-hydrilla management period has emerged, albeit at the very slow rate of 0.0004 animals per year. As with other very low-density carnivorous wading birds, this may be an artifact of random movements.

<u>Seven species have exhibited significant decreases over the past nine and a half years</u>: American coot, American wigeon, common gallinule, great blue heron, manatee, osprey, and wood duck. Trends for all but the great blue heron are discussed above. **Great blue herons** are year-round residents of the upper Wakulla River that sometimes breed there, with one or two active nests along the river boat tour route in 2015-2017 (personal observation). Counts range as high as seven, with annual means between one and three (see Figure 37). The occasional higher counts, may, therefore, reflect local breeding. Higher

**Figure 33. Anhinga Annual Mean Abundance 1994-2020**

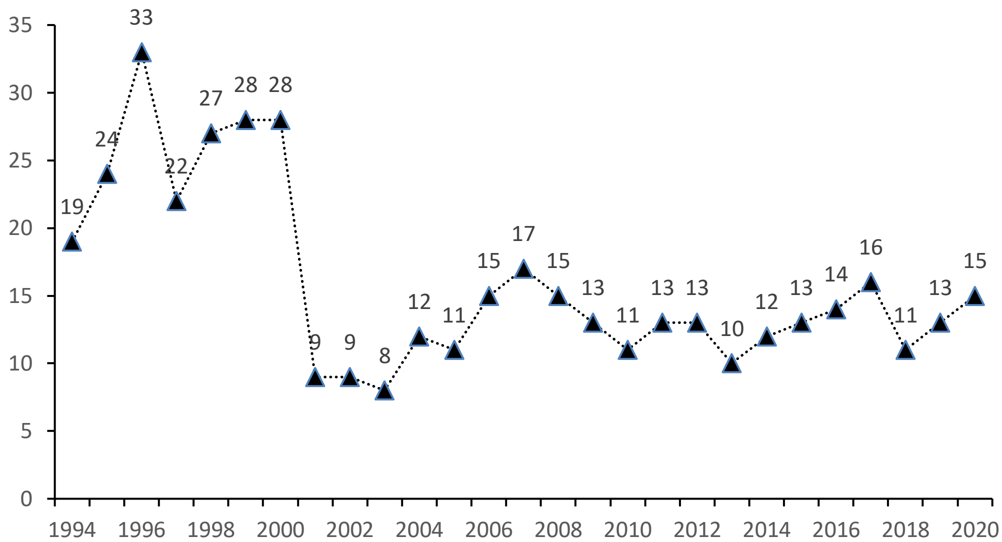



**Figure 34. Anhinga Monthly Mean Abundance Jun-May 2019-2020**

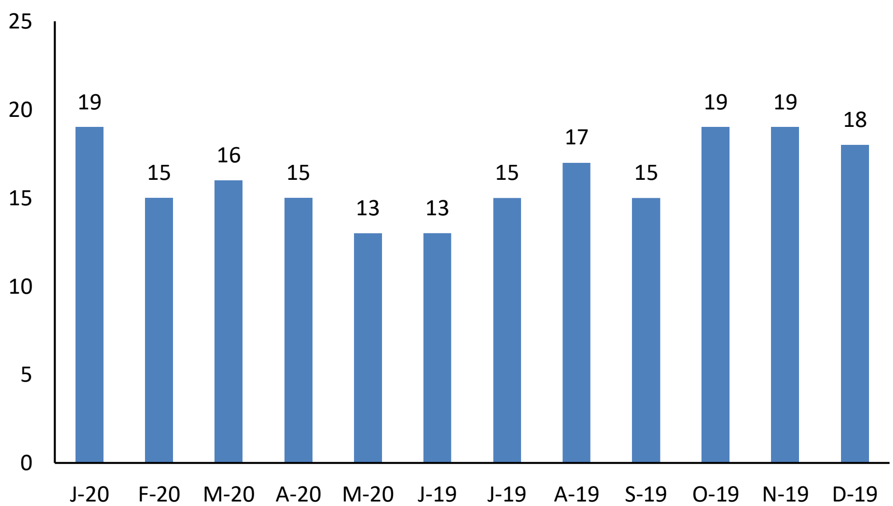



**Figure 35. Anhinga Monthly Mean Abundance Jun-May 2020-2021**

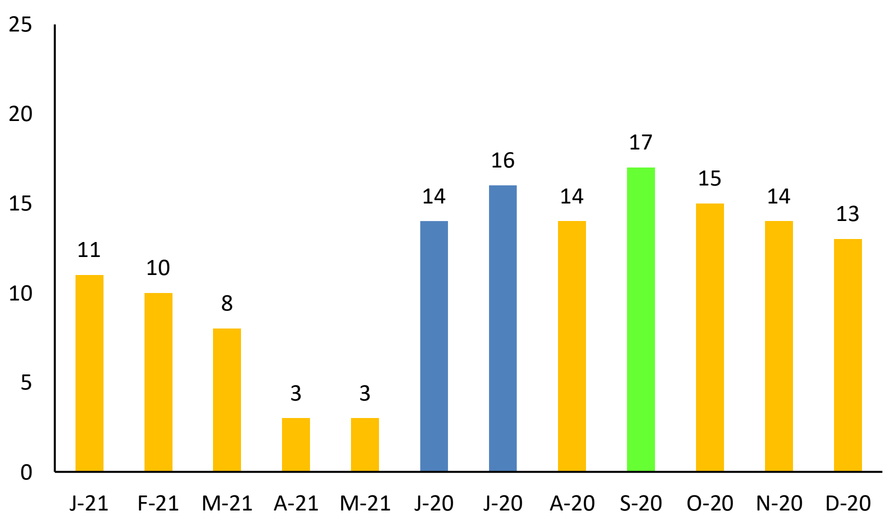
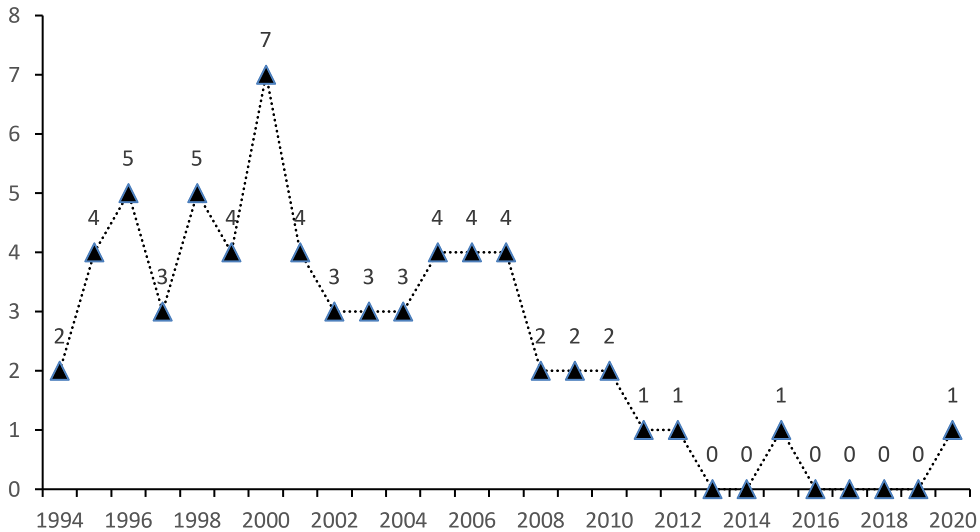
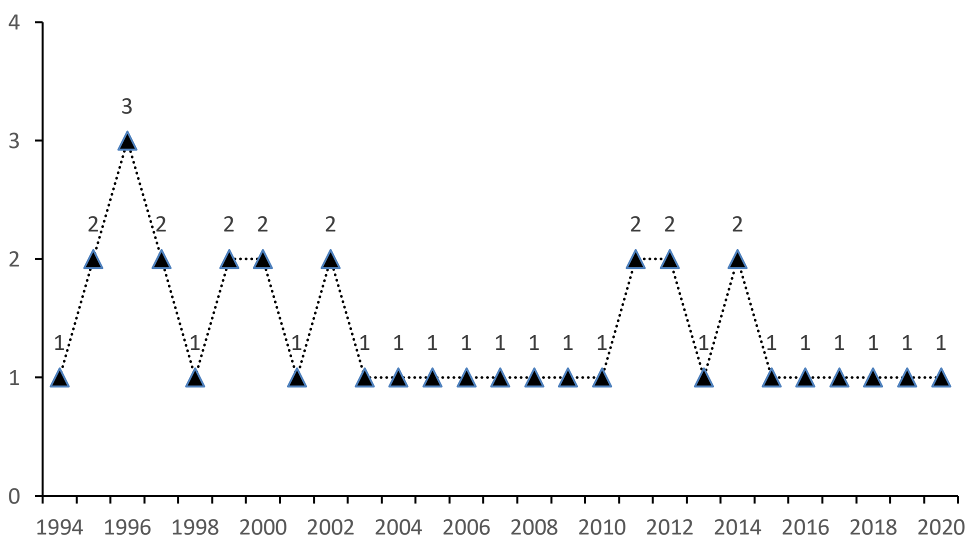


**Figure 36. Great Egret Annual Mean Abundance 1994-2020**




monthly means in November through February may reflect an influx of winter migrants from northern breeding territories (The Cornell Lab of Ornithology, 2019). No long-term abundance trend is evident for the full period of record, but they did exhibit a significant decreasing trend during the post-hydrilla management period despite nesting during some of those years. Great blues are solitary feeders that defend their feeding territories and consume a variety of prey including fish, reptiles, and amphibians, small mammals, and other birds, although they are primarily fish eaters (Vennesland and Butler, 2011). It is likely that the carrying capacity of the upper river is limited. The recent decline may reflect decreased biological productivity of the ecosystem and/or a decline in fish in the size classes they typically consume.

**Figure 37. Great Blue Heron Annual Mean Abundance 1994-2020**




Summary of Abundance Trends

Aggregate wildlife abundance, measured as total numbers of individual animals counted per survey for the 24 species analyzed, has decreased significantly over the 29.5 years of this monitoring project: September 1992 through May 2021. These species have exhibited the following patterns of statistically significant trends in abundance over the period of record and during the three ecosystem perturbation periods analyzed:

- Period of record: September 1992 – May 2021
    - Aggregate wildlife abundance decreased
    - Five species increased in abundance
    - Fourteen species decreased
    - Five species exhibited no long-term trend
- Hydrilla invasion: 1992-2000[19]
    - Aggregate wildlife abundance increased
    - Nine species increased
    - Two species decreased
    - Thirteen exhibited no trend
- Hydrilla management: 2000-2012
    - Aggregate wildlife abundance decreased
    - Four species increased
        - One after decreasing during the previous period
        - Two after exhibiting no trend during the previous period
        - One for which no data are available for the previous period
    - Twelve species decreased
        - Six after increasing during the previous period
        - Six after exhibiting no trend during the previous period
    - Eight species exhibited no trend
        - Three after increasing during the previous period
        - One after decreasing during the previous period
        - Four continued to exhibit no trend
- Post-hydrilla management: 2012-2021
    - Aggregate wildlife abundance continued to decrease
    - Ten species increased
        - Two after increasing during the previous period
        - Five after decreasing during the previous period
        - Three after exhibiting no trend during the previous period
    - Seven species decreased
        - One after increasing during the previous period
        - Four continued to decrease during this period
        - Two after exhibiting no trend during the previous period
    - Seven species exhibited no trend
        - Three after decreasing during the previous period
        - One after increasing during the previous period
        - Three continued to exhibit no trend

The five species that have increased in abundance during the period of record include (in decreasing rate of increase) hooded merganser, white ibis, cattle egret, pied-billed grebe, and double-crested cormorant. Among the 14 species that have decreased significantly, the five that have declined most rapidly include (in decreasing rate of decline) American wigeon, common gallinule, American coot, wood duck, and American alligator.

The hydrilla invasion, which began in 1997 spurred by high levels of nitrogen in the spring and river, appears to have stimulated significant increases over the period 1992 to 2000 in the populations of some

[19] The species total is 23 for the hydrilla invasion period because of the lack of manatee data during that time.

wildlife species that fed upon the hydrilla and/or the invertebrates and small fish that proliferated in the habitat it created. These included the American wigeon, American coot, green heron, little blue heron, purple gallinule, tricolored heron, white ibis, and wood duck. Osprey also increased during this period, perhaps because the larger fish upon which it feeds also benefited from the increased biological productivity of the disturbed river ecosystem. One other species, the common gallinule, experienced a short-term increase in winter counts in January and February 2000 that did not yield a significant trend over the entire hydrilla invasion period.

The pied-billed grebe decreased in abundance at this time, perhaps because the dense hydrilla mats interfered with its diving for the small fish and crustaceans upon which it feeds. The limpkin all but disappeared at the same time, but most likely because of the loss of its primary food source, the native apple snail, from abnormally high water in 1994 including two tropical storms.

Efforts to control the hydrilla created new disruptions to the upper river ecosystem during the hydrilla management period from 2000-2012. Mechanical harvesting removed large quantities of the hydrilla but also many of the invertebrates and juvenile fish that inhabited it. Herbicide treatments initially caused a massive die back of the hydrilla resulting in short-term decreases in dissolved oxygen and a surge of flow that scoured the river channel. Native submerged aquatic vegetation species such as American eelgrass and springtape succumbed both to the herbicide and the scouring, resulting in a net large decrease in plant biomass and, presumably, the associated biological productivity of the ecosystem.

Six of the nine species that increased during the hydrilla invasion period experienced significant decreases during the subsequent hydrilla management period, probably due at least in part to loss of habitat and/or food supply. Four of these species either remained at lower levels during the post-hydrilla management period or decreased further: American wigeon, osprey, purple gallinule, and wood duck. The wigeon decline was likely due both to local ecosystem changes as well as a northward shift in its wintering range and a broad geographic decline in breeding populations. The green heron increased during the post-hydrilla management period due primarily to nesting in 2020 along the river boat tour route. The tricolored heron also exhibited an increasing trend during the post-hydrilla management period, pulled up largely by a single high count of five on April 3, 2021.

Another six species, which had exhibited no trend during the hydrilla invasion, experienced significant decreases during hydrilla management, most likely because of decreased food supplies. Three of these subsequently increased during the post-hydrilla management period: American alligator, double-crested cormorant, and yellow-crowned night-heron. The other three either remained at lower levels of abundance or decreased further during the post-hydrilla management period: blue-winged teal, common gallinule, and snowy egret.

Three of the species that increased during the hydrilla invasion exhibited no trend during the hydrilla management period. The white ibis continued more or less at elevated levels resulting in a long-term increasing trend. The American coot subsequently decreased yielding a net long-term decline. The little blue heron exhibited no significant trends in either subsequent perturbation period, nor did it experience a long-term trend in abundance.

Two species that did not exhibit significant decreases in counts per survey during the hydrilla management period nonetheless experienced sharp decreases in annual means at some point during this period. As shown in Appendix E, the hooded merganser exhibited a short-term decline in winter monthly mean counts per survey associated with the initial herbicide treatment in 2002 and/or the crayfish kills that resulted that year and in 2008, yet it experienced a net significant increase in abundance during this period which continued during the post-hydrilla management period. The anhinga underwent a steep decline in annual mean in 2001 during the second year of intense hydrilla mechanical harvesting from which it has only recently begun to apparently recover.

The pied-billed grebe, which had experienced a decrease during the hydrilla invasion, posted significant increases in the hydrilla management period and had been exhibiting a continuing increase during the post-hydrilla management period until a downturn in 2019 that has continued into 2021.

The cattle egret, which exhibited no significant trend during the hydrilla invasion, increased during the hydrilla management period. It began nesting in a colony along the river boat tour route in 2012 at the end of this period. The egrets relocated their colony to an area about two miles downriver in 2015 yielding a net decrease in abundance for the post-hydrilla management period. However, counts since 2015 have increased coincident with expansion of the downriver colony.

Manatee showed up in the upper river in the late 1990s grazing on the hydrilla and other submerged aquatic vegetation. They were not routinely counted until 2007. Numbers increased during the hydrilla management period to a peak in 2013 and subsequently declined during the post-hydrilla management period as the hydrilla failed to recover from annual grazing likely due to the substantial decrease in nitrogen resulting from upgrading the Tallahassee wastewater treatment facility. A seven-year peak in December 2020 likely reflected a colder early winter than in recent years. Monthly means in December 2020 and January 2021 were greater than those between 2003 and 2020. However, heavy grazing decimated eelgrass (*Vallisneria americana*) beds in and near the spring basin with a steep drop in counts in February and March 2021.

Ten species exhibited increasing trends during the post-hydrilla management period (2012-2021). As noted, these were continuations of increasing trends from the previous period for two species: the cattle egret, a summer breeder, and the hooded merganser, a winter migrant. The cattle egret increase reflects increasing size of the summer nesting colony in the second mile of the river. The merganser's winter range has shifted south, and its northern summer breeding populations have increased.

Five others reversed decreasing trends from the previous period: American alligator, double-crested cormorant, green heron, tricolored heron, and yellow-crowned night-heron. For two species, the post-hydrilla management increases marked the first significant period trend: the anhinga, which exhibited a significant long-term decreasing trend, and the great egret, which exhibited no significant long-term trend. The limpkin, which had only been observed sporadically since 1999, posted a significant increase during the post-hydrilla management period, appearing on six occasions and remaining on the river for several weeks at a time in some instances. Two individuals were spotted on March 25, 2017, and on three different dates in winter and spring 2020.

Of the seven species that experienced significant decreases during the post-hydrilla management period, four continued decreasing trends from the previous period: American wigeon, common gallinule, osprey, and wood duck. As discussed above, the manatee reversed an increasing trend from the previous period. The American coot decreased during this period after increasing during the hydrilla invasion and remaining unchanged during the hydrilla management period. Its long-term decline is consistent with changes in its winter range and reductions in breeding populations. The great blue heron's decrease during the post-hydrilla management period comprises its only significant abundance trend.

*Encouraging Signals*

- Significant increasing abundance trends for several carnivorous species during the post-hydrilla period: American alligator, double-crested cormorant, great egret, green heron, hooded merganser, limpkin, tricolored heron, and yellow-crowned night-heron. These include shifts from no trend to increasing with the addition of 2019-2021 data for green heron, limpkin, and tricolored heron. However, counts for these three species are very low, so small random variations can have a large impact on apparent trends.
- Continued stability of white ibis after increasing during the hydrilla invasion.

*Discouraging Signals*

- Continuing decreases for the common gallinule, osprey, and wood duck and new decreasing trends for the American coot and great blue heron.

*Mixed Signals*

- While the anhinga's post-hydrilla increasing trend has been maintained, decreases in winter and spring 2020-21 may signal a decreasing food supply. Since relocating its nesting colony to the second mile of the river in 2017, the cattle egret has exhibited increasing abundance. However, since it does not feed in the spring and river ecosystem, this change offers no clear signal about the state of the upper river ecosystem.
- Manatee decreases since 2013 are likely the result of the demise of the hydrilla. Heavy grazing in early winter 2020-21 may limit carrying capacity in subsequent years.
- The pied-billed grebe's previous increasing trend during the post-hydrilla management period reverted to no significant trend with the addition of 2019-2021 data.

*Possible Implications*

The upper Wakulla River ecosystem may be shifting to a system where detrital- rather than SAV-based food webs are more prevalent. Species that can and/or do feed primarily or substantially on crayfish, which are detrital feeders, continue to exhibit stable or increasing trends: hooded merganser, yellow-crowned night-heron, pied-billed grebe, white ibis, and American alligator (juveniles). Species that feed predominantly on SAV, including common gallinule, American coot, and manatee, are declining. Those that depend more heavily on medium to large fish also appear to be in decline: osprey, great blue heron, and anhinga. These generalizations are complicated, however, by other phenomena including vagaries of continental and regional migration patterns and summer breeding success of winter migrants (American coot, blue-winged teal, common gallinule, hooded merganser, white ibis) and summer nesting (cattle egret, double-crested cormorant).

References Cited


Bryan, D.C. 2020a. Apple Snails and Limpkins at Wakulla Springs. http://wakullaspringsalliance.org/wp-content/uploads/2016/11/Apple-Snails-and-Limpkins-at-Wakulla.Bryan_.2020.pdf.

Bryan, D.C. 2020b. Wakulla Timeline. Updated. http://wakullaspringsalliance.org/wp-content/uploads/2021/07/WAKULLA-TIMELINE-BRYAN-4-14-2020-UPDATE-1.doc

Darby, P.C. et al. 1997. *Ecological Studies of Apple Snails (Pomaceapaludosa, SAY)*. Special Publication SJ98-SP6. Gainesville, FL: Florida Cooperative Fish & Wildlife Research Unit. http://static.sjrwmd.com/sjrwmd/secure/technicalreports/SP/SJ98-SP6.pdf.

Drizd, L.K. 2011. *Aspects of the Abundance, Density, and Movement of Apple Snails Relative to Invasive Submerged Aquatic Plants in a Central Florida Lake*. Master's Thesis. Gainesville, FL: University of Florida. https://ufdc.ufl.edu/UFE0043504/00001.

Florida Fish and Wildlife Conservation Commission. 2003. *Florida's Breeding Bird Atlas: A Collaborative Study of Florida's Birdlife*. http://www.myfwc.com/bba/.

Florida Department of Environmental Protection (FDEP). 2005. *An Investigation of the Potential for Acute Toxicity to the Crayfish, Procambarus peninsulanus, Caused by the Application of the Herbicide, Aquathol, at Wakulla Springs State Park*. Tallahassee, FL.

Florida Springs Institute. 2014. *Wakulla Spring Restoration Plan*. https://floridaspringsinstitute.org/wp-content/uploads/2018/07/2014.08-V3-Wakulla-Restoration-Plan.pdf.

Frederick, B.C. 2013. Tricolored Heron *Egretta tricolor*. *Birds of North America*. The Cornell Lab of Ornithology. https://birdsna.org/Species-Account/bna/species/triher/introduction.

Gabrey, S.W. 2010. Demographic and Geographic Food Habits of American Alligators (*Alligator mississippiensis*) in Louisiana. *Herptological Conservation and Biology* 5(2): 241-250.

Heath, J.A., Frederick, P.C., Kushlan, J.A. and K.L. Bildstein. 2009. White Ibis *Eudocimus albus*. *Birds of North America*. The Cornell Lab of Ornithology. https://birdsna.org/Species-Account/bna/species/whiibi/introduction.

Kearns, L. 2009. "Anhinga anhinga" (On-line), Animal Diversity Web. Accessed August 22, 2021 at https://animaldiversity.org/accounts/Anhinga_anhinga/.

La Sorte, F.A. and F.R. Thompson, III. 2007. Poleward Shifts in Winter Ranges of North American Birds. *Ecology* 88(7): 1803–1812.

Mazzotti, F.J., Best, G.R., Brandt, L.A., Cherkiss, M.S., Jeffrey, B.M., and K.G. Rice. 2009. Alligators and Crocodiles as Indicators for Restoration of Everglades Ecosystems. *Ecological Indicators* 9(6): S137-S149.

Mini, A.E., Harrington, E.R., Rucker, E., Dugger, B.D. and T.B. Mowbray. 2014. American Wigeon *Mareca Americana*. Version 2.0. *Birds of North America*. https://birdsna.org/Species-Account/bna/species/amewig/introduction.

Monette, D., Mark, S., Ewe, S., and M. Dinkins. 2015. Vegetation Community Relationship with Pomacea paludosa. and Pomacea maculata in Lake Okeechobee Florida. https://conference.ifas.ufl.edu/geer/past/geer2015/Documents/Speaker%20Presentations/SESSION%2039/1645_Monette_Dean.pdf.

Notaro, M., Schummer, M., Zhong, Y., Vavrus, S., Van Den Elsen, L., Coluccy. J., et al. 2016. Projected Influences of Changes in Weather Severity on Autumn-Winter Distributions of Dabbling Ducks in the Mississippi and Atlantic Flyways during the Twenty-First Century. *PLoS ONE* 11(12). doi:10.1371/journal.

Pesticide Action Network. 2019. Pesticide Database: Endothall Aquatic Ecotoxicity. http://www.pesticideinfo.org/Detail_Chemical.jsp?Rec_Id=PRI3004#Ecotoxicity

Rohwer, F.C., Johnson, W.P., and E.R. Loos. 2002. Blue-winged Teal *Spatula discors*. *Birds of North America*. The Cornell Lab of Ornithology. https://birdsna.org/Species-Account/bna/species/buwtea/introduction.

Sauer, J.R., Niven, D.K., Hines, J.E., Ziolkowski, Jr, D.J., Pardieck, K.L., Fallon, J.E., and W. Link. 2017. *The North American Breeding Bird Survey, Results and Analysis 1966 - 2015*. Version 2.07.2017. Patuxent Wildlife Research Center, Laurel, MD. https://www.mbr-pwrc.Sauer et al.,.gov/bbs/specl15.shtml.

Sauer, J.R., Link, W.A., and Hines, J.E. 2020. *The North American Breeding Bird Survey, Analysis Results 1966 – 2019*. U.S. Geological Survey data release, https://doi.org/10.5066/P96A7675.

Savery, S. 2005. Appendix E. History of Hydrilla Removal Efforts at Wakulla Springs. In, *Degradation of Water Quality at Wakulla Springs Florida: Assessment and Recommendations*. http://wakullasprings.org/wp-content/uploads/2014/09/WakullaPeerReportFinal.pdf.

Sharfstein, B. and A.D. Steinman. 2001. Growth and Survival of the Florida Apple Snail (Pomaceapaludosa) Fed 3 Naturally Occurring Macrophyte Assemblages. *J. N. Am. Benthol. Soc.*, 20(1): 84-95.

Stevenson, H. M., and B. H. Anderson. 1994. *The Birdlife of Florida*. University Press of Florida, Gainesville, FL, USA

The Cornell Lab of Ornithology. 2019. All About Birds. https://www.allaboutbirds.org/guide/.

Thompson, B. 2019. Summary of SAV Monitoring from 4/25/13 through 2/20/19. Unpublished manuscript.

United States Fish and Wildlife Service (USFWS). 2018. *Waterfowl Population Status 2018*. U.S. Department of the Interior, Washington, D.C. USA. https://www.fws.gov/migratorybirds/pdf/surveys-and-data/Population-status/Waterfowl/WaterfowlPopulationStatusReport18.pdf.

University of Florida Institute of Food and Agricultural Sciences (UF IFAS). 2019. Herbicides Registered for Use in Florida Waters. http://plants.ifas.ufl.edu/manage/developing-management-plans/chemical-control-considerations/herbicides-registered-for-use-in-florida-waters/.

Van Dyke, J. 2019. Controlling Hydrilla at Wakulla Springs State Park (1997-2007). Unpublished manuscript.

Vennesland, R.G. and R.W. Butler. 2011. Great Blue Heron *Ardea Herodias*. *Birds of North America*. The Cornell Lab of Ornithology. https://birdsna.org/Species-Account/bna/species/grbher3/introduction.

Wakulla Springs Archive. 2004. River Boat Tour with Mike Nash. https://www.youtube.com/watch?v=0Ghho9BD6cM&feature=share.

Watts, B.D. 2011. Yellow-crowned Night-Heron *Nyctanassa violacea*. *Birds of North America*. The Cornell Lab of Ornithology. https://birdsna.org/Species-Account/bna/species/ycnher/introduction.

Wikipedia. 2019. American white ibis. https://en.wikipedia.org/wiki/American_white_ibis#Distribution_and_habitat.

# APPENDIX A
## Current Survey Form

**<u>Routing of Completed Surveys:</u> Please place in Wildlife Survey mail slot at the Waterfront**

### Weekly Wakulla Springs Tour Boat Route Wildlife Survey Report

**DATE**: ____ / ____ / ____ (Month, Day, Year); **SURVEY BEGIN TIME**: ____ : ____ (Hour:Minute) AM
**NAME OF VOLUNTEER**: ______________________________________________
**RIVER HEIGHT**: ____ . ___ (Feet & tenths of a foot, measured on river stage gauge mounted on T-dock)
**AIR TEMP** _____ (Degrees F, measured on stick thermometer, cypress tree on WF deck)
**WEATHER**: ___ Clear; ___ Some Clouds; ___ Overcast; ___ Fog; ___ Raining (Check all that apply)

| | Dock to Railroad | Railroad to Turn | Turn to Railroad | Railroad to Dock | Total |
|---|---|---|---|---|---|
| American Alligator < 3 ft | | | | | |
| American Alligator ≥ 3 ft | | | | | |
| Cooter (sp.) | | | | | |
| Florida Softshell Turtle | | | | | |
| Snake (any) | | | | | |
| Pied-billed Grebe | | | | | |
| Double-Cr Cormorant | | | | | |
| Anhinga | | | | | |
| American Bittern | | | | | |
| Least Bittern | | | | | |
| Great Blue Heron | | | | | |
| Great Egret | | | | | |
| Snowy Egret | | | | | |
| Tri-colored Heron | | | | | |
| Little Blue Heron | | | | | |
| Cattle Egret | | | | | |
| Green Heron | | | | | |
| Yellow-crowned Night H. | | | | | |
| White Ibis | | | | | |
| Wood Duck | | | | | |
| Blue-winged Teal | | | | | |
| Lesser Scaup | | | | | |
| Bufflehead | | | | | |
| Hooded Merganser | | | | | |
| Red-shouldered Hawk | | | | | |
| Bald Eagle | | | | | |
| Osprey | | | | | |
| Purple Gallinule | | | | | |
| Common Gallinule (Moorhen) | | | | | |
| American Coot | | | | | |
| Limpkin | | | | | |
| Spotted Sandpiper | | | | | |
| Barred Owl | | | | | |
| Belted Kingfisher | | | | | |
| Manatee | | | | | |

Comments:

Revised 4/6/18

# APPENDIX B
## Wakulla Springs State Park Mechanical Removal of Hydrilla

| Year | Removal Mechanisms | Amount Removed (kg) |
|---|---|---|
| 1998 | Hand pulling -swimming area and spring | 260,000 |
| 1999 | Hand pulling & mechanical harvesting | 444,000 |
| 2000 | Hand pulling & mechanical harvesting | 1,296,000 |
| 2001 | Hand pulling & mechanical harvesting | |
| 2002 | Hand pulling & mechanical harvesting | |
| | Total: | 2,000,000 |

Source: Savery (2005)

# APPENDIX C
## Wakulla Springs State Park Herbicide Treatments for Hydrilla Control

| **Dates of Application** | **Gallons Used** | **Resulting Dose (ppm)*** |
|---|---|---|
| April 1998 | Granular treatment swimming area | n/a |
| April 15-17, 2002 | 1750 | 4.24 |
| November 9-11, 2002 | 2000 | 2.09 |
| November 12-14, 2003 | 1500 | 2.07 |
| May 3, 2004 | 1500 | 1.41 |
| April 27-29, 2005 | 1500 | 1.65 |
| April 17-19, 2006 | 1500 | 2.23 |
| March 26-28, 2007 | 1000 | 2.14 |
| April 21-23, 2008 | 1500 | n/a |
| May 19-20, 2009 | 1500 | n/a |
| May 10-12, 2010 | 1500 | n/a |
| May 10, 2011 | Spot granular treatments | n/a |
| August 30, 2011 | Spot granular treatments | n/a |
| May 1-3, 2012 | 675 | n/a |

*Resulting dose in parts per million calculated from gallons used, stream flow, and duration of application.

Sources: Bryan (2020b); Van Dyke (2019)

APPENDIX D
Wakulla Springs Nitrogen Trends

Figure D-1. Total Nitrogen from City of Tallahassee Wastewater Sources

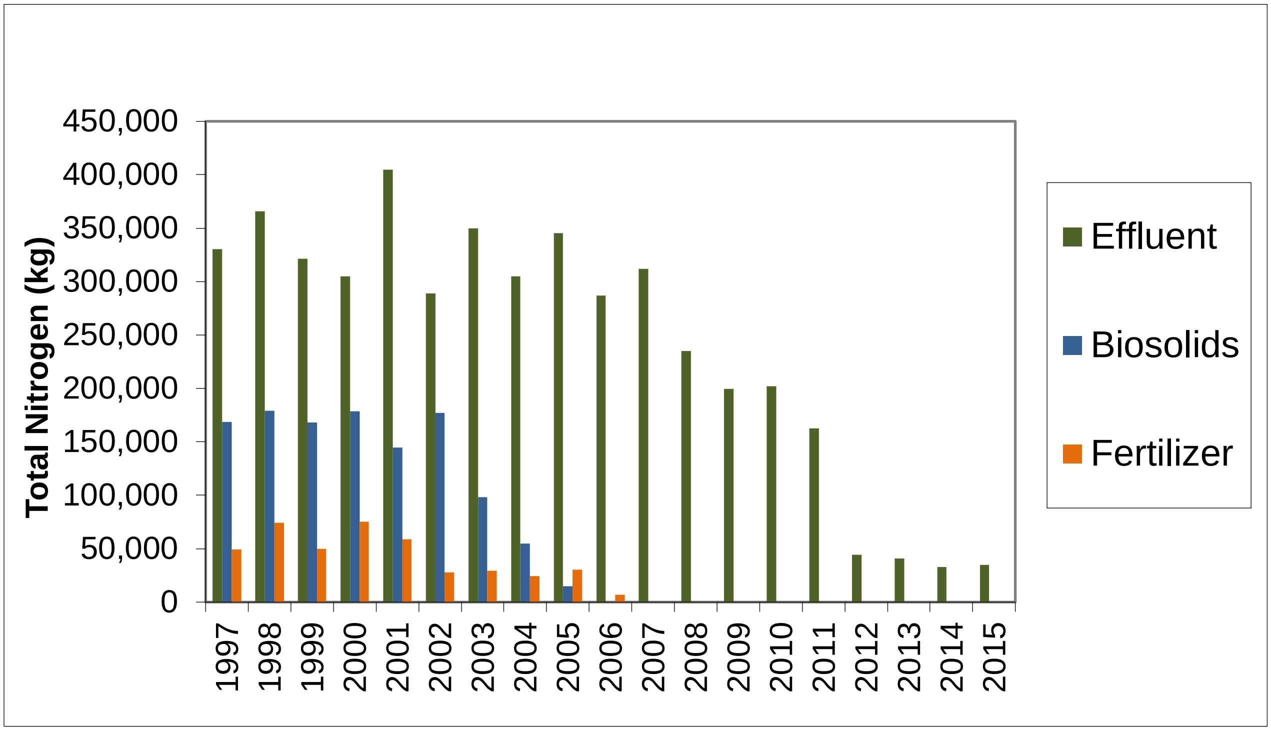
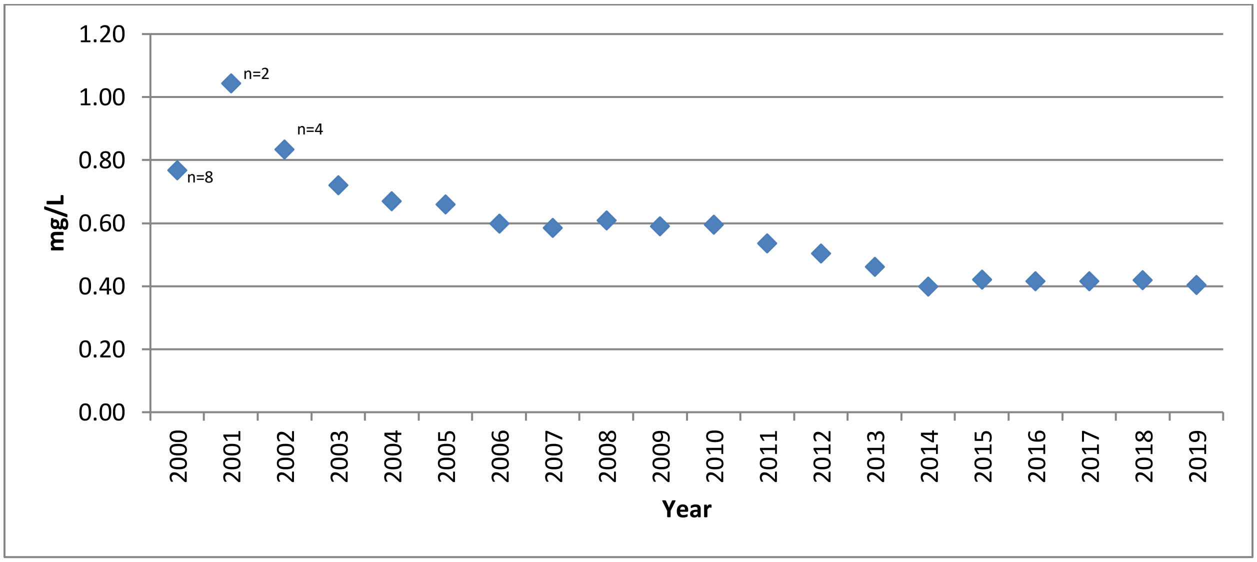



Figure D-2. Wakulla Spring Mean Annual Nitrate Concentration




Source: Barr (2020)

# APPENDIX E
## Wildlife Abundance Plots and Trends

This appendix presents plots of counts-per-survey and annual means for aggregate wildlife abundance, i.e. the total numbers of animals counted per survey, for all 24 species analyzed and for seven year-round resident breeders. It also presents average monthly mean count histograms, counts-per-survey plots, and annual or seasonal means for each wildlife species monitored plus short explanatory narratives. Plots are included for the entire period of record, September 1992 through May 2021, and for three perturbation periods described above: hydrilla invasion (1992-2000), hydrilla management (2000-2012), and post-hydrilla management (2012-2021).[1]

Trend lines and associated linear regression statistics are depicted on counts-per-survey plots where the linear regression trend is statistically significant at the 95% level or better (Prob(F) $\leq$ 0.05). Where the regression model is not significant, only the Prob(F) value is reported on the graph. Where species abundance is strongly seasonal, i.e. individuals are entirely absent or nearly so for several months, statistical trend analysis is conducted only for the months when the species is predominantly present and annual seasonal monthly means are reported in lieu of annual means. Where seasonal data are analyzed, the counts-per-survey data are presented as scatter plots without lines connecting the data points because of the seasonal gaps. Multivariate models, including river stage (height), air temperature, and cloud cover (sunshine dummy variable), as well as date, are included for the post-hydrilla management period (2012-2021) for a few species whose abundance may be affected by one or more of those variables: American alligator, cooter turtle, common gallinule, pied-billed grebe, and wood duck. Survey data for the park section of the annual full-river summer survey are included for three species that frequently nest in colonies along the upper river: cattle egret, double-crested cormorant, and little blue heron.

<u>Legend for Plots</u>

- • Number of animals observed on survey date
- ▲ Annual or annual seasonal monthly mean number of animals observed during monitoring
- - - **Decreasing Abundance Trend**: Statistically significant linear regression trend line with a negative slope
- - - **Increasing Abundance**: Statistically significant linear regression trend line with a positive slope

<u>Regression Statistics</u>

- Prob(F): model fit (included in all counts-per-survey plots) - The F-test in ordinary least-squares regression tests the null hypothesis that the model tested is equal to a model with no predictor variables (Minitab Blog Editor, 2015). The F-test probability (Prob(F)) indicates the probability that the null hypothesis is correct, i.e. that the regression model provides no prediction of the dependent variable. The smaller the Prob(F) value, the better the "model fit," i.e. the greater the likelihood that the alternative hypothesis is true, that the observed variation in species abundance over time is better explained by the passage of time (and other variables in multivariate models) than by a model with no predictor variables.
- Slope (included for all statistically significant trends) – The slope of the regression trend line is *m* in the regression equation y = mx + b where *y* is the value on the vertical axis for the animal counts per survey or annual mean number of animals counted on wildlife surveys, *x* is the survey date or year value on the horizontal axis, and *b* is the y intercept. The slope parameter *m* is calculated as the change in *y* divided by the change in *x*: $m = (y_2 - y_1)/(x_2 - x_1)$.

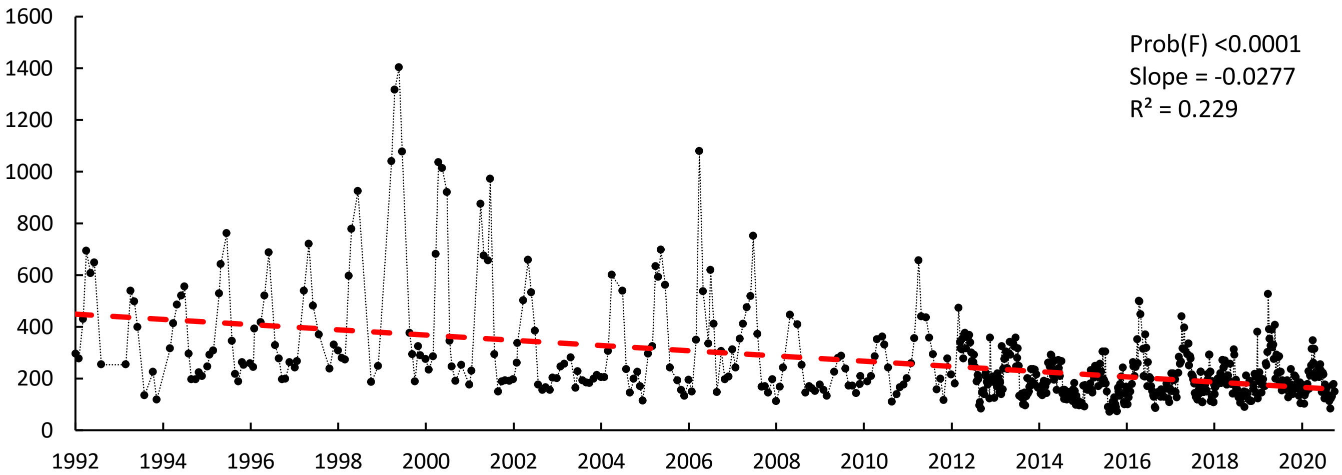
[1] Park staff conducted wildlife surveys monthly beginning in fall 1992. Volunteers began weekly monitoring in fall 2012 resulting in a higher density of data points thereafter.

- $R^2$: model explanatory power (included for all statistically significant trends) – R-squared ($R^2$), the coefficient of determination, measures the percent of variation in counts-per-survey or mean counts explained by survey date or year. Thus, for example, where the $R^2$ value is 0.30 for a model of the long-term abundance trend of a species between 1992 and 2021, the predictor variable, date, explains 30% of the observed variation in the counts-per-survey of the species.

# AGGREGATE WILDLIFE ABUNDANCE

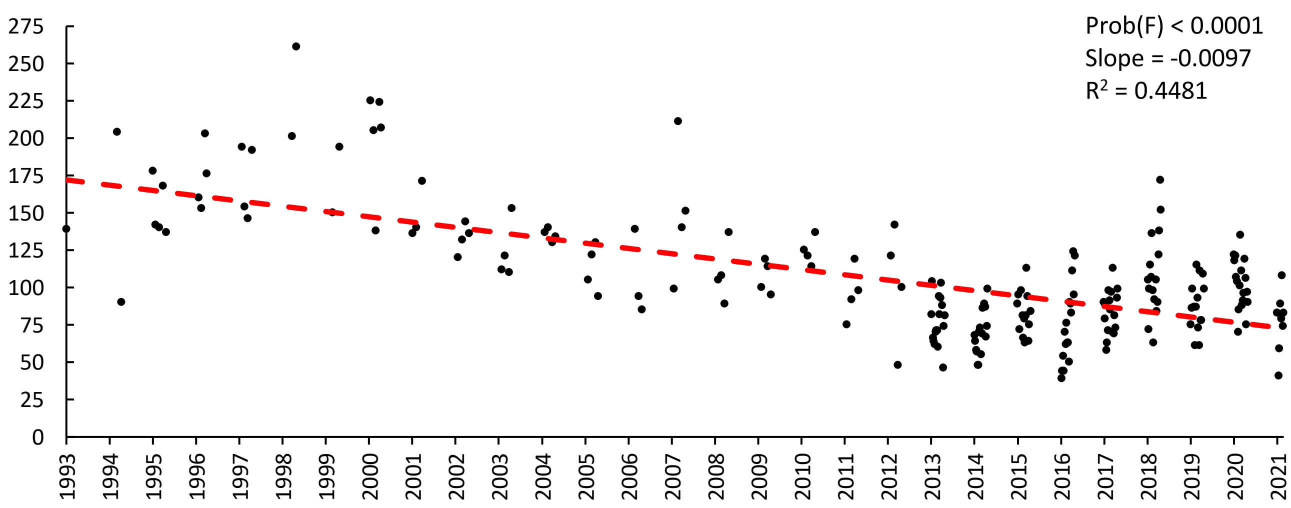
This section presents parallel analyses of the two aggregate abundance measures: the total numbers of animals counted annually per survey (a) for 12 months each year for all 24 species analyzed and (b) during the months of April through July for seven year-round resident breeders.

<u>1992-2021 Total Counts per Survey 24 Species</u>




Total animal counts per survey for all 24 species on the upper Wakulla River exhibit a significant (better than 99.99% level) decreasing abundance trend of -0.0277 animals counted per day or 10.10 counts per year[2] over the period of record, 9/1/92 – 5/29/21. Survey date explains 22.9% of the observed variation in counts per survey.

<u>April - July 1993-2021 Total Counts per Survey Year-Round Resident Breeders</u>



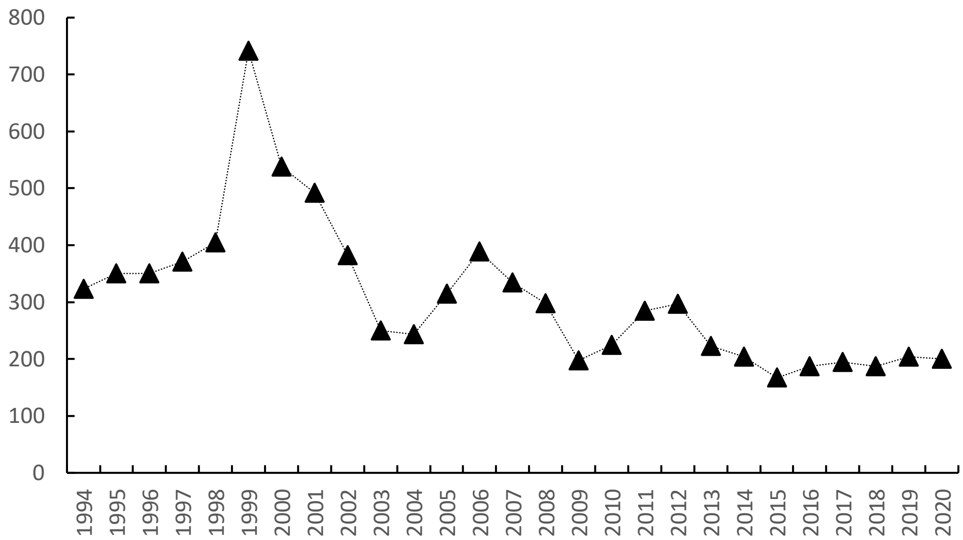

American alligator, anhinga, common gallinule, green heron, pied-billed grebe, wood duck, yellow-crowned night-heron

Total animal counts per survey during the months of April through July for the seven year-round resident breeders on the upper Wakulla River also exhibit a significant (better than 99.99% level) decreasing abundance trend. However, the rate of decrease is slower: -0.0097 animals counted per day or 3.53 counts per year over the period of record, 4/5/93 – 5/29/21. Survey date explains a much greater percentage of the observed variation in counts per survey – 44.81% – most likely reflecting the much lesser influence of factors outside the river ecosystem.

