Upper Wakulla River Wildlife Abundance Trends 1992 through 2018

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Executive Summary

This report analyzes long-term trends in the abundance of 24 species surveyed by park staff and volunteers from 1992 through 2018. It 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 used to combat the invasive exotic plant, and (3) the post-hydrilla management period (2012-2018) following the cessation of herbicide treatment in 2013. Total wildlife abundance, measured as total numbers of individual animals counted per survey, decreased significantly over the 27 years of this monitoring project. Four species increased in abundance over this period, fourteen decreased, and six exhibited no statistically significant long-term trend. Total wildlife abundance and nine species increased in abundance during the hydrilla invasion, probably because of increased food supply. During the hydrilla management period, total wildlife abundance decreased as did twelve 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. Total wildlife abundance continued to decrease during the post-hydrilla management period, as did three species while a fourth began to decline for the first time. However, seven species increased during this period including three that had decreased during the hydrilla management period. 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.

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 27 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 previous analyses completed by Bob Thompson who organized and managed the volunteer monitoring initiative until his "retirement" in 2018.[3] The report analyzes long-term trends in total wildlife abundance and the abundance of individual species. It also analyses trends for three shorter time periods defined by significant perturbations to the upper Wakulla River ecosystem. For the first time, this report presents monthly means to identify important seasonal patterns in the abundance of individual animal species. It also examines possible explanations for the observed trends drawing on available scientific literature and documented changes to the river ecosystem.

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[1] Many thanks to the volunteers who spent portions of their Saturday mornings monitoring wildlife during the two years since the last analysis of monitoring data: Doug Alderson, Connie Bersok, Melissa Forehand, Kim Forehand-van der Linde, 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. Thanks also to park volunteer coordinator, Jackie Turner, for coordinating the monitoring program following Bob Thompson's retirement as volunteer monitoring program manager, and to Bob for his encouragement, support, and straight-shooting feedback on my several forays into new ways of looking at the data. 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.

[3] Bob Thompson managed this program as a volunteer following his official retirement as a park ranger in April 2012.

This report analyzes long-term wildlife abundance using two approaches:

- animal counts for each survey for 1992-2018 for statistical analysis of trends
- annual mean or annual seasonal monthly mean[4] animal counts for 1994-2018 for visual analysis of patterns.

The counts per survey approach offers the greatest statistical power for testing the significance of apparent trends,[5] but the high variance among individual surveys makes it difficult to visually detect temporal patterns. Therefore, the analyses of total animal abundance and individual species in Appendix E include graphs of annual mean or annual seasonal monthly mean animal counts.[6] 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.

This report also includes analysis of trends during three periods defined by several significant perturbations to the upper Wakulla River ecosystem: 1994-2000; 2000-2012; and 2012-2018.[7]

- Hydrilla Invasion (1992-2000): This 9-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 was first observed near the boat dock in April 1997. By December of that year it had

[4] Annual means were calculated for each month and then averaged for the months when an individual species is most commonly observed, e.g. the months in residence for winter migrants.

[5] 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.

[6] Data from 1992 and 1993 are excluded from the means graphs because data were only collected for a few months in each of those years and the distribution of those months was not seasonally balanced. Thus, means for any species whose abundance varies seasonally are skewed for those two years.

[7] This summary is drawn principally from Bryan (2018), Savery (2005), and Van Dyke (2019).

spread down the river 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. 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. 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 encompasses 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."