[2] Calculated from 6-digit values in regression output rather than rounded slope values displayed in figure.

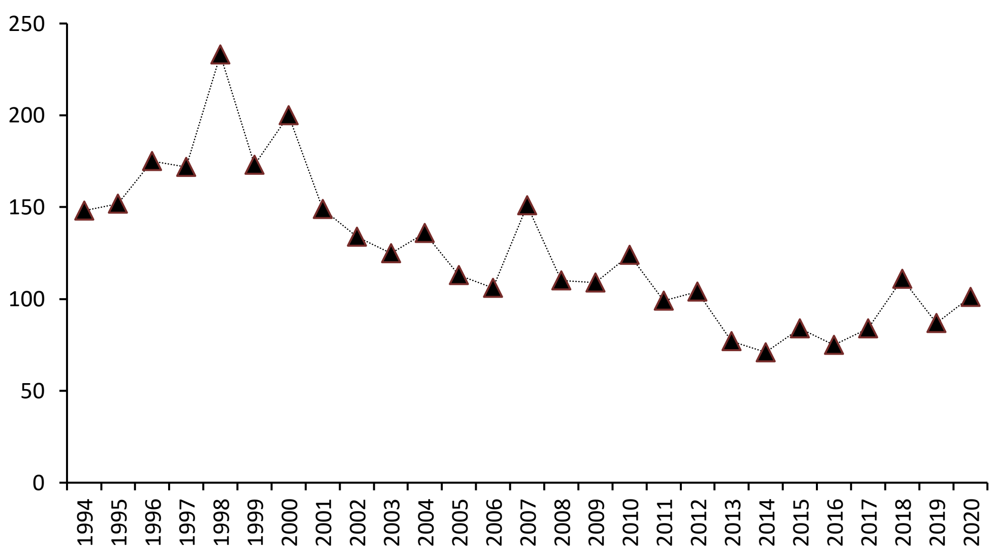
Annual means trends for the two measures of aggregate abundance differ considerably although both exhibit peaks between 1998 and 2000 and both show apparent decreasing trends over the period of record – 1994-2020.

1994-2020 Total Annual Mean Counts per Survey 24 Species




Annual means reveal the decreasing abundance trend in total animal counts per survey. Peak abundance occurred in 1999 followed by a steep decline. Secondary, much smaller peaks, occurred in 2006 and 2011-12. Annual means began to increase in 2016.

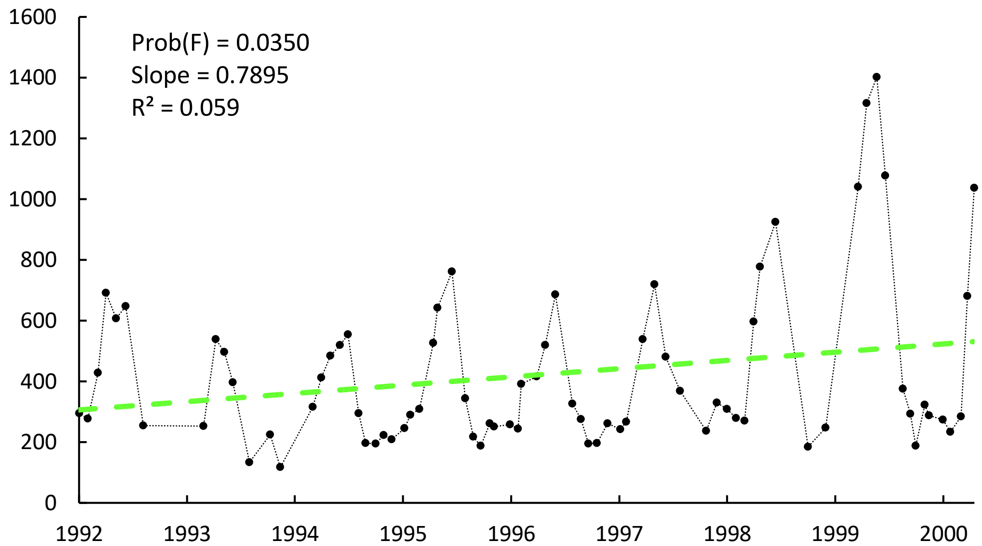
1994-2020 Total Annual Summer Mean Counts per Survey Year-Round Breeders




Annual summer means for year-round resident breeders also exhibit a long-term decreasing abundance trend. However, peak abundance occurred in 1998 with secondary peaks in 2000 and 2007 followed by a steep decline. Annual summer means for these species began to increase in 2015.

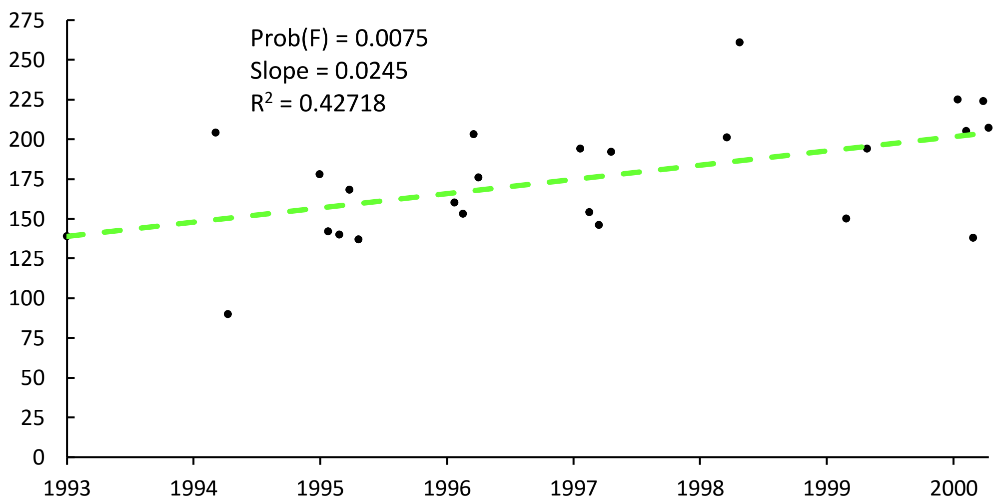
During the hydrilla management period, annual means trends for the two measures of aggregate abundance exhibit similar trends – both show statistically significant increases. The slope is steeper for the full 24 species compared to the seven year-round resident breeders, likely because of the very high counts of American wigeon in 1999. However, the trend model for the year-round breeders explains a much greater proportion of the observed variation in annual mean counts per survey: 42.7% versus 5.9%.

Abundance During Hydrilla Invasion: 1992-2000 for 24 Species (counts per survey)




Total animal abundance increased significantly (96.5% level) during the 1992-2000 hydrilla invasion period with a trend that explains 5.9% of the observed variation.

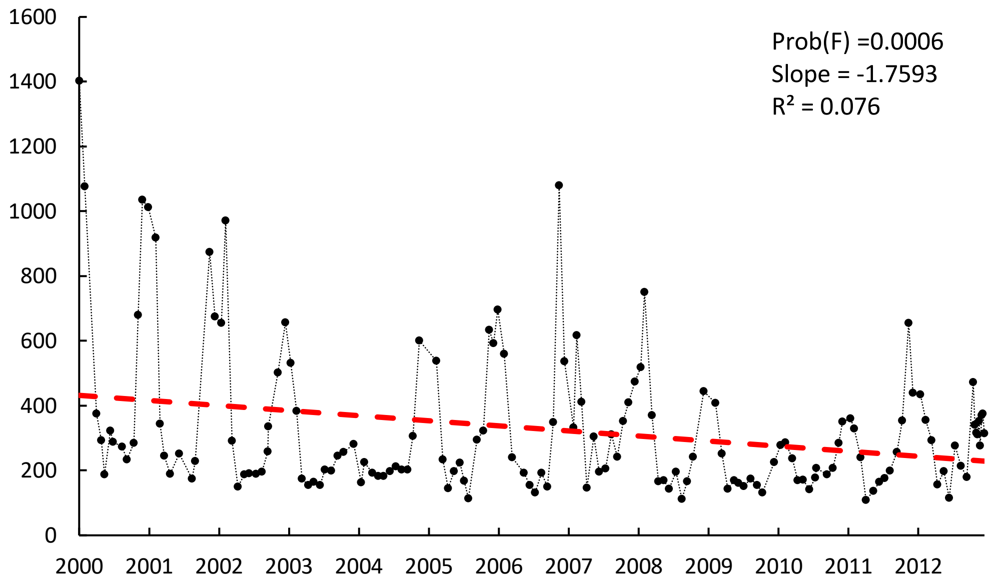
Abundance During Hydrilla Invasion: 1993-2000 for Year-Round Resident Breeders (counts per survey)




American alligator, anhinga, common gallinule, green heron, pied-billed grebe, wood duck, yellow-crowned night-heron

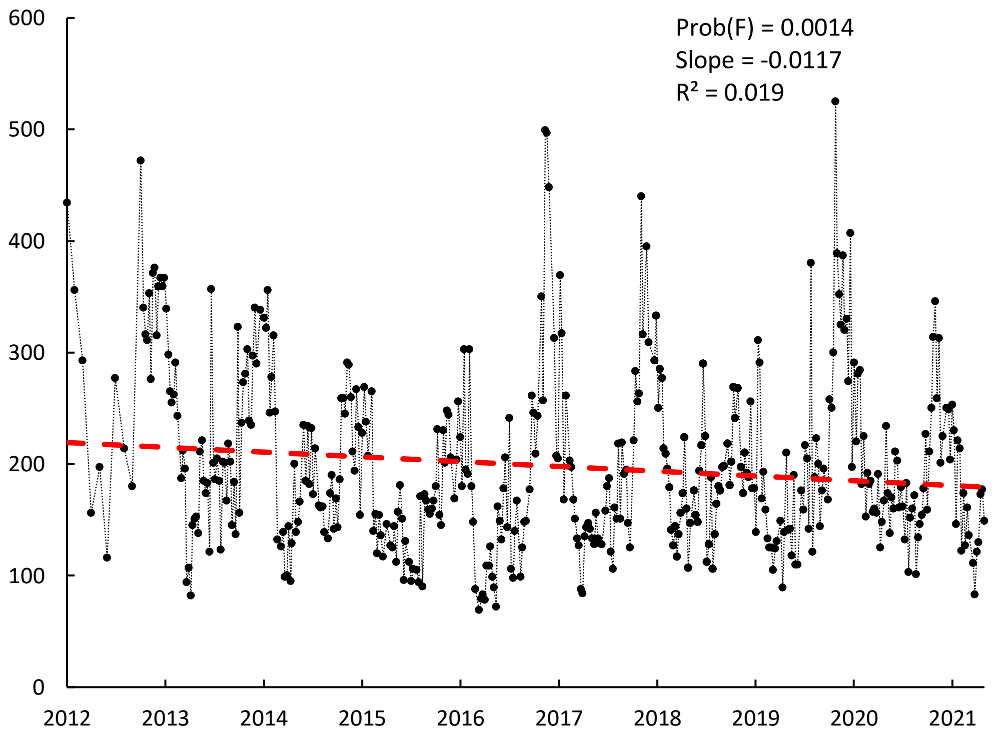
Total animal abundance increased significantly (99.25% level) during the 1993-2000 period of intense hydrilla management efforts with a trend that explains 42.7% of the observed variation.

Abundance During Hydrilla Management: 2000-2012 for 24 Species (counts per survey)




Total animal abundance decreased significantly (99.94% level) during the 2000-2012 period of intense hydrilla management efforts with a trend that explains 7.6% of the observed variation.

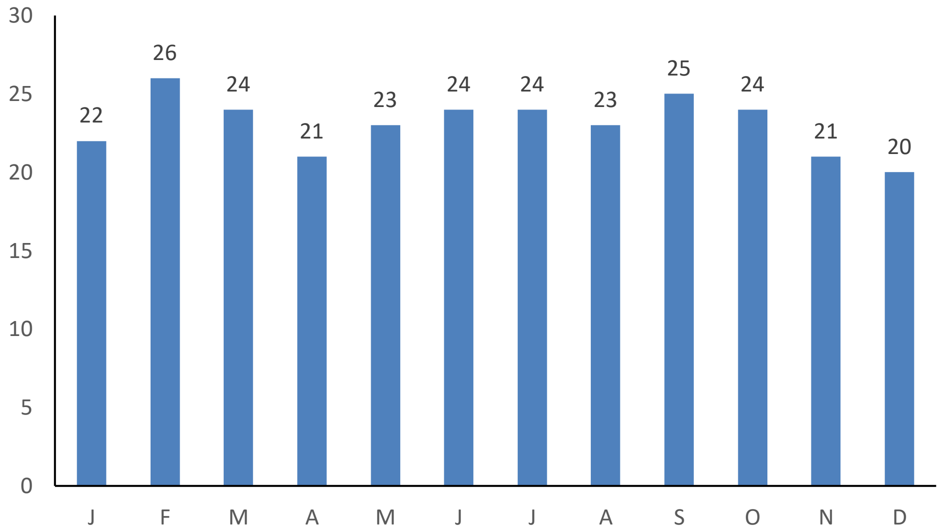
Abundance Post- Hydrilla Management: 2012-2021 for 24 Species (counts per survey)




Total animal abundance continued to decrease significantly (99.86% level) during the 2012-2021 post-hydrilla management period with a trend that explains 1.9% of the observed variation.

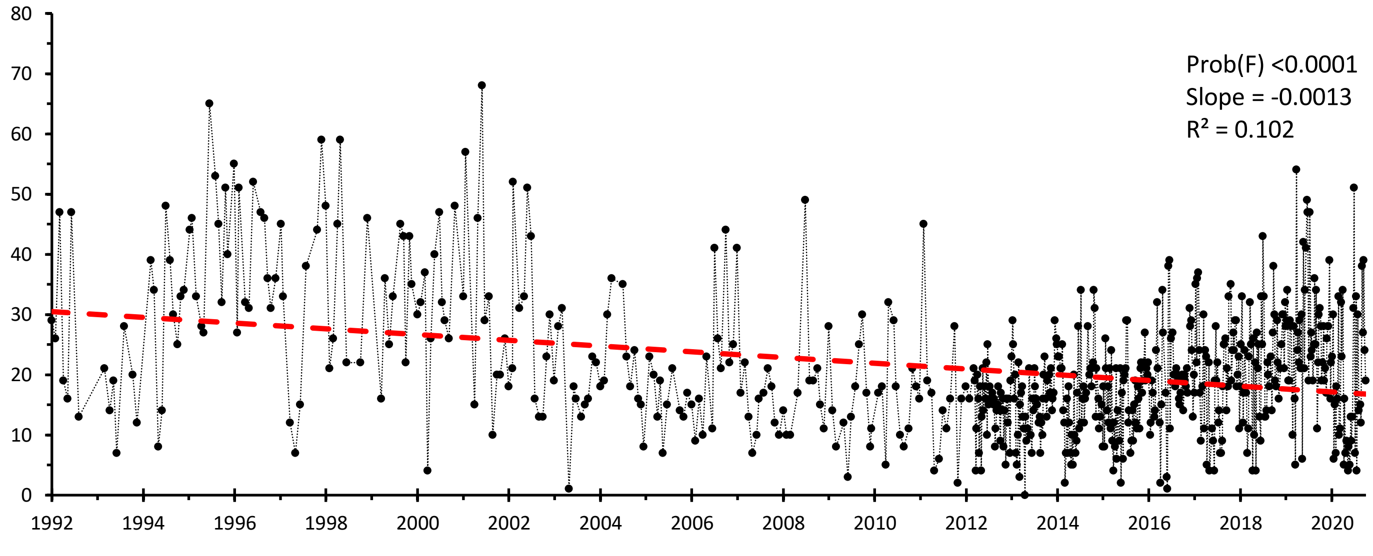
# AMERICAN ALLIGATOR

Seasonal Abundance 1992-2020 (average monthly means)



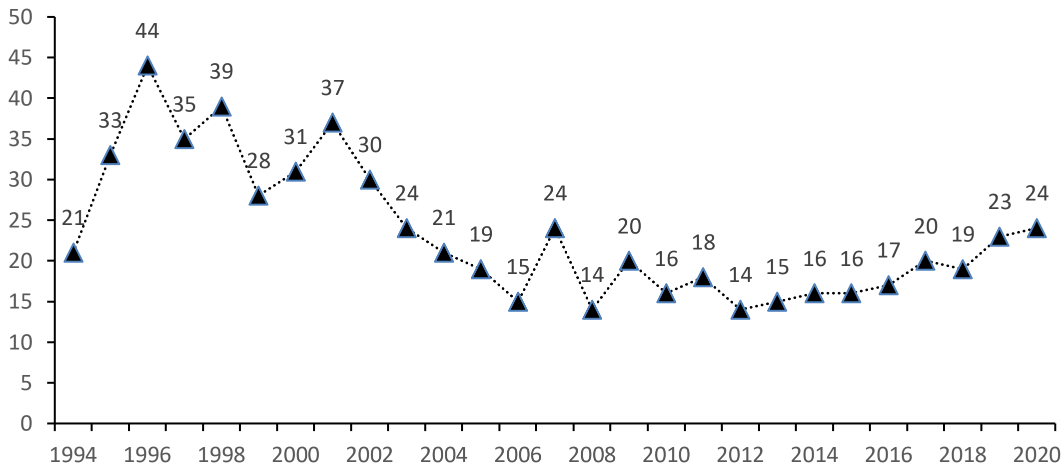

The American alligator is a year-round breeding resident of the upper Wakulla River. Abundance is fairly constant throughout the year.

Abundance 1992-2021 (counts per survey)



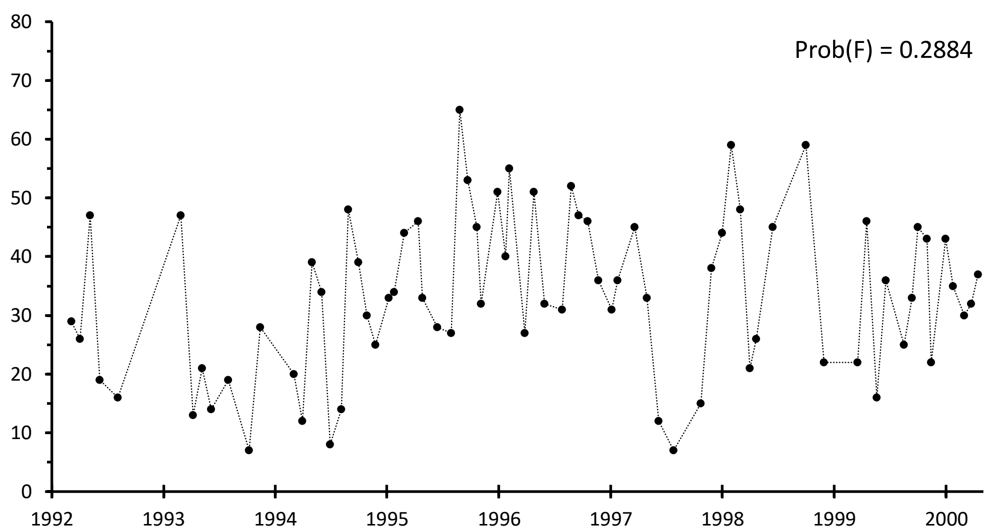

The alligator exhibited a significant (better than 99.99% level) decreasing abundance trend of -0.0013 animals counted per day or -0.48 counts per year over the period of record, 9/1/92 – 5/29/21. Survey date explains 10.2% of the observed variation in counts per survey.

Abundance 1994-2020 (annual means)



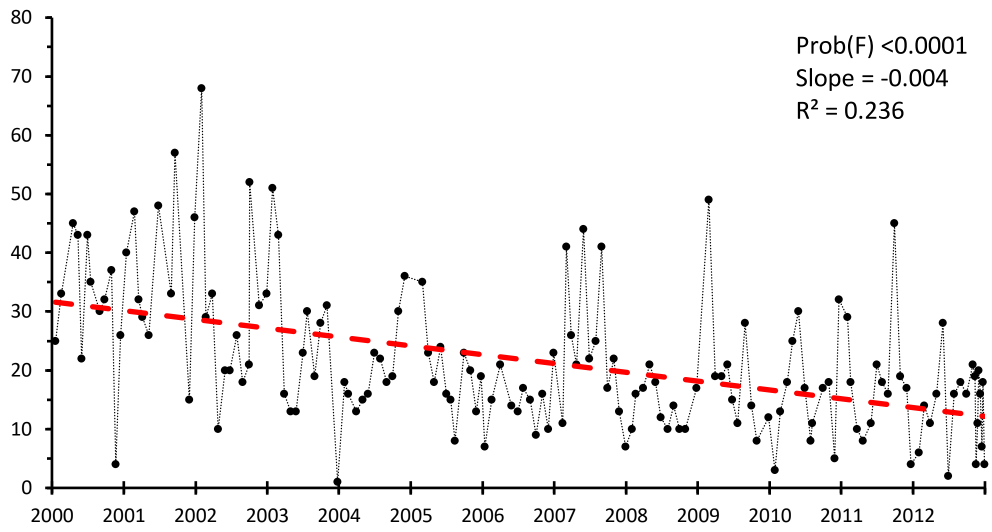

Annual means reveal a decreasing abundance trend through 2012. Peak abundance occurred in 1996, while a sharp decline began in 2001 and continued to 2006. Annual means began a steady increase in 2013.

Abundance During Hydrilla Invasion: 1992-2000 (counts per survey)



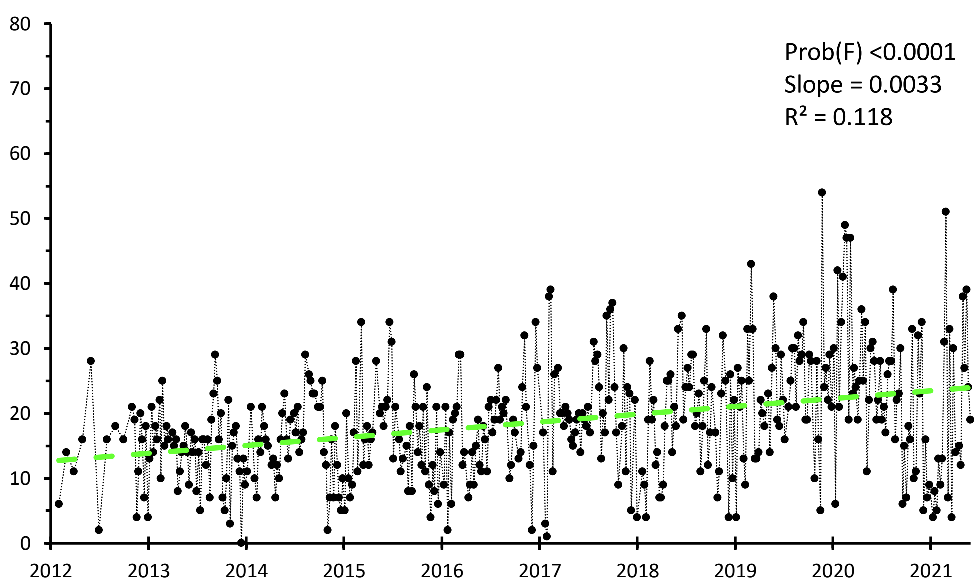

Alligator abundance exhibited no statistically significant trend during the 1992-2000 hydrilla invasion period. Counts per survey ranged from 7 to 65 and averaged 33 alligators.

Abundance During Hydrilla Management: 2000-2012 (counts per survey)




Alligator abundance decreased significantly (better than 99.99% level) during the 2000-2012 period of intense hydrilla management efforts with a trend that explains 23.6% of the observed variation.

Abundance Post- Hydrilla Management: 2012-2021 (counts per survey)




Alligator abundance began to increase in 2013. The significant positive trend (better than 99.99% level) explains 11.8% of the observed variation in alligator counts per survey.

Multivariate Analysis of Recent Trend

Because alligators are ectothermic, i.e. cannot regulate their body temperature internally, their abundance on any given day may be influenced by air temperature and sunshine/cloud cover. River stage also may affect how many are observed: if water levels are higher, basking sites may be underwater. A multivariate regression model that controls for these variables for the period during which weekly data have been collected, November 10, 2012, through May 29, 2021, reveals that the apparent increasing trend (date) is significant even after accounting for river stage, air temperature, and sunshine.[3]

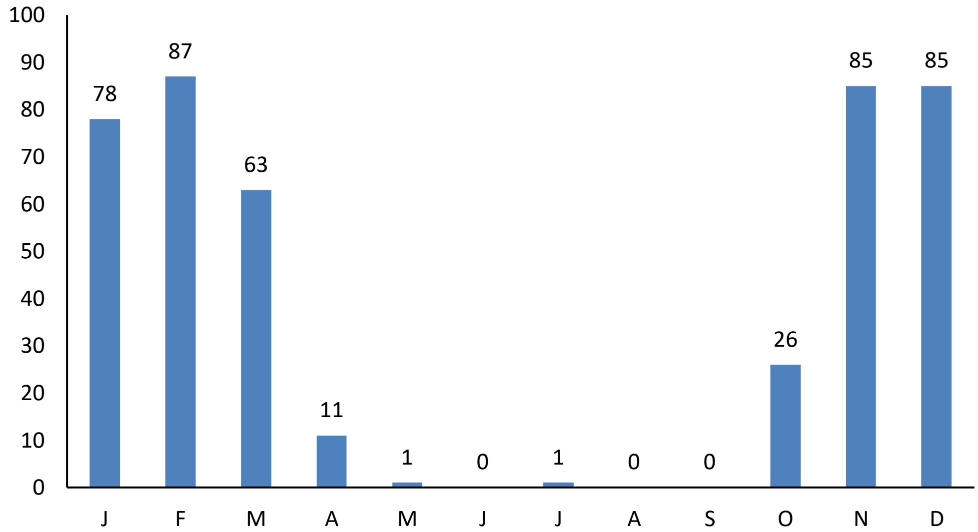
[3] Sunshine was coded as a dummy/categorical variable based on cloud cover categories included on the survey form: coded 1 for "clear" and "some clouds"; coded 0 for "fog," "overcast,' and "rain."

| | test stat | p-value |
|---|---|---|
| F-test | 32.909 | < 0.0001 |
| Adjusted R-squared | 0.243 | |
| Date | 0.003 | < 0.0001 |
| River stage | -3.141 | 0.0001 |
| Air temperature | 0.170 | < 0.0001 |
| Sunshine | 5.097 | < 0.0001 |

The model explains 24.3 percent of the observed variation in counts per survey and is significant at better than the 99.99 percent level. Each of the independent variables is significant at the 99.99 percent level or better. Thus, alligator counts are higher when river stage is lower (negative coefficient), air temperature is warmer, and the weather is clear or has some clouds.

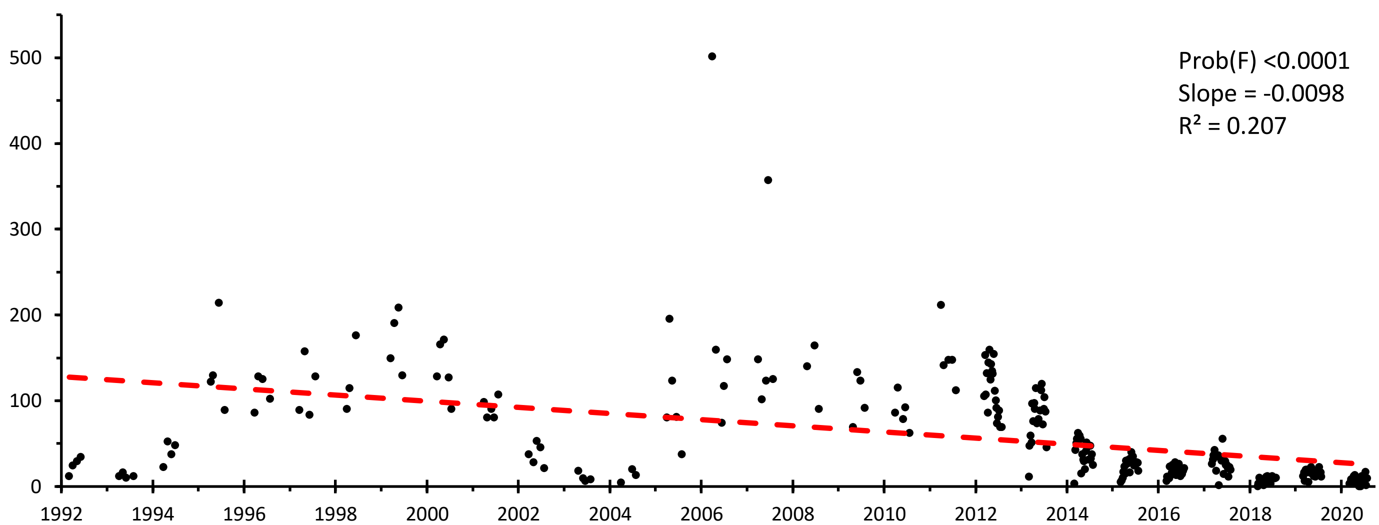
# AMERICAN COOT

Seasonal Abundance 1992-2020 (average monthly means)



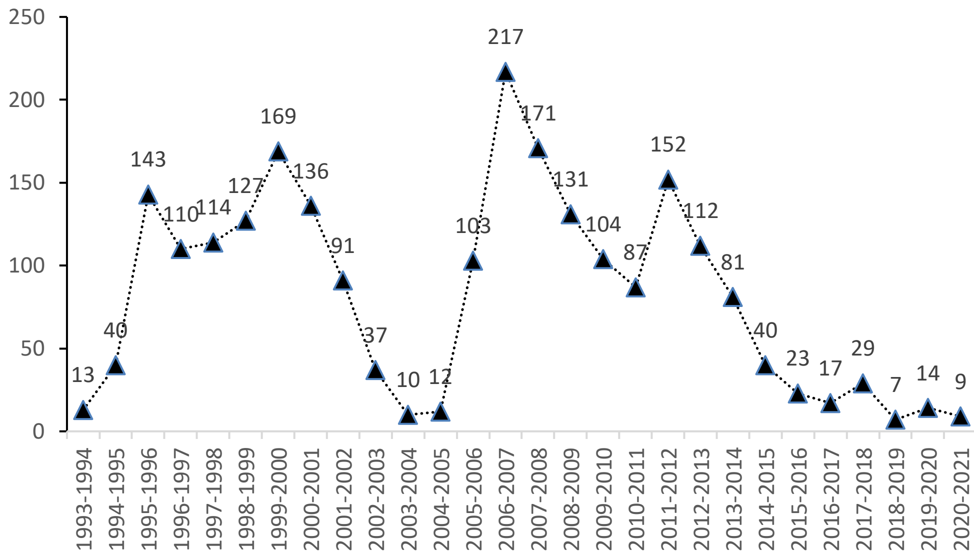

The American coot is a winter migrant to the upper Wakulla River. Abundance peaks during the months of November through March.

Seasonal Abundance Nov-Mar 1992-93 – 2020-21 (counts per survey)



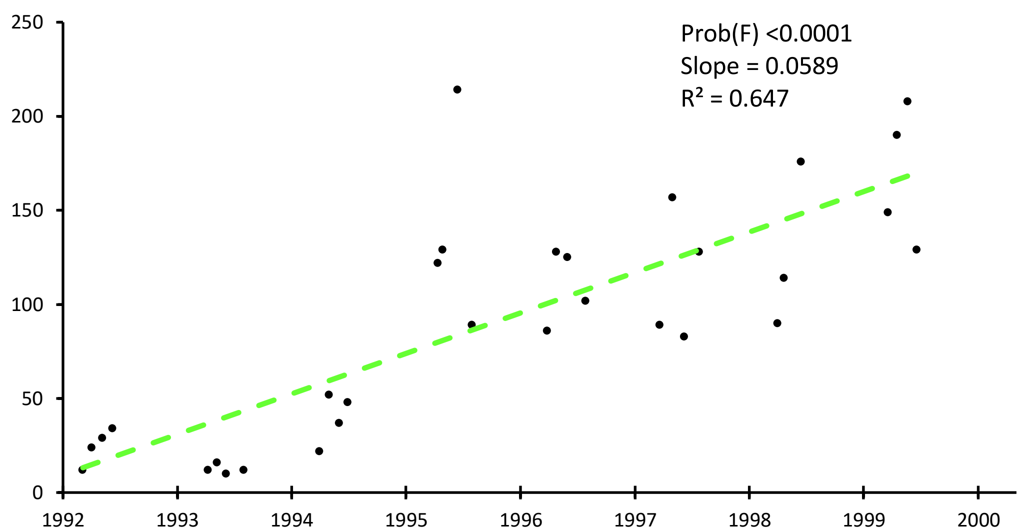

The American coot exhibited a significant (better than 99.99% level) decreasing seasonal abundance trend of -0.0098 animals counted per day or -3.58 counts per year over the period of record, 9/1/92 – 3/27/21. Survey date explains 20.7% of the observed variation in counts per survey.

Seasonal Abundance Nov-Mar 1993-94 – 2020-21 (winter monthly means)



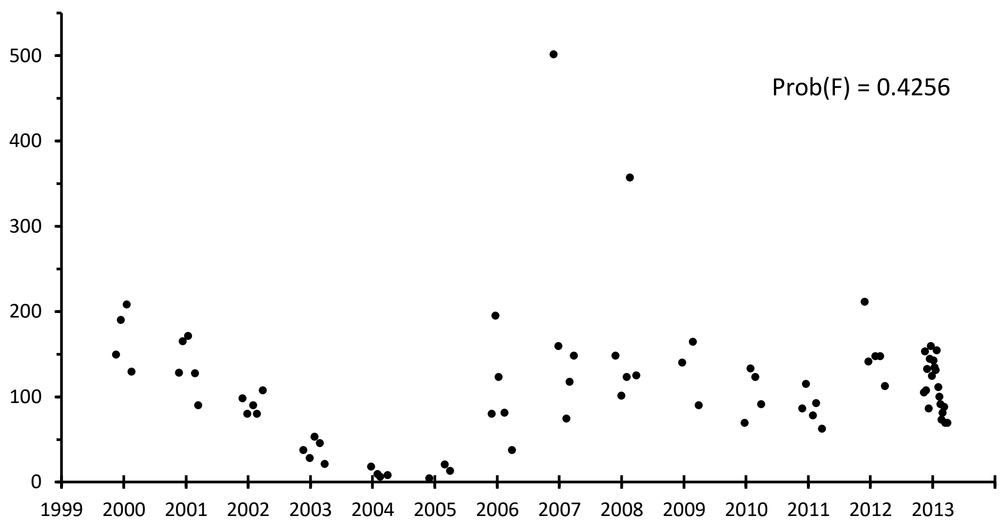

Winter monthly means reveal multiple peaks and valleys with an initial decline beginning in 2000-2001. Secondary peaks occurred in 2006-07 and 2011-12 after which winter monthly means have generally declined.

Seasonal Abundance During Hydrilla Invasion: Nov-Mar 1992-93 – 1999-2000 (counts per survey)



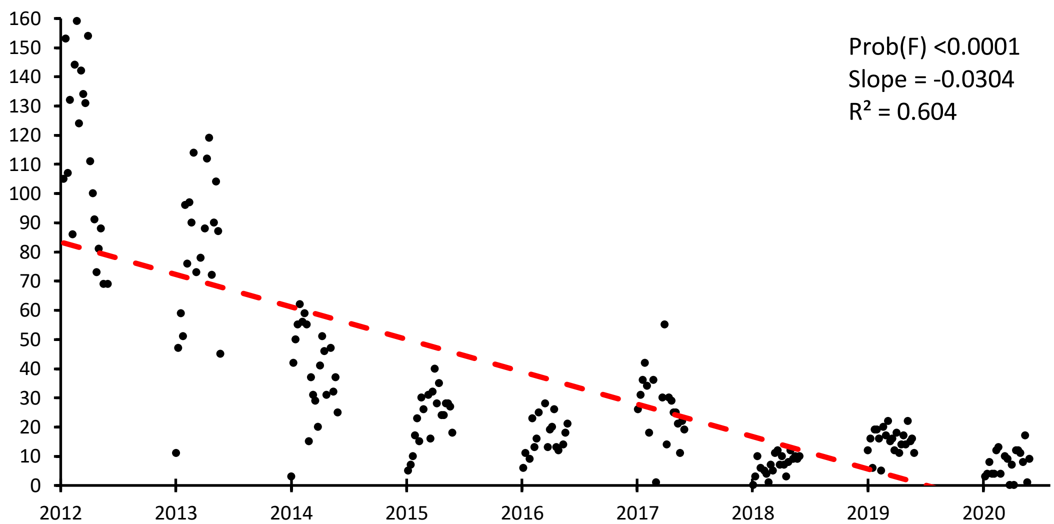

American coot seasonal abundance exhibited a significant increase (better than 99.99% level) during the 1992-2000 hydrilla invasion period with a trend that explains 64.7% of the observed variation.

Seasonal Abundance During Hydrilla Management: Nov-Mar 1999-2000 – 2012-13 (counts per survey)




The American coot exhibited no significant trend in seasonal abundance during the hydrilla management period. Counts per survey ranged from 4 to 501 and averaged 112 coots.

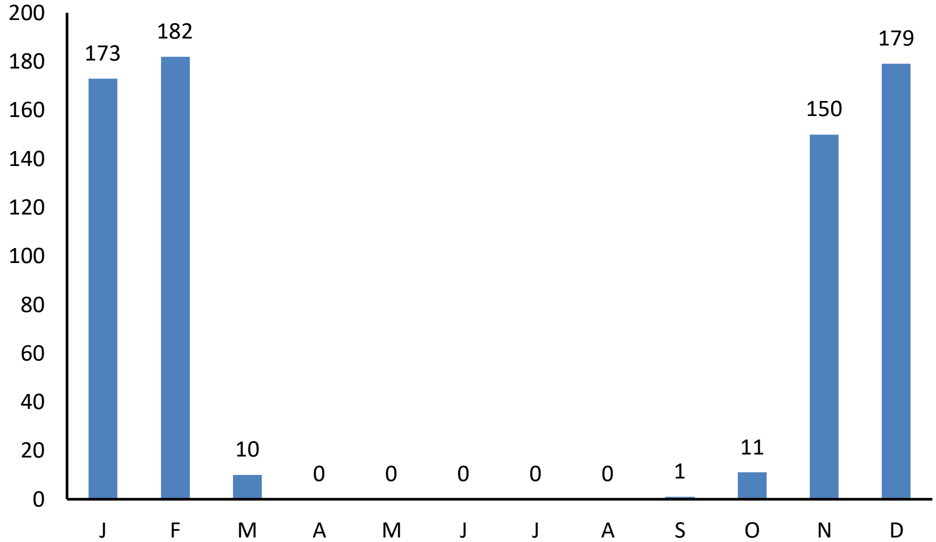
Seasonal Abundance Post- Hydrilla Management: Nov-Mar 2012-13 – 2020-21 (counts per survey)




American coot seasonal abundance decreased significantly (better than 99.99% level) during the post-hydrilla management period with a trend that explains 60.4% of the observed variation.

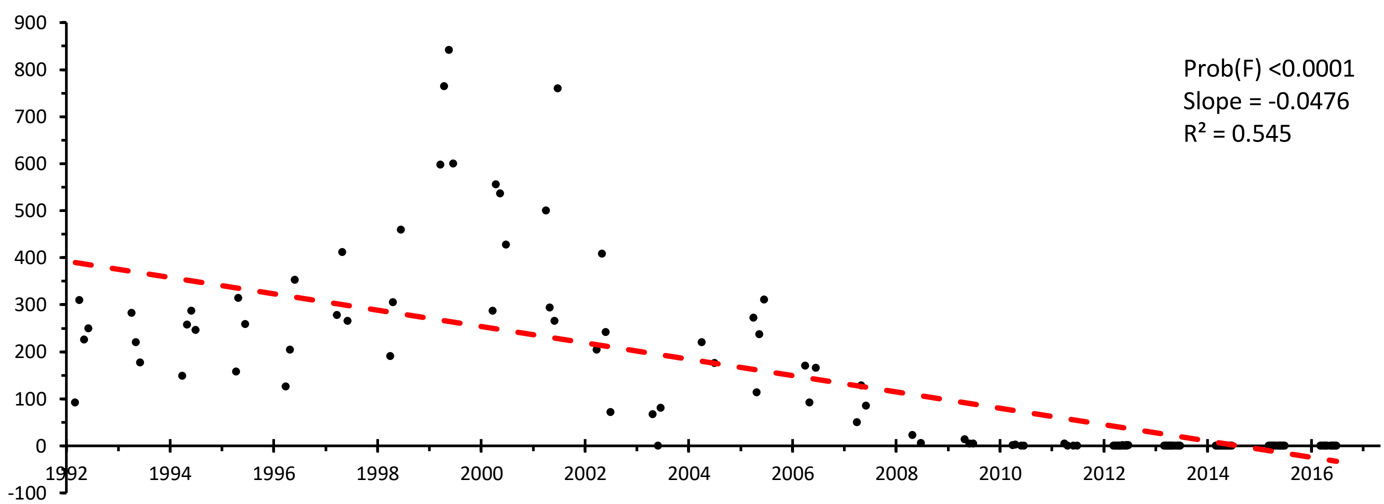
# AMERICAN WIGEON

Seasonal Abundance 1992-2017 (average monthly means)[4]




The American wigeon is a winter migrant to the upper Wakulla River. Abundance peaks during the months of November through February. It is virtually absent April through September.

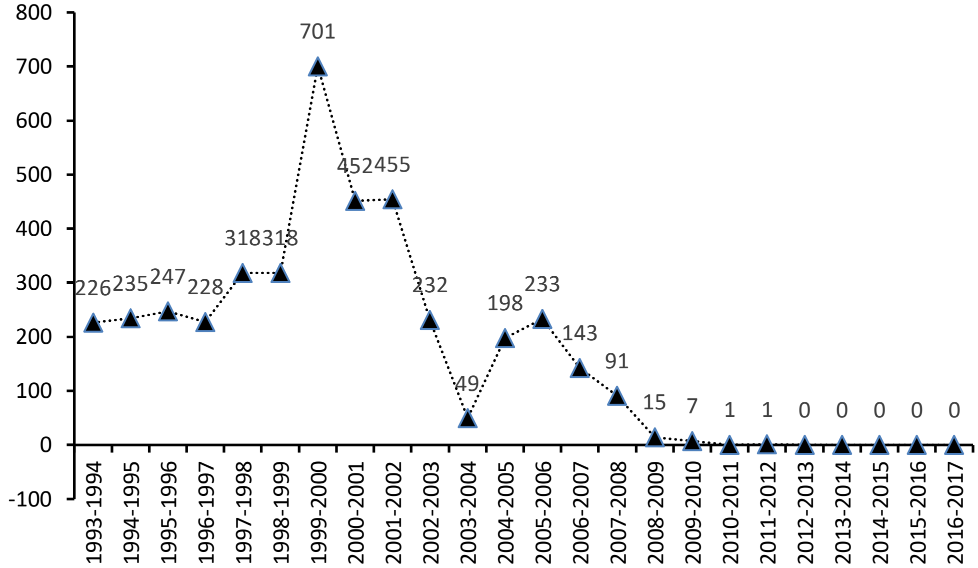
Seasonal Abundance Nov-Feb 1992-93 – 2016-17 (counts per survey)




The American wigeon exhibited a significant (99.9% level or better) decreasing seasonal abundance trend of -0.0476 animals counted per day or -17.37 counts per year over the period of record, 9/1/92 – 12/30/17. Survey date explains 54.5% of the observed variation in counts per survey.

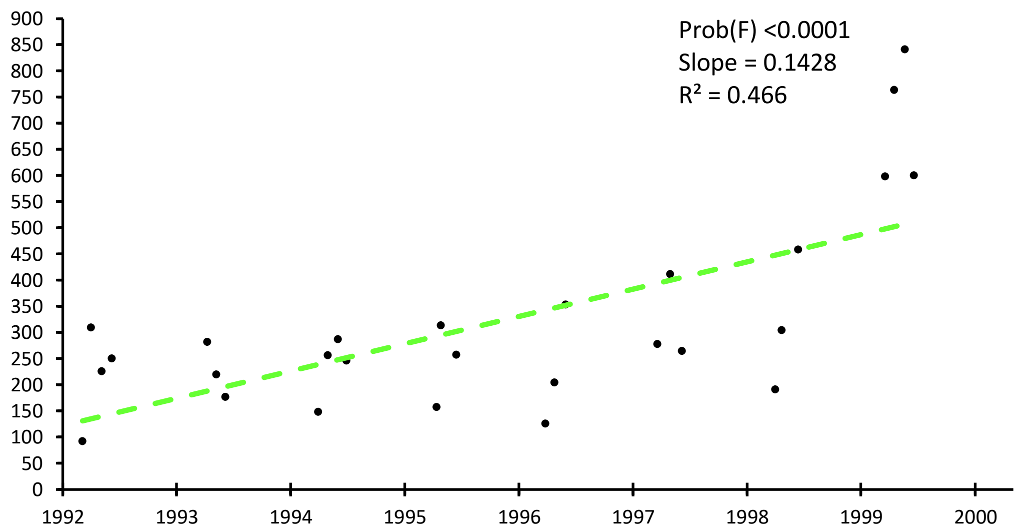
[4] The American wigeon was dropped from the survey in 2018.

Seasonal Abundance Nov-Feb 1993-94 – 2016-17 (winter monthly means)



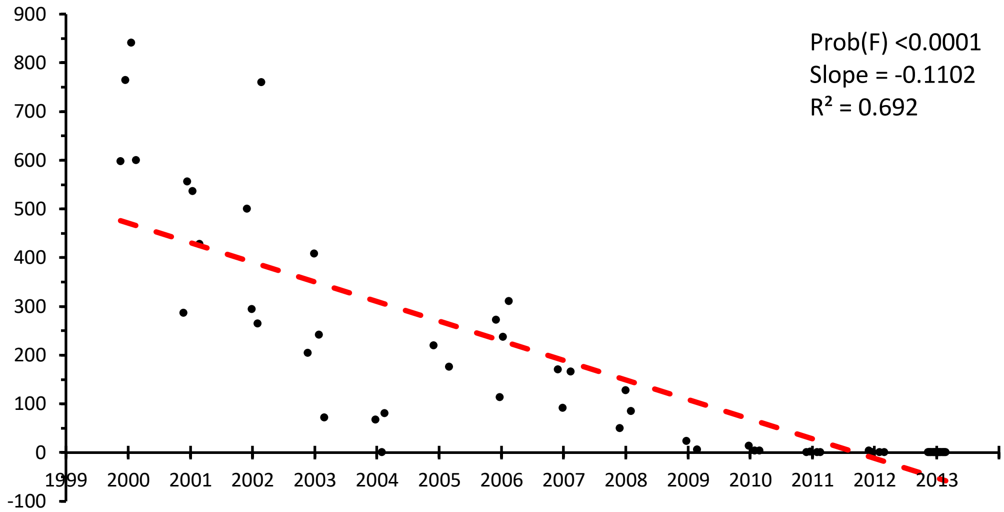

Winter monthly means reveal a prominent peak in 1999-2000 followed by a small secondary peak in 2005-06 after which winter monthly mean abundance declined to 1 in 2010-2011 and 0 by 2012-13.

Seasonal Abundance During Hydrilla Invasion: Nov-Feb 1992-93 – 1999-2000 (counts per survey)



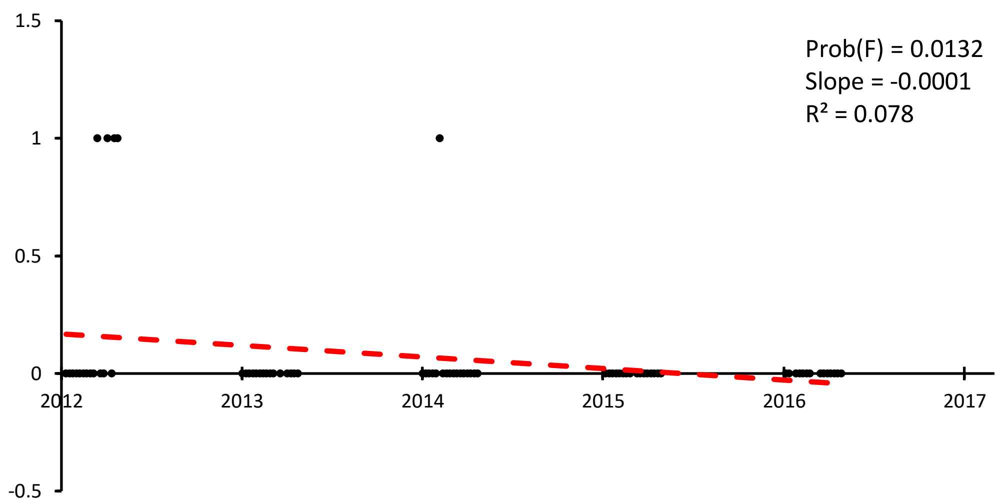

American wigeon seasonal abundance exhibited a significant increase (better than 99.99% level) during the 1992-2000 hydrilla invasion period with a trend that explains 46.6% of the observed variation.

Seasonal Abundance During Hydrilla Management: Nov-Feb 1999-2000 – 2012-13 (counts per survey)




The trend in seasonal abundance reversed during the hydrilla management period exhibiting a significant decrease (better than 99.99% level) that explains 69.2% of the observed variation in winter counts per survey.

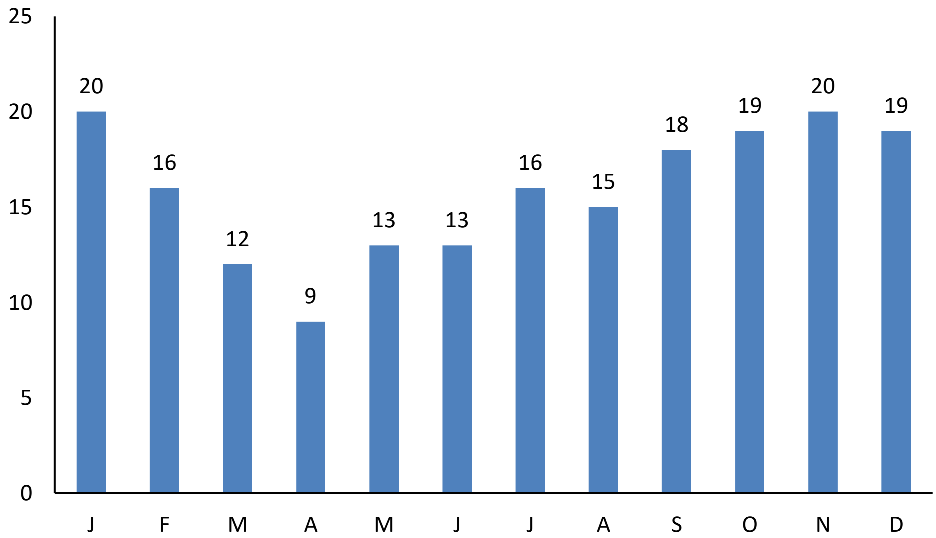
Seasonal Abundance Post- Hydrilla Management: Nov-Feb 2012-13 – 2016-17 (counts per survey)




The American wigeon had all but disappeared by the onset of the post-hydrilla management period. Nevertheless, winter counts per survey exhibited a statistically significant (98.68% level) decrease with a trend that explains 7.8% of the observed variation.

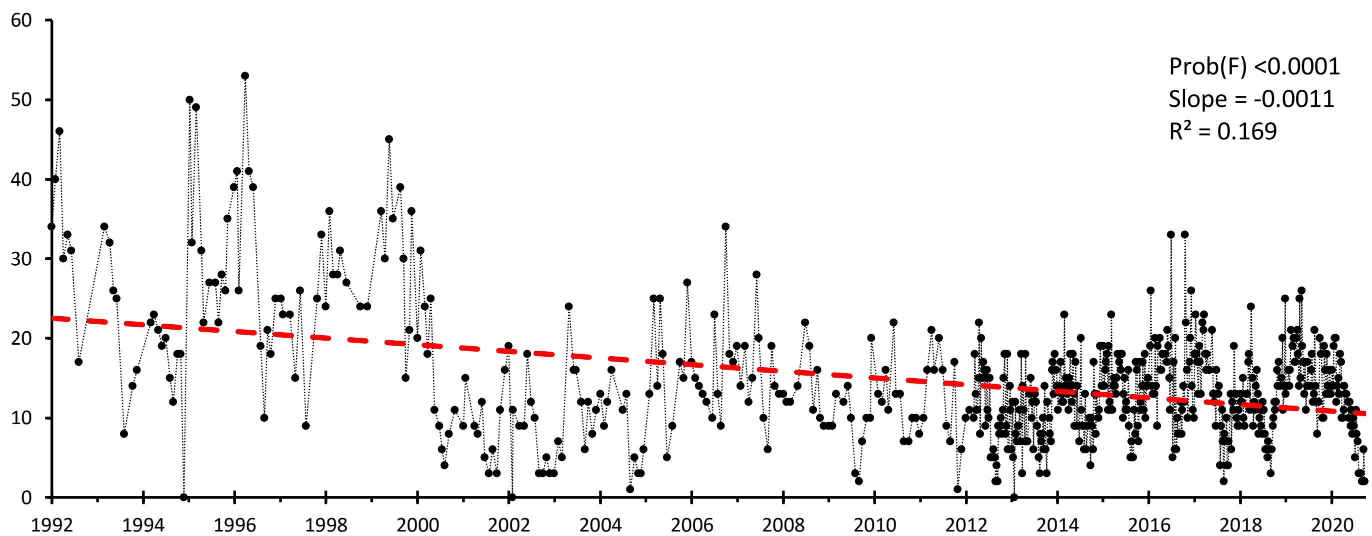
## ANHINGA

Seasonal Abundance 1992-2020 (average monthly means)



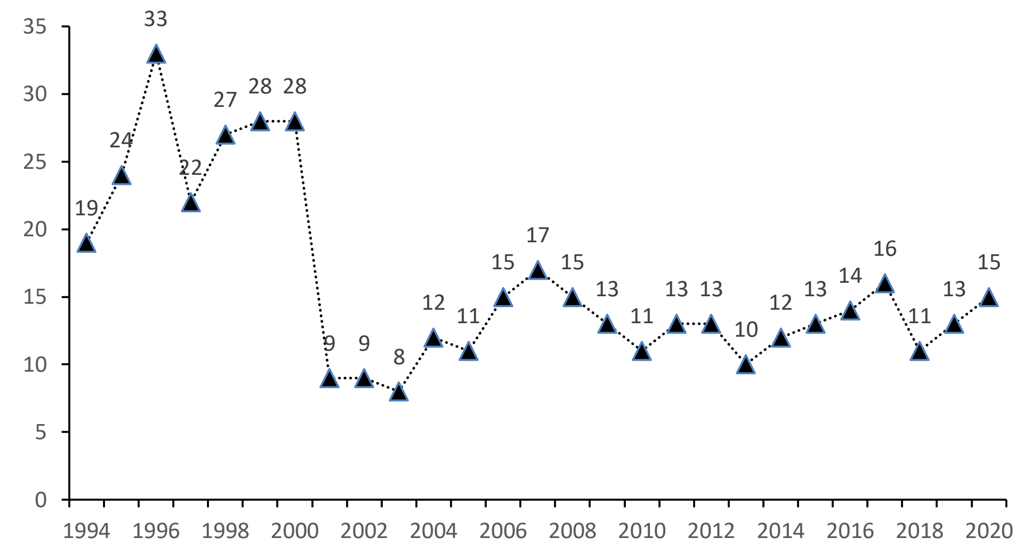

The anhinga is a year-round breeding resident of the upper Wakulla River. Abundance peaks during fall and early winter and is lowest leading into the late spring/early summer breeding period.

Abundance 1992-2021 (counts per survey)



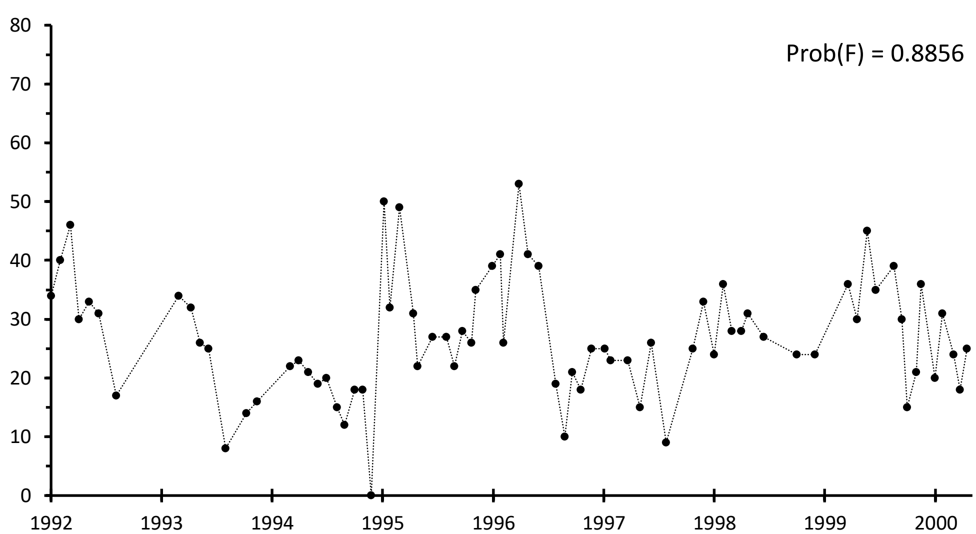

The anhinga exhibited a significant (better than 99.99% level) decreasing abundance trend of -0.0011 animals counted per day or -0.42 counts per year over the period of record, 9/1/92 – 5/29/21. Survey date explains 16.9% of the observed variation in counts per survey.

Abundance 1994-2020 (annual means)



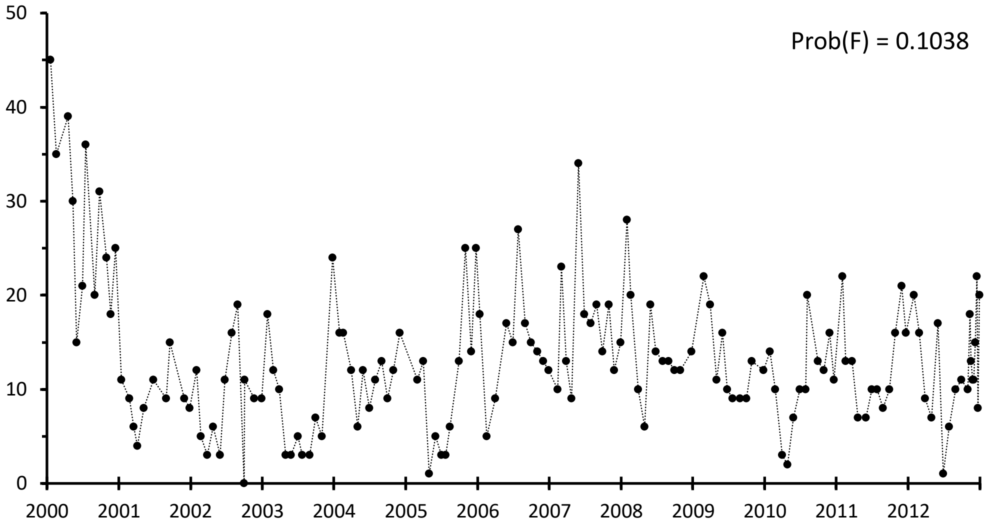

Annual means reveal a steep decrease in 2001 from which the species has not fully recovered exhibiting a fairly steady oscillation since 2005.

Abundance During Hydrilla Invasion: 1992-2000 (counts per survey)



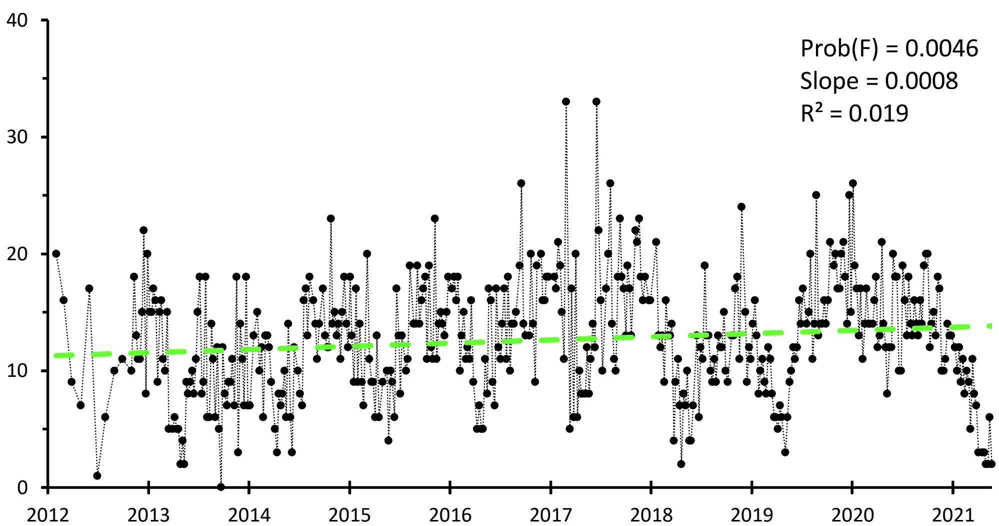

The anhinga exhibited no statistically significant trend in abundance during the 1992-2000 hydrilla invasion period. Counts per survey ranged from 0 to 53 and averaged 27 animals.

Abundance During Hydrilla Management: 2000-2012 (counts per survey)




The lack of a significant trend continued during the hydrilla management period despite the initial steep decline. Counts per survey ranged from 0 to 45 and averaged 13; half that of the hydrilla invasion period.

Abundance Post- Hydrilla Management: 2012-2021 (counts per survey)

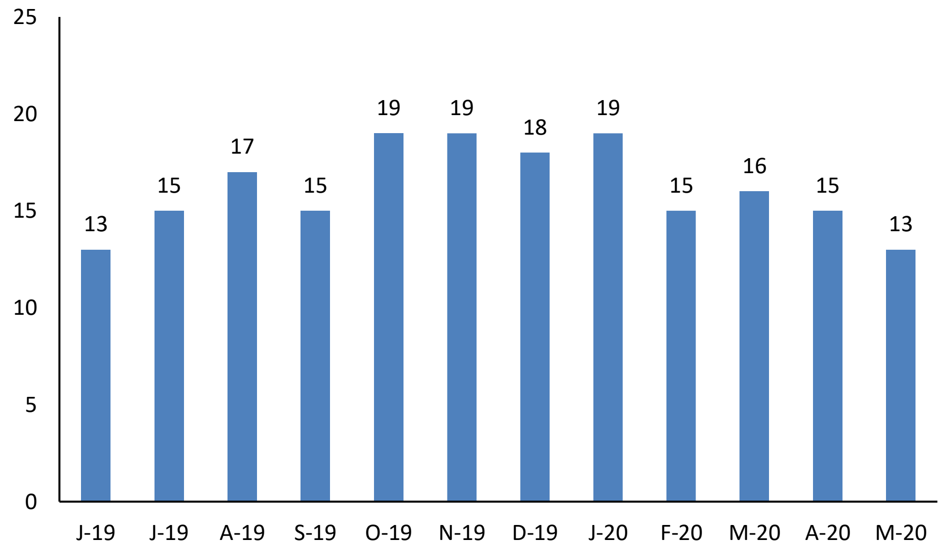



A significant (99.54% level) positive trend emerged during the post-hydrilla management period that explained 1.9% of the observed variation in counts per survey. Note, however, a steep decline beginning in November 2020 that is more prolonged than the typical seasonal dip.

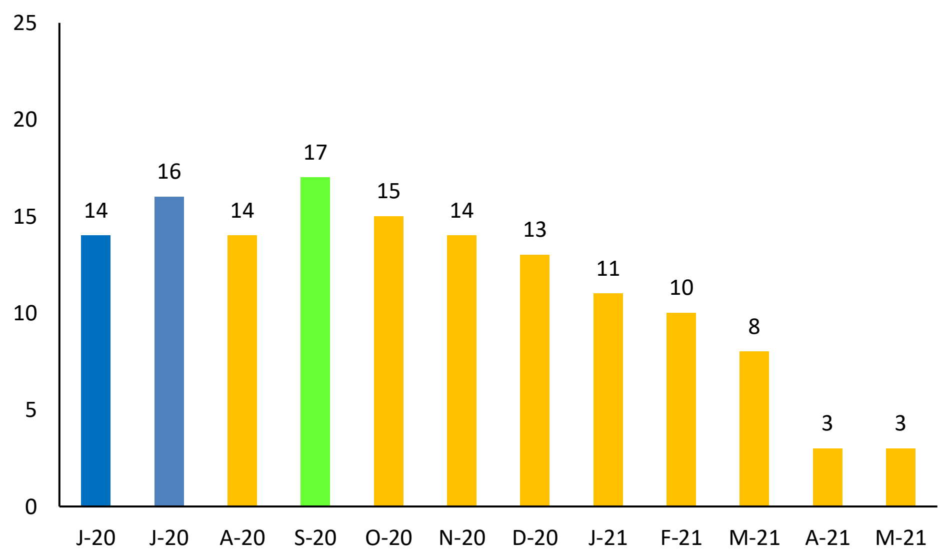
Comparison of 2019-20 and 2020-21 Monthly Means

Very low counts in March 2021 prompted a comparison of monthly means for June through May for 2019-20 and 2020-21. In the second chart, months colored orange are 2 or more counts lower in 2020-21 than 2019-20. Months colored green are two or more counts higher.

## June 2019 – May 2020

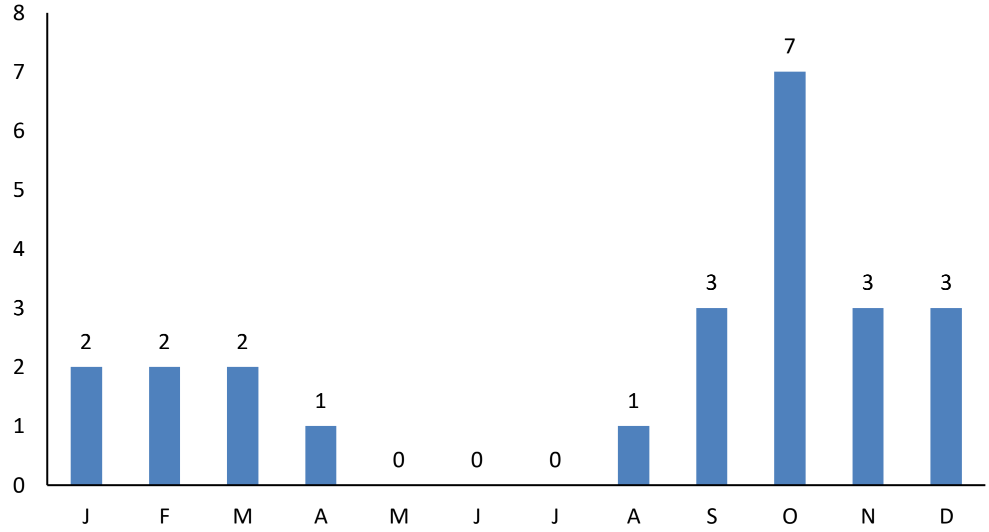



## June 2020 – May 2021



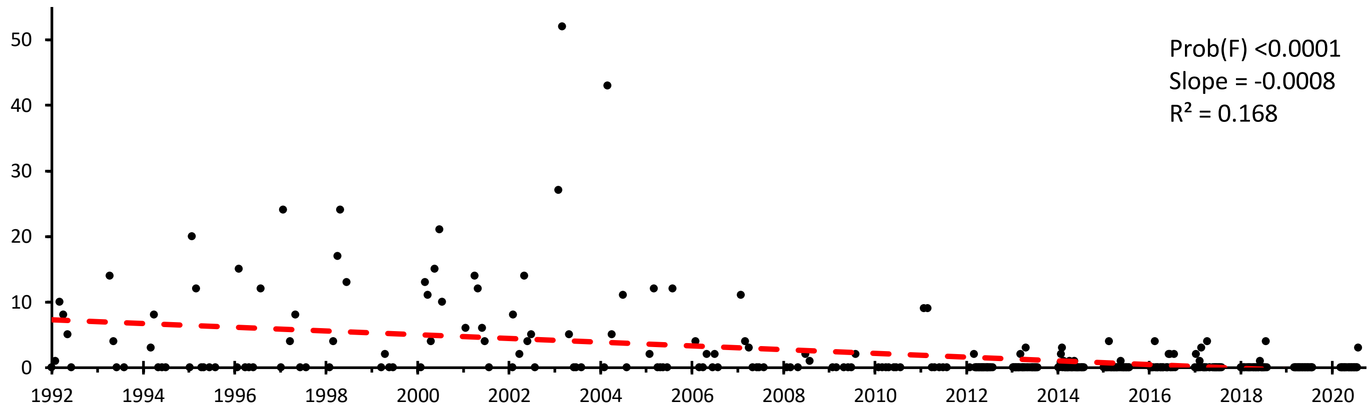
## BLUE-WINGED TEAL

Seasonal Abundance 1992-2020 (average monthly means)



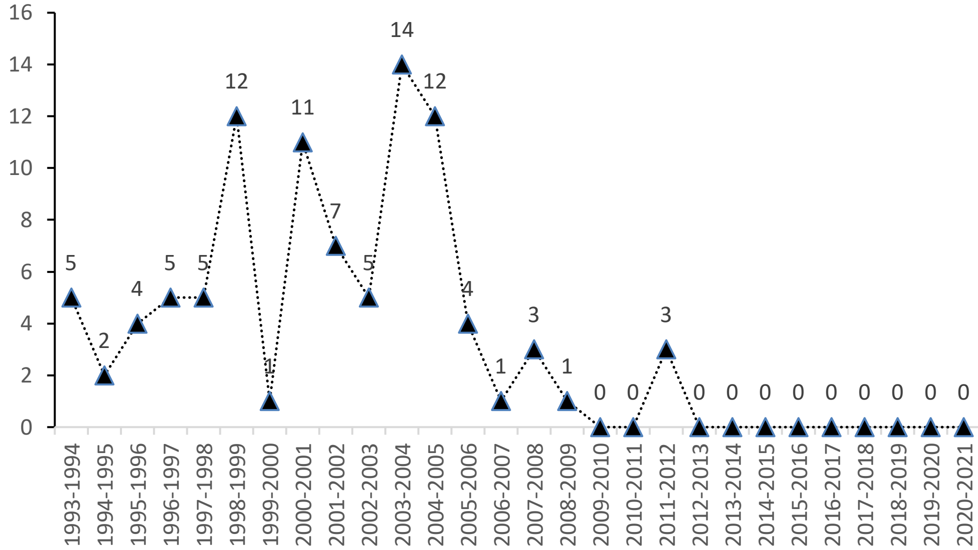

The blue-winged teal is a winter migrant to the upper Wakulla River that has not been present in large numbers since the early 2000s. It is most commonly seen in the fall and early winter (Sept-Mar).

Seasonal Abundance Sep-Mar 1992-93 – 2020-21 (counts per survey)



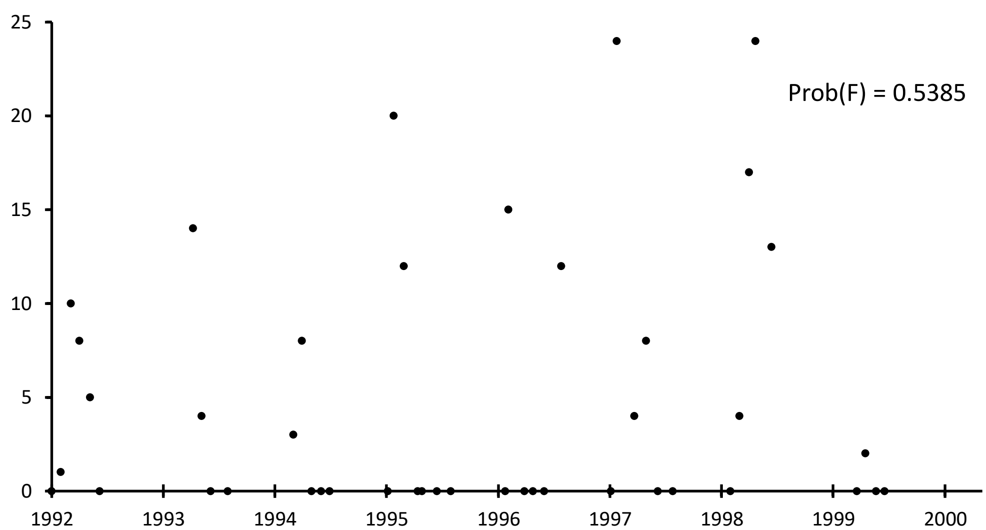

The blue-winged teal exhibited a significant (better than 99.99% level) decreasing seasonal abundance trend of -0.0008 animals counted per day or -0.29 counts per year over the period of record, 9/1/92 – 3/27/21. Survey date explains 16.8% of the observed variation in counts per survey.

Seasonal Abundance Sep-Mar 1993-94 – 2020-21 (winter monthly means)



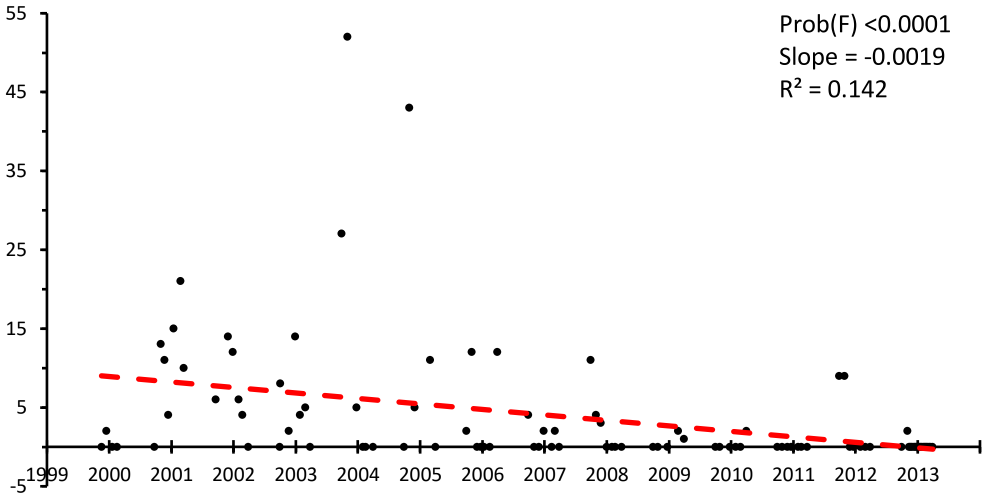

Winter monthly means reveal large oscillations between 1997-98 and 2003-04 followed by a steep decline from which the species has not recovered.

Seasonal Abundance During Hydrilla Invasion: Sep-Mar 1992-93 – 1999-2000 (counts per survey)



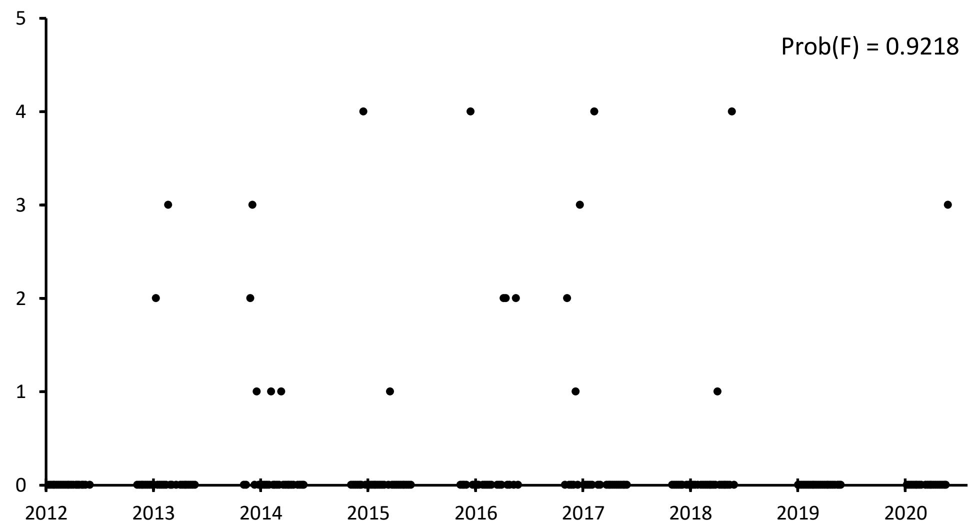

Blue-winged teal exhibited no statistically significant trend in abundance during the 1992-2000 hydrilla invasion period. Counts per survey ranged from 0 to 24 and averaged 5 animals.

Seasonal Abundance During Hydrilla Management: Sep-Mar 1999-2000 – 2012-13 (counts per survey)




A significant decreasing abundance trend (better than 99.99% level) emerged during the hydrilla management period. It explains 14.2% of the observed variation in winter counts per survey.

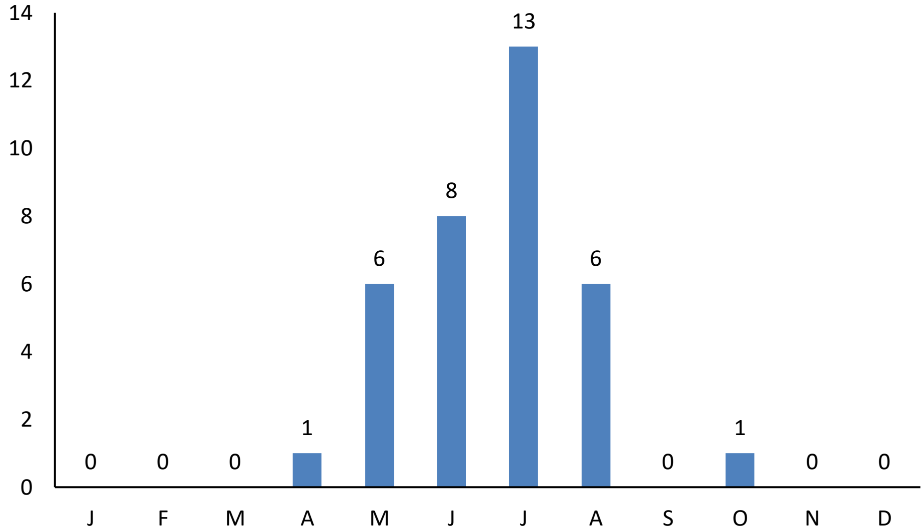
Seasonal Abundance Post- Hydrilla Management: Sep-Mar 2012-13 – 2020-21 (counts per survey)



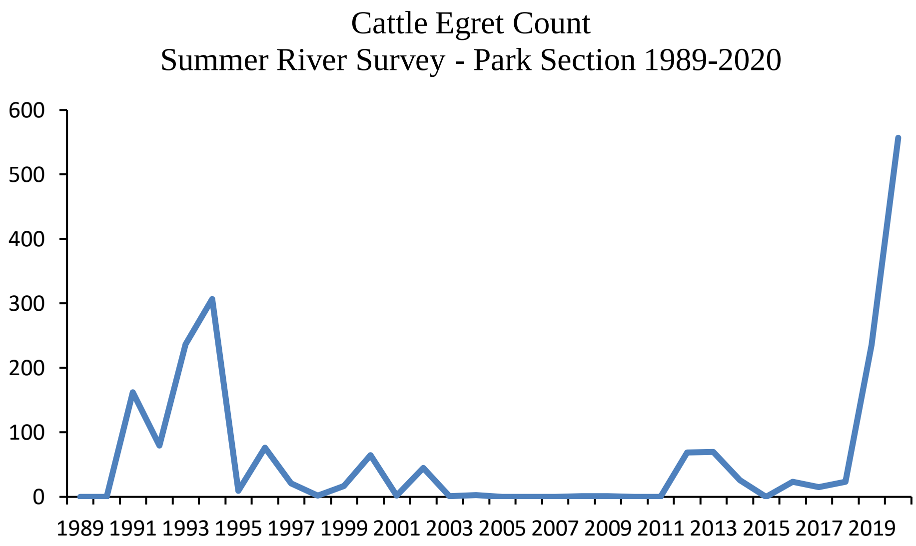

The blue-winged teal exhibited no significant trend during the post-hydrilla management period as the average count per survey dropped to 0.21 with a range of 0 to 4 animals.

## CATTLE EGRET

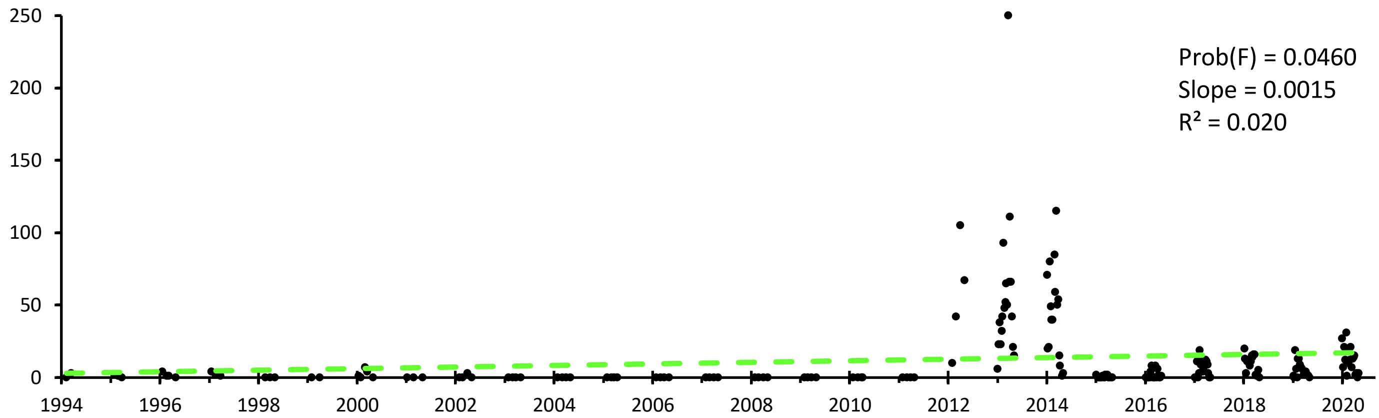
Seasonal Abundance 1992-2020 (average monthly means)




The cattle egret has been a periodic summer breeder (May-Aug) on the upper Wakulla River. It feeds in pastures and fields and therefore is generally only seen on the river during the breeding season. As shown in the following figure, it has nested in varying numbers along the upper river on and off since the early 1990s, peaking in 2020. It nested in colonies along the river boat tour route from 2012 through 2014; in other years, the nesting colony has been along the second mile of the river below the tour boat turnaround.

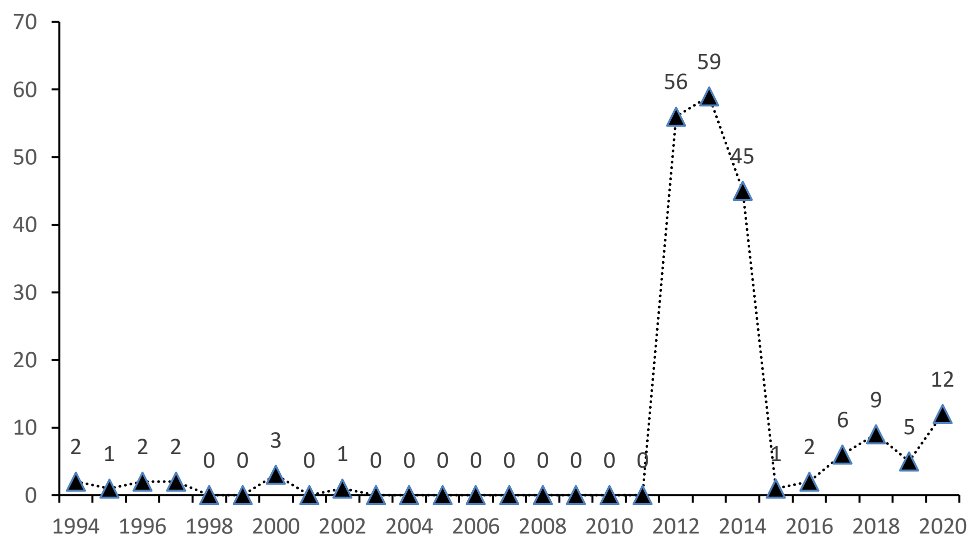


Seasonal Abundance May-Aug 1994-2020 (counts per survey)[5]




The cattle egret exhibited a significant (95.40% level) increasing seasonal abundance trend of 0.0015 animals counted per day or 0.86 counts per year over the period analyzed, 6/8/94 – 8/25/18. Survey date explains 2.0 % of the observed variation in counts per survey. Abundance dropped from the highs of 2012-2014 when the nesting colony was moved down river.

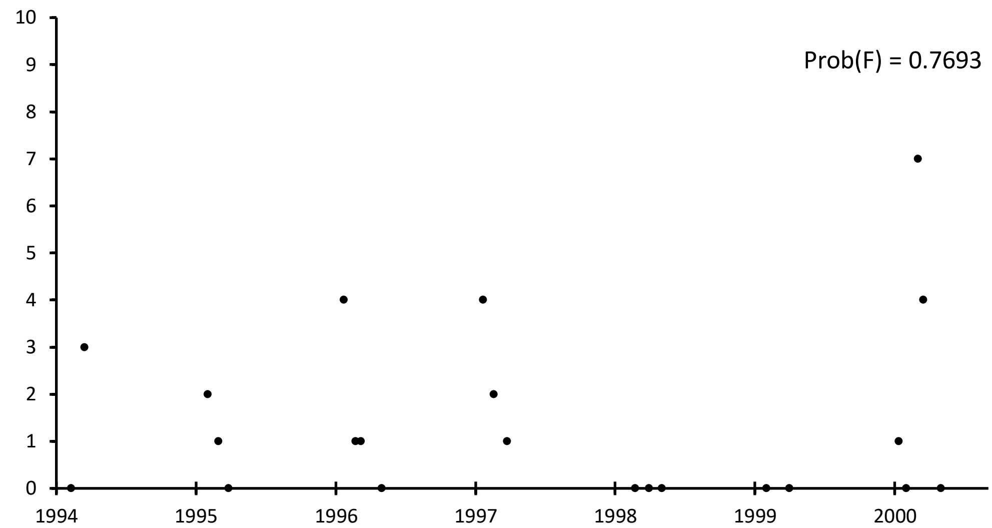
Seasonal Abundance May-Aug 1994-2020 (summer monthly means)




Summer monthly means reveal the peak cattle egret abundances associated with nesting on the upper river in 2012-2014.

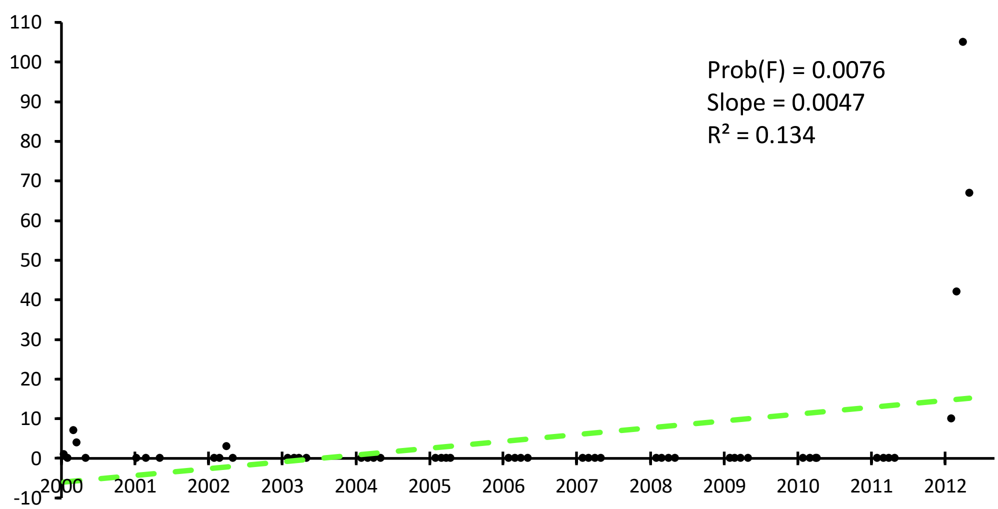
[5] No data were recorded for this species during its breeding season in 1992 or 1993.

Seasonal Abundance During Hydrilla Invasion: May-Aug 1994-2000 (counts per survey)



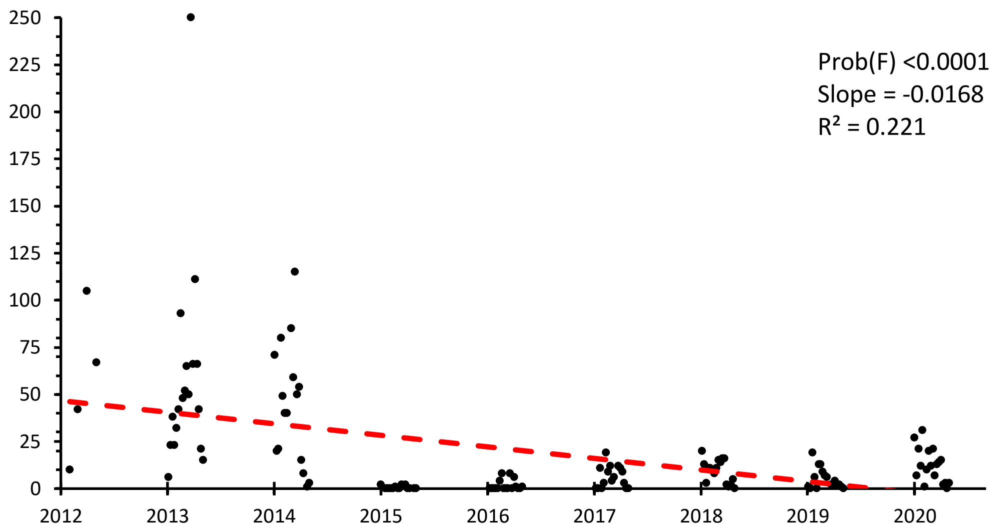

The cattle egret exhibited no statistically significant trend in abundance during the 1994-2000 hydrilla invasion period. Counts per survey ranged from 0 to 7 and averaged 1.4 animals.

Seasonal Abundance During Hydrilla Management: May-Aug 2000-2012 (counts per survey)



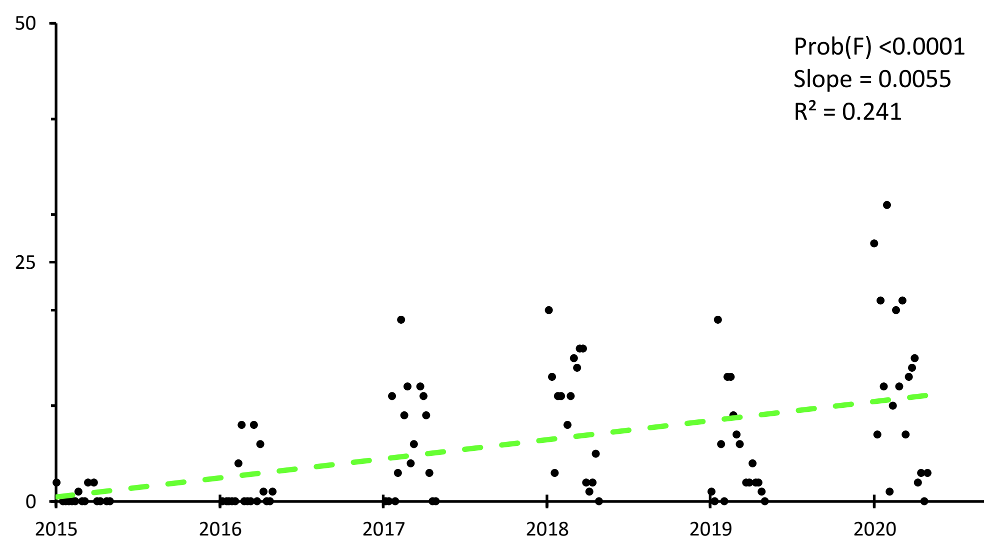

A significant increasing abundance trend (99.24% level) emerged during the hydrilla management period with the onset of nesting on the upper river in 2012. The trend explains 13.4% of the observed variation in breeding season counts per survey.