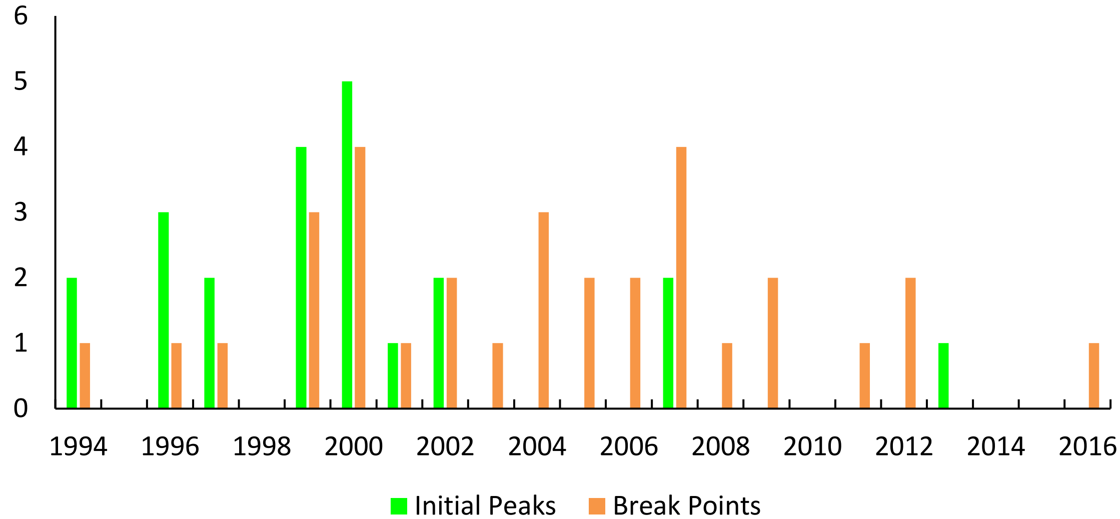
  In 2002, the state park resorted to treating the upper river with liquid Aquathol applied across the spring basin.[8] During the ensuing 11 years, liquid Aquathol was applied in most years (see Appendix C). The initial treatment succeeded in killing back the stems of 70 to 80 percent of the hydrilla (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[9] 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, 2018). Experiments conducted by the Florida Department of Environmental Protection in 2005 indicate that the initial 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 city's T.P. Smith wastewater treatment plant went on line (see Appendix D, Figure D-1). These changes were reflected in a decline in nitrate-nitrogen levels at the spring, which levelled off at 0.41 mg/L in 2014 (see Figure D-2).

[8] 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).

[9] 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*.

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).[10] This pattern may reflect a lagged effect of the initial perturbations.

Figure 1. Initial Peaks and Break Points in Annual Mean Abundance of 23 Monitored Animal Species: 1994-2016[11]



- Post Hydrilla Management (2012-2018): This 7-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;
  - the 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, cloudiness, aptitude of the surveyor, distractions during the boat tour, etc.

The next section summarizes findings from this analysis. Subsequent sections present trend analysis for total animal abundance and summary tables of individual species abundance trends for the several analysis time periods. Detailed results for total animal 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

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[10] "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.

[11] The manatee is excluded from this chart because it was not surveyed until 2003.

and graphs of counts per survey and means versus time for the various time periods for total animal abundance and individual species. Trend lines and associated statistics (model fit - prob(F); model explanatory power - R-squared 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).[12]

Summary of Abundance Trends

Total wildlife abundance, measured as total numbers of individual animals counted per survey, has decreased significantly over the 27 years of this monitoring project: 1992-2018. Individual 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: 1992-2018
  - Total wildlife abundance decreased
  - Four species increased in abundance
  - Fourteen species decreased
  - Six species exhibited no long-term trend
- Hydrilla invasion: 1992-2000
  - Total wildlife abundance increased
  - Nine species increased
  - Two species decreased
  - Thirteen exhibited no trend
- Hydrilla management: 2000-2012
  - Total 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: 2012-2018
  - Total wildlife abundance continued to decrease
  - Seven species increased
    - Two after increasing during the previous period
    - Three after decreasing during the previous period
    - Two after exhibiting no trend during the previous period
  - Eight species decreased
    - Two after increasing during the previous period
    - Four continued to decrease during this period
    - Two after exhibiting no trend during the previous period
  - Nine species exhibited no trend
    - Five after decreasing during the previous period
    - Four continued to exhibit no trend

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

The four species that have increased in abundance during the period of record include (in decreasing rate of increase) hooded merganser, cattle egret, pied-billed grebe, and white ibis. 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, American alligator, and wood duck.

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 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 annual means 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 associated with tropical storm Beryl and three subsequent months of above-average rainfall.

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 subsequently experienced significant decreases during the hydrilla management period, probably due at least in part to loss of habitat and/or food supply. All these species either remained at lower levels during the post-hydrilla management period or decreased further: American wigeon, green heron, osprey, purple gallinule, tricolored heron, 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.

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 (2012-2018): 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. The hooded merganser exhibited evidence of a short-term decline in annual 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 both the hydrilla management period and the post-hydrilla management period. Two other species which exhibited no significant trends during the hydrilla invasion increased during the hydrilla management period. The cattle egret began nesting in the second mile of the river in 2012 at the end of this period. It discontinued nesting after three years yielding a net decrease in abundance during the post-hydrilla management period. Manatee showed up in the upper river during this time and increased in numbers grazing on the hydrilla. They subsequently declined as the hydrilla failed to recover from annual grazing with the significant decrease in nitrogen resulting from upgrading the Tallahassee wastewater treatment facility.