Seasonal Abundance Post- Hydrilla Management: May-Aug 2012-2020 (counts per survey)




The relocation of nesting from the tour route to further down river resulted in a significant (better than 99.99% level) decrease in summer breeding season abundance during the post-hydrilla management period with a trend that explains 22.1% of the observed variation in counts per survey.

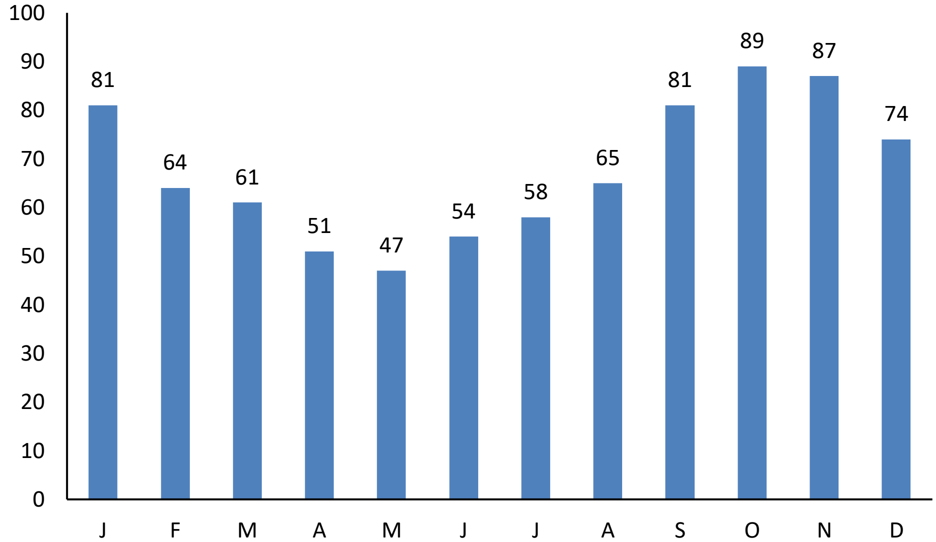
Seasonal Abundance After Nesting Colony Relocation: May-Aug 2015-2020 (counts per survey)




Counts per survey have increased significantly, however, since 2015 (better than 99.99% level), after relocation of the nesting colony to the second mile of the river in 2016. The trend explains 24.1% of the observed variation in counts per survey.

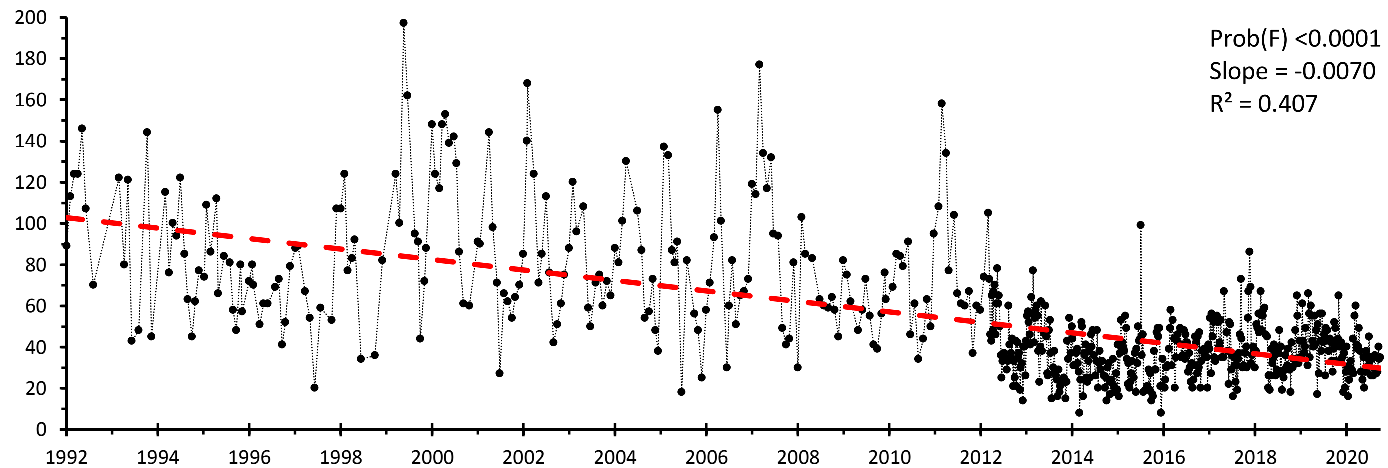
# COMMON GALLINULE

Seasonal Abundance 1992-2020 (average monthly means)



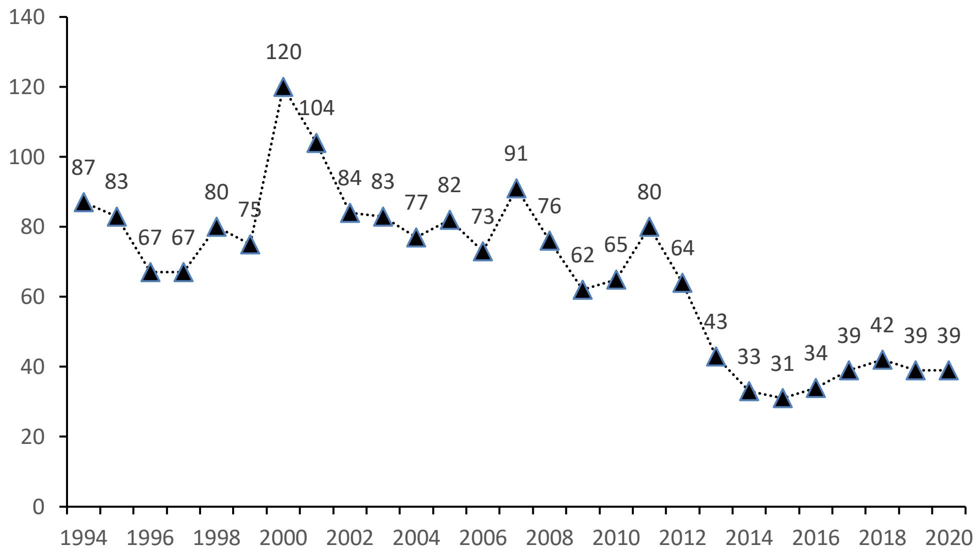

The common gallinule, formerly called the common moorhen, is a year-round breeding resident of the upper Wakulla River with a seasonal pattern of abundance which likely reflects both a summer breeding season with 2-3 broods per pair coupled with an influx of winter migrants joining the resident population (Bannor and Kiviat, 2002).

Abundance 1992-2021 (counts per survey)



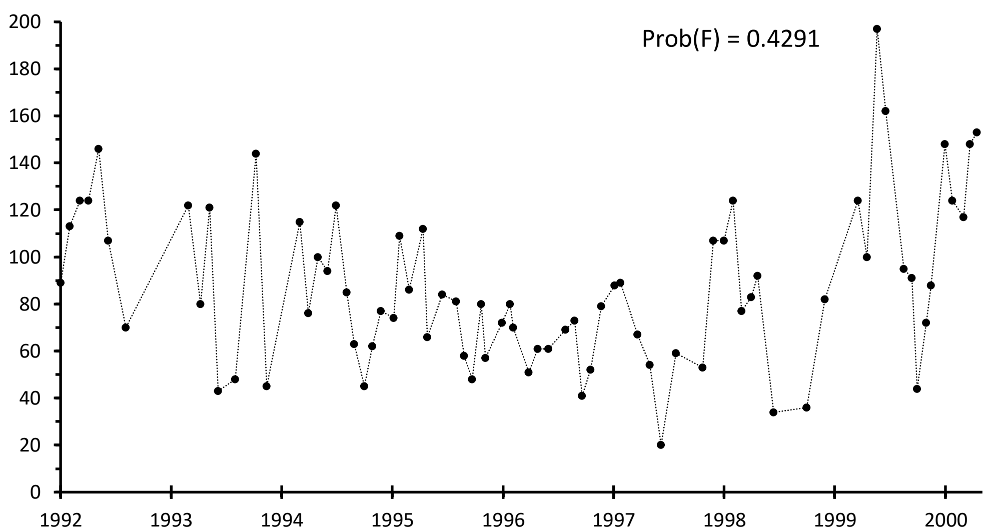

The common gallinule exhibited a significant (better than 99.99% level) decreasing abundance trend of -0.0070 animals counted per day or -2.56 counts per year over the period of record, 9/1/92 – 5/29/21. Survey date explains 40.7% of the observed variation in counts per survey.

Abundance 1994-2020 (annual means)



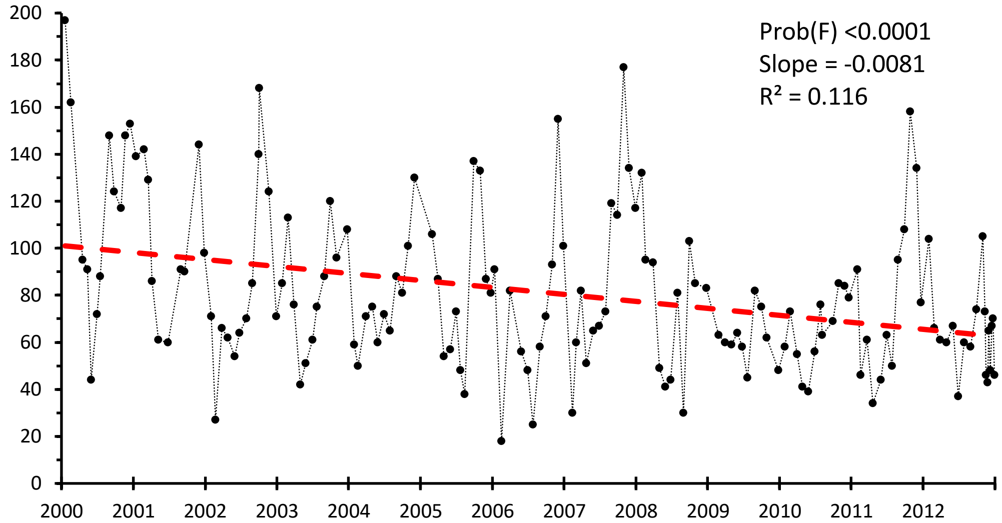

Annual means reveal a generally declining pattern since a peak in 2000. A second steep decline began in 2012 following an oscillating but slowly declining pattern between 2000 and 2011. Most recently, annual means increased after 2015 and have since levelled off.

Abundance During Hydrilla Invasion: 1992-2000 (counts per survey)



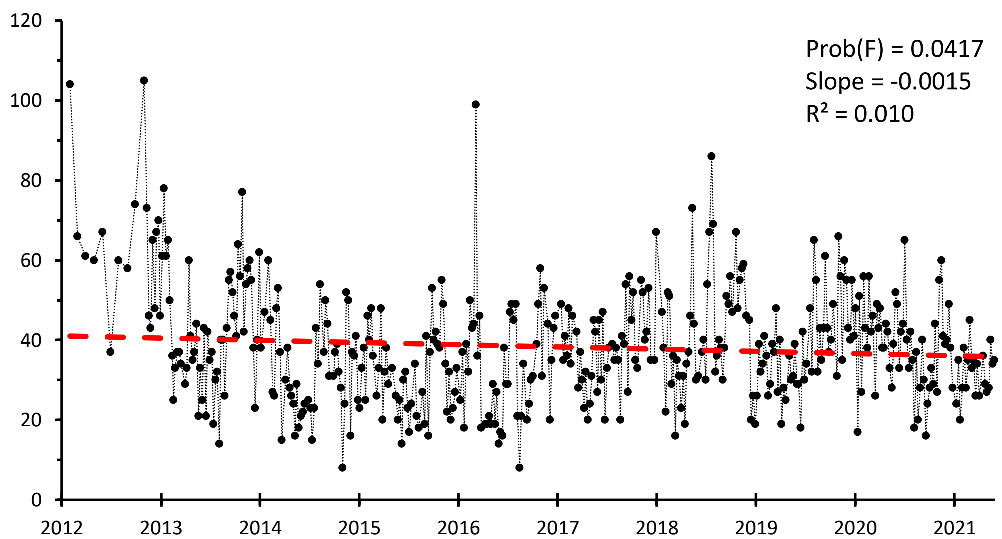

The common gallinule exhibited no statistically significant trend in abundance during the hydrilla invasion period. Counts per survey ranged from 20 to 197 and averaged 87 animals.

Abundance During Hydrilla Management: 2000-2012 (counts per survey)




A significant (better than 99.99% level) decline in abundance emerged during the hydrilla management period with a trend that explains 11.6% of the observed variation in counts per survey.

Abundance Post- Hydrilla Management: 2012-2021 (counts per survey)




The decline continued through the post-hydrilla management period with a significant (95.83% level) negative trend that explained 1.0% of the observed variation in counts per survey.

## Multivariate Analysis of Recent Trend

As warm-blooded (endothermic) vertebrates, common gallinules are less likely to be influenced by air temperature or sunshine/cloudiness. River stage may, however, affect how many are observed: gallinules build nests at the water's edge, thus if water levels are lower, adults and chicks may be observed more often. Data collected by the Northwest Florida Water Management District at its gauge at the Ways (aka boat tram) indicate that the upper Wakulla River stage has experienced a long-term declining trend since the early 2000s.

The modest decreasing trend in abundance depicted above for 2012-2021 becomes insignificant when the time period is shifted to that beginning with the onset of weekly monitoring on November 10, 2012, and date remains insignificant in a multivariate regression model that includes river stage, air temperature, and sunshine.[6]

[6] Sunshine was coded as a dummy/categorical variable based on cloud cover categories included on the survey form: coded 1 for "clear" and "some clouds"; coded 0 for "fog," "overcast,' and "rain."

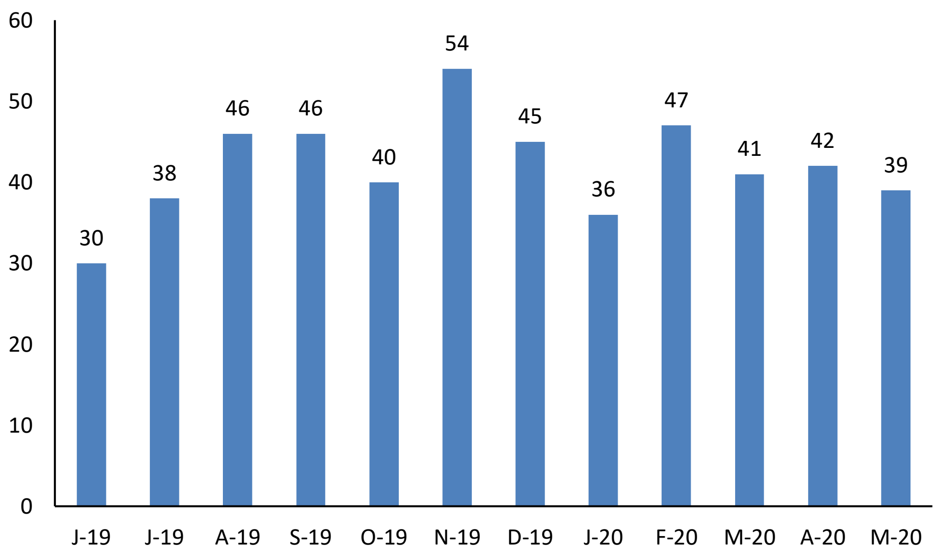
| | test stat | p-value |
|---|---|---|
| F-test | 5.967 | 0.0001 |
| Adjusted R-squared | 0.048 | |
| Date | -0.001 | 0.4284 |
| River stage | -4.606 | 0.0005 |
| Air temperature | -0.104 | 0.0544 |
| Sunshine | -0.931 | 0.0101 |

The model explains only 4.8 percent of the observed variation in counts per survey and is significant at the 99.99 percent level. River stage is significant and has the expected negative sign: more common gallinules are observed when the stage is lower. Air temperature and the sunshine dummy also are significant and negative, likely reflecting the influx of winter migrants which results in higher counts in cooler months at a time when there is, perhaps less sunshine.

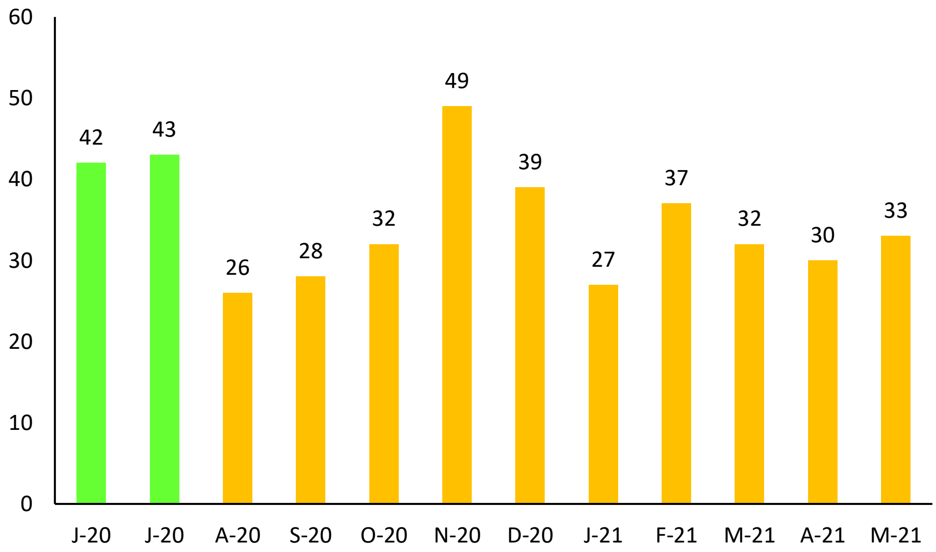
Comparison of 2019-20 and 2020-21 Monthly Means

Very low counts in April 2021 prompted a comparison of monthly means for June through May for 2019-20 and 2020-21. In the second chart, months colored orange were 2 or more counts lower in 2020-21 than 2019-20. Months colored green were two or more counts higher. The lower winter counts may reflect fewer seasonal migrants.

**2019-2020**

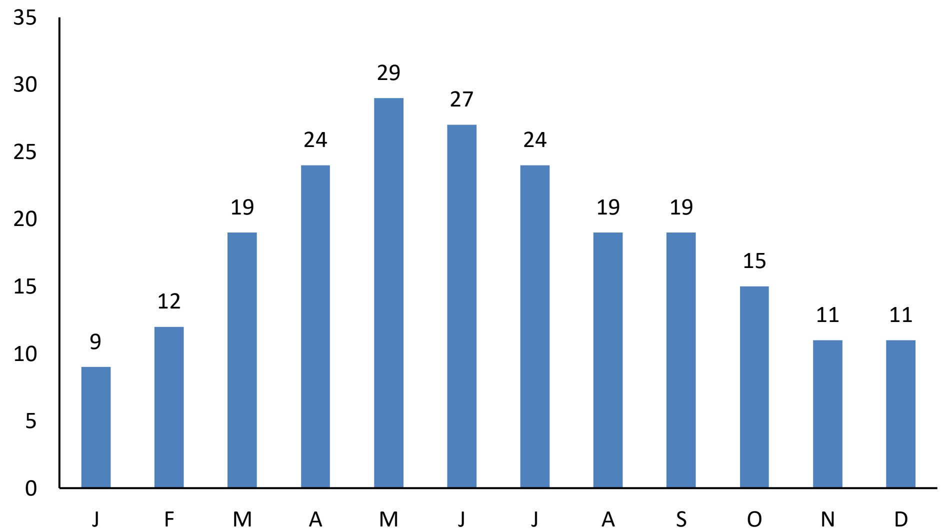


**2020-2021**


60
50
40
30
20
10
0
42
43
26
28
32
49
39
27
37
32
30
33
J-20
J-20
A-20
S-20
O-20
N-20
D-20
J-21
F-21
M-21
A-21
M-21

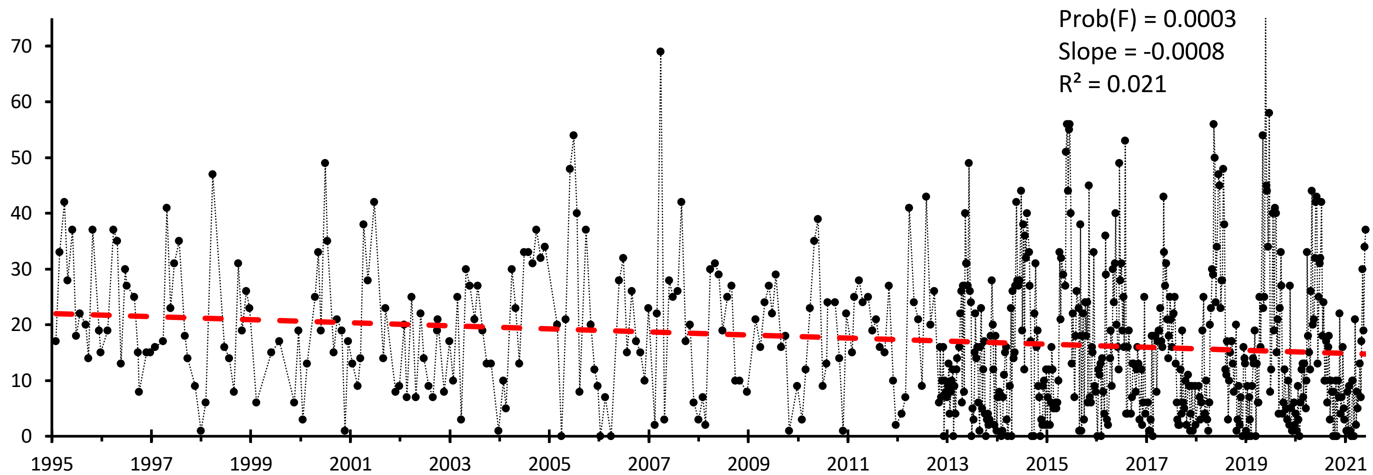
# COOTER TURTLE

Seasonal Abundance 1995-2020 (average monthly means)[7]




Cooter turtles, which include both the Suwannee cooter (*Pseudemys concinna suwanniensis*) and the coastal plain cooter (*Pseudemys floridana floridana*) (Krysko et al., 2019), are year-round breeding residents of the upper Wakulla River with a distinctive seasonal pattern of abundance that peaks in May. This may be due in part to the turtles' reproductive cycles with multiple clutches laid during spring and summer, peaking in May and June (pp. 262; 264).

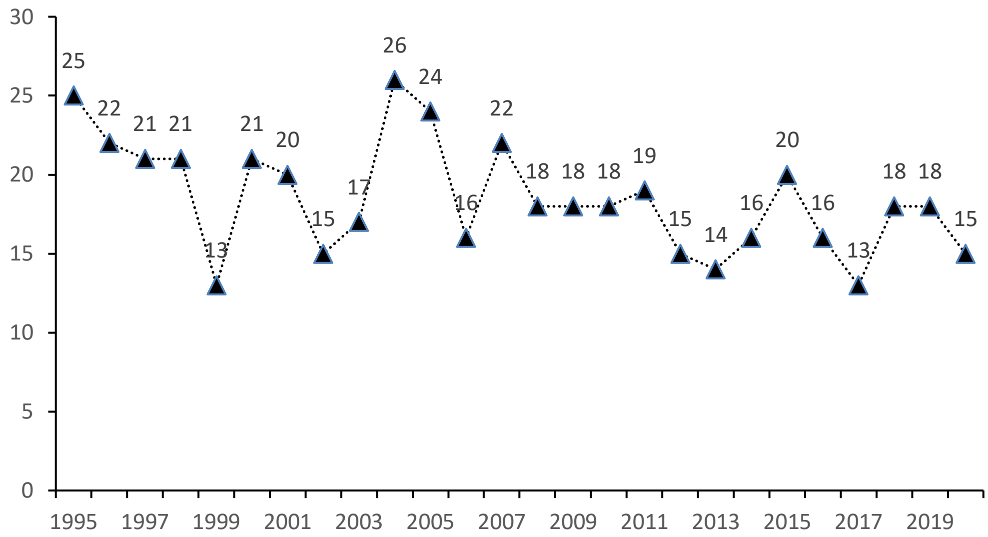
Abundance 1995-2021 (counts per survey)




Cooter turtles exhibited a significant (99.97% level) decreasing abundance trend of -0.0008 animals counted per day or -0.27 counts per year over the period analyzed, 1/30/95 – 5/29/21. Survey date explains 2.1% of the observed variation in counts per survey. High variation between surveys likely reflects the effects of air temperature and cloud cover on basking behavior and the effects of varying water visibility depth on observing turtles.

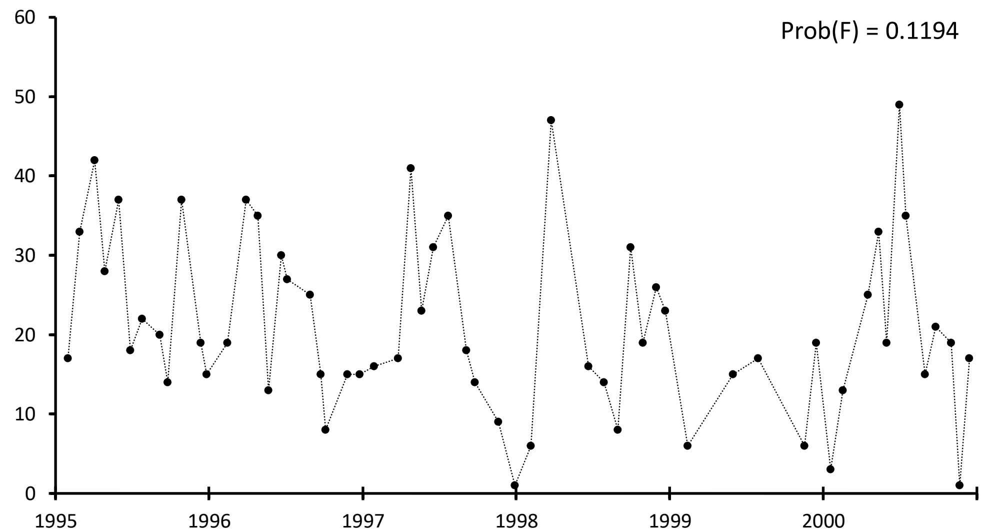
[7] Data excluded from 1992-1994 for these analyses because of apparent counting irregularities; i.e. multiple zero counts in 1993 and 1994.

Abundance 1995-2020 (annual means)



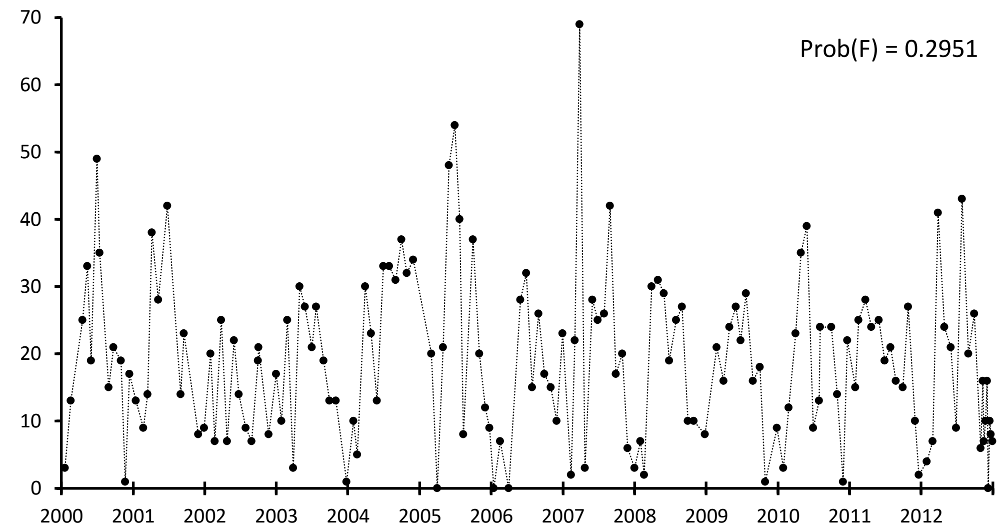

Annual means reveal an abundance pattern with multiple peaks and valleys.

Abundance During Hydrilla Invasion: 1995-2000 (counts per survey)



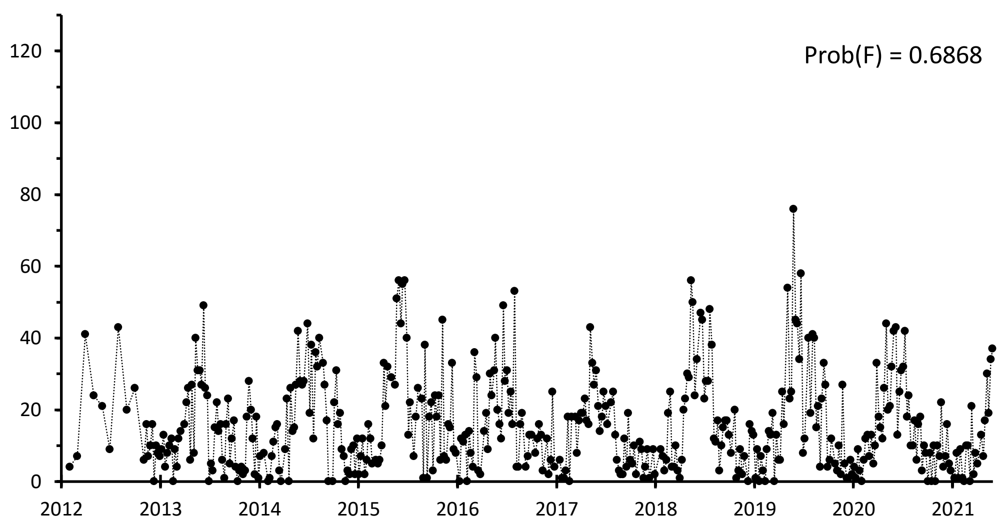

Cooter turtles exhibited no statistically significant trend in abundance during the hydrilla invasion between 1995 and 2000. Counts per survey ranged from 1 to 49 and averaged 21 animals.

Abandance During Hydrilla Management: 2000-2012 (counts per survey)




No significant trend in abundance was manifest during the hydrilla management period either. Counts per survey ranged from 0 to 69 and averaged 19 animals, slightly fewer than during the hydrilla invasion.

Abundance Post- Hydrilla Management: 2012-2021 (counts per survey)




The absence of a significant trend continued through the post-hydrilla management period with counts per survey ranging from 0 to 76 and averaging 16, a further decline from the preceding period.

Multivariate Analysis of Recent Trend

Like alligators, turtles are ectothermic, i.e. cannot regulate their body temperature internally, thus their abundance on any given day may be influenced by air temperature and sunshine/cloud cover. [8] River stage also may affect how many are observed: if water levels are higher, basking sites may be underwater. A multivariate regression model that controls for these variables for the period during which weekly data have been collected, November 10, 2012, through May 29, 2021, is statistically significant at the 99.99 percent level or better and explains 39.4 percent of the observed variation in counts per survey.

As was the case for the post-hydrilla management analysis reported above, the trend over time (date) is not significant. However, each of the other independent variables is significant at better than the 99.99 percent level. Thus, while cooter

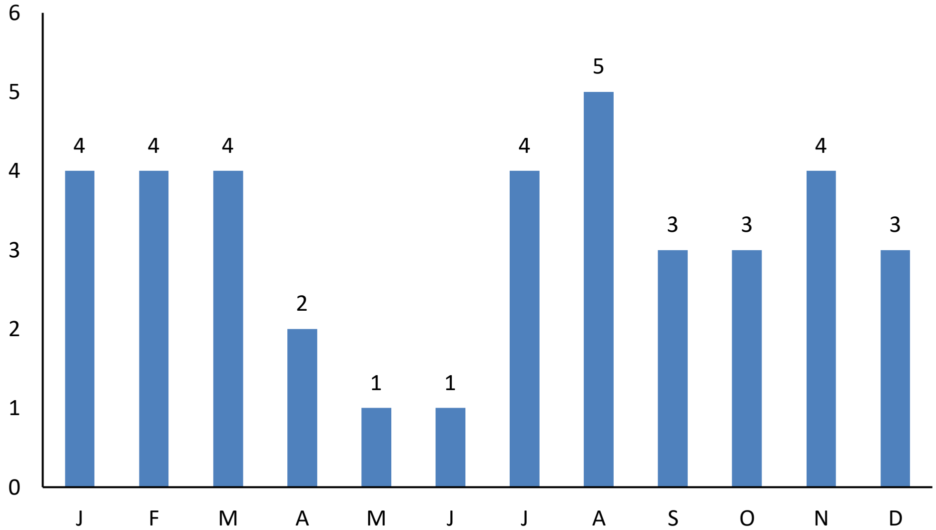
[8] Sunshine was coded as a dummy/categorical variable based on cloud cover categories included on the survey form: coded 1 for "clear" and "some clouds"; coded 0 for "fog," "overcast,' and "rain."

turtle counts exhibit no significant recent trend, like alligators, they are more abundant when river stage is lower (negative coefficient), air temperature is warmer, and the weather is clear or has some clouds.

| | test stat | p-value |
|---|---|---|
| F-test | 65.626 | < 0.0001 |
| Adjusted R-squared | 0.394 | |
| Date | -0.001 | 0.0600 |
| River stage | -7.834 | < 0.0001 |
| Air temperature | 0.576 | < 0.0001 |
| Sunshine | 8.685 | < 0.0001 |

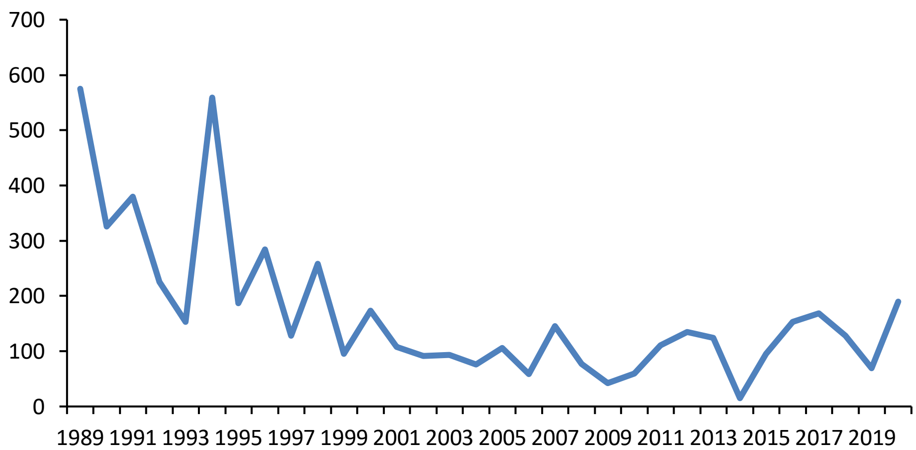
# DOUBLE-CRESTED CORMORANT

Seasonal Abundance 1992-2020 (average monthly means)

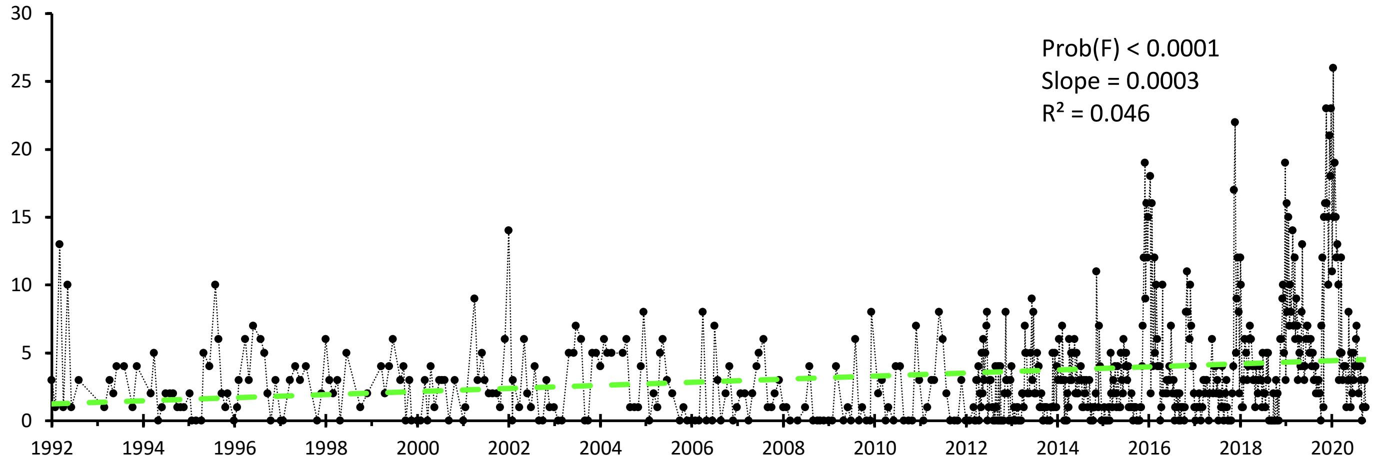



The double-crested cormorant is a year-round resident of the upper Wakulla River that has bred in colonies in the second mile of the river below the spring every year since at least 1989, with the possible exception of 2014, as documented by the park's summer full-river wildlife surveys (see next figure). Local breeding may explain the high monthly means in July and August while higher means in November through March may reflect an influx of winter migrants from northern breeding territories (Dorr, Hatch, and Weseloh, 2014).

Cormorant Count
Summer River Survey - Park Section 1989-2020

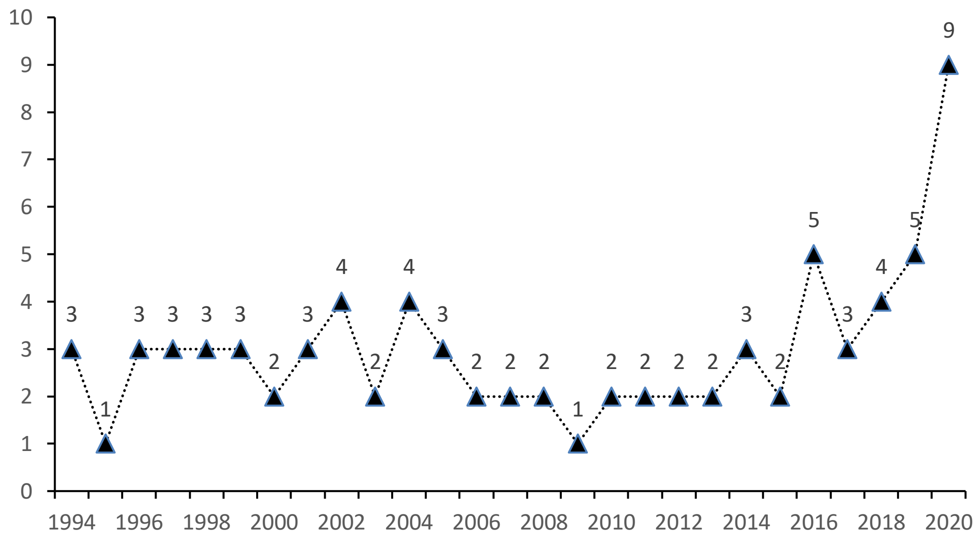


Abundance 1992-2021 (counts per survey)



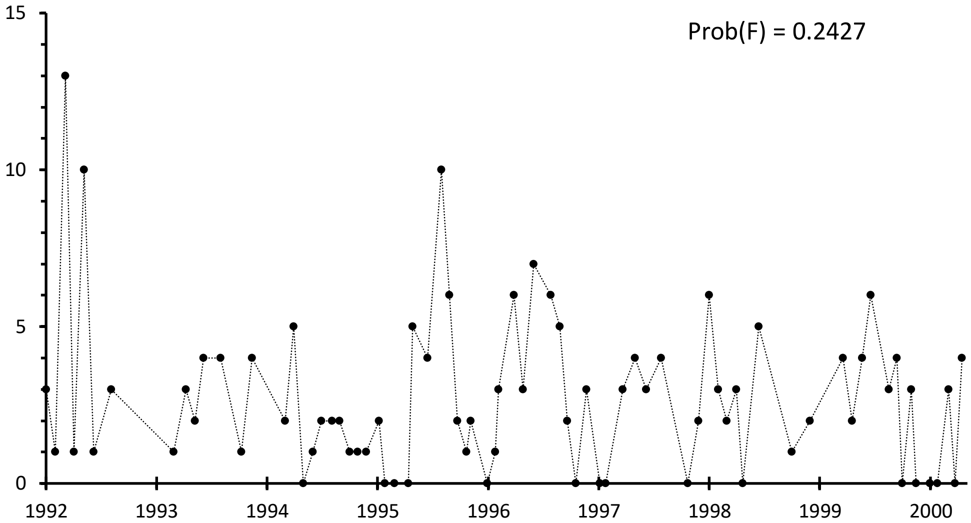

Continued nesting by the double-crested cormorant in colonies on the second mile of the river has resulted in the development of a long-term significant (better than 99.99% level) increasing abundance trend of 0.0003 animals counted per day or 0.11 counts per year over the period analyzed, 9/1/92 – 5/29/21. Survey date explains 4.6% of the observed variation in counts per survey.

Abundance 1994-2020 (annual means)



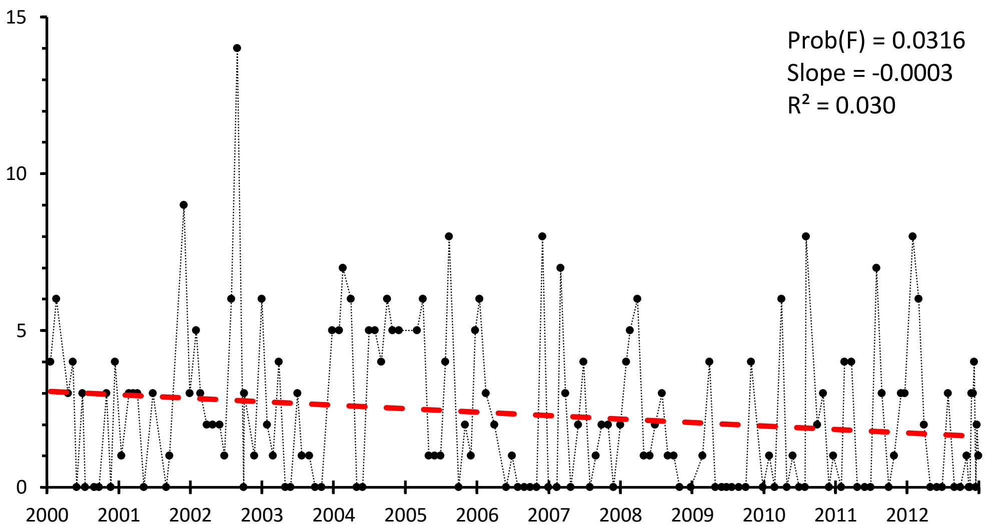

Annual mean counts per survey have been low, ranging from 1 to 5 until 2020. They also show highs in 2016 and 2018-2020 that likely reflect local breeding colonies. No patterns are evident that suggest impacts from ecosystem perturbations analyzed here.

Abundance During Hydrilla Invasion: 1992-2000 (counts per survey)



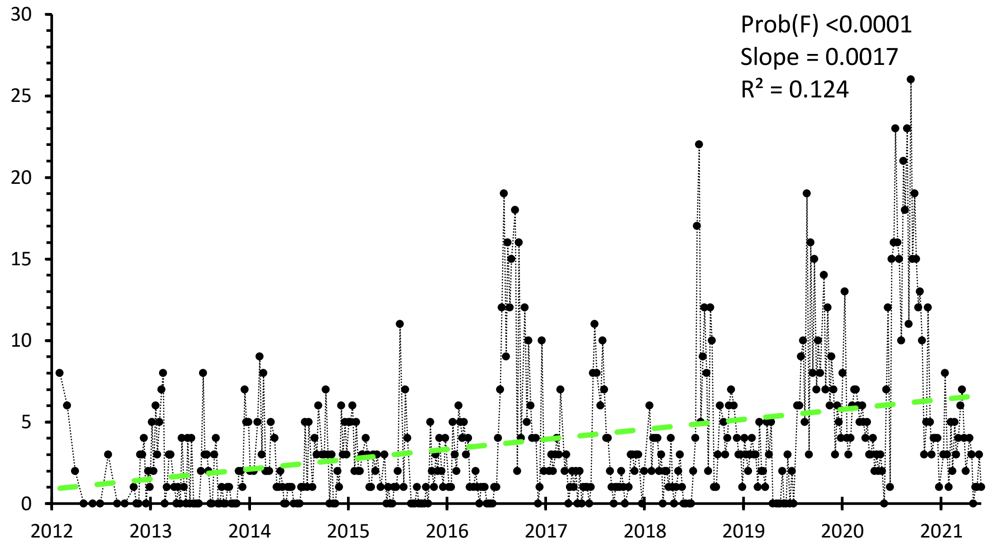

Double-crested cormorants exhibited no statistically significant trend in abundance during the hydrilla invasion. Counts per survey ranged from 0 to 13 and averaged 3 animals.

Abundance During Hydrilla Management: 2000-2012 (counts per survey)




A significant (96.84% level) decline in abundance emerged during the hydrilla management period with a trend that explains 3.0% of the observed variation in counts per survey.