Seven species exhibited increasing trends during the most recent post-hydrilla management period (2012-2018). As noted, these were continuations of increasing trends from the previous period for the hooded merganser, a winter migrant, and the pied-billed grebe, a year-round resident whose Wakulla population is supplemented by winter migrants. In both cases, their winter ranges have shifted south, and their northern summer breeding populations have increased.

Three others reversed decreasing trends from the previous period: American alligator, double-crested cormorant, and yellow-crowned night-heron. For two species, the post-hydrilla management increases marked the first significant trend: the anhinga, which exhibited a significant long-term decreasing trend and the great egret which exhibited no significant long-term trend.

Of the eight 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, two reversed increasing trends from the previous period: cattle egret and manatee. The American coot decreased during this period after increasing during the hydrilla invasion. 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 signs: Significant increasing abundance trends for several carnivorous species during the post-hydrilla period: American alligator, anhinga, double-crested cormorant, great egret, hooded merganser, pied-billed grebe, and yellow-crowned night-heron.

Discouraging signs: Continuing decreases for the common gallinule, wood duck, and osprey and new decreasing trend for the great blue heron.

<u>Total Wildlife Abundance Trends</u>

Changes in the total numbers of individual animals counted per survey can serve as an indicator of shifts in the relative biological productivity of the upper river ecosystem. The long-term trends analyzed here indicate a significant decline over the past 27 years following an initial increase during the hydrilla invasion.

Figure 2 presents total animal abundance counts per survey date for the 27-year period of record from September 1, 1992, through December 29, 2018. A statistically significant (prob(F) < 0.001) negative trend is present with relatively weak explanatory power ($R^2 = 0.215$). The slope of -0.028 animals counted per day translates into a decrease of 10 animals counted per year. As shown in Figure 3, smoothing the data by calculating annual mean total animal counts per survey makes it easier to discern year-to-year changes. This reveals a strong peak in 1999 and secondary peaks in 2006 and 2011-12.

Figure 2. Total Animal Counts per Survey 1992-2018

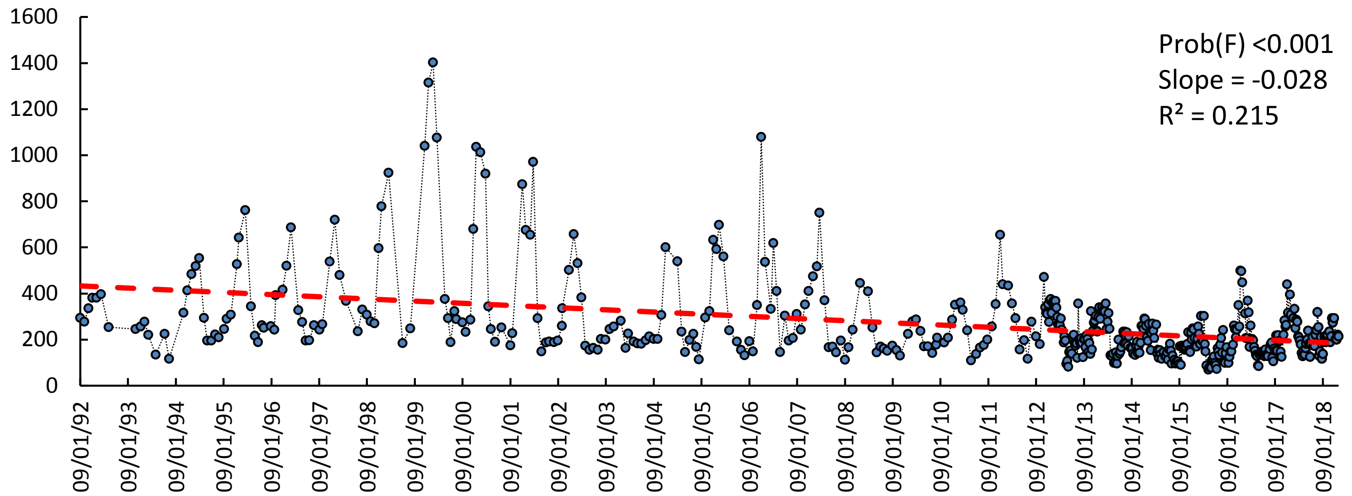
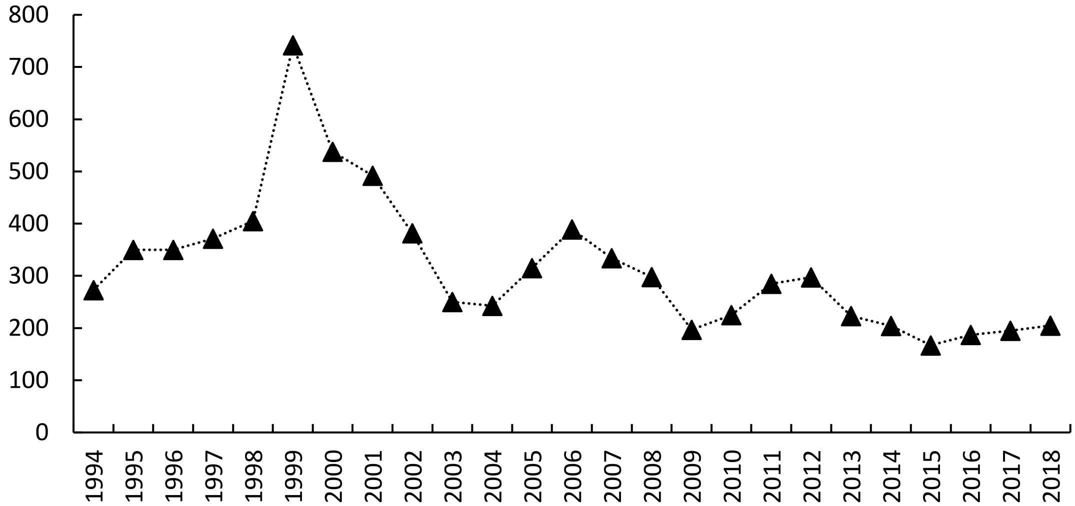


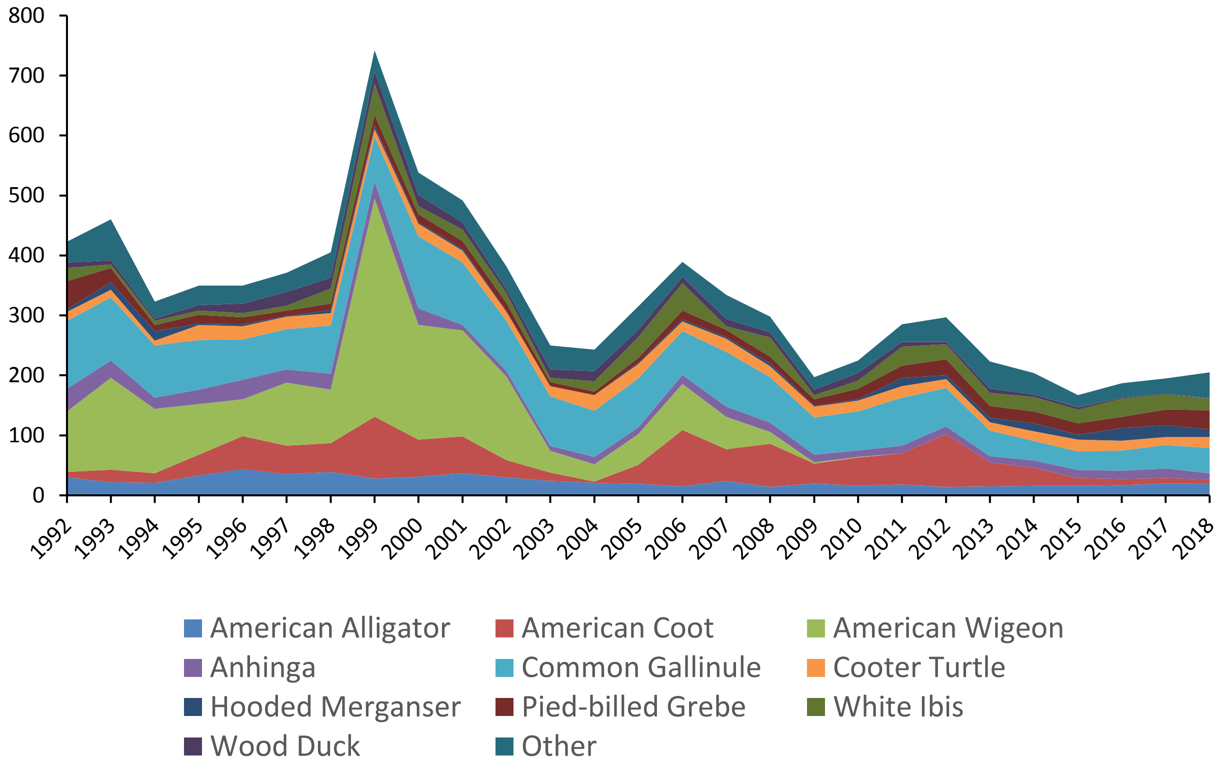
Figure 3. Annual Mean Total Animal Counts per Survey 1994-2018