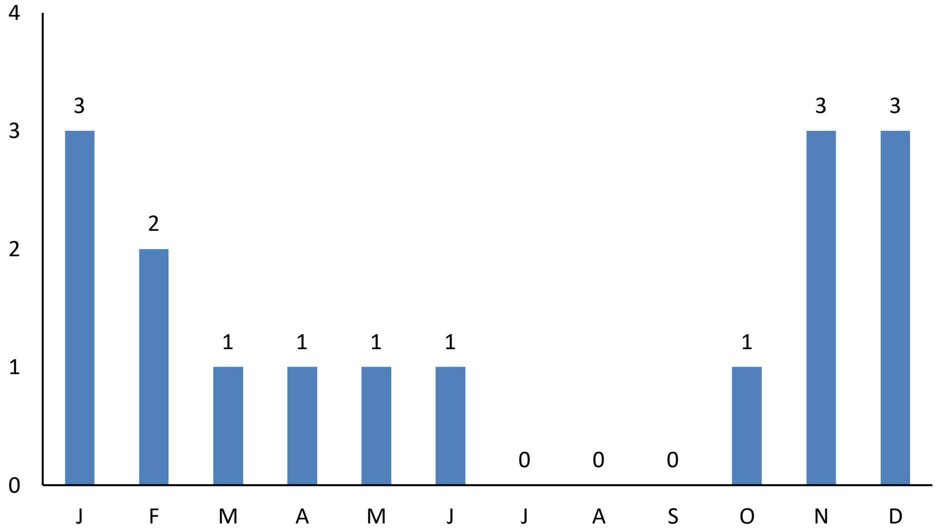
Abundance Post- Hydrilla Management: 2012-2021 (counts per survey)




The cormorant abundance trend reversed during the post-hydrilla management period with a positive trend significant at better than the 99.99% level. The trend explains 12.4% of the observed variation in counts per survey during this period.

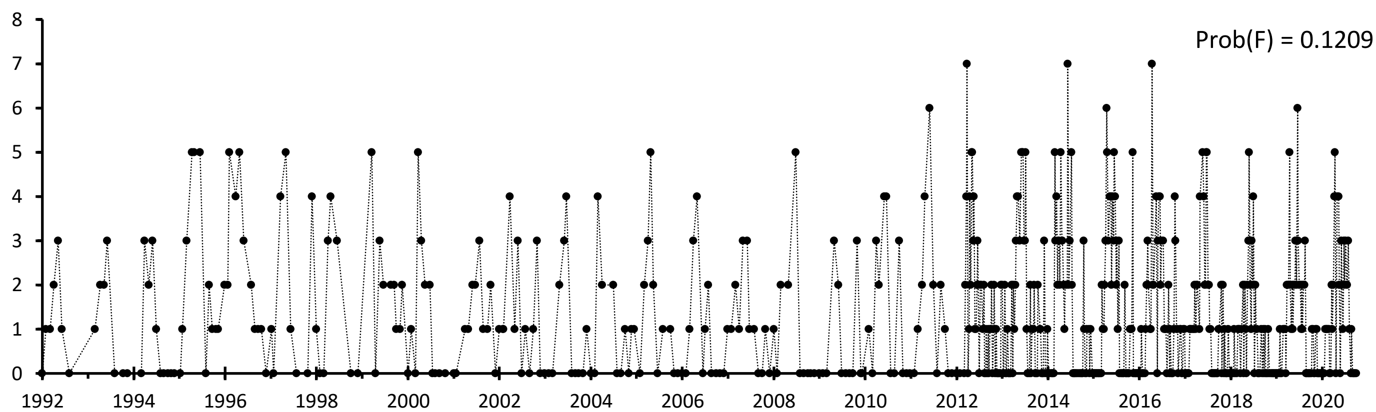
# GREAT BLUE HERON

Seasonal Abundance 1992-2020 (average monthly means)



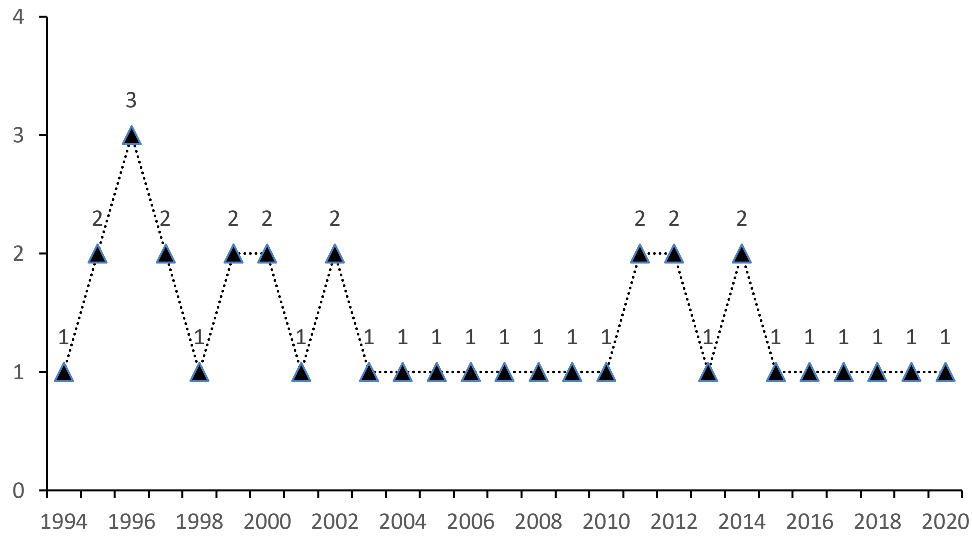

The great blue heron is a year-round resident of the upper Wakulla River that sometimes breeds along the river boat tour route (personal observation). Numbers are small throughout the year likely reflecting relatively large feeding territories. Higher means in November through February may reflect an influx of winter migrants from northern breeding territories (The Cornell Lab of Ornithology, 2019).

Abundance 1992-2021 (counts per survey)



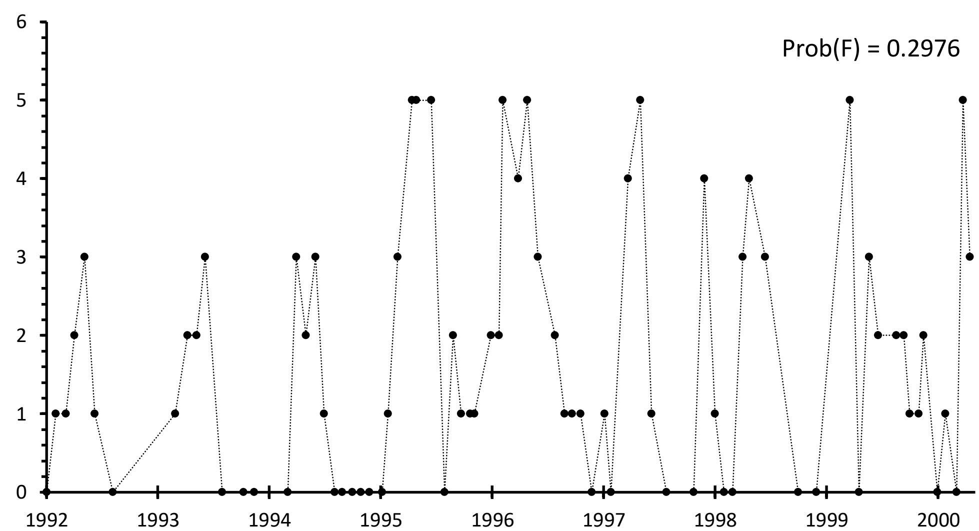

The great blue heron has been present in small numbers and exhibited no significant long-term abundance trend over the period of record, 9/1/92 – 5/29/21. Counts per survey ranged from 0 to 7 with an average of 1.3. Higher counts occurred during winter months when the local population may have been augmented by winter migrants.

Abundance 1994-2020 (annual means)



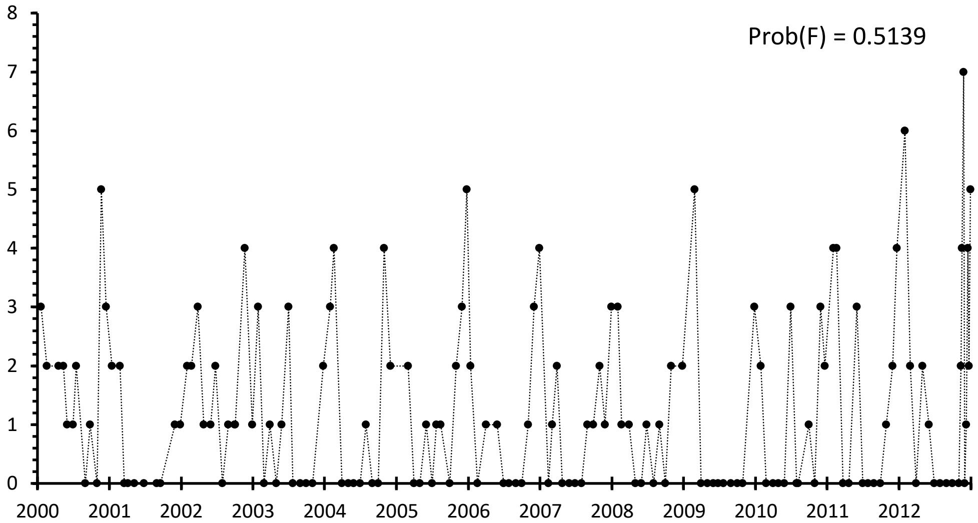

Annual mean counts per survey are very low ranging from 1 to 3. With such low numbers, no trends are apparent.

Abundance During Hydrilla Invasion: 1992-2000 (counts per survey)



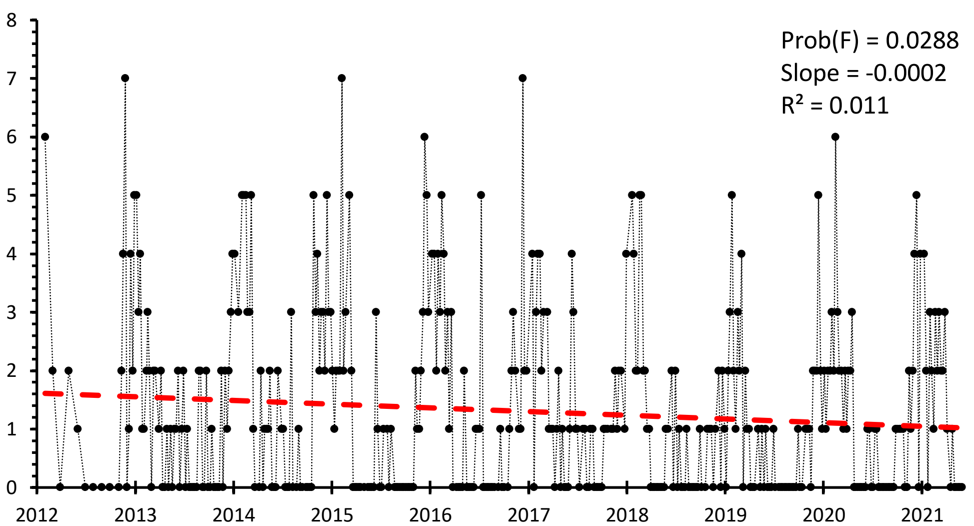

Great blue herons exhibited no statistically significant trend in abundance during the hydrilla invasion between 1992 and 2000. Counts per survey ranged from 0 to 5 and averaged 2 animals.

Abundance During Hydrilla Management: 2000-2012 (counts per survey)




The lack of a significant abundance trend continued through the hydrilla management period. Counts per survey ranged from 0 to 7 with a mean of 1.

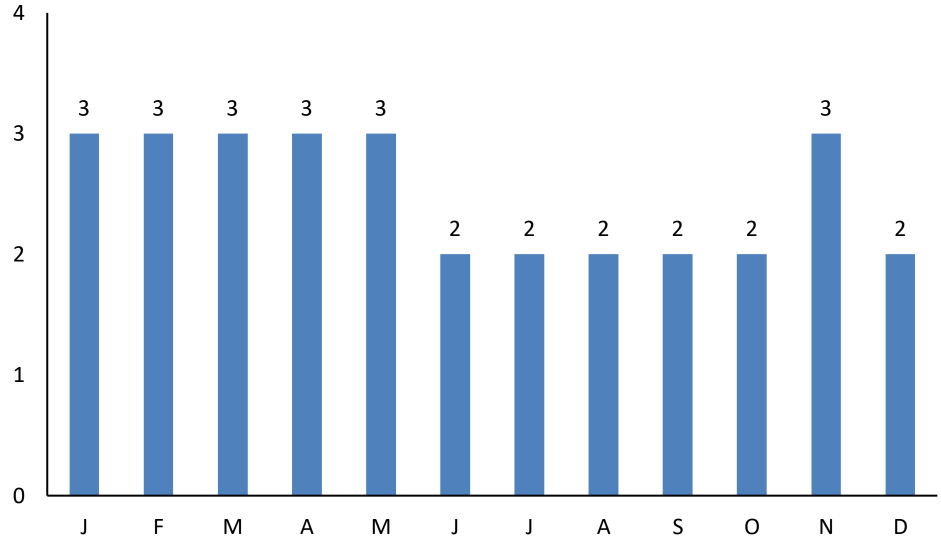
Abundance Post- Hydrilla Management: 2012-2021 (counts per survey)




The great blue heron did exhibit a significant decrease in abundance (97.12% level) during the post-hydrilla period with a trend that explains 1.1% of the observed variation in counts per survey.

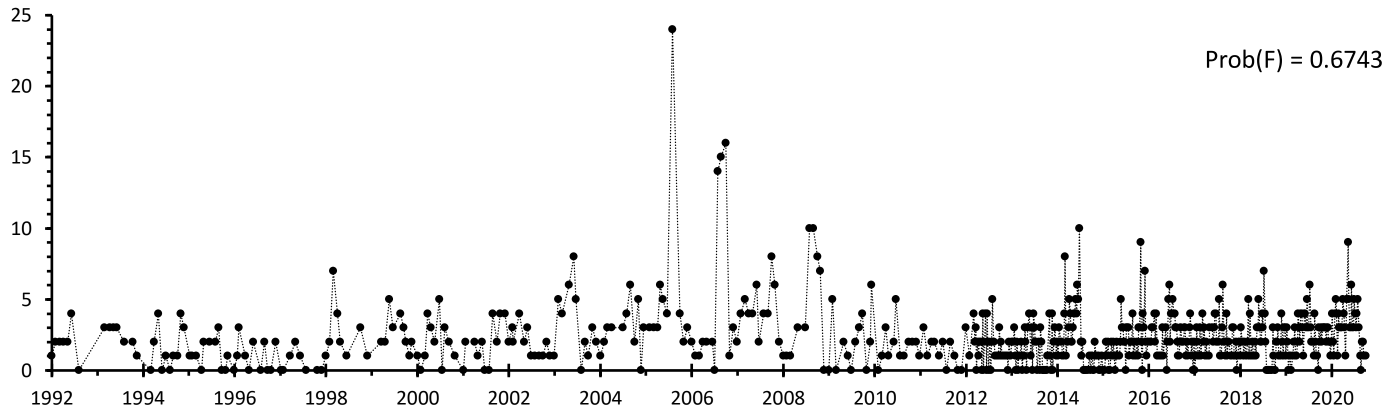
# GREAT EGRET

Seasonal Abundance 1992-2020 (average monthly means)



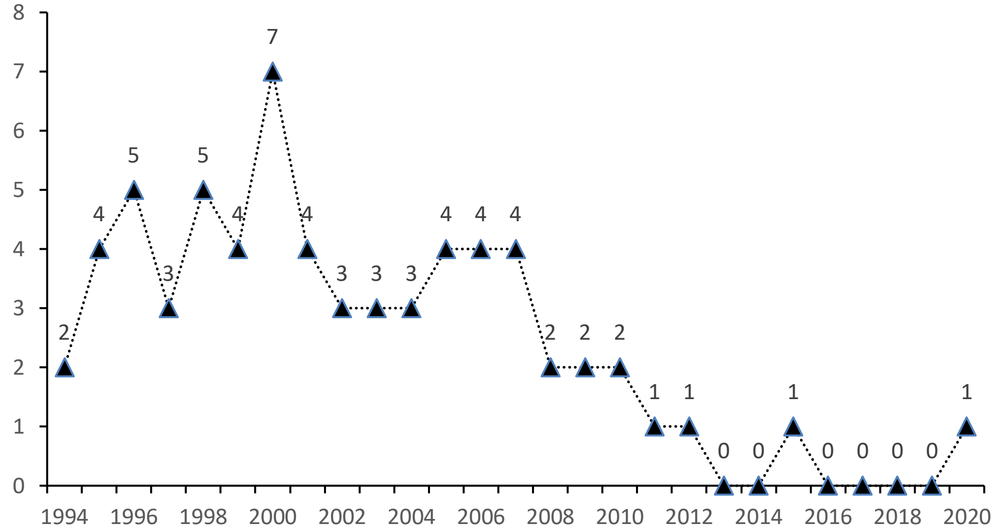

The great egret is a year-round resident of the upper Wakulla River that has bred at times along the upper river in the past (Bob Thompson, personal communication) and along the second mile of the river (personal observation). Numbers are small throughout the year, likely reflecting relatively large feeding territories.

Abundance 1992-2021 (counts per survey)



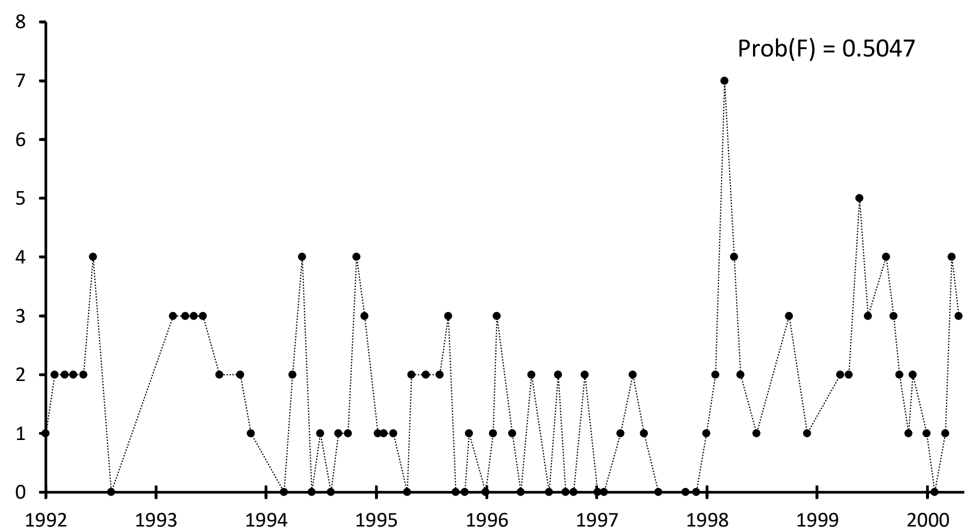

The great egret has been present in small numbers and exhibited no significant long-term abundance trend over the period of record, 9/1/92 – 5/29/21. Counts per survey ranged from 0 to 24 with an average of 2.3.

Abundance 1994-2020 (annual means)



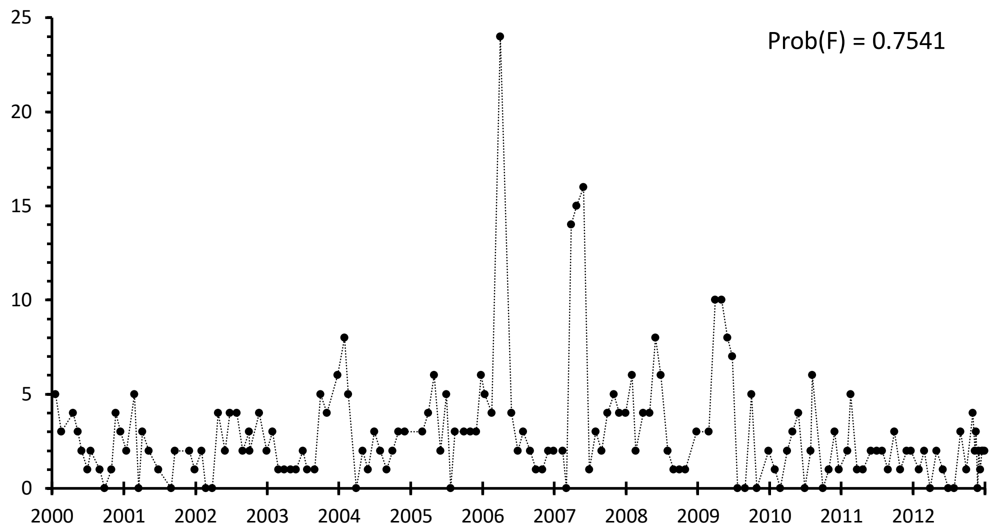

Annual mean counts per survey are very low ranging from 1 to 7. An increase from 2003 to 2007 was followed by a steep decline in 2010 and generally stable annual mean abundance thereafter. Bob Thompson documented nesting along the river boat tour route in 2009 and 2010.

Abundance During Hydrilla Invasion: 1992-2000 (counts per survey)



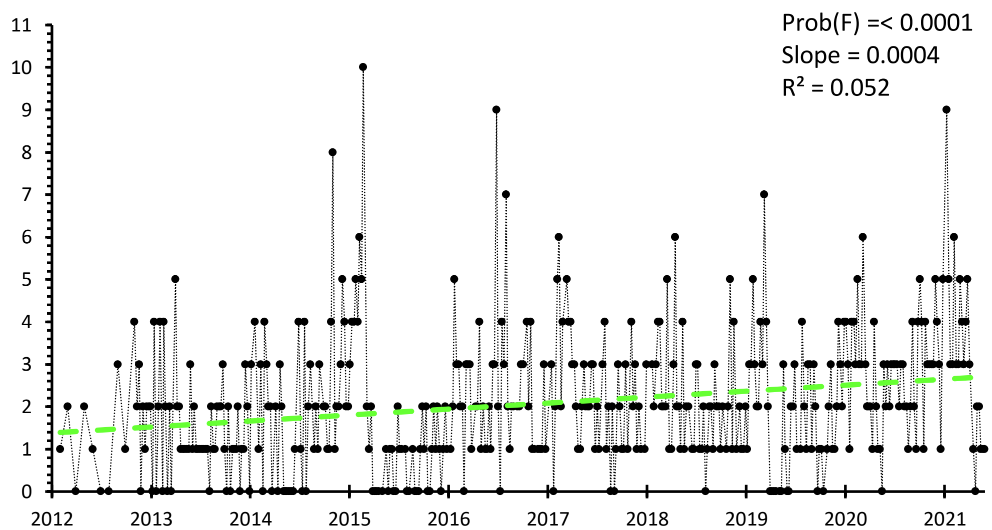

Great egrets exhibited no statistically significant trend in abundance during the hydrilla invasion between 1992 and 2000. Counts per survey ranged from 0 to 7 and averaged 2 animals.

Abundance During Hydrilla Management: 2000-2012 (counts per survey)




The lack of a significant abundance trend continued through the hydrilla management period. Counts per survey ranged from 0 to 24 with a mean of 3.

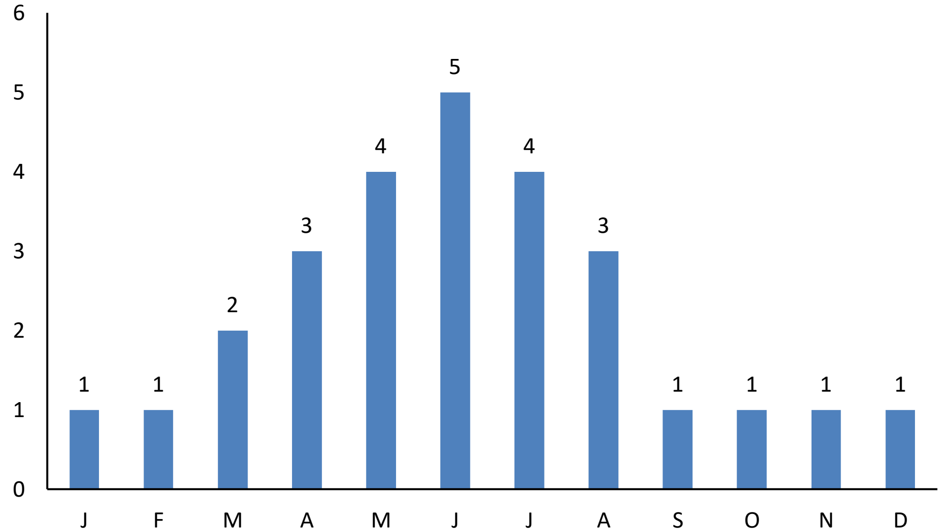
Abundance Post- Hydrilla Management: 2012-2021 (counts per survey)




The great egret did exhibit a significant increase in abundance (better than 99.99% level) during the post-hydrilla period with a trend that explains 5.2% of the observed variation in counts per survey.

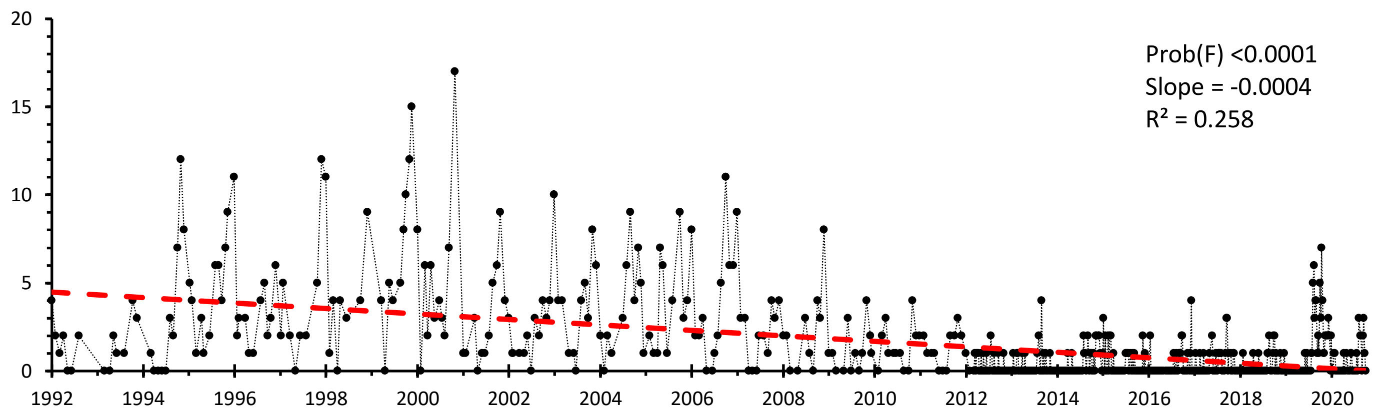
## GREEN HERON

Seasonal Abundance 1992-2020 (average monthly means)



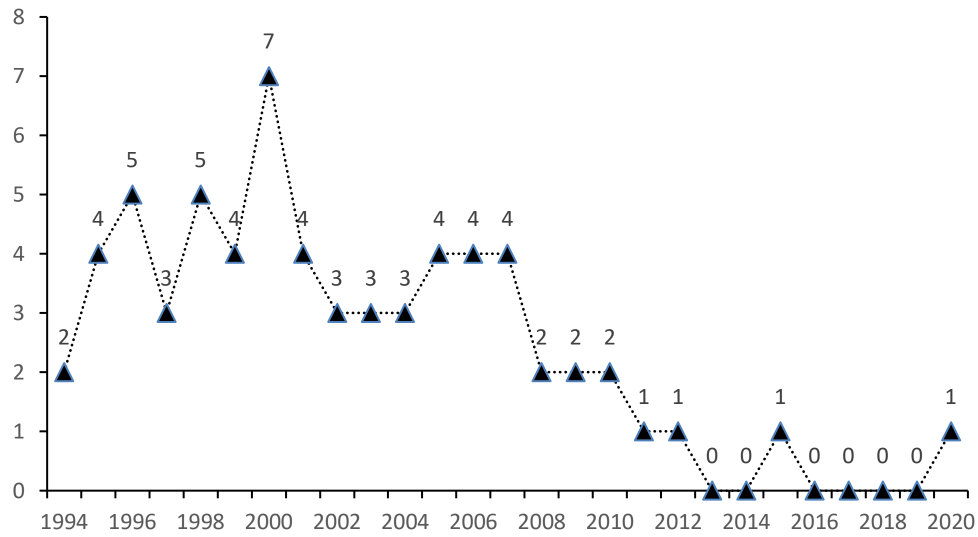

The green heron is a secretive year-round resident breeder on the upper Wakulla River. Peak abundance in May through July may reflect the breeding cycle and/or their propensity for wandering after the breeding season (The Cornell Lab of Ornithology, 2019). Small numbers throughout the year likely reflect relatively large breeding territories and their tendency for solitary rather than colony nesting.

Abundance 1992-2021 (counts per survey)



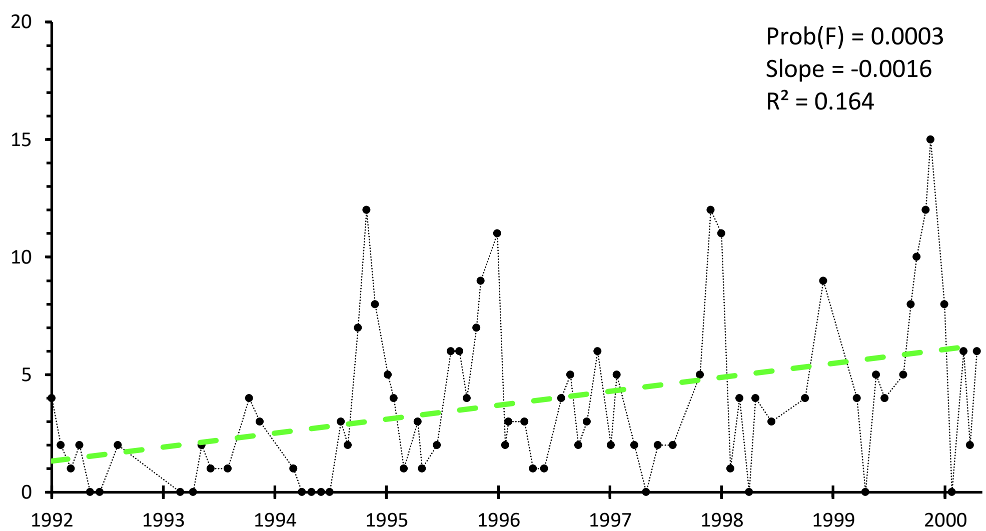

The green heron exhibited a significant (better than 99.99% level) decreasing abundance trend of -0.0004 animals counted per day or -0.16 counts per year over the period analyzed, 9/1/92 – 5/29/21. Survey date explains 25.8% of the observed variation in counts per survey.

Abundance 1994-2020 (annual means)



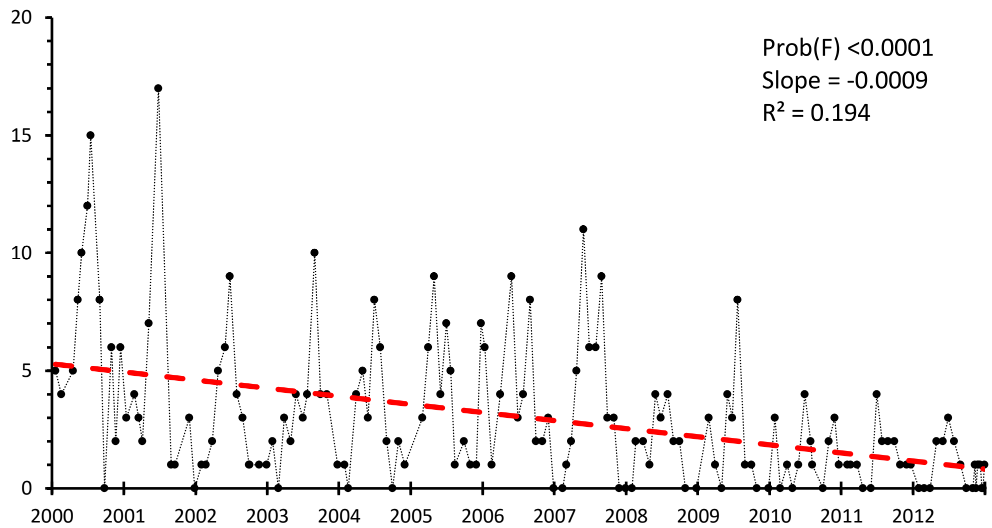

Annual mean counts per survey of the green heron peaked in 2000 near the onset of intensive hydrilla management and have generally declined since.

Abundance During Hydrilla Invasion: 1992-2000 (counts per survey)



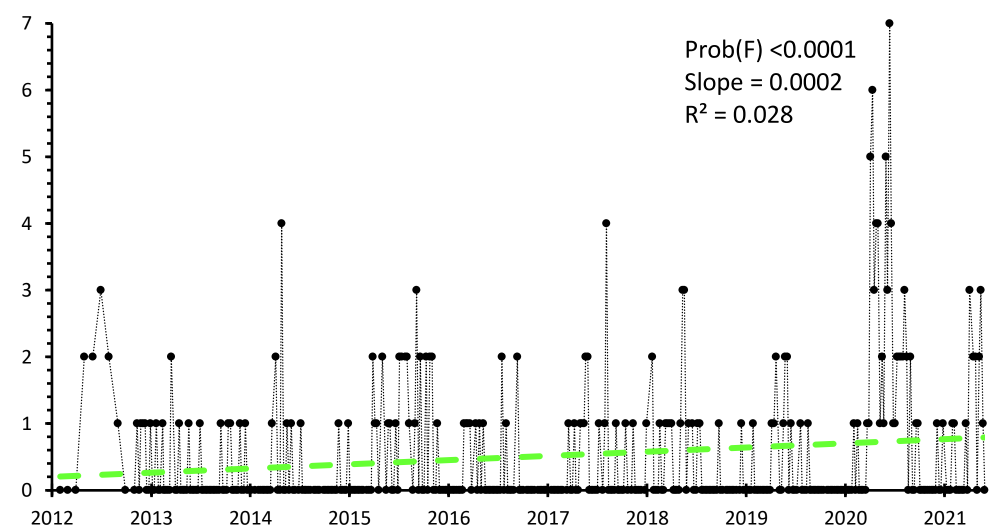

Green herons exhibited a significant (99.97% level) increasing trend in abundance during the hydrilla invasion between 1992 and 2000 that explains 16.4% of the observed variation in counts per survey.

Abundance During Hydrilla Management: 2000-2012 (counts per survey)




The green heron exhibited a significant (better than 99.99% level) decreasing trend in abundance during the hydrilla management period which explains 19.4% of the observed variation in survey counts per day.

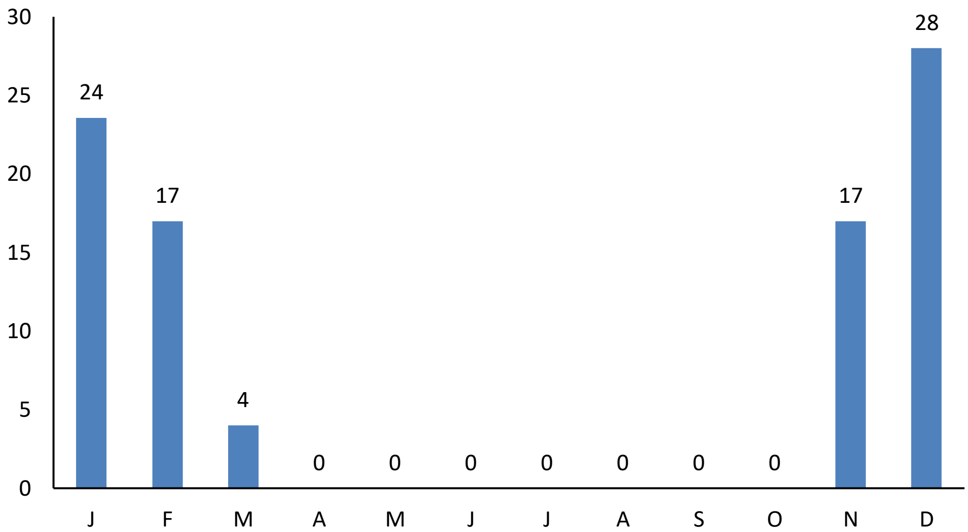
Abundance Post- Hydrilla Management: 2012-2021 (counts per survey)




The green heron exhibited a significant (better than 99.99% level) increasing trend in abundance during the hydrilla management period which explains 2.8% of the observed variation in survey counts per day. The higher counts in 2020 reflect nesting at the turnaround on the river boat tour route.

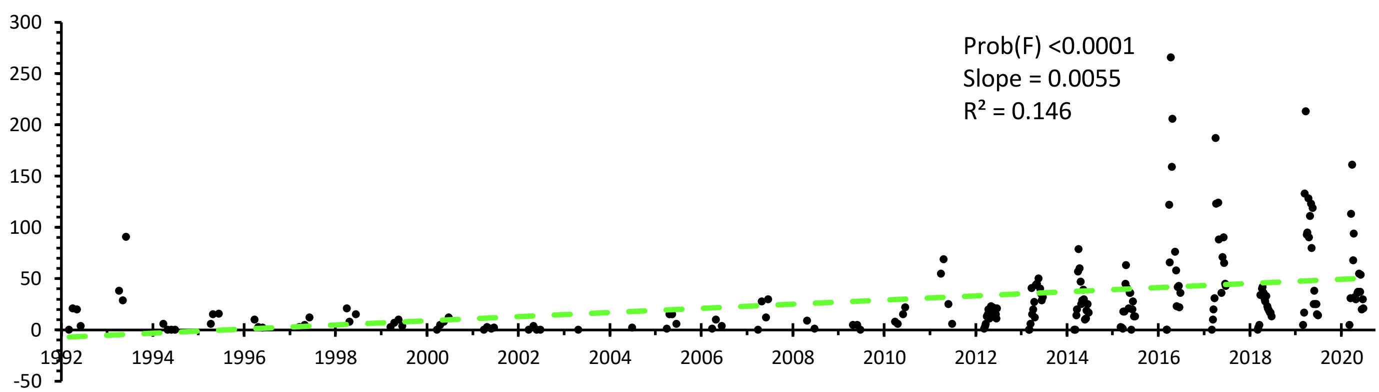
# HOODED MERGANSER

Seasonal Abundance 1992-2020 (average monthly means)




The hooded merganser is a winter migrant typically observed between November and March each year.

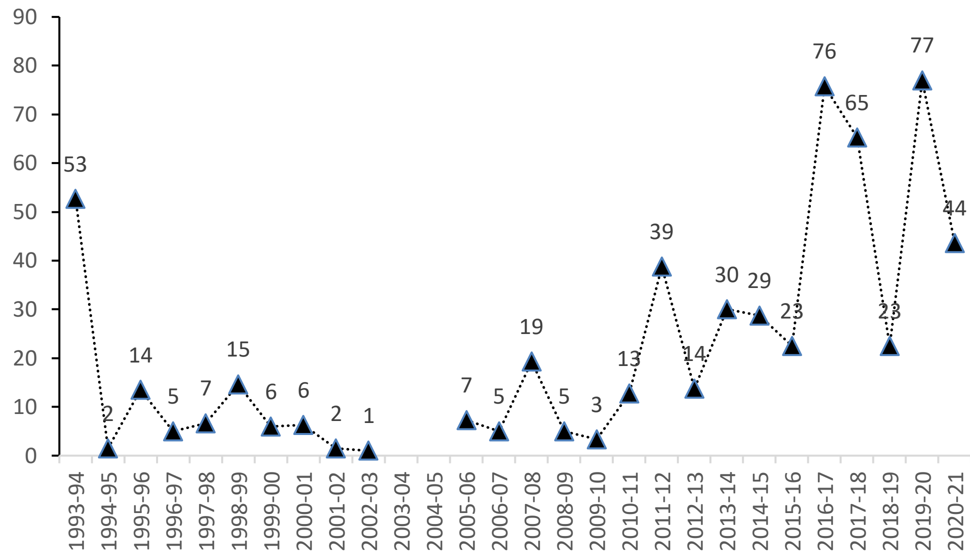
Seasonal Abundance Nov-Feb 1992-93 – 2020-21 (counts per survey)[9]




The hooded merganser exhibited a significant (better than 99.99% level) increasing abundance trend of 0.005 animals counted per day or 2.02 counts per year over the period analyzed, 9/1/92 – 2/27/21. Survey date explains 14.6% of the observed variation in counts per survey.

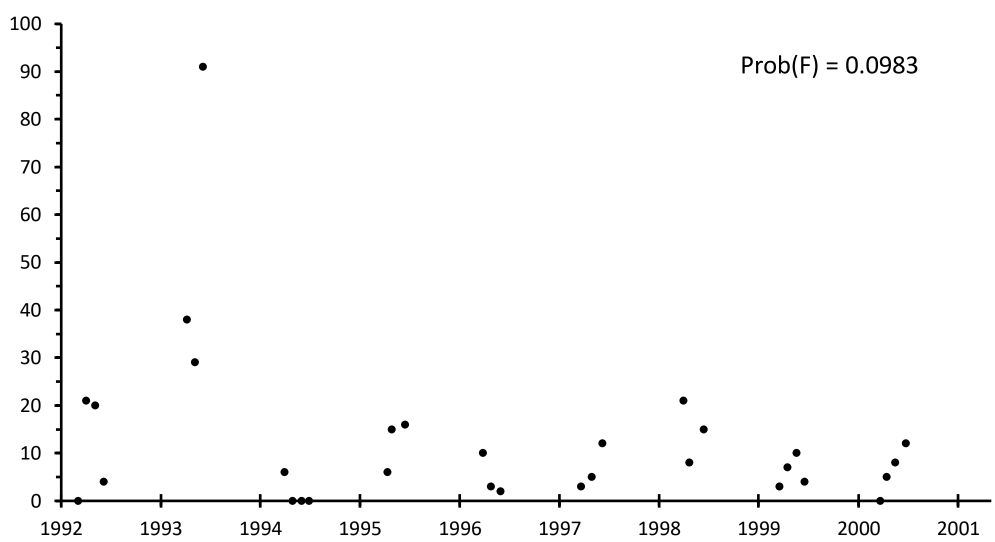
[9] No data available for 2004.

Seasonal Abundance Nov-Feb 1993-94 – 2020-21 (winter monthly means)



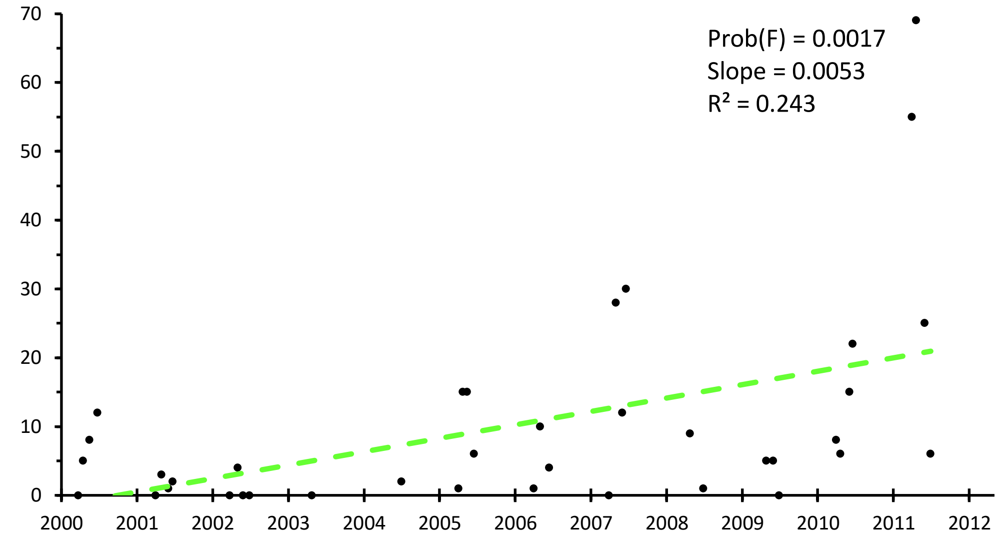

Annual winter monthly mean counts per survey of the hooded merganser began with a high in 1993-94, then settled into relatively low numbers before beginning an up-and-down ascending trend in 2011-12.

Seasonal Abundance During Hydrilla Invasion: Nov-Feb 1992-93 – 1999-2000 (counts per survey)



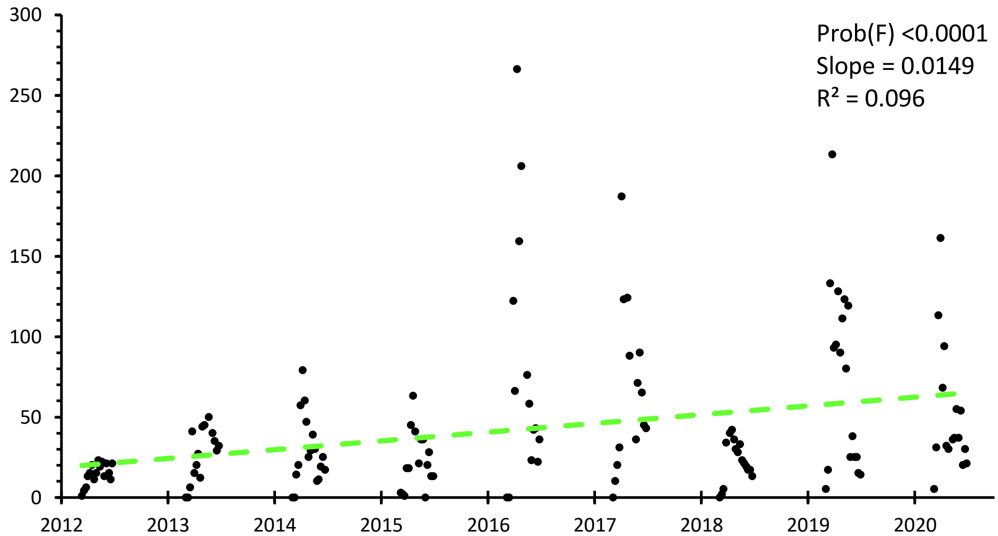

Hooded mergansers exhibited no significant winter seasonal abundance trend during the hydrilla invasion. Counts per survey ranged from 0 to 91 with an average of 12.

Seasonal Abundance During Hydrilla Management: Nov-Feb 1999-2000 – 2011-2012 (counts per survey)




The hooded merganser exhibited a significant (99.83% level) increasing trend in winter seasonal abundance during the hydrilla management period. The trend explains 24.3 % of the observed variation in survey counts per day.