The count peaks and high annual sample means in 1999, 2000, and 2001 were driven in part by very high counts of American wigeon (459 on 2/12/99; 598 on 11/17/99; 764 on 12/16/99; 841 on 1/19/00; 600 on 2/17/00; 536 on 1/14/01, 428 on 2/23/01). The secondary peaks in 2006 were more broadly distributed with especially high counts on 11/30/06 of American coot (501), American wigeon (170), white ibis (169), and common gallinule (155). By 2011-12 the wigeon were almost entirely absent. Peak counts in those years were driven by coot, common gallinule, and white ibis. Removing American wigeon counts from the data does not change the findings, however. The significant negative trend remains with a somewhat lower R^2 value: 0.121 for total animal counts without wigeon versus 0.215 including wigeon.

Figure 4 illustrates the variation over the period of record in the relative numbers of the most prevalent monitored animal species tabulated as annual means. This reveals the demise of the wigeon and the rise and fall of wintering coot populations. Annual mean counts of alligators decreased as have those of the common gallinule, while hooded merganser, pied-billed grebe, and white ibis increased.

Figure 4. Total Annual Mean Animal Counts for Most Prevalent Species



As shown in Appendix E, regression analysis reveals a significant increase in total animal abundance during the hydrilla invasion period, 1992-2000 (Prob(F) = 0.035), followed by significant decreases during both the hydrilla management period, 2000-2012 (Prob(F) <0.001), and the post-hydrilla management period, 2012-2018 (Prob(F) = 0.022).

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[13] and enhanced floating aquatic vegetation habitat that probably favored the American wigeon and American coot and perhaps the common gallinule. 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 (2012-2018). *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, 2019).

[13] 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).

Long-Term Species Abundance Trends

Table 2 presents long-term species abundance trends based on animal counts per survey for the full period of record (1992-2018) 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: $R^2 < 0.30$; moderate: $R^2 \geq 0.30$ and $R^2 < 0.70$; and strong: $R^2 \geq 0.70$. Regression slopes measured as the change in animal counts per day are converted to counts per year.

Table 2. Summary of Long-Term Trends in Wildlife Species Abundance 1992-2018

Abundance Trend	Species	Annual Rate of Change (Counts per Year) 09/1/92 – 12/29/18[14]
Decreasing	†American wigeon**	-17.37
	Common gallinule**	-2.92
	American coot*	-1.46
	American alligator*	-0.72
	Wood duck*	-0.59
	Anhinga*	-0.50
	Blue-winged teal*	-0.31
	Cooter turtle*	-0.28
	Green heron*	-0.18
	Limpkin**	-0.17
	Osprey*	-0.12
	Snowy egret*	-0.08
	Tricolored heron*	-0.08
	Purple gallinule*	-0.05
Increasing	Hooded merganser*	1.84
	Cattle egret*	0.86
	Pied-billed grebe*	0.59
	White ibis*	0.55
No significant trend	Double-crested cormorant	0.00
	Great blue heron	0.00
	Great egret	0.00
	Little blue heron	0.00
	Manatee	0.00
	Yellow-crowned night-heron	0.00

† Trends based on annual seasonal monthly means rather than counts per survey.
* $R^2 < 30$; ** $R^2 \geq 30$ and < 70; ***$R^2 \geq 70$

[14] Calculated from 6-digit values in regression output rather than rounded slope values in Appendix E.

Fourteen of the 24 species analyzed (58 percent) exhibited statistically significant decreasing trends over the study period, while only four experienced significant increases, and six remained unchanged. The American wigeon, common gallinule, American coot, American alligator, and wood duck experienced the most rapid rates of decline, displayed in Table 2 and Figure 5 as annual rates of change based on the slopes of the regression models for each species with a significant trend. The hooded merganser and cattle egret exhibited the most rapid rates of increase.