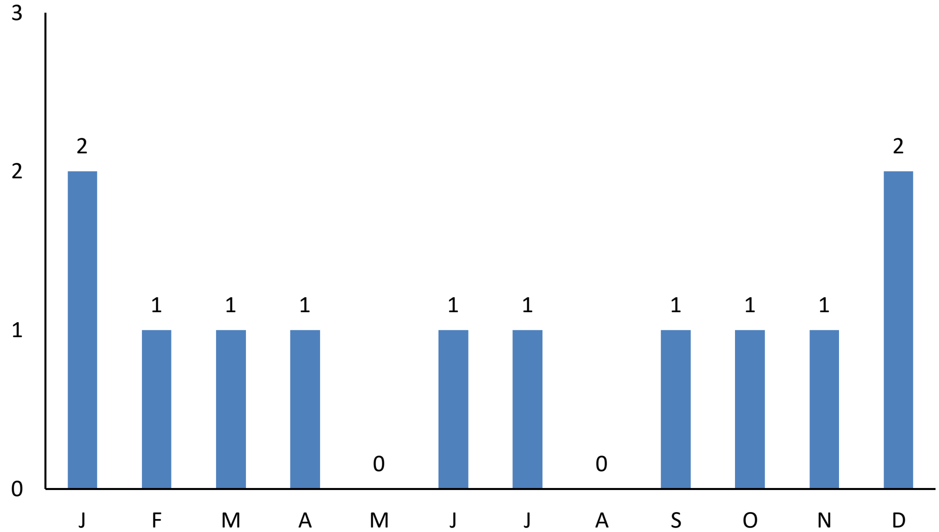
Seasonal Abundance Post- Hydrilla Management: Nov-Feb 2011-12 – 2020-21 (counts per survey)




Hooded merganser winter seasonal abundance continued to increase with a significant trend (better than 99.99% level) during the post-hydrilla management period. The trend explains 9.6 % of the observed variation in survey counts per day.

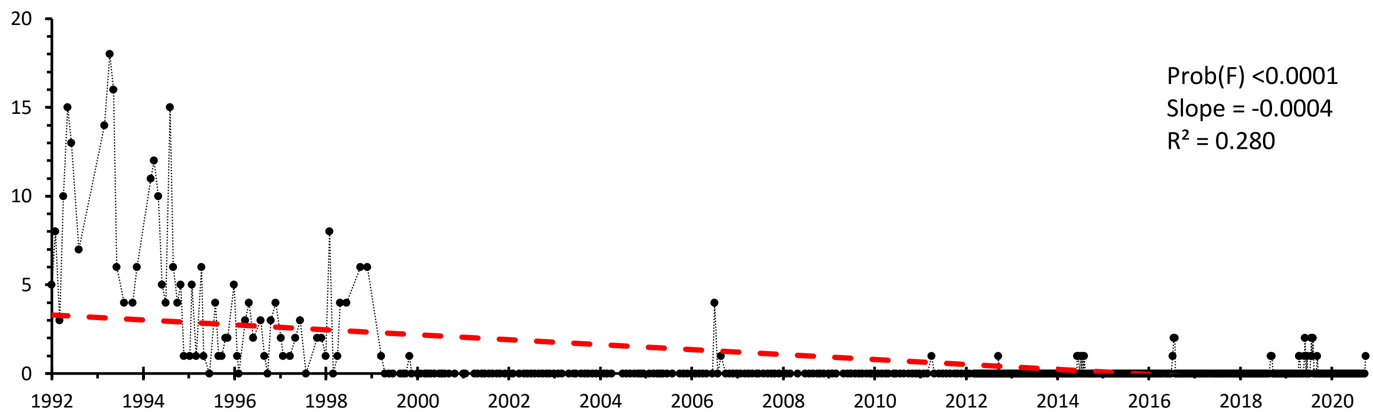
# LIMPKIN

Seasonal Abundance 1992-2020 (average monthly means)



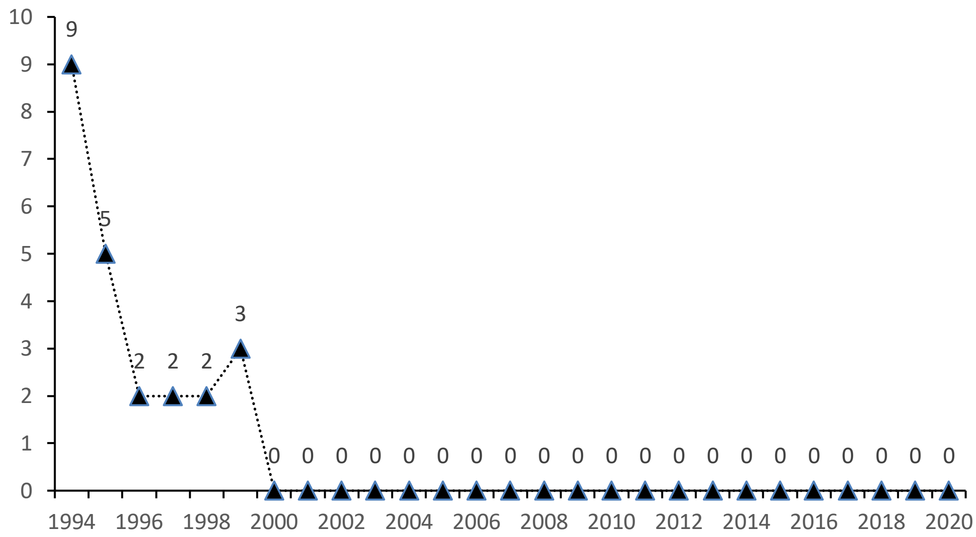

The limpkin was a year-round breeding resident of the upper Wakulla River until its near complete disappearance in 2000 most likely as a result of the demise of its primary food source, the apple snail. It is now an occasional visitor. Low average monthly means reflect this dramatic shift in population levels.

Abundance 1992-2021 (counts per survey)



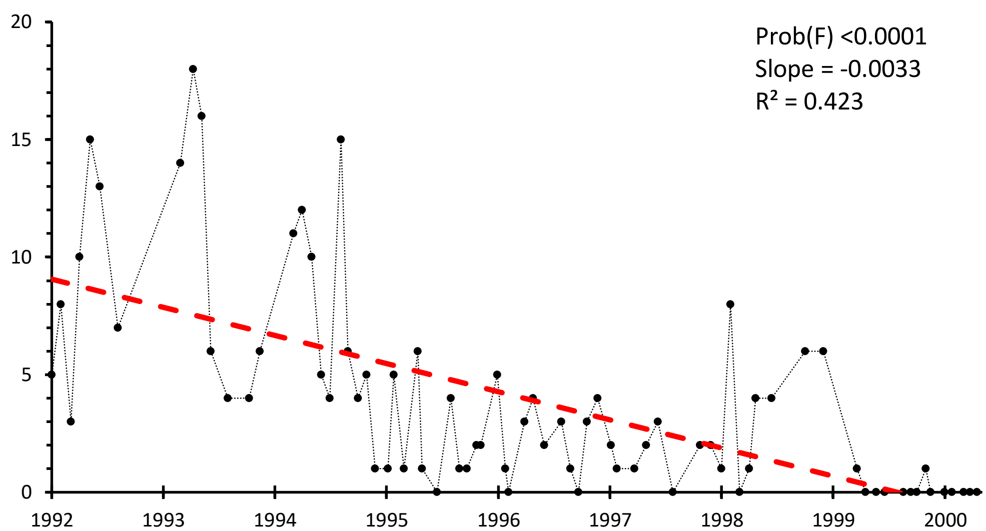

The limpkin exhibited a significant (better than 99.99% level) decreasing abundance trend of -0.0004 animals counted per day or -0.14 counts per year over the period of record, 9/1/92 – 5/29/21. Survey date explains 28.0% of the observed variation in counts per survey.

Abundance 1994-2020 (annual means)



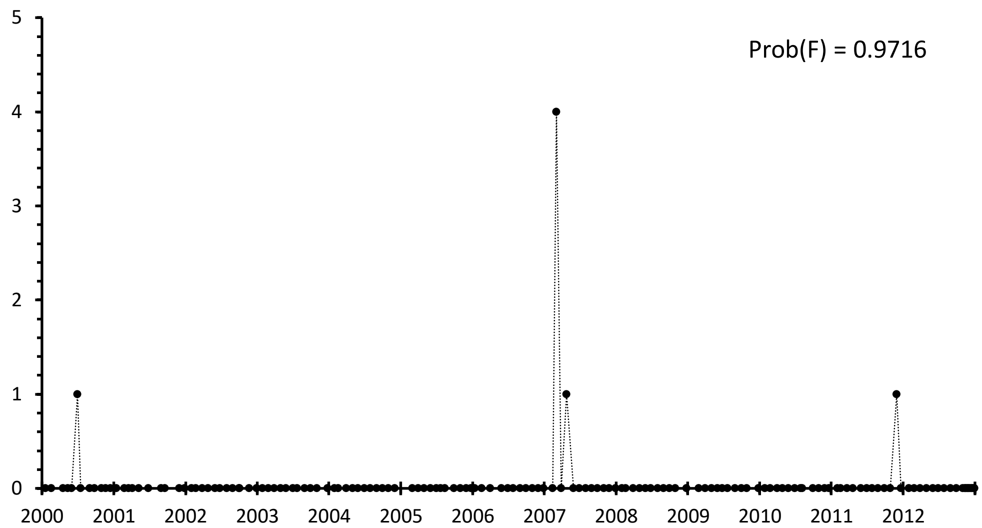

Annual mean counts per survey of the limpkin dropped immediately after 1994 and bottomed out at 0 in 2000.

Abundance During Hydrilla Invasion: 1992-2000 (counts per survey)



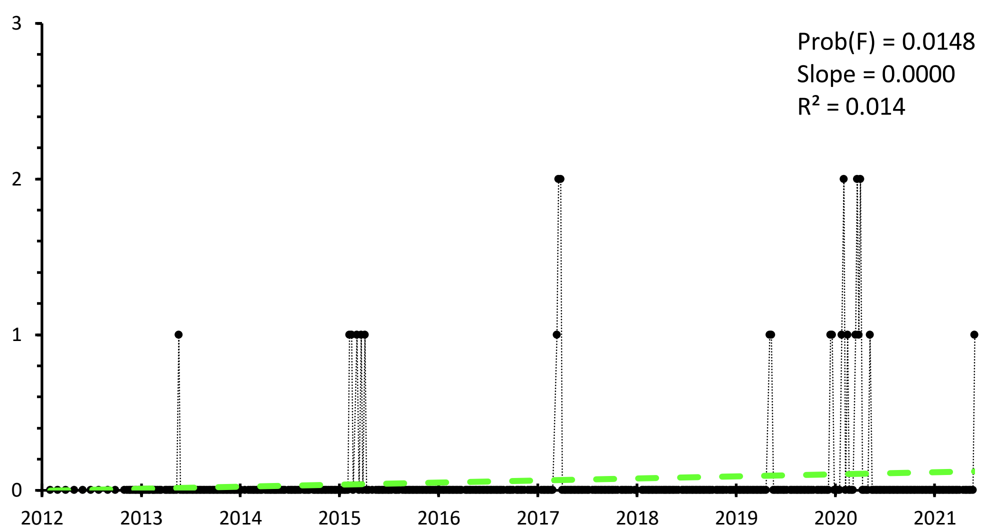

The limpkin exhibited a significant (better than 99.99% level) decreasing trend in abundance during the hydrilla invasion period that explains 42.3% of the observed variation in counts per survey.

Abundance During Hydrilla Management: 2000-2012 (counts per survey)




The limpkin exhibited no significant trend during the hydrilla management period because the mean counts per survey during this period were 0 with a range of 0 to 4.

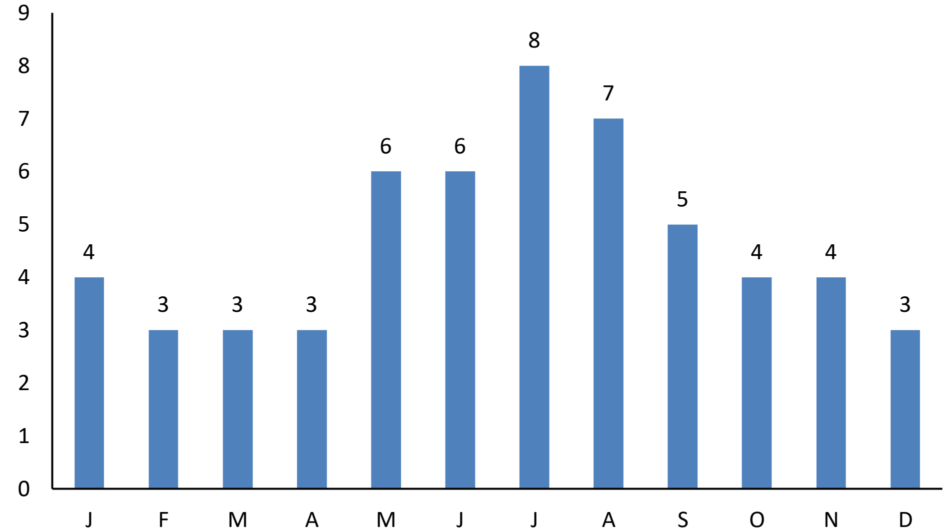
Abundance Post- Hydrilla Management: 2012-2021 (counts per survey)



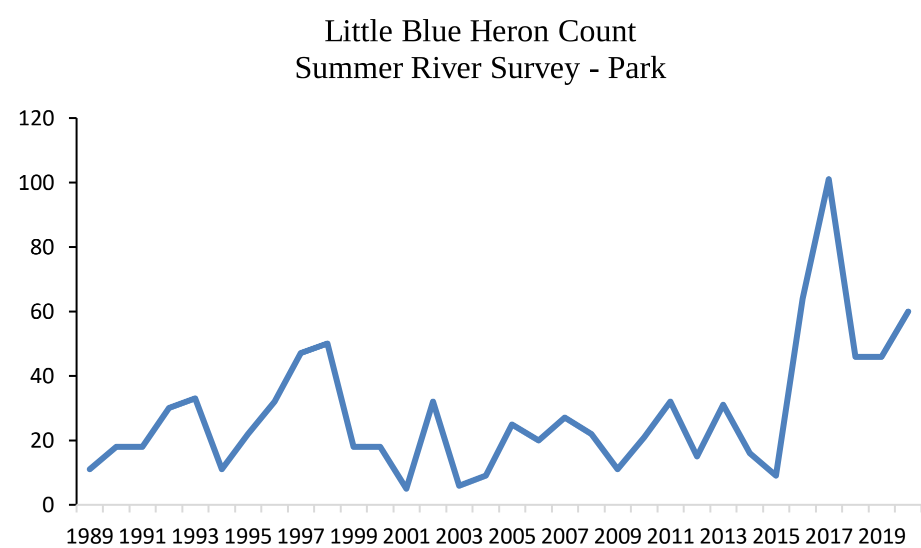

A cluster of visits in 2020 resulted in a significant (98.52% level) but very small increasing trend (slope < 0.0001) in abundance for the limpkin during the hydrilla management period that explains 1.4% of the observed variation in counts per survey.

# LITTLE BLUE HERON

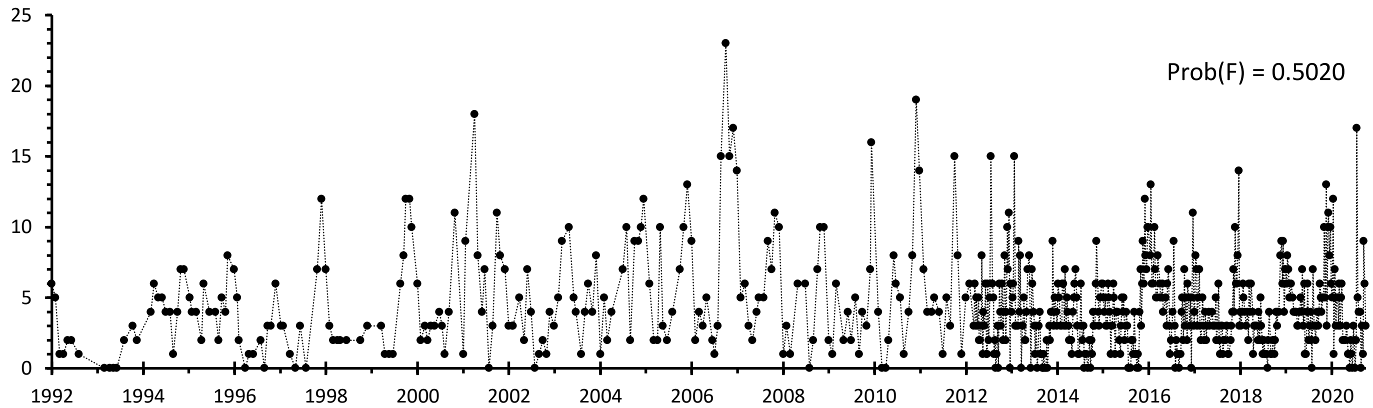
Seasonal Abundance 1992-2020 (average monthly means)




The little blue heron is a year-round resident that has bred in nesting colonies along the second mile of the upper Wakulla River periodically since 1989, as documented by the park's summer full-river wildlife surveys (see next figure). Most recently it has nested there since 2016. Lower monthly means from October through April likely reflect this species's tendency to wander after the breeding season (Kaufman, 2019a).

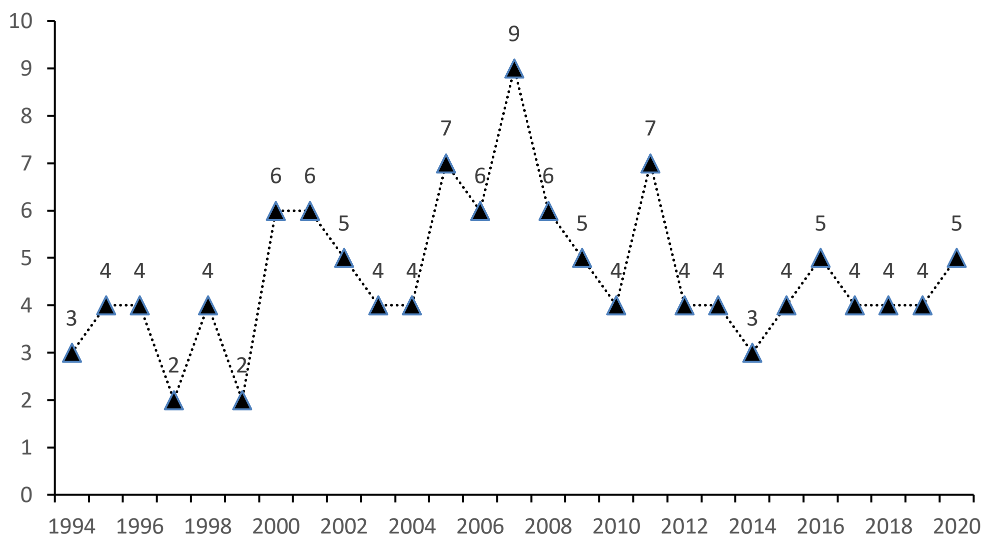


Abundance 1992-2021 (counts per survey)



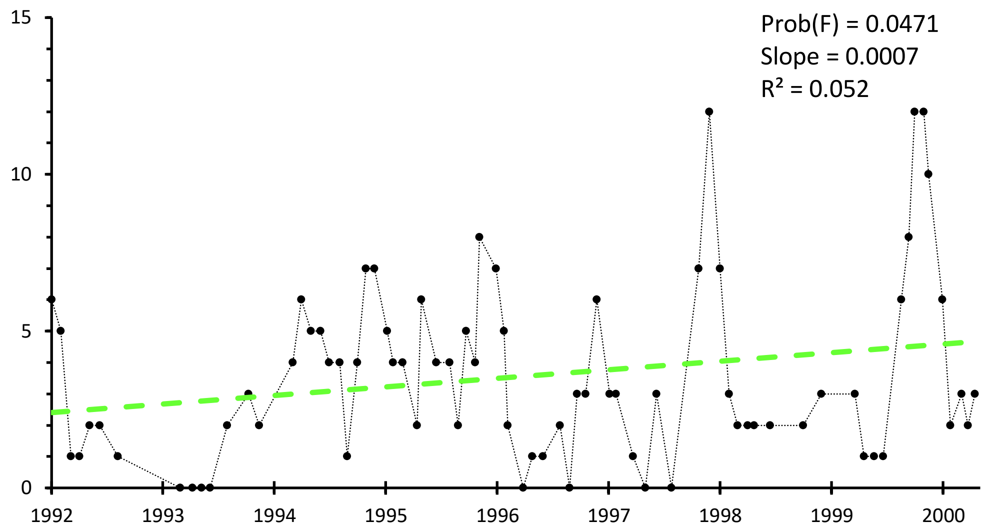

While little blue heron counts per survey during the period of record, 9/1/92 – 5/29/21, have ranged from 0 to 23, they exhibited no significant long-term trend, averaging 4.3 birds counted per survey.

Abundance 1994-2020 (annual means)



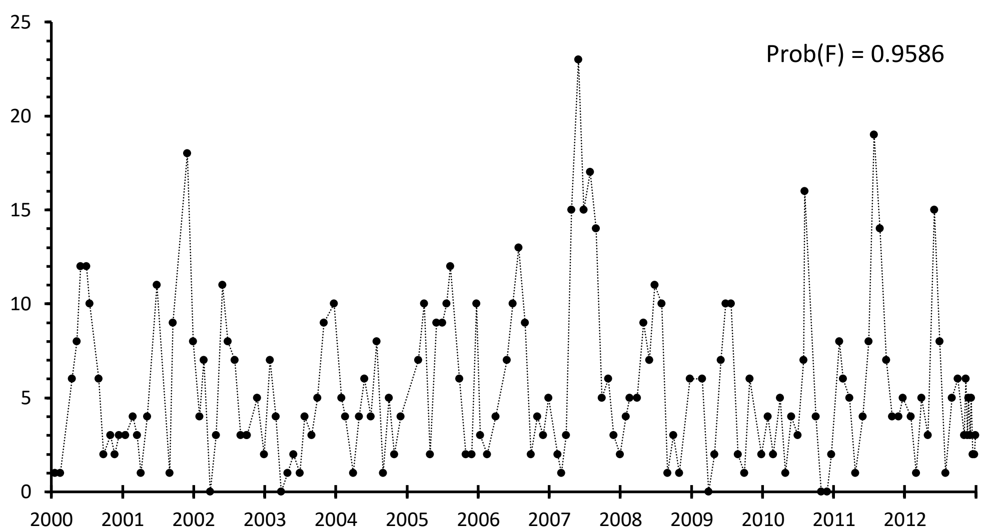

Annual mean counts per survey of the little blue heron exhibited substantial variation until recently with a peak in 2007 and a levelling off since 2012.

Abundance During Hydrilla Invasion: 1992-2000 (counts per survey)



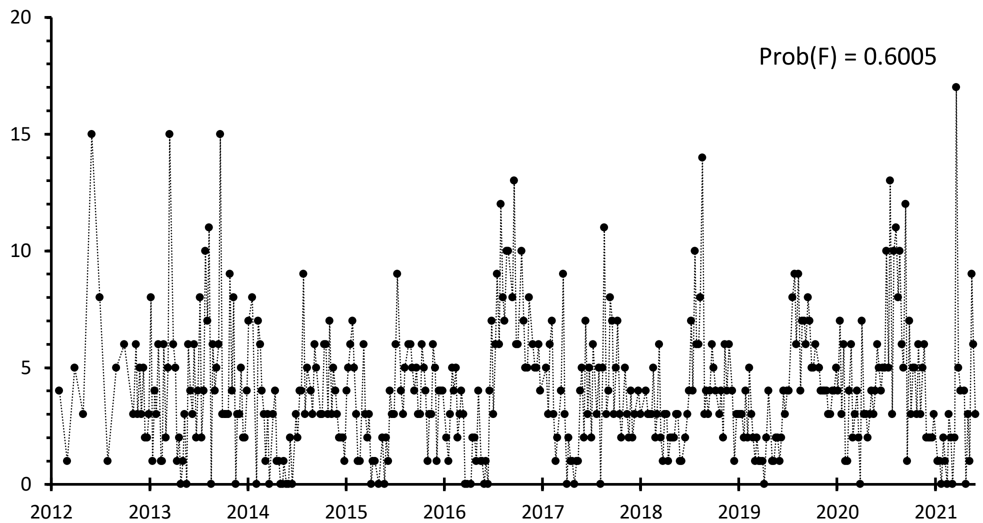

The little blue heron exhibited a significant increasing trend in abundance during the hydrilla invasion between 1992 and 2000 that explains 5.2% of the observed variation in counts per survey.

Abundance During Hydrilla Management: 2000-2012 (counts per survey)




The little blue heron exhibited no significant trend during the hydrilla management period. Counts per survey ranged from 0 to 23 with an average of 5.5.

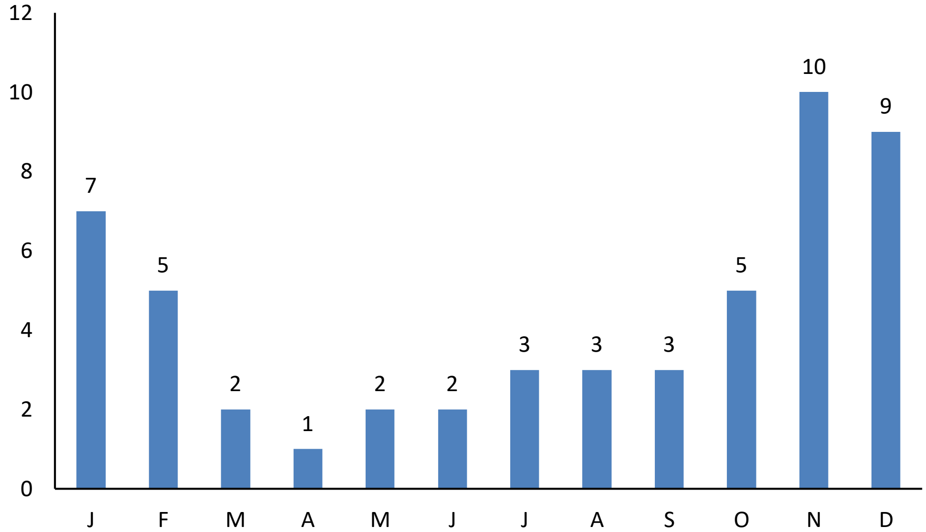
Abundance Post- Hydrilla Management: 2012-2021 (counts per survey)




The lack of a significant abundance trend for the little blue heron continued during the post-hydrilla management period with average counts per survey of 4.0 and a range of 0 to 17.

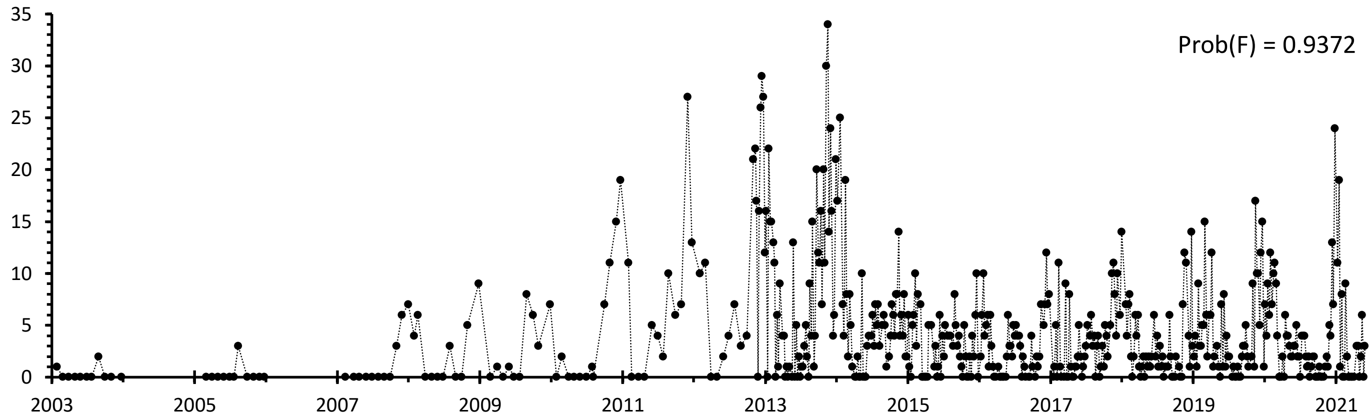
## MANATEE

Seasonal Abundance 2003-2020 (average monthly means)[10]




The manatee is a year-round resident of Wakulla Spring and the upper Wakulla River, present in higher numbers in the winter (October – February) when manatee seek thermal refuge in the 69-70° F (21 C °) spring.

Abundance 2003-2021 (counts per survey)



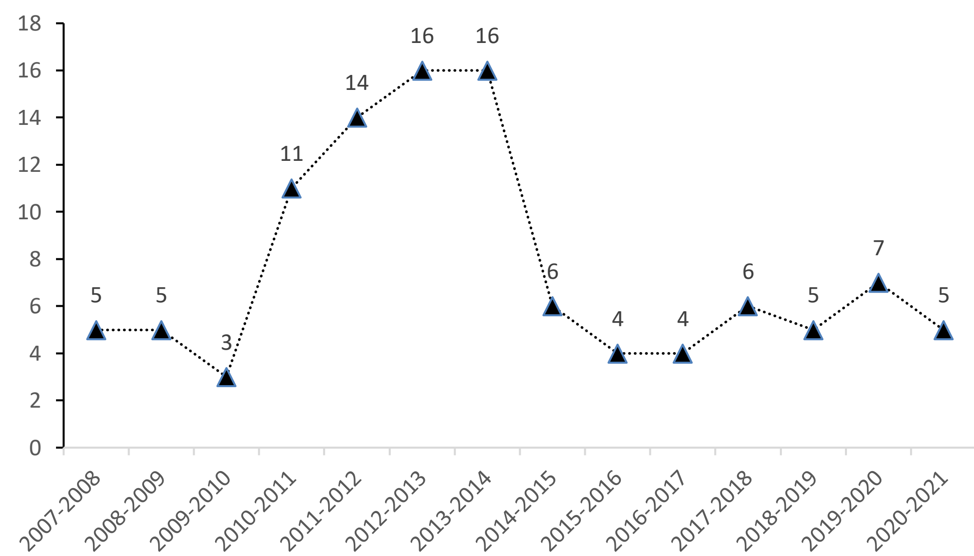

Manatee exhibited no significant long-term trend, with counts per survey ranging from 0 to 34 and averaging 4.4 animals over the shorter 18.5-year period of record, 1/27/03 – 5/29/21.

[10] Manatee were not included on the survey form until 2007. Data prior to 2007 are likely incomplete. Observations recorded in 2003 and 2005 are from the open-ended "Comments" section at the bottom of the survey form. None were recorded for 2004 or 2006.

Abundance 2003-2020 (annual means)


Manatee annual mean counts per survey gradually increased to a peak of 12 in 2012 and then declined levelling off at 3 to 4 from 2015 through 2020.

Seasonal Abundance Oct-Feb 2007-08 - 2020-21 (winter monthly means)

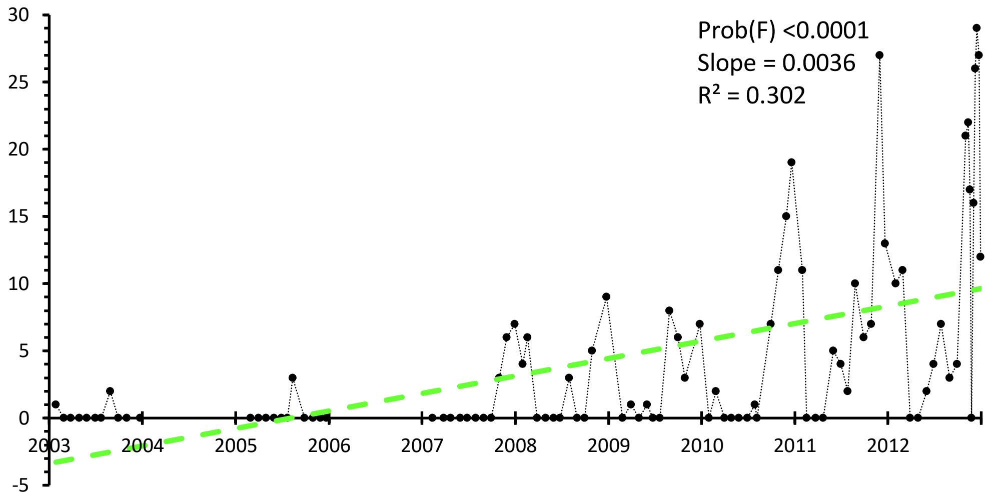



Examination of winter monthly means reveals a more gradual increase peaking in the winters of 2012-13 and 2013-14.

Abundance During Hydrilla Invasion: 1992-2000 (counts per survey)

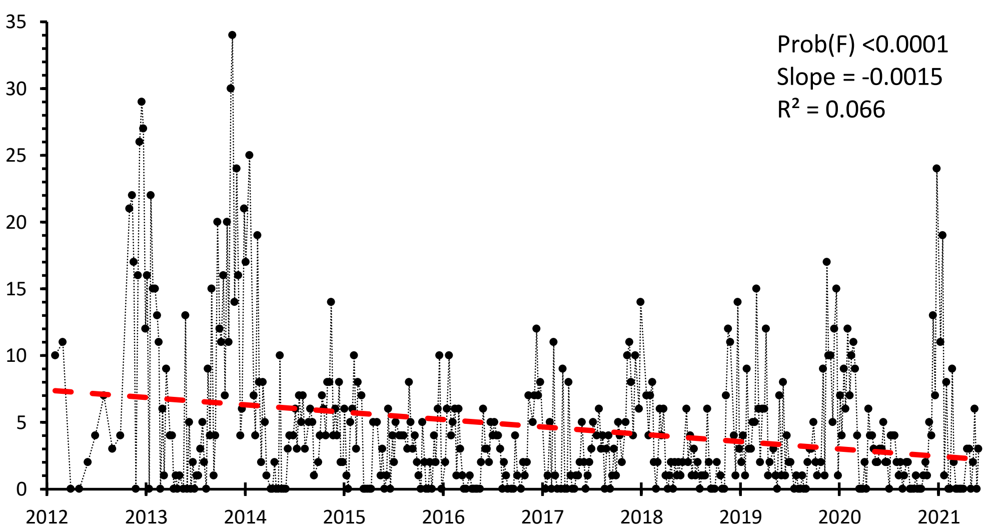
Manatee were not counted during this time.

Abundance During Hydrilla Management: 2000-2012 (counts per survey)




Manatee were not counted during the first three years of this period. They exhibited an overall significant increasing trend (better than 99.99% level) that explains 30.2% of the observed variation in counts per survey.

Abundance Post- Hydrilla Management: 2012-2021 (counts per survey)

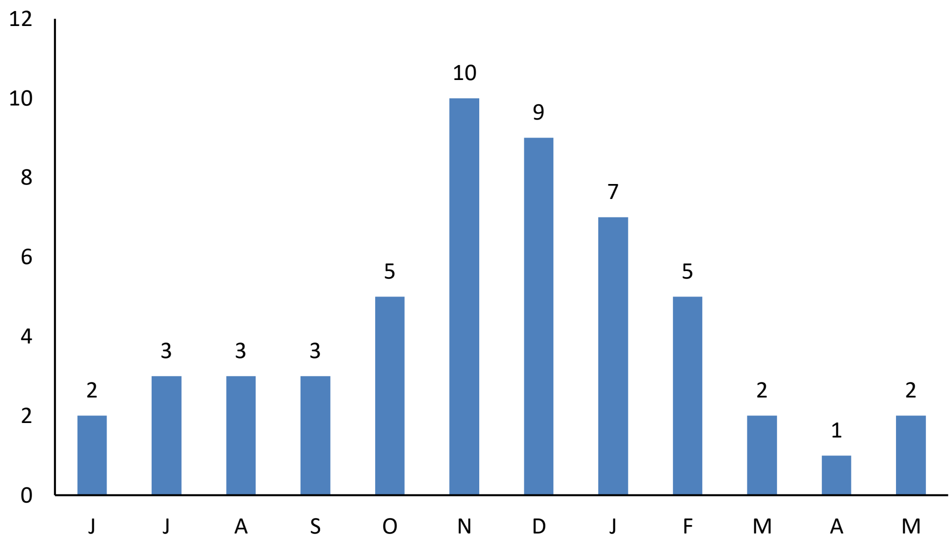



The decline in manatee abundance following the peak winters of 2012-13 and 2013-14 resulted in a significant decrease (better than 99.99% level) in abundance overall for the post-hydrilla management period with the trend explaining 6.6% in the observed variation in counts per survey.

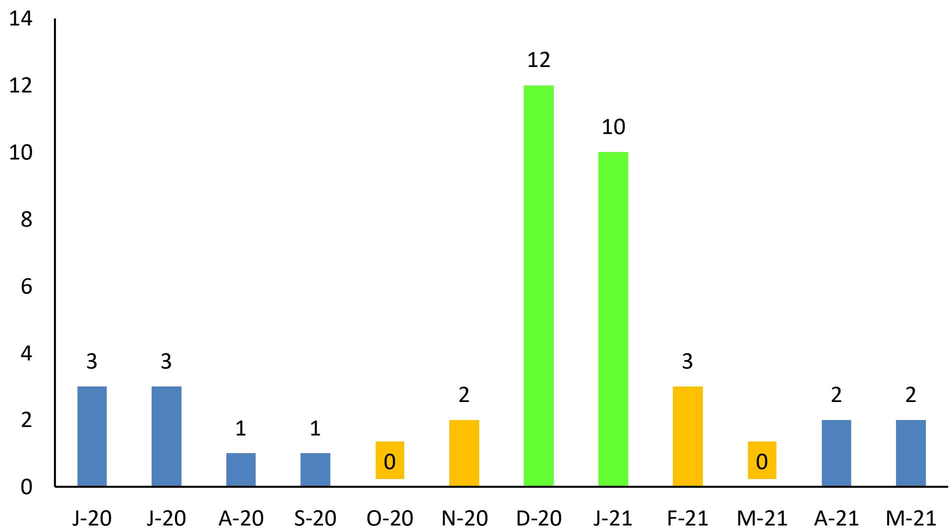
Comparison of 2020-21 and 2003-2020 Monthly Means

A seven-year peak in December 2020 followed by heavy grazing of eelgrass (*Vallisneria americana*) beds in and near the spring bowl and subsequent steep drop in February 2021 prompted a comparison of monthly means for June through May for 2020-21 with the longer-term pattern between 2003 and 2020. In the second chart, months colored orange are 2 or more counts lower in 2020-21 than 2003-20. Months colored green are two or more counts higher.

**2003-2020**

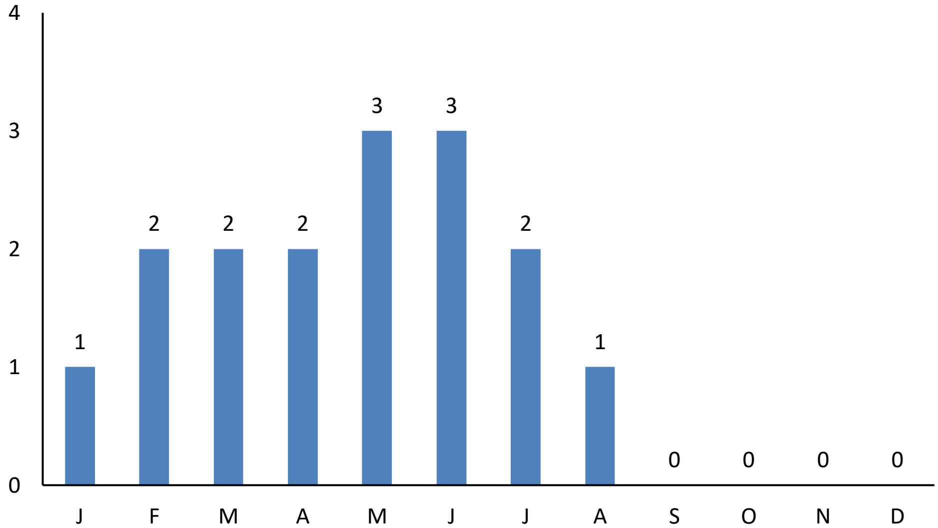



**2020-2021**



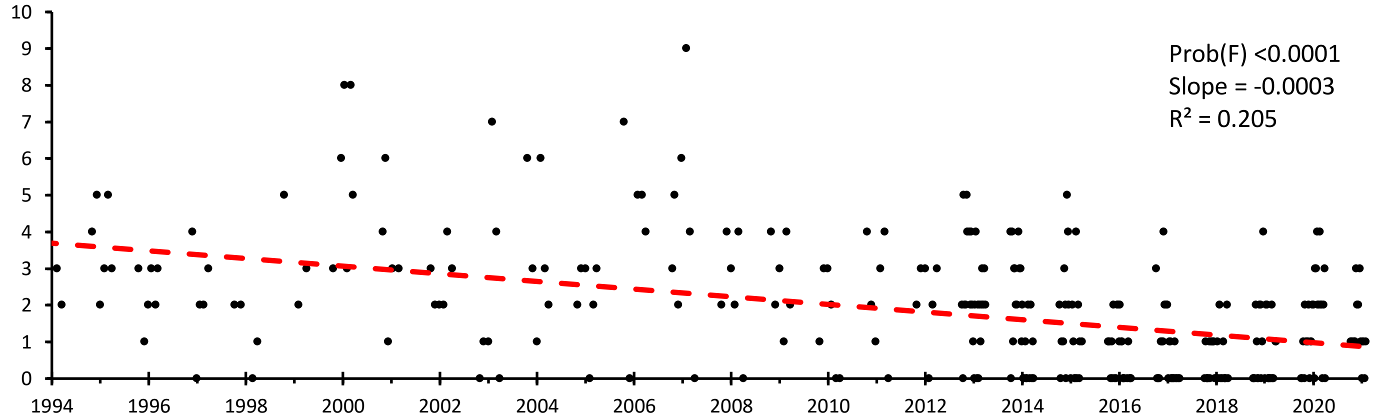
# OSPREY

Seasonal Abundance 1992-2020 (average monthly means)




The osprey is a spring-summer breeder (Feb-Jul) on the upper Wakulla River that is seen occasionally in other months of the year.

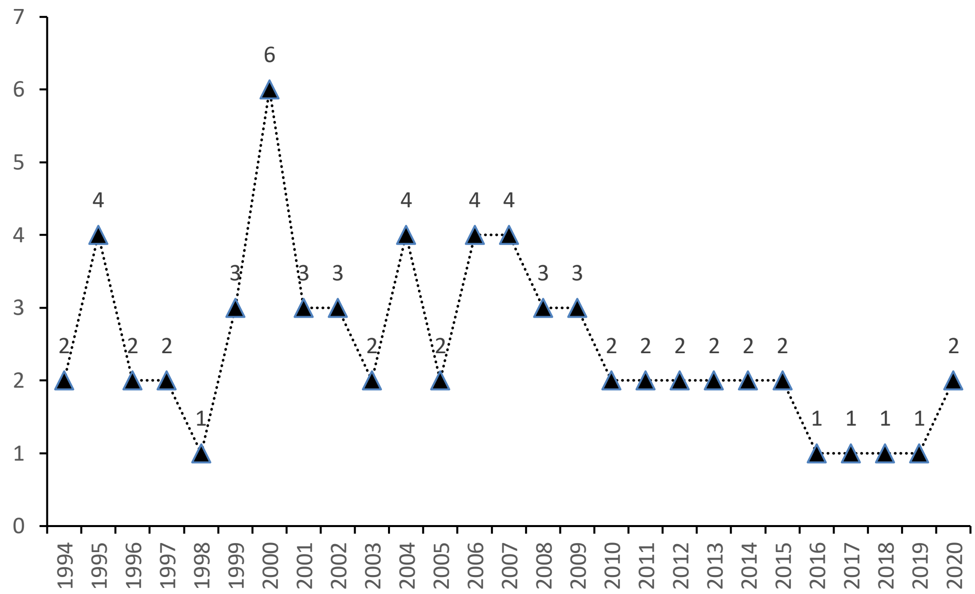
Seasonal Abundance Feb-Jul 1994 – 2021 (counts per survey)




The osprey exhibited a significant (better than 99.99% level) decreasing seasonal abundance trend of -0.0003 animals counted per day or -0.10 counts per year over the period analyzed, 2/3/94 – 5/29/21.[11] Survey date explains 20.5% of the observed variation in counts per survey.

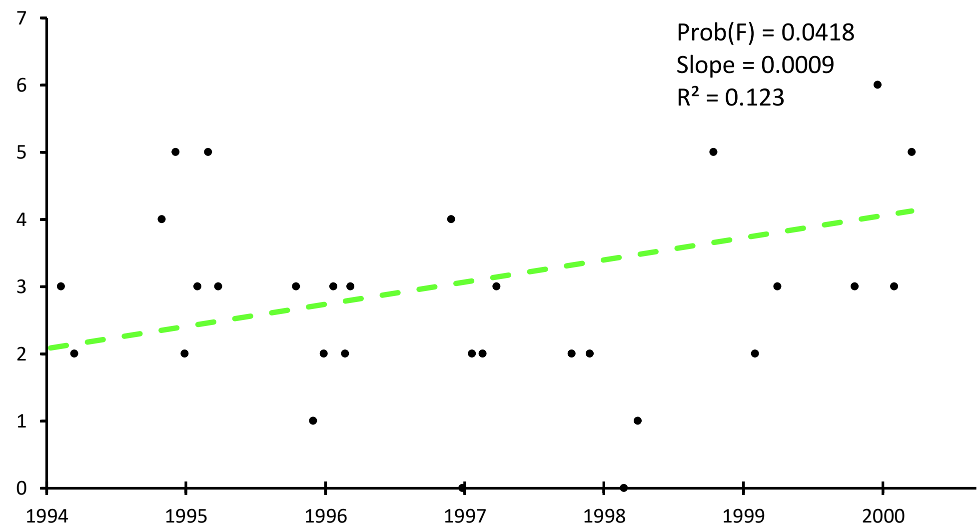
[11] The period of analysis begins 2/3/94 because of incomplete seasonal data in 1992 and 1993.

Seasonal Abundance Feb-Jul 1994-2020 (breeding season monthly means)



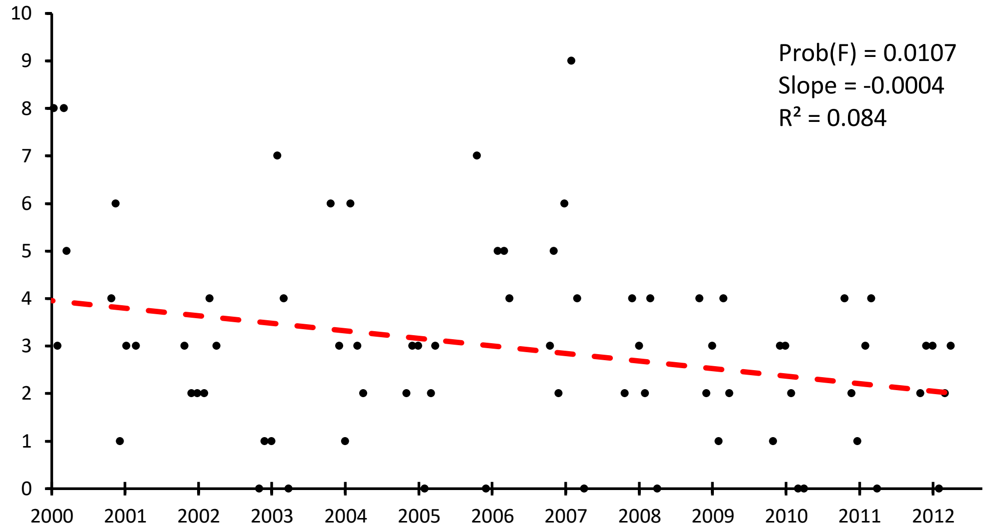

Breeding season monthly means range from 1 to 6, most likely as a function of the number of active nests which have varied from as many as 4 or 5 to none (Bob Thompson, personal communication).

Seasonal Abundance During Hydrilla Invasion: Feb-Jul 1994-2000 (counts per survey)



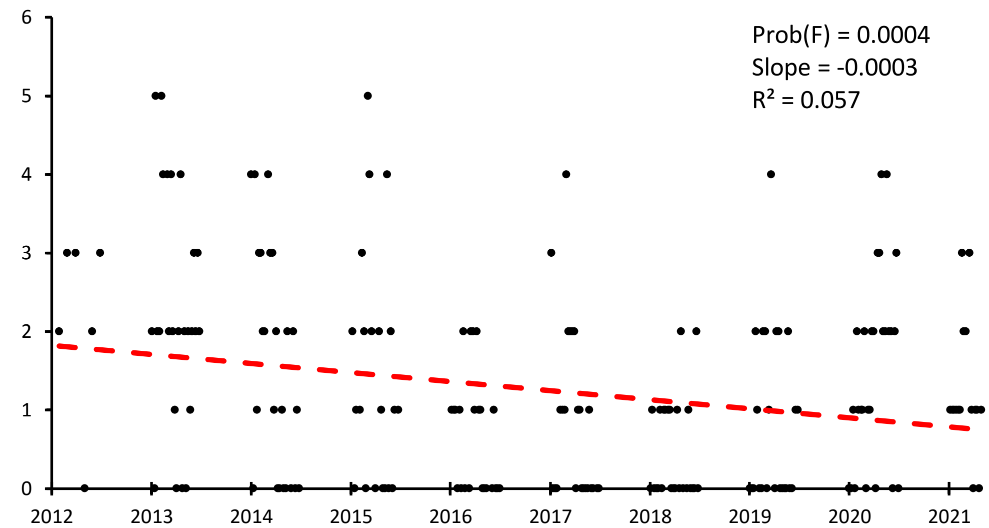

The osprey exhibited a significant increasing trend (95.82% level) in breeding season abundance from 1994 to 2000 during the hydrilla invasion period. The trend explained 12.3% of the observed variation in counts per survey.

Seasonal Abundance During Hydrilla Management: Feb-Jul 2000-2012 (counts per survey)




The osprey began its long-term decline during the hydrilla management period with a significant decreasing trend (98.93% level) that explains 8.4% of the observed variation in counts per survey.

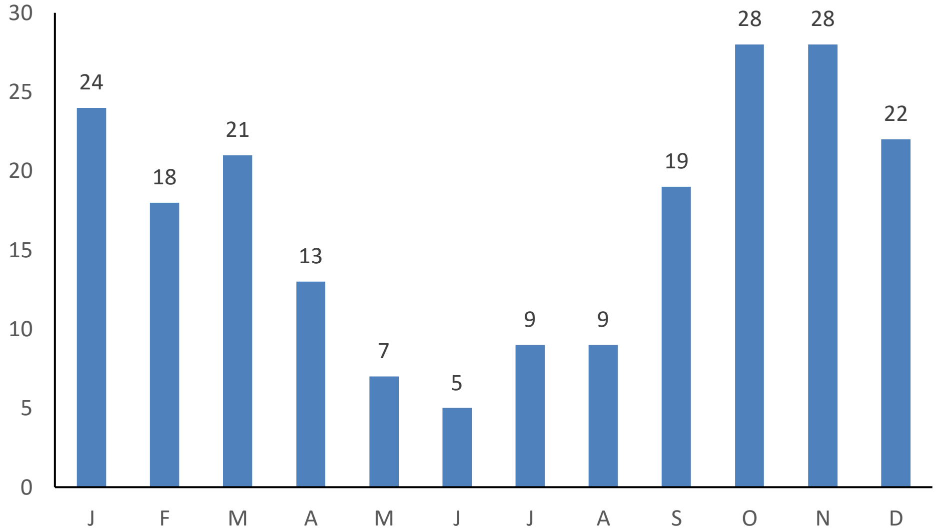
Seasonal Abundance Post- Hydrilla Management: Feb-Jul 2012-2021 (counts per survey)




A significant (99.96% level or better) trend of decreasing breeding season abundance emerged during the post-hydrilla management period that explains 5.7% of the observed variation in counts per survey.

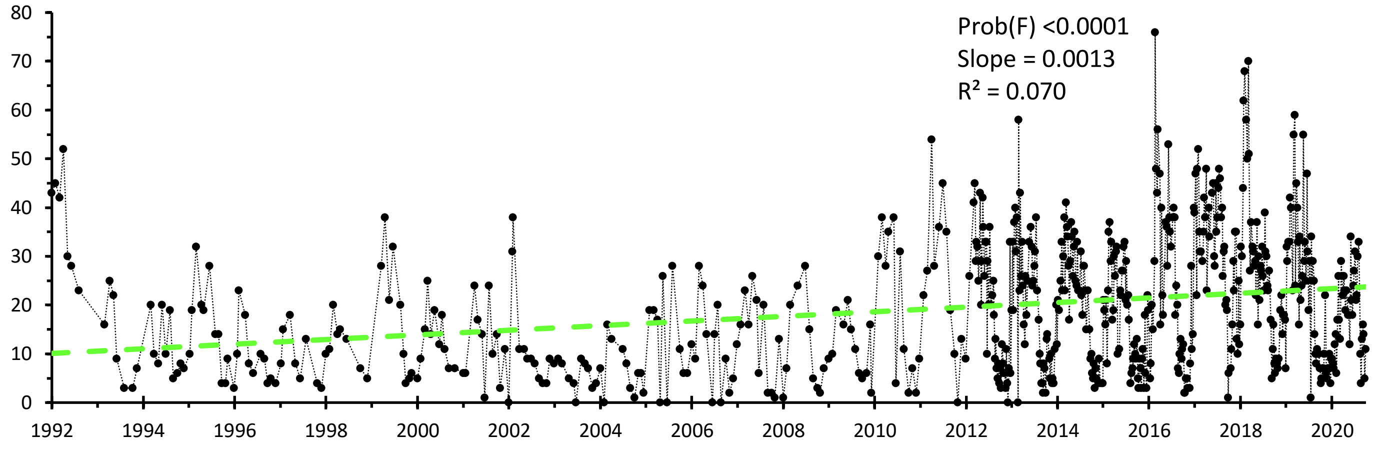
# PIED-BILLED GREBE

Seasonal Abundance 1992-2020 (average monthly means)



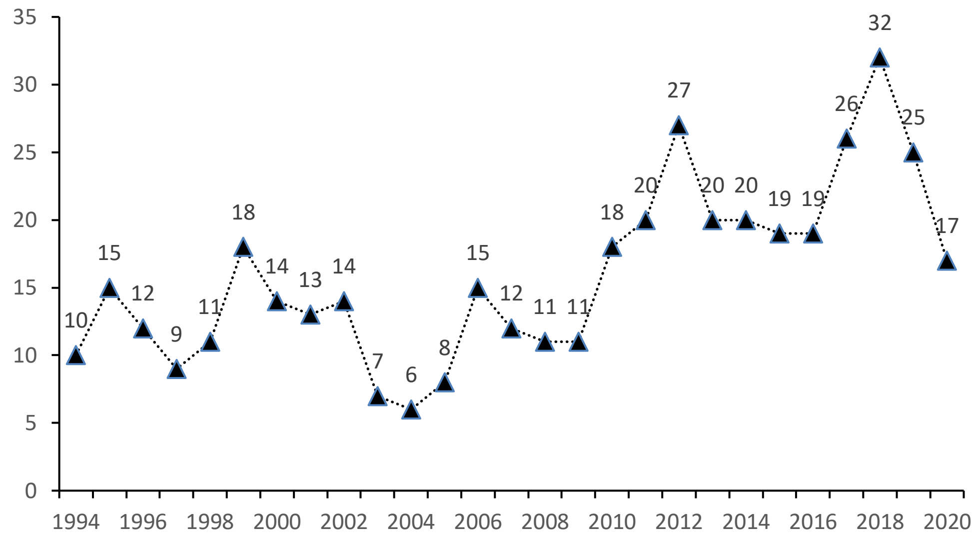

The pied-billed grebe is a year-round breeding resident whose numbers are augmented by winter migrants from September through March (Muller Storer, 1999).

Abundance 1992-2021 (counts per survey)



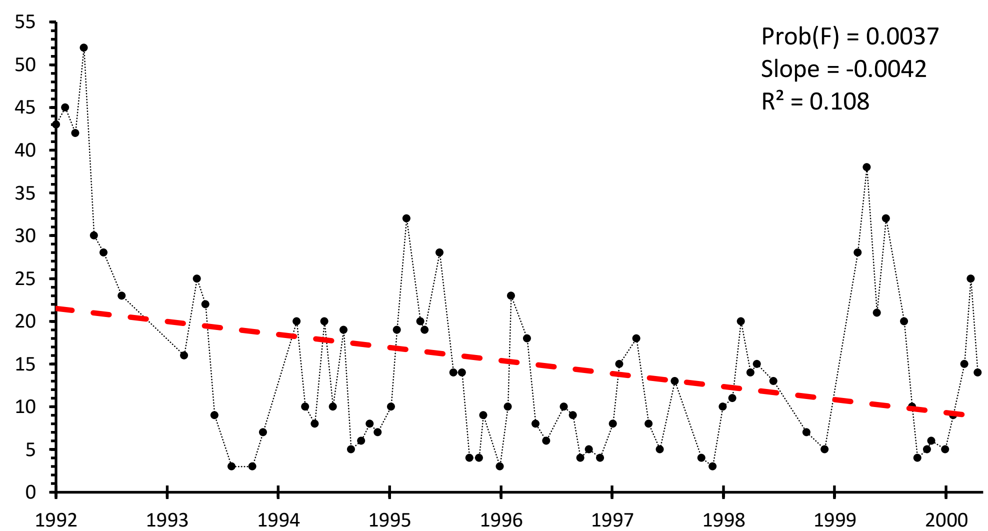

The pied-billed grebe exhibited a significant (better than 99.99% level) increasing trend of 0.0013 animals counted per day or 0.47 counts per year over the period of record, 9/1/92 – 5/29/21. Survey date explains 7.0% of the observed variation in counts per survey.

Abundance 1994-2020 (annual means)



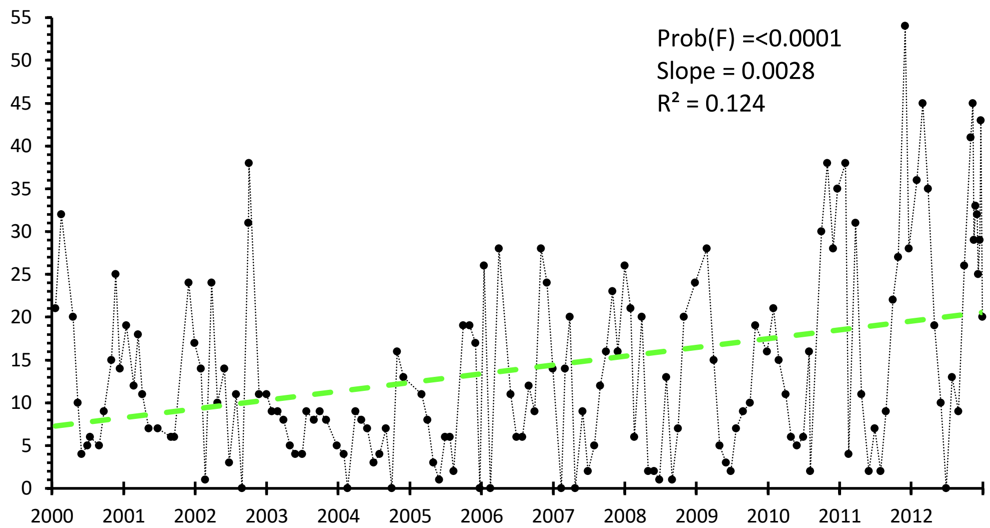

Annual mean counts per survey of the pied-billed grebe also suggest a long-term increase with several ups and downs including a decline beginning in 2000 that continued to 2004 during the hydrilla management period and a recent decline after 2018.

Abundance During Hydrilla Invasion: 1992-2000 (counts per survey)



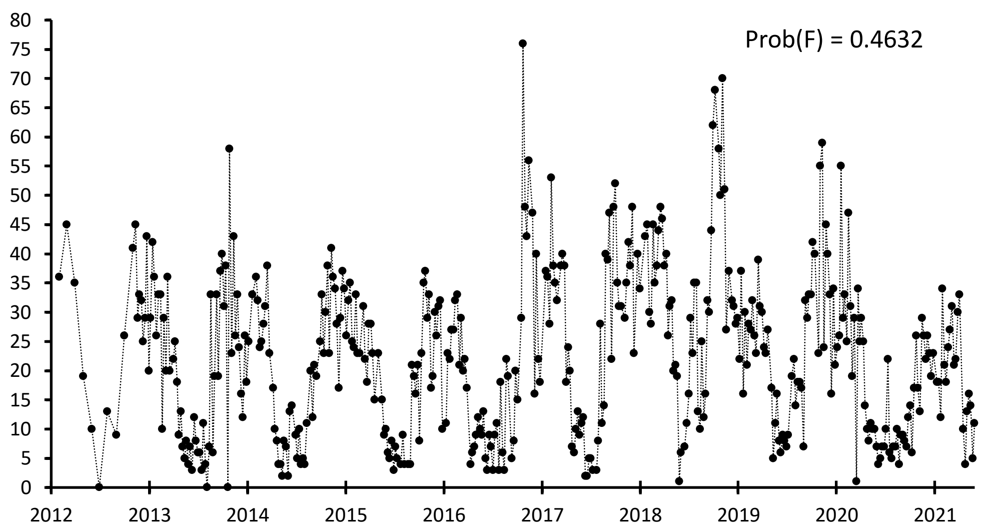

Despite its long-term trend of increasing abundance, the pied-billed grebe experienced a significant decreasing trend (99.63% level) during the hydrilla invasion that explains 10.8 % of the observed variation in counts per survey.

Abundance During Hydrilla Management: 2000-2012 (counts per survey)




Pied-billed grebe abundance turned around during the hydrilla management period exhibiting a significant increase (better than 99.99% level) that explains 12.4% of the observed variation in counts per survey.

Abundance Post- Hydrilla Management: 2012-2021 (counts per survey)




The pied-billed grebe had exhibited a significant increasing abundance trend continued during the post-hydrilla management period through 2018. However, lower counts in 2020 and 2021 have rendered the trend no longer statistically significant.

Multivariate Analysis of Recent Trend

As for other birds, pied-billed grebes are less likely to be influenced by air temperature or sunshine/cloudiness than reptiles. River stage may, however, affect how many are observed: pied-billed grebes build floating nests where the water is at least nine inches deep (The Cornell Lab of Ornithology, 2021). Thus, if water levels are lower, nests may be built closer to the edge of emergent marshes along the riverbanks and adults and chicks may be observed more often. Data collected by the Northwest Florida Water Management District at its gauge at the Ways (aka boat tram) indicate that the upper Wakulla River stage has experienced a long-term declining trend since the early 2000s.

The trend (date) for the post-hydrilla management period remains insignificant in a multivariate regression model for this somewhat shorter period that includes river stage, air temperature, and sunshine.[12]

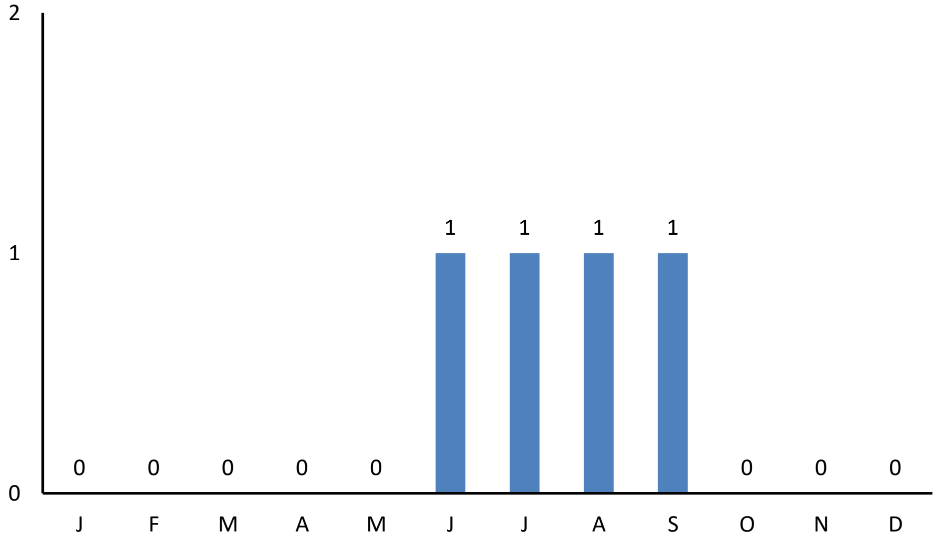
| | test stat | p-value |
|---|---|---|
| F-test | 29.607 | < 0.0001 |
| Adjusted R-squared | 0.224 | |
| Date | 0.001 | 0.2782 |
| River stage | -1.598 | 0.1994 |
| Air temperature | -0.527 | < 0.0001 |
| Sunshine | 1.704 | 0.2185 |

Nonetheless, the model explains 22.4 percent of the observed variation in counts per survey and is significant at better than the 99.99 percent level. As for the common gallinule, river stage is the only significant explanatory variable and has the expected negative sign: more pied-billed grebes are observed when the stage is lower. Also as is the case for the common gallinule, air temperature is not significant at the 95 percent level or better in the multivariate model, but when tested alone it is negative and significant (Prob(F) < 0.0001; adjusted R-squared = 0.220), likely reflecting the influx of winter migrants which results in higher counts in cooler months.

[12] Sunshine was coded as a dummy/categorical variable based on cloud cover categories included on the survey form: coded 1 for "clear" and "some clouds"; coded 0 for "fog," "overcast,' and "rain."

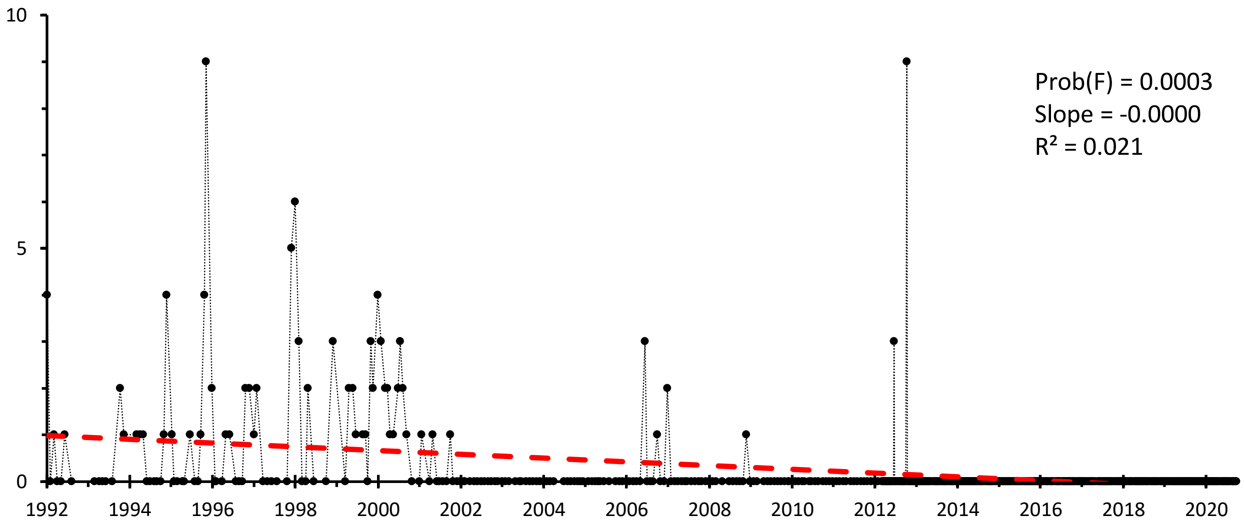
## PURPLE GALLINULE

Seasonal Abundance 1992-2021 (average monthly means)



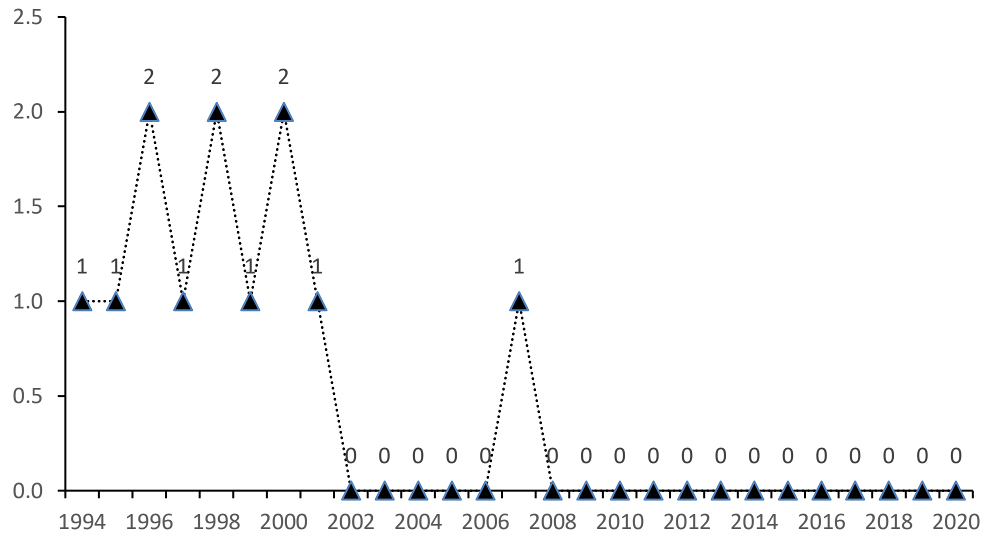

The purple gallinule is uncommon on the upper Wakulla River, most often seen during summer months of June through September. Monthly means range from 0 to 1.

Abundance 1992-2021 (counts per survey)



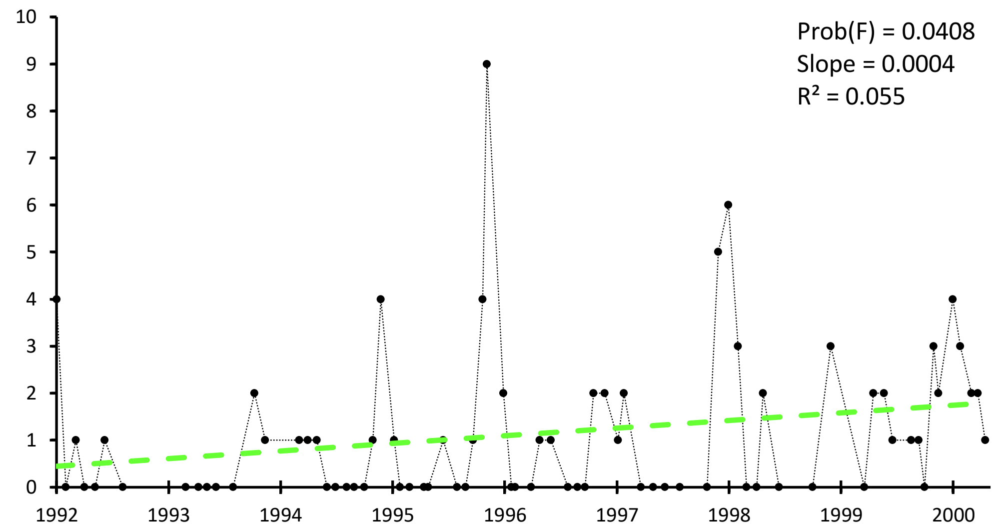

The purple gallinule exhibited a significant (99.97% level) but very slowly decreasing trend of -0.0001 animals counted per day or -0.03 counts per year over the period of record, 9/1/92 – 5/29/21. Survey date explains 2.1% of the observed variation in counts per survey. The historically low numbers coupled with very sporadic low counts since 2002 account for the small slope and low $R^2$.

Abundance 1994-2020 (annual means)



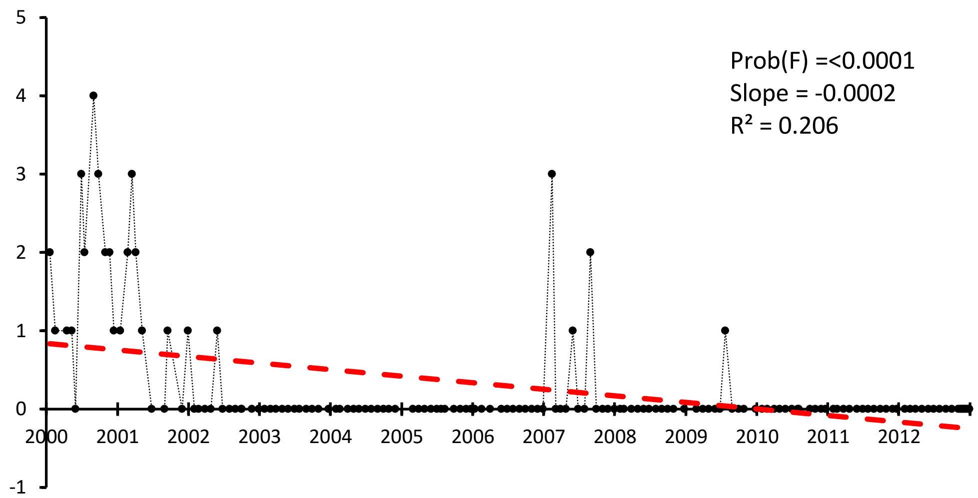

Annual mean counts per survey of the purple gallinule are very low ranging from 0 to 2. Nonetheless they suggest a dramatic decline in 2002 after which the species has been virtually absent.

Abundance During Hydrilla Invasion: 1992-2000 (counts per survey)



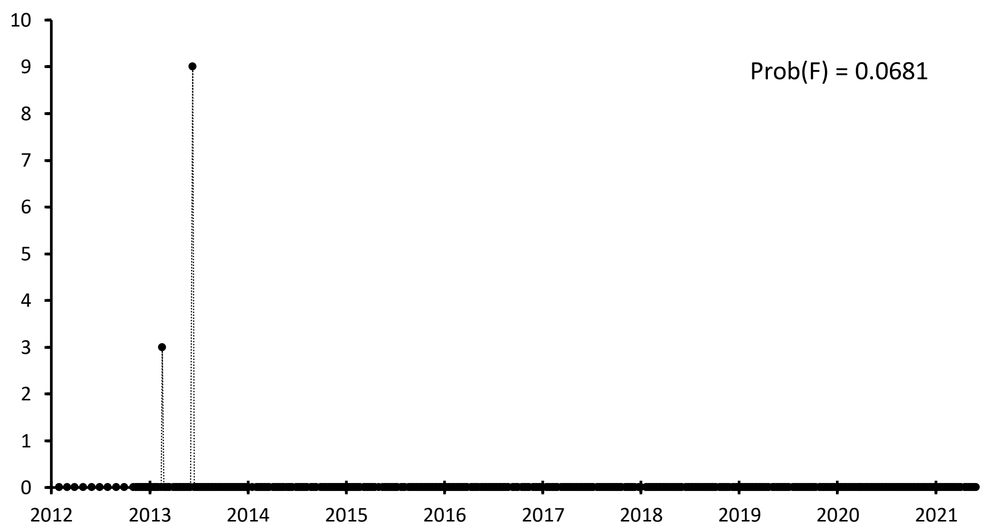

Despite its long-term trend of decreasing abundance, the purple gallinule experienced a significant increasing trend (95.92% level) during the hydrilla invasion that explains 5.5 % of the observed variation in counts per survey. While the hydrilla mat likely provided suitable habitat, the increases began before the mat became established.

Abandance During Hydrilla Management: 2000-2012 (counts per survey)




Purple gallinule abundance turned around during the hydrilla management period exhibiting a significant decrease (better than 99.99% level) that explains 20.6% of the observed variation in counts per survey.

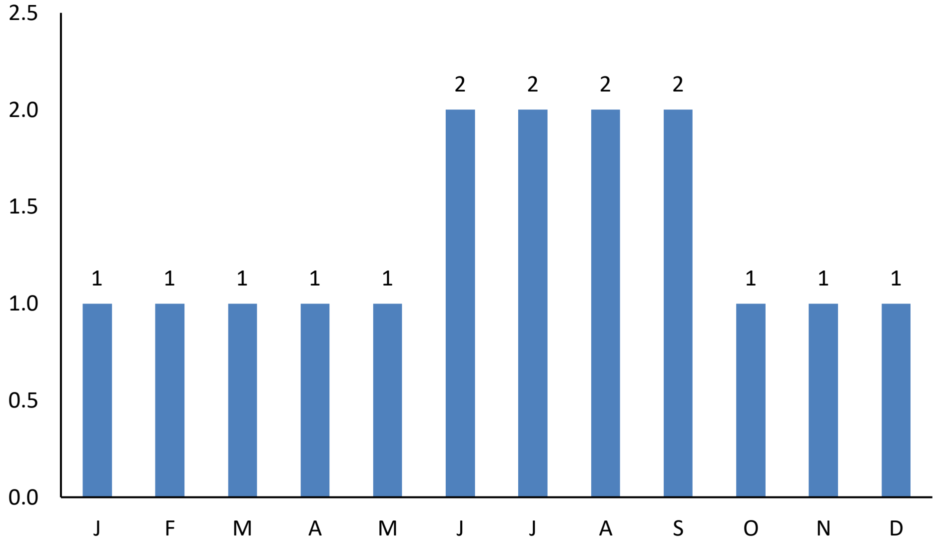
Abundance Post- Hydrilla Management: 2012-2021 (counts per survey)




The purple gallinule was virtually gone by the onset of the post-hydrilla management period with sightings during only two surveys in 2013. There was not, therefore, a significant abundance trend during this period.

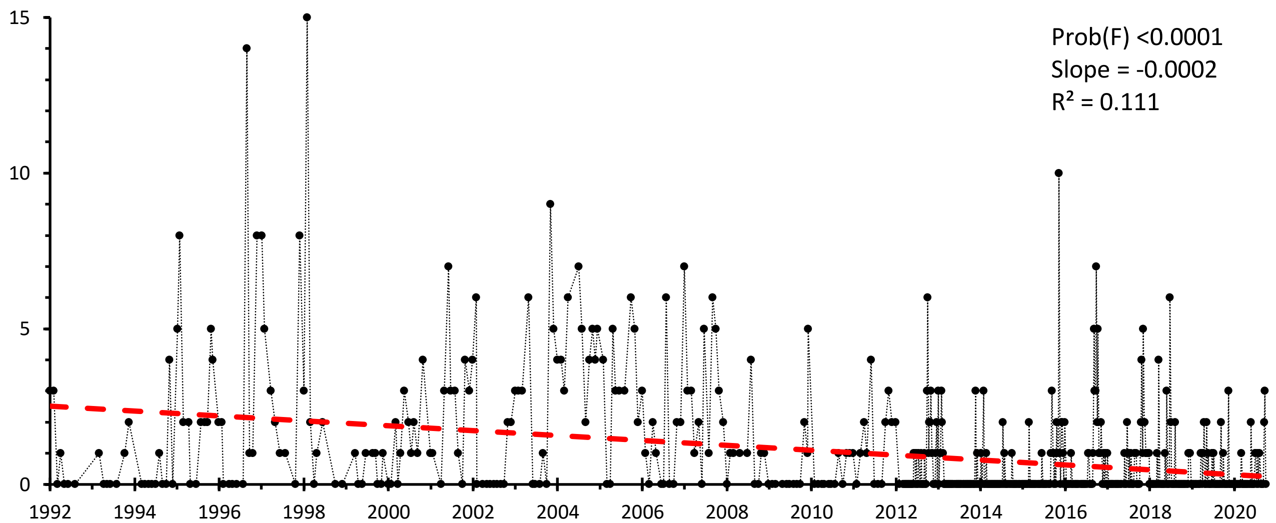
## SNOWY EGRET

Seasonal Abundance 1992-2020 (average monthly means)



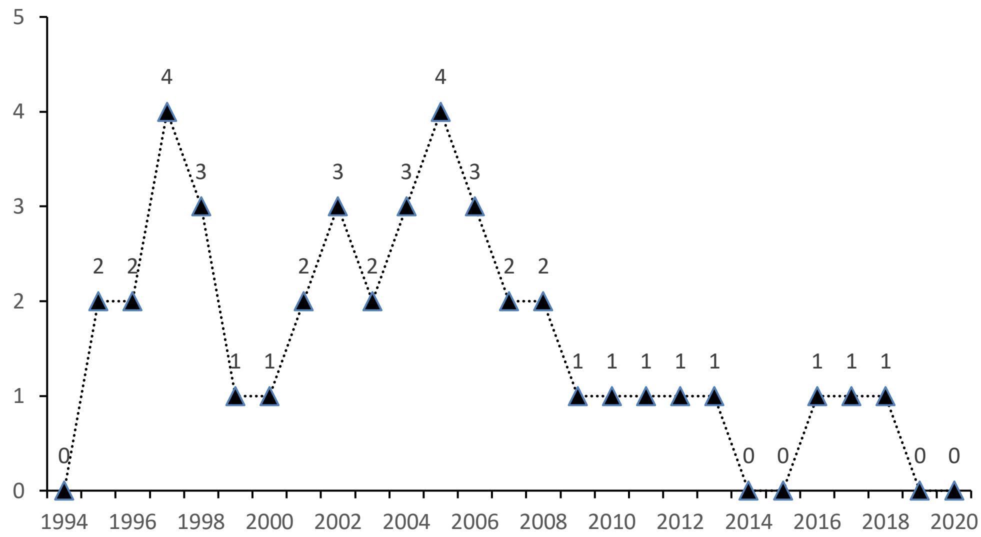

The snowy egret occurs in small numbers on the upper Wakulla River. It is somewhat more common during the summer months of June through September. Monthly means range from 1 to 2.

Abundance 1992-2021 (counts per survey)



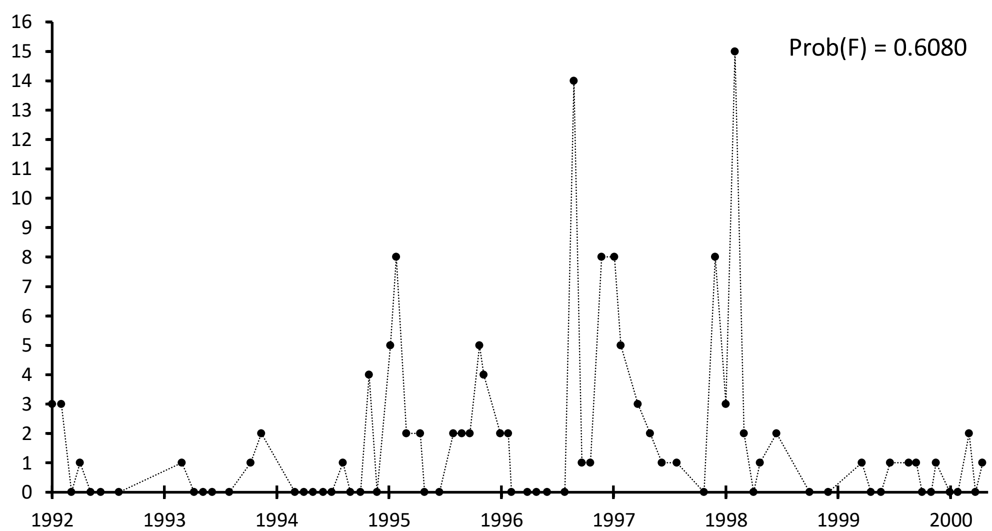

The snowy exhibited a significant (better than 99.99% level) but very slowly decreasing trend of -0.0002 animals counted per day or -0.08 counts per year over the period of record, 9/1/92 – 5/29/21. Survey date explains 11.1% of the observed variation in counts per survey.

Abundance 1994-2020 (annual means)



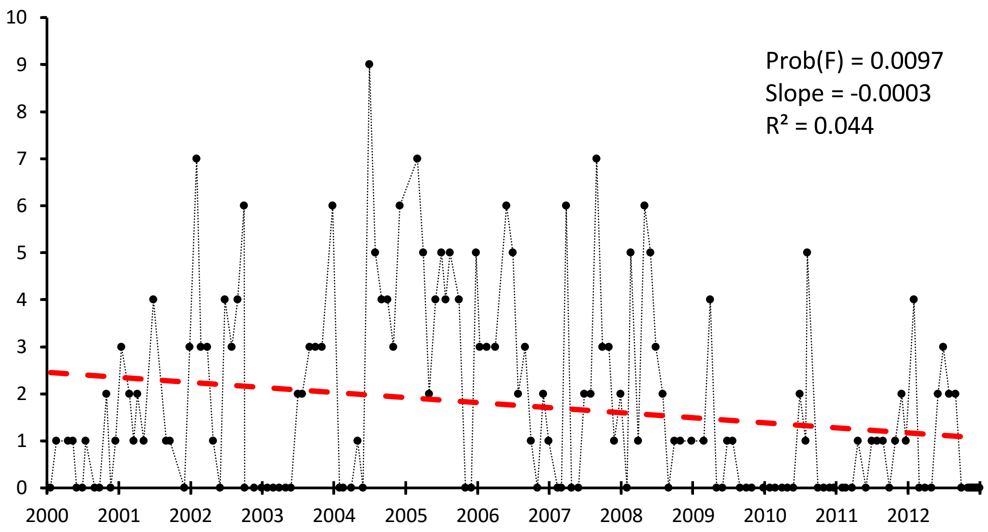

Annual mean counts per survey of the snowy egret are quite variable ranging from 0 to 4 with multiple peaks and valleys that do not appear to be directly related to any of the ecosystem perturbations on the upper Wakulla River.

Abundance During Hydrilla Invasion: 1992-2000 (counts per survey)



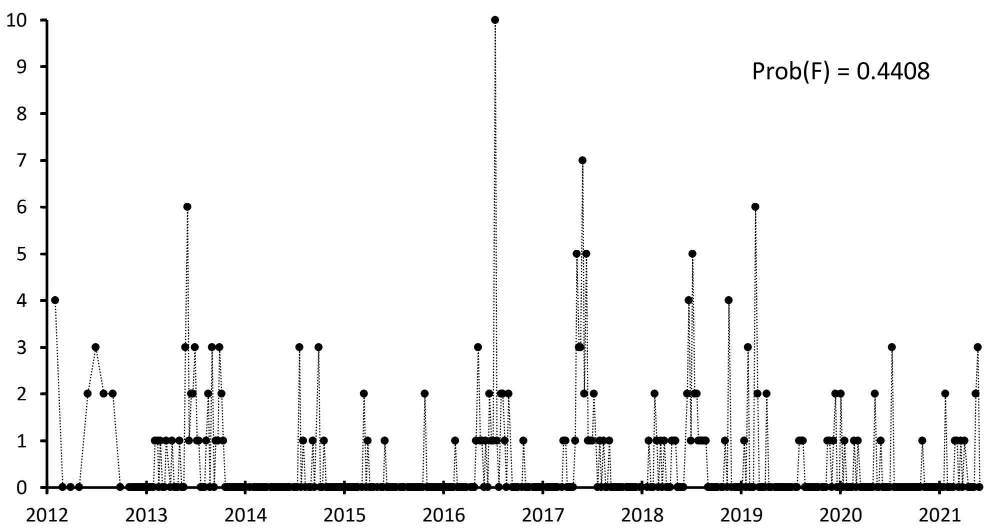

The snowy egret exhibited no significant trend in abundance during the hydrilla invasion with counts per survey ranging from 0 to 15 and an average of 2.

Abundance During Hydrilla Management: 2000-2012 (counts per survey)




Snowy egrets exhibited a significant (99.03% level) decreasing trend of abundance during the hydrilla management period that explains 4.4% of the observed variation in counts per survey.

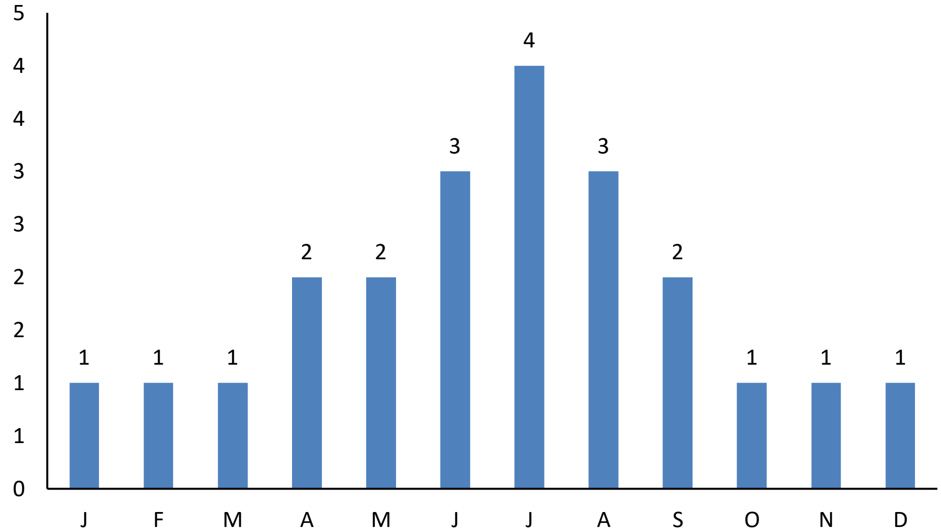
Abundance Post- Hydrilla Management: 2012-2021 (counts per survey)




The snowy egret exhibited no significant abundance trend during the post-hydrilla management period with counts ranging from 0 to 10 and an average of 0.50.

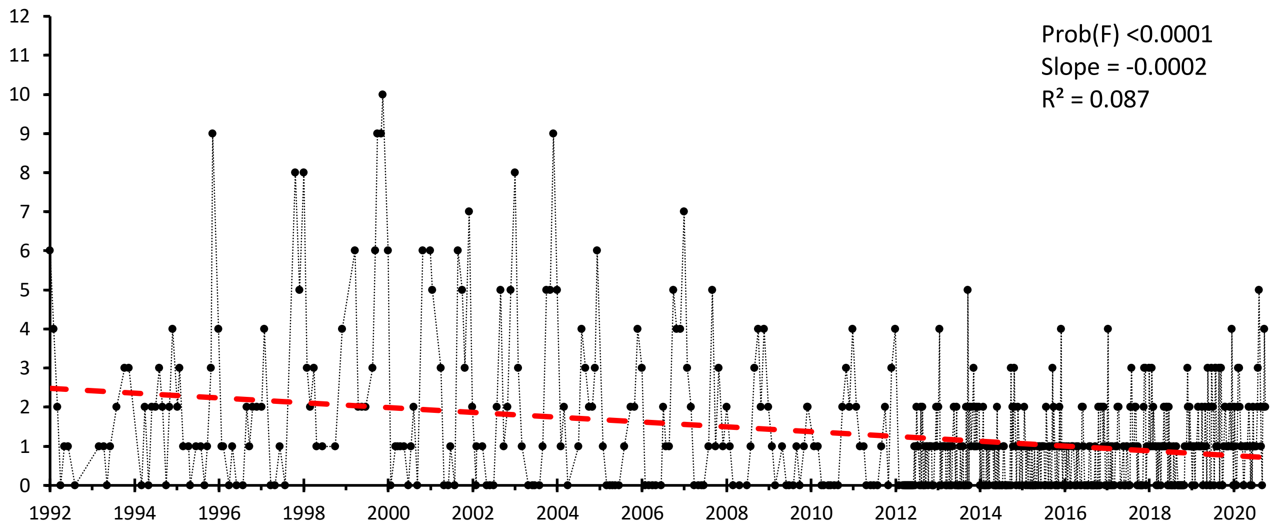
## TRICOLORED HERON

Seasonal Abundance 1992-2020 (average monthly means)



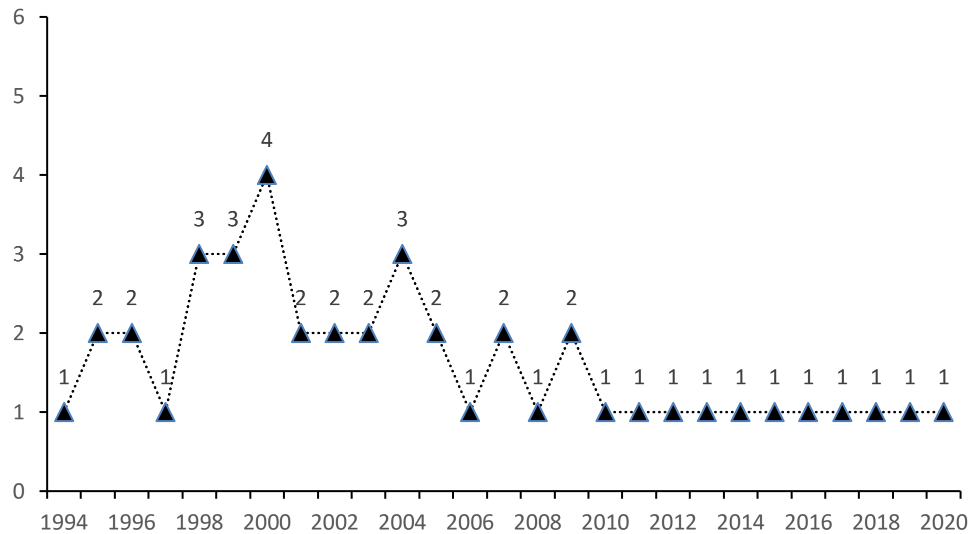

The tricolored heron also occurs in relatively small numbers on the upper Wakulla River and is somewhat more common during the summer months of June through August. Monthly means range from 1 to 4.