Analysis of Abundance Trends by Species and Current Status

Table 3 presents individual wildlife species abundance trends based on counts per survey for the full period of record (1992-2018), and for the three disturbance periods, 1992-2000, 2000-2012, and 2012-2018, employing the same classification scheme as Table 2.

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 occasional 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.

One species, the cooter turtle, has 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. **Cooter turtles** (predominantly if not exclusively Suwannee cooter) are year-round breeders that primarily eat SAV, especially *Vallisneria* spp., *Naias* spp., *Sagittaria kurziana*, and *Ceratophyllum demersum* (Krysko et al., 2019). These are all genera that were affected by the Aquathol treatment of the hydrilla. Quarterly SAV surveys begun in 2013 have recorded almost no *Naias* 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. *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 but is now virtually absent. High variation 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. The high variation between surveys also may explain the absence of significant trends during any of the ecosystem perturbation periods. Nonetheless, annual means graphical analysis does reveal a steep one-year drop in 1999 at the onset of mechanical hydrilla harvesting and steep drops in 2002 and 2006 (see Appendix E). 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 5. Species Annual Rates of Change in Abundance 1992-2018

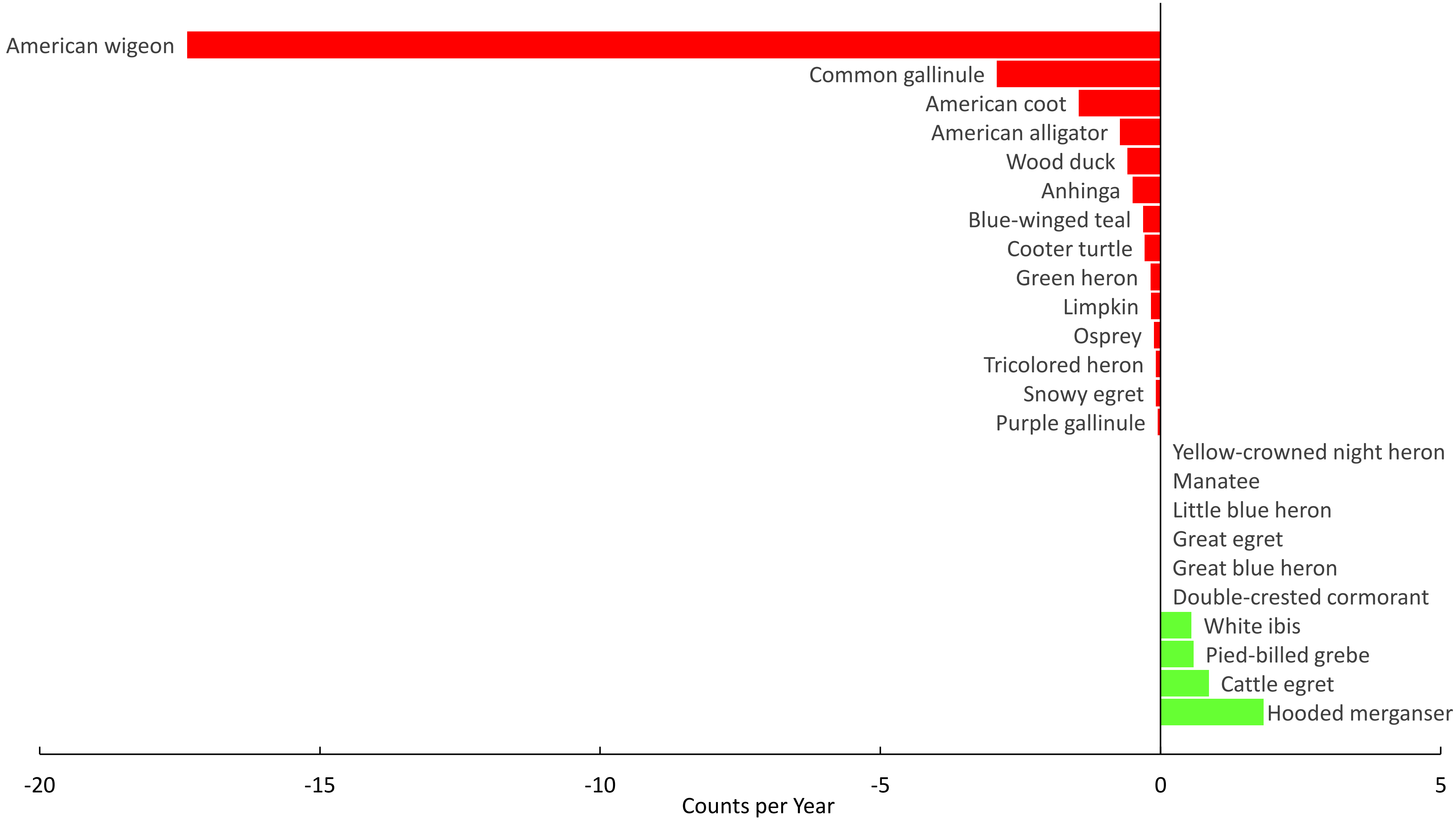


Table 3. Wildlife Abundance Trends and Current Status by Species

Species	Seasonal Distribution	Long-Term Counts per Survey (1992-2018)	Hydrilla Invasion Counts per Survey (1992-2000)	Hydrilla Management Counts per Survey (2000-2012)	Post-Hydrilla Management Counts per Survey (2012-2018)	Current Apparent Status
American alligator	YB	Decreasing*	No Trend	Decreasing*	Increasing*	Long-term decrease, possibly recovering
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 during surveys since 2014
Anhinga	YB	Decreasing*	No Trend	No Trend	Increasing*	Long-term decrease; recent increase
Blue-winged teal	WM Sep-Mar	†Decreasing*	†No Trend	†Decreasing*	†No trend	Long-term decrease
Cattle egret	SB May-Aug	†Increasing*	†No Trend	†Increasing*	†Decreasing*	Decreasing after cessation 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††	No Trend	No Trend	Decreasing*	Increasing*	Small numbers; recent nesting in 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*	No Trend	Long-term decrease started during hydrilla management
Hooded merganser	WM Nov-Feb	†Increasing*	†No Trend	†Increasing*	†Increasing*	Continuing long-term increase; some flux
Limpkin	OV	Decreasing**	Decreasing**	No trend	No trend	Occasional after precipitous decline 1994-2000.
Little blue heron	YOB	No Trend	Increasing*	No Trend	No Trend	No long-term trend
Manatee	WP Oct-Feb	No Trend	No data	Increasing**	Decreasing*	Decreasing after 2012-13 and 2013-14 winter peaks