Abundance 1992-2021 (counts per survey)



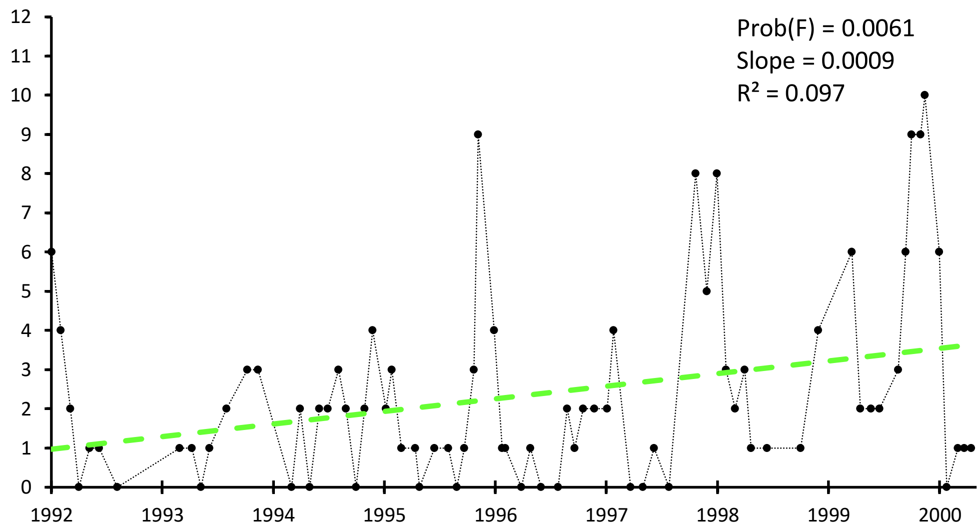

The tricolored heron exhibited a significant (better than 99.99% level) but very slowly decreasing trend of -0.0002 animals counted per day or -0.08 counts per year over the period of record, 9/1/92 – 5/29/21. Survey date explains 8.7% of the observed variation in counts per survey.

Abundance 1994-2020 (annual means)



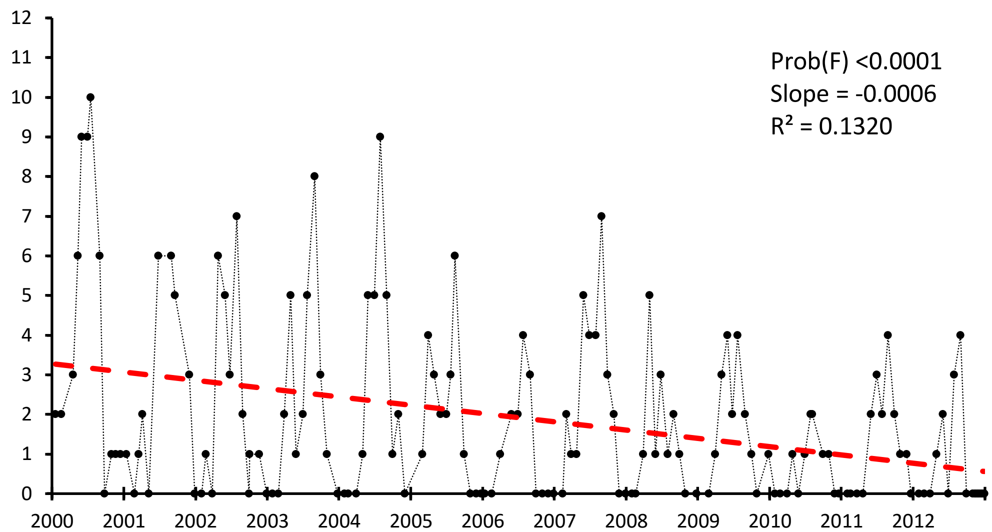

Annual mean counts per survey of the tricolored heron are quite variable from 1994 to 2005 after which there is a general decline flattening out to a mean annual count of 1 from 2010 through 2020.

Abundance During Hydrilla Invasion: 1992-2000 (counts per survey)



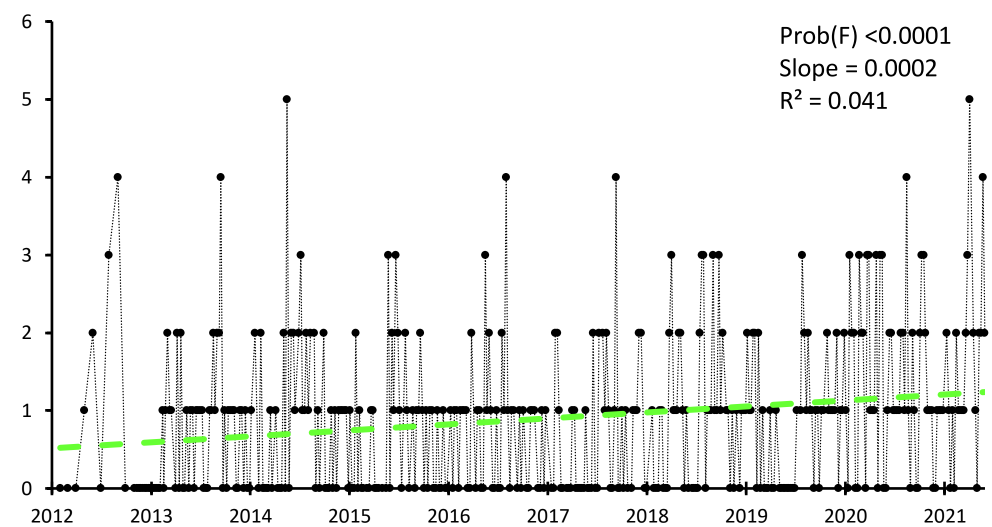

The tricolored heron exhibited a significant trend (99.39%) of increasing abundance during the hydrilla invasion that explains 9.7% of the observed variation in counts per survey.

Abundance During Hydrilla Management: 2000-2012 (counts per survey)




The tricolored heron's decline in abundance began during the hydrilla management period with a significant trend (better than 99.99% level) that explains 13.2% of the observed variation in counts per survey.

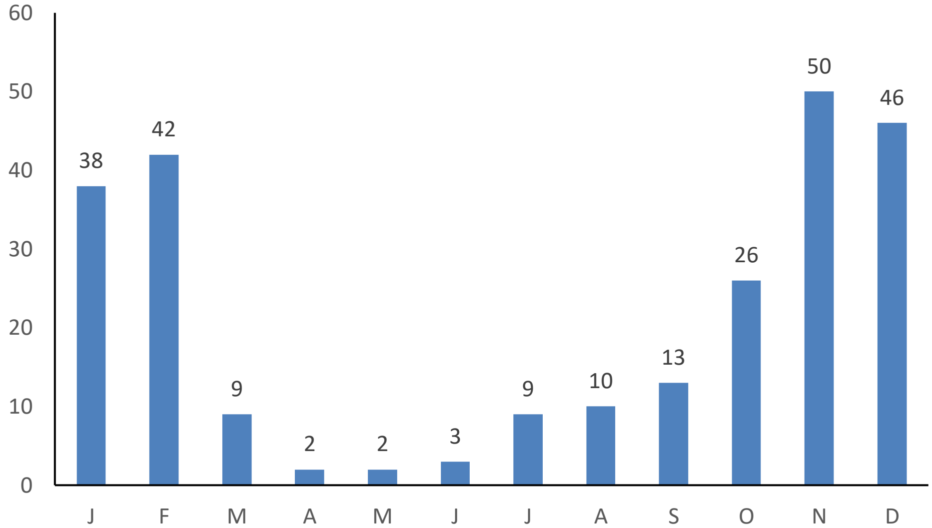
Abundance Post- Hydrilla Management: 2012-2020 (counts per survey)




What had been no significant abundance trend for the tricolored heron during the post-hydrilla management period is now significantly positive due to some higher counts in 2020 and 2021. However, the slope is slight at 0.0002 animals counted per day.

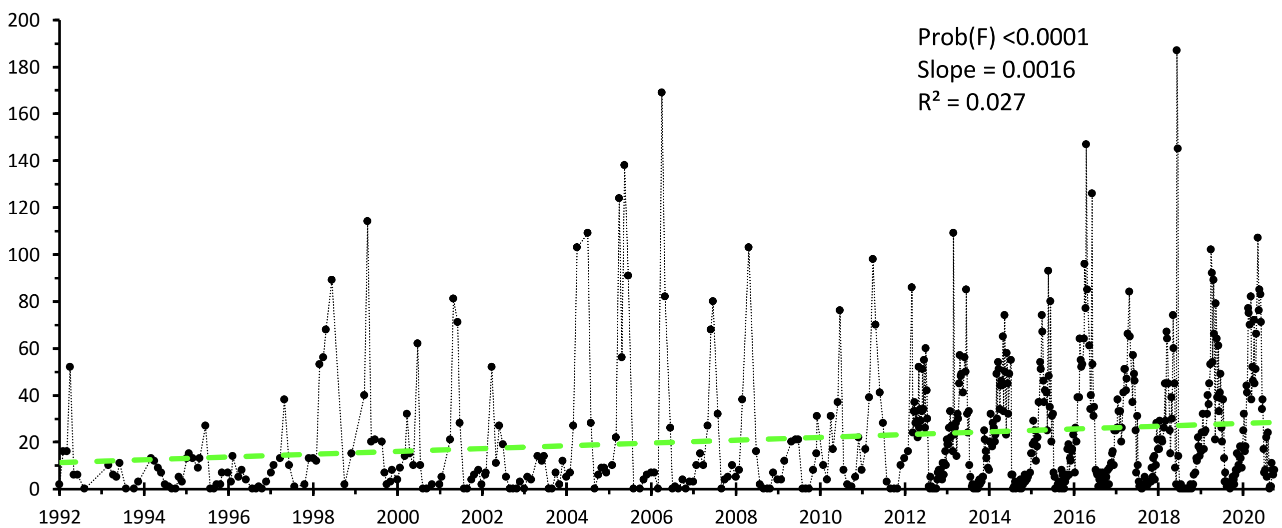
## WHITE IBIS

Seasonal Abundance 1992-2020 (average monthly means)



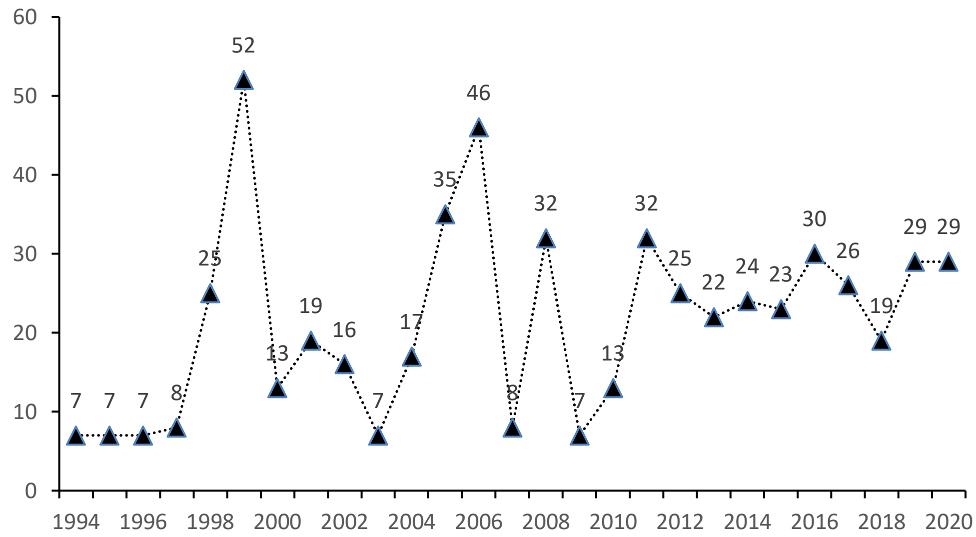

The white ibis does not breed on the upper Wakulla River. However, adults congregate there outside the breeding season beginning in July. Late spring and early summer populations comprise primarily juveniles (personal observation).

Abundance 1992-2021 (counts per survey)



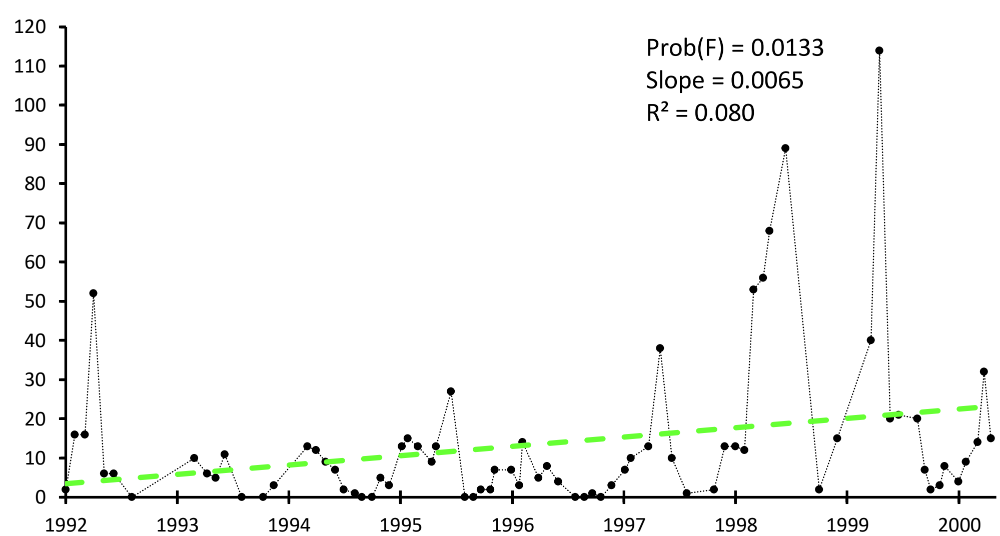

White ibis exhibited a significant (better than 99.99% level) increasing abundance trend of 0.0016 animals counted per day or 0.60 counts per year over the period of record, 9/1/92 – 5/29/21. Survey date explains 2.7% of the observed variation in counts per survey.

Abundance 1994-2020 (annual means)



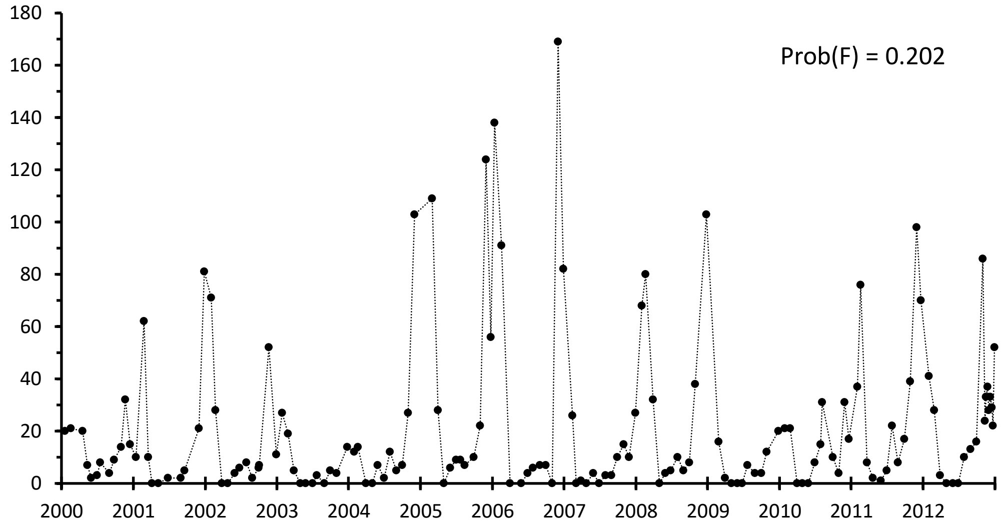

Annual mean counts per survey of the white ibis vary substantially with high peaks and deep valleys, particularly between 1997 and 2011. The trend has been more stable since then.

Abundance During Hydrilla Invasion: 1992-2000 (counts per survey)



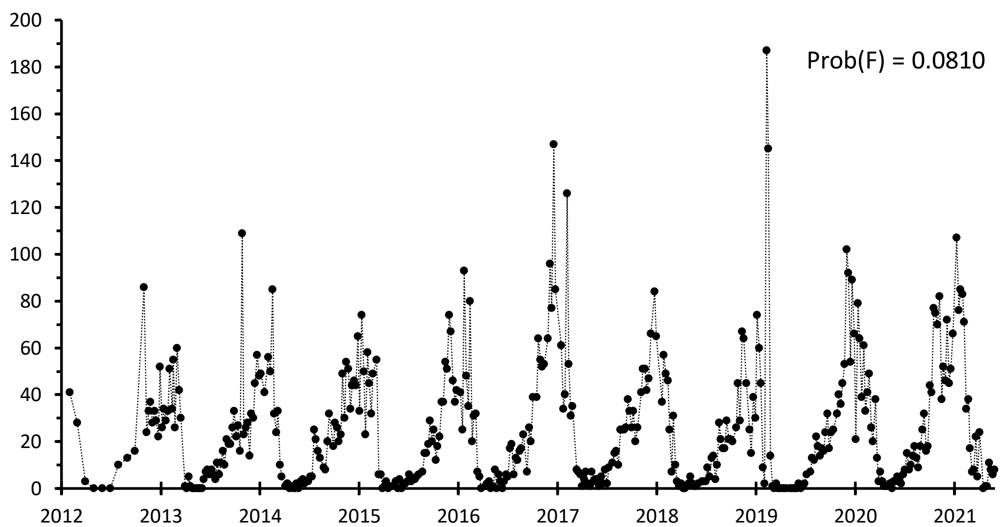

The white ibis exhibited a significant trend (98.67%) of increasing abundance during the hydrilla invasion that explains 8.0% of the observed variation in counts per survey.

Abundance During Hydrilla Management: 2000-2012 (counts per survey)




The white ibis exhibited no significant trend in abundance during the hydrilla management period. Counts per survey ranged from 0 to 169 with an average of 21.

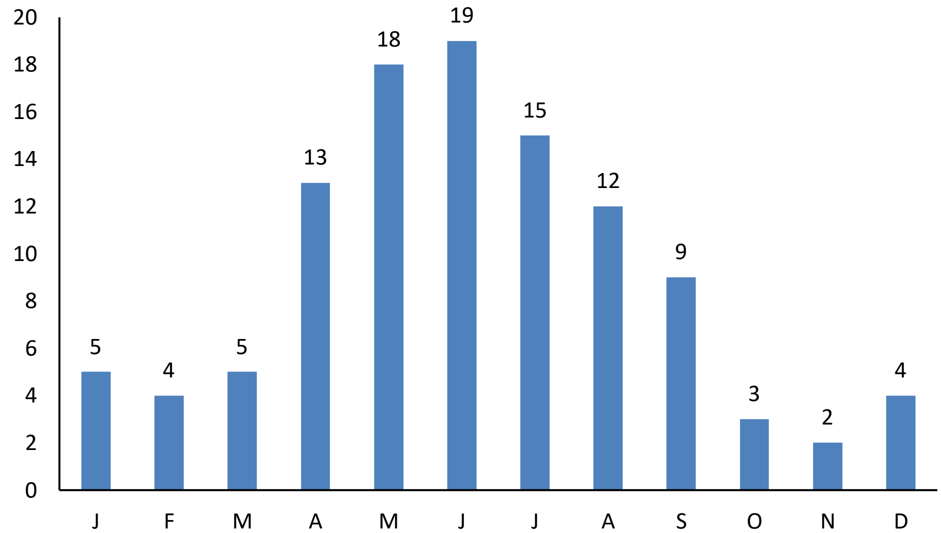
Abundance Post- Hydrilla Management: 2012-2020 (counts per survey)




No significant abundance trend occurred during the post-hydrilla management period either. Counts per survey ranged from 0 to 187 with an average of 25.49. The seasonal abundance pattern is evident in these denser data.

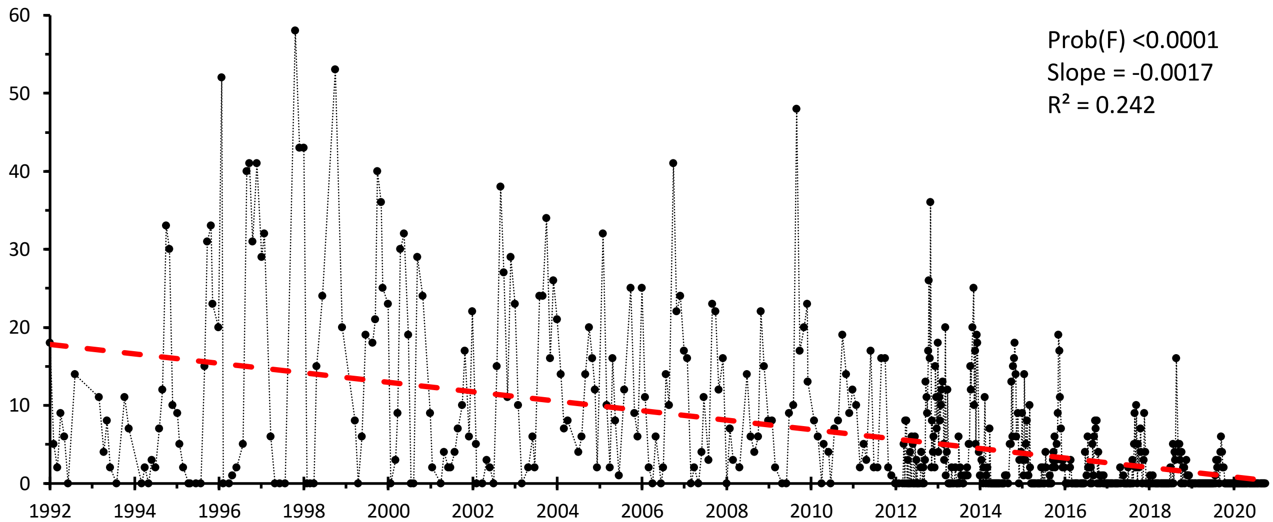
# WOOD DUCK

Seasonal Abundance 1992-2020 (average monthly means)



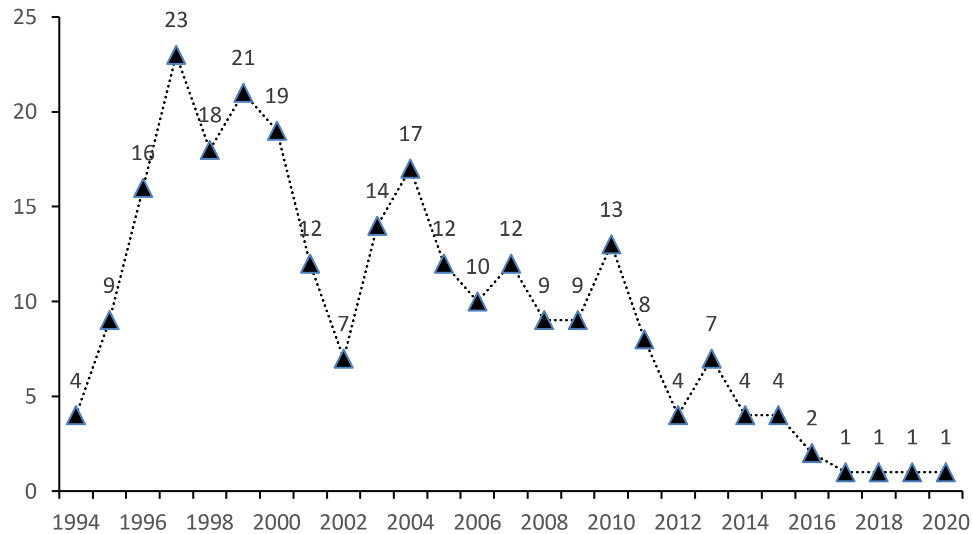

The wood duck is a year-round breeding resident that may have two broods per year. Females are permanent residents while males are not (Kaufman, 2019b), which may account in part for lower numbers outside the summer breeding season.

Abundance 1992-2021 (counts per survey)



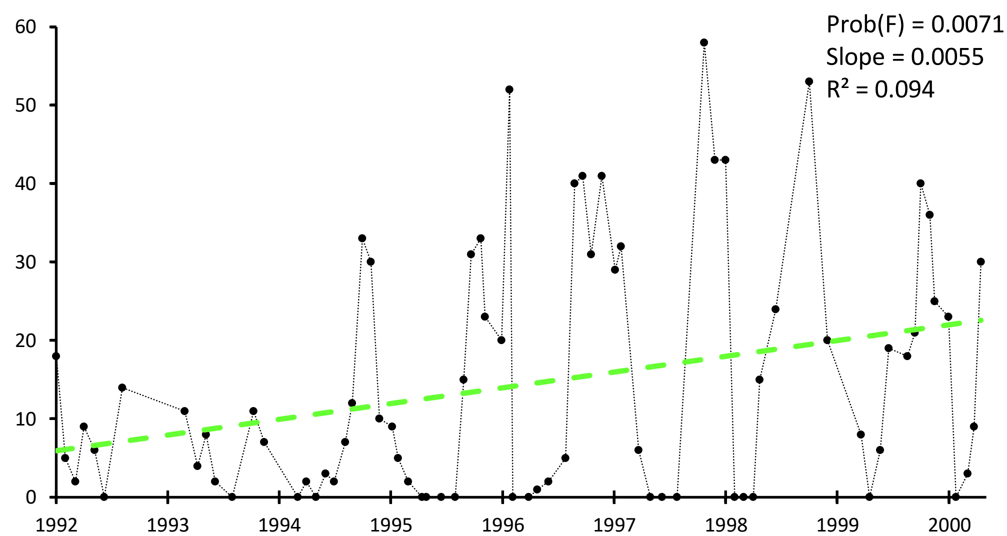

The wood duck exhibited a significant (better than 99.99% level) decreasing abundance trend of -0.0017 animals counted per day or -0.61 counts per year over the period of record, 9/1/92 – 5/29/21. Survey date explains 24.2% of the observed variation in counts per survey.

Abundance 1994-2020 (annual means)



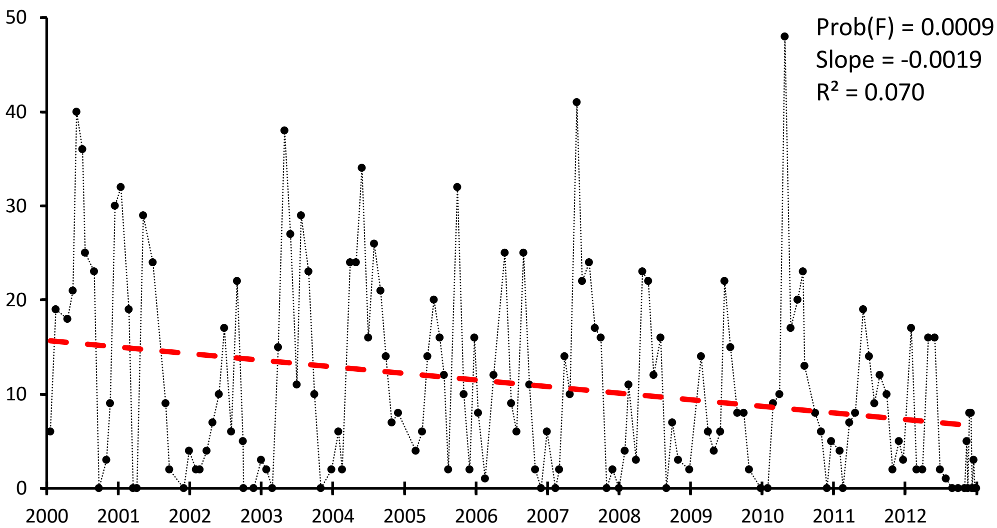

Wood duck annual mean counts per survey peaked between 1997 and 1999, declined steeply to 2002, rebounded to 2004, and then generally declined to very low values in since 2015.

Abundance During Hydrilla Invasion: 1992-2000 (counts per survey)



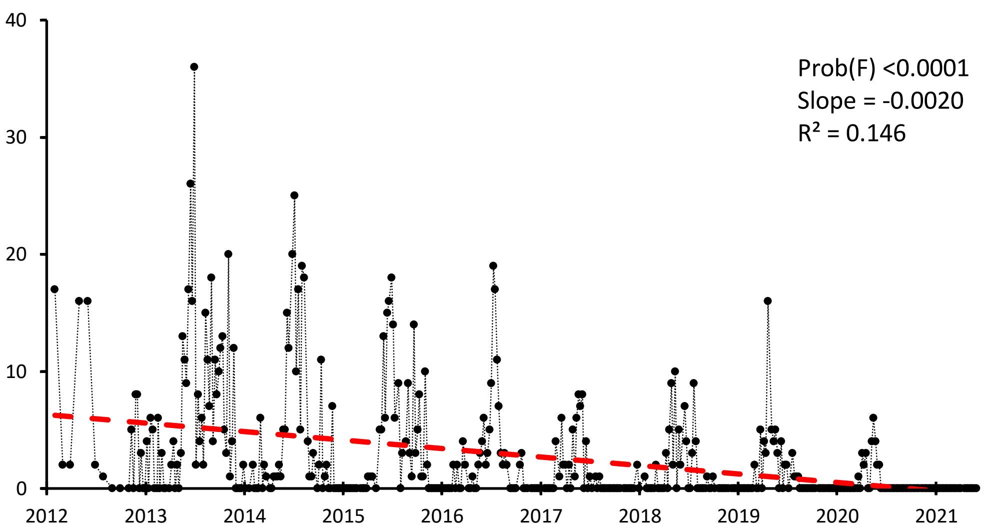

The wood duck exhibited a significant trend (99.29%) of increasing abundance during the hydrilla invasion that explains 9.4% of the observed variation in counts per survey.

Abundance During Hydrilla Management: 2000-2012 (counts per survey)




The wood duck began a significant decreasing trend (99.91% level) in abundance during the hydrilla management period that explains 7.0% of the observed variation in counts per survey.

Abundance Post- Hydrilla Management: 2012-2020 (counts per survey)




The significant decrease (better than 99.99% level) in wood duck abundance continued through the post-hydrilla management period with a trend that explains 14.6% of the observed variance in counts per survey.

Multivariate Analysis of Recent Trend

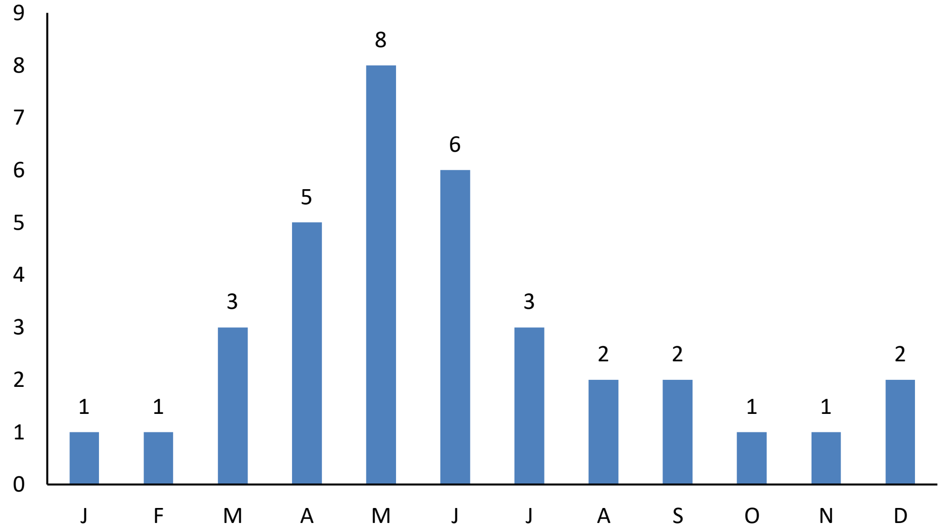
As for other birds, wood ducks are less likely to be influenced by air temperature or sunshine/cloudiness than reptiles. River stage may, however, affect how many are observed because they often take cover under low-hanging trees and shrubs along the river's edge. A multivariate regression model that controls for these variables for the period during which weekly data have been collected, November 10, 2012, through May 29, 2021, reveals that the apparent decreasing trend (date) is significant even after accounting for river stage and air temperature.

| | test stat | p-value |
|---|---|---|
| F-test | 59.370 | < 0.0001 |
| Adjusted R-squared | 0.306 | |
| Date | -0.002 | < 0.0001 |
| River stage | -2.388 | < 0.0001 |
| Air temperature | 0.145 | < 0.0001 |

The model explains 30.6 percent of the observed variation in counts per survey and is significant at better than the 99.99 percent level. Each of the independent variables is significant at better than the 99.99 percent level. Thus, wood duck counts are higher when river stage is lower (negative coefficient) and air temperature is warmer, the latter reflecting their greater abundance during spring and summer months.

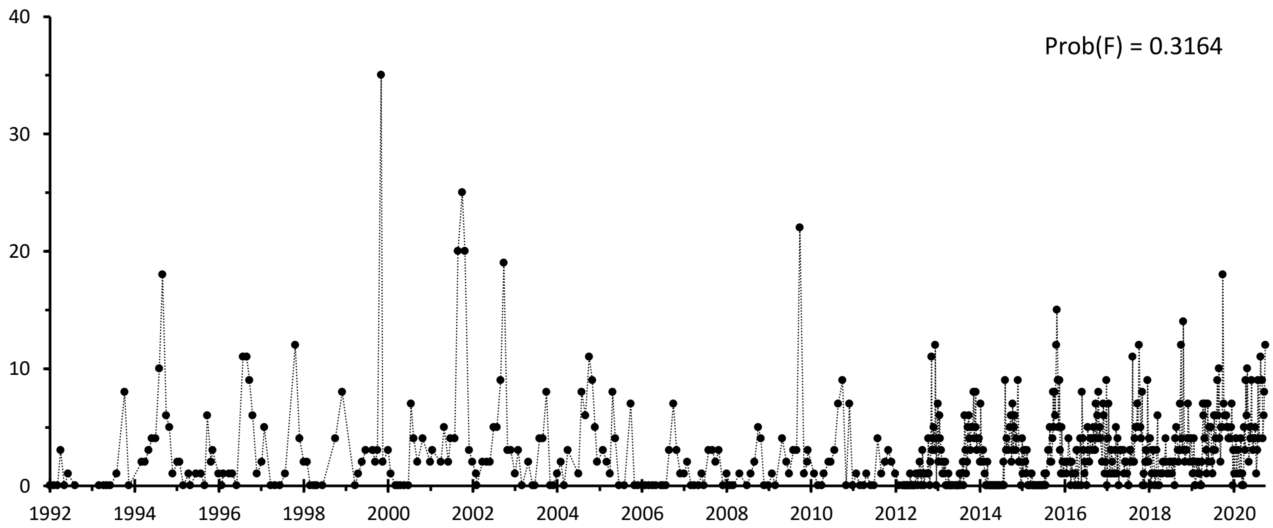
# YELLOW-CROWNED NIGHT-HERON

Seasonal Abundance 1992-2020 (average monthly means)



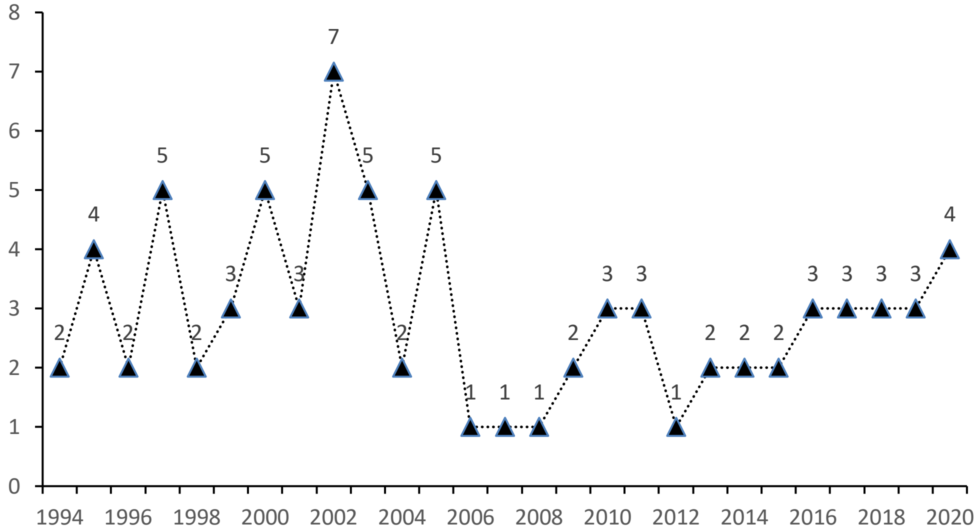

The yellow-crowned night-heron is a year-round resident that breeds in the summer. However, some individuals may migrate to south Florida or beyond in the winter (Watts, 2011).

Abundance 1992-2021 (counts per survey)



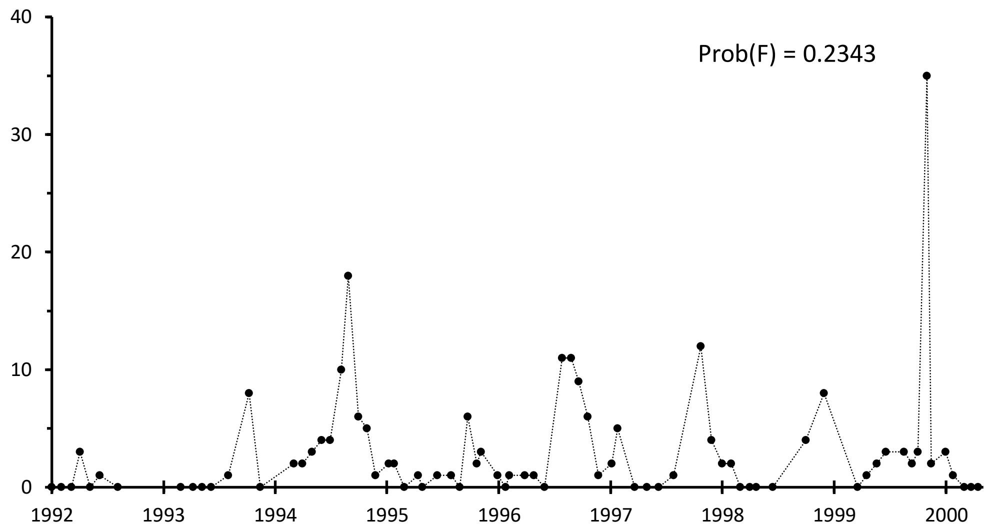

The yellow-crowned night-heron exhibited no significant abundance trend over the period of record, 9/1/92 – 5/29/21. Counts per survey ranged from 0 to 35 with an average of 2.9.

Abundance 1994-2020 (annual means)



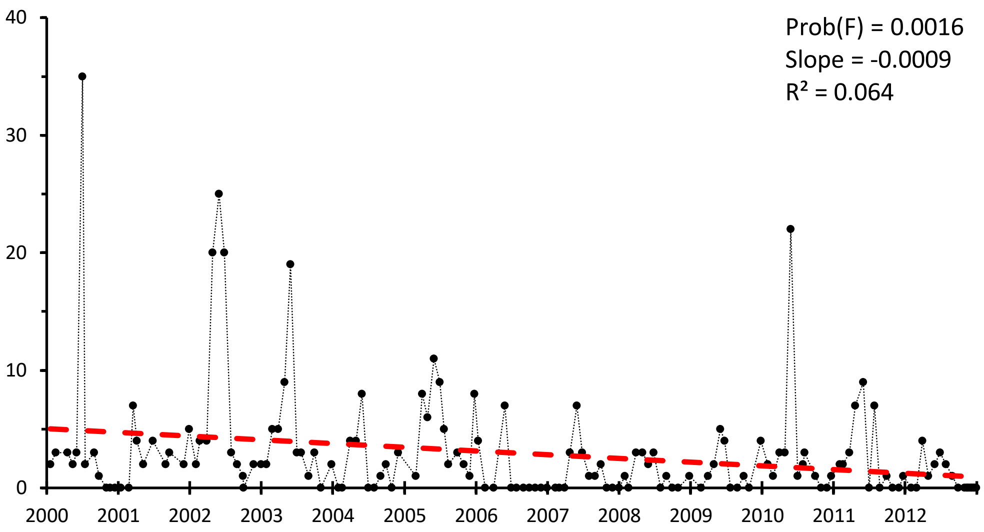

Despite the lack of a significant long-term trend in counts per survey, annual mean counts appear to have decreased with counts ranging from 2 to 7 between 1992 and 2005 decreasing to a range of 1 to 3 until 2020 when it increased to 4.

Abundance During Hydrilla Invasion: 1992-2000 (counts per survey)



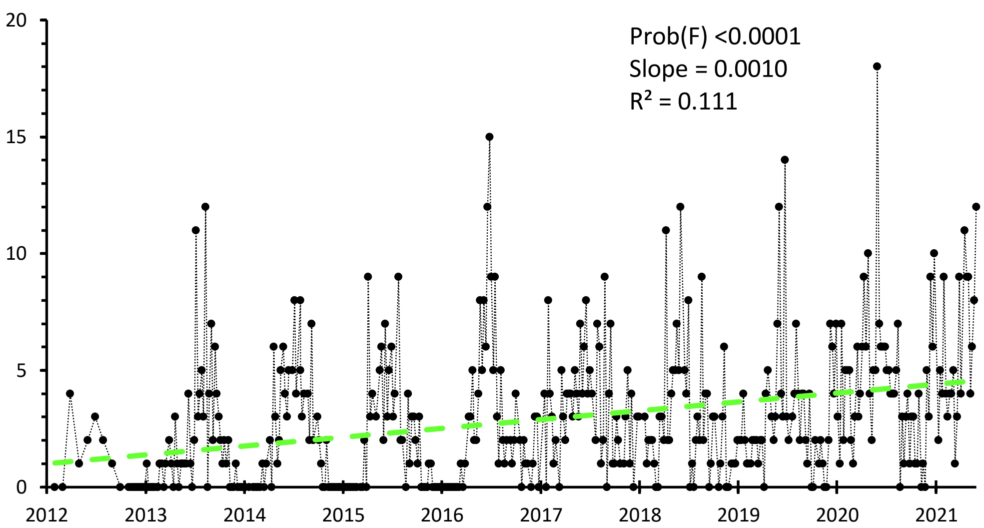

The yellow-crowned night-heron exhibited no significant abundance trend during the hydrilla invasion period. Counts per survey ranged from 0 to 35 with an average of 2.9.

Abundance During Hydrilla Management: 2000-2012 (counts per survey)




The yellow-crowned night-heron exhibited a significant decreasing trend (99.84% level) in abundance during the hydrilla management period that explains 6.4% of the observed variation in counts per survey.

Abundance Post- Hydrilla Management: 2012-2021 (counts per survey)




The yellow-crowned night-heron abundance trend reversed during the post-hydrilla management period with a significant positive trend (better than 99.99% level) that explains 11.1% of the observed variance in counts per survey.

# REFERENCES CITED


Bannor, B.K. and E. Kiviat. 2002. Common Gallinule *Gallinula galeata*. *Birds of North America*. The Cornell Lab of Ornithology. https://birdsna.org/Species-Account/bna/species/comgal1/introduction.

Barr, D.E. 2020. Update of Nitrogen Concentrations in Discharge from the Main Vent of Wakulla Springs. http://wakullaspringsalliance.org/wp-content/uploads/2016/11/Update-on-Nitrogen-Concentration-from-the-Main-Vent-of-Wakulla-Springs.7-6-20.docx.

Bryan, D.C. 2020b. Wakulla Timeline. Updated. http://wakullaspringsalliance.org/wp-content/uploads/2021/07/WAKULLA-TIMELINE-BRYAN-4-14-2020-UPDATE-1.doc

Dorr, B.S., Hatch, J.J., and D.V. Weseloh. 2014. Double-crested Cormorant *Phalacrocorax auratus*. *Birds of North America*. The Cornell Lab of Ornithology. https://birdsna.org/Species-Account/bna/species/doccor/introduction.

Gilbert, D. 2012. *Nutrient (Biology) TMDL for the Upper Wakulla River (WBID 1006)*. Tallahassee, FL: Florida Department of Environmental Protection.

Kaufman, K. 2019a. Little Blue Heron. Guide to North American Birds. https://www.audubon.org/field-guide/bird/little-blue-heron.

Kaufman, K. 2019b. Wood Duck. Guide to North American Birds. https://www.audubon.org/field-guide/bird/wood-duck.

Krysko, K.L., Enge, K.M., and P.E. Moler. 2019. *Amphibians and Reptiles of Florida*. Gainesville, FL: University of Florida Press.

Minitab Blog Editor. 2015. What Is the F-test of Overall Significance in Regression Analysis? https://blog.minitab.com/blog/adventures-in-statistics-2/what-is-the-f-test-of-overall-significance-in-regression-analysis.

Muller, M.J. and R.W. Storer. 1999. Pied-billed Grebe *Podilymbus podiceps*. *Birds of North America*. The Cornell Lab of Ornithology. https://birdsna.org/Species-Account/bna/species/pibgre/introduction.

Savery, S. 2005. Appendix E. History of Hydrilla Removal Efforts at Wakulla Springs. In, *Degradation of Water Quality at Wakulla Springs Florida: Assessment and Recommendations*. http://wakullasprings.org/wp-content/uploads/2014/09/WakullaPeerReportFinal.pdf.

The Cornell Lab of Ornithology. 2019. All About Birds. https://www.allaboutbirds.org/guide/.

The Cornell Lab of Ornithology. 2021. All About Birds. Pied-Billed Grebe Life History. https://www.allaboutbirds.org/guide/Pied-billed_Grebe/lifehistory#.

Thompson, Bob. 2020. Summary of SAV Monitoring from 4/25/13 through 8/24/20.

Van Dyke, J. 2019. Controlling Hydrilla at Wakulla Springs State Park (1997-2007). Unpublished manuscript.

Watts, B.D. 2011. Yellow-crowned Night-Heron *Nyctanassa violacea*. *Birds of North America*. The Cornell Lab of Ornithology. https://birdsna.org/Species-Account/bna/species/ycnher/introduction.