Osprey	SB Feb-Jul	†Decreasing*	†Increasing*	†Decreasing*	†Decreasing*	Small numbers; continuing long-term decline
Pied-billed grebe	YB††	Increasing*	Decreasing*	Increasing*	Increasing*	Continuing long-term increase punctuated by decrease during hydrilla invasion
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*	No trend	Stable after hydrilla management period decline
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.
*$R^2 < 30$; **$R^2 \geq 30$ and < 70; ***$R^2 \geq 70$

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 Appendix E, the **limpkin** began to decline in 1994 following high water levels due to tropical storm Beryl and higher than normal rainfall thereafter. 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 (2019) suggests that the limpkin's demise was due to drowning of the eggs of the apple snail which is the limpkin's primary food source. Efforts to rejuvenate the apple snail population through reintroduction have been unsuccessful.

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 primarily feeds (The Cornell Lab of Ornithology, 2019; personal observation[15]). Trends in counts per survey turned around during the hydrilla management period with significant increases then and during the subsequent post-hydrilla management period. However, annual means show a decline between 2000 and 2004 during the intensive mechanical harvesting and herbicide treatment of the hydrilla. By-catch from the mechanical harvesting and the crayfish kill following the initial April 2002 Aquathol treatment may have contributed to this period of 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. However, the long-term increase in abundance 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., 2017) indicates that pied-billed grebe breeding populations in eastern North America increased by 2.45 percent per year over the period 2005-2015 perhaps resulting in larger numbers of migrants coming to the Wakulla River.

<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).

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 Appendix E). 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 non-breeding season (The Cornell Lab of Ornithology, 2019). This is plausible, but migrant bird distributions in any given winter 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

[15] I served as a regular volunteer river boat tour guide between April 2013 and July 2018, 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 surveys of the upper river. I am currently on a one-year sabbatical during which I have conducted river tours approximately once every three months.

biomass that resulted from the herbicide treatments and accompanying impacts. However, analysis of Christmas Bird Count (CBC) circles[16] 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 exhibiting a net long-term decline (see Appendix E) that 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 a decrease in the breeding population in eastern North America (-1.79 percent per year) over the period 2005-2015 (Sauer et al., 2017), and a northward shifting of its winter range (La Sorte and Thompson, 2007).

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 2018. 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). The green heron has not recovered since, exhibiting no significant trend in counts per survey during the post-hydrilla management period. Annual mean counts per survey bottomed out in 2013 with annual means of zero for all but one of the subsequent five years, and an annual mean of one in 2015. 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.

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). They nested in a colony in the second mile of the river in 2016, and possibly other years (personal observation). Annual means peaked in 2000 and 2001 followed by declines from 2002 through 2004. 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 but returned to pre-2000 levels in 2012.

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

[16] 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.

means over the period of record (1992-2018) 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 three in 2000, then declined to two by 2010 and to one by 2016. As many as four or five active nests have been observed along the river 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 none for the past three 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 Figure 2 and/or a loss of fish in the size classes it typically consumes: six to twelve inches (The Cornell Lab or Ornithology, 2019), perhaps due in part to the by-catch of juvenile fish during the use of mechanical harvesting.[17]

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 27-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. 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 or 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 decreasing trend of abundance during the hydrilla management period. It is plausible that the hydrilla mats provided 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.

The **tricolored heron**, while more common than the purple gallinule, also is present in small numbers with annual means ranging from one to five, peaking in 2007 and stable at one since 2010 (see Appendix E). 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. 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, Sauer et al., (2017) report that Florida populations of tricolored herons exhibited a declining trend during the 1966-2015 breeding bird survey (-2.26 percent per year) and during the most recent 10-year period analyzed, 2005-2015 (-1.73 percent per year), so the Wakulla declines may be associated, at least in part, with a larger-scale shift in regional metapopulation.[18]

The **white ibis** has experienced a long-term increasing trend in abundance spurred by a significant increase during the hydrilla invasion period. Ibis migrate regionally and their site allegiance can be low for both breeding and roosting habitat (Heath et al., 2009). During summer months, counts are low on the

[17] 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 monitoring site was located two miles downriver from the spring (Florida Springs Institute, 2014).

[18] "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).

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 (October - February). White ibis eat primarily insects and crustaceans, especially crayfish (Wikipedia, 2019). 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. The 2002 crayfish kill may have contributed to this decline. While no significant trends in counts per survey are exhibited during the hydrilla management period or the post-management period, annual mean counts per survey peaked again in 2006, fluctuated widely until 2011 and then more or less levelled off. Some of this variation may be due to other factors affecting the species's choice of nonbreeding-season roosting sites.

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 2016-2018. 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. Sauer et al. (2017) report that Florida populations of wood ducks exhibited a long-term declining trend during the 1966-2015 breeding bird survey (-2.39 percent per year) and during the most recent 10-year period analyzed, 2005-2015 (-2.04 percent per year).

Hydrilla Management Period (2000-2012)

As shown in Table 3, <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.

Annual winter monthly means of the winter migrant **blue-winged teal** show a statistically significant long-term decrease with several large amplitude swings between the winters of 1997-98 and 2005-06 (see Appendix E). Winter monthly means have ranged from three to zero since 2006-07 and have been zero since 2012-13. Their decline on the upper Wakulla River is not consistent with La Forte's and Thompson's (2007) data which suggest that the blue-winged teal shifted its winter range <u>south</u> between 1975 and 2004. The Wakulla trend also is running contrary to both the Sauer et al., (2017) and USFWS (2018) breeding population data which show increases. It may be, therefore, that lower availability of aquatic plant seeds resulting from the annual SAV fluxes during the herbicide treatments may have influenced winter populations. However, the species has never been plentiful at Wakulla Spring, with highest monthly mean counts per survey of eight in October, suggesting that the river ecosystem may never have been prime winter habitat.

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 winter migrants from the north. It attained a peak in annual means in 2000 at the end of the hydrilla expansion period, but that increase was not sufficient to generate a statistically significant positive trend (see Appendix E). It experienced a significant decreasing trend 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. The decline continued to 2015, three years after the last liquid herbicide treatment, after which an apparent possible rebound began. The net trend for the post-hydrilla management period was, however, decreasing. 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' decline. It's not clear what may be behind the increases over the last three years.

<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) which, as reported above, appears to have declined over the period of record. Alligator abundance began a protracted decline in 2002 at the onset of intensive Aquathol treatment following fluctuating levels during the preceding hydrilla invasion period (see Appendix E). Its abundance numbers turned around beginning in 2013, yielding a significant increasing trend since 2012, a possible indication of increasing biological productivity. There has not been a parallel significant increase in total animal abundance over the same period (see Appendix E), although annual means have increased during the last three years (see Figure 3). Another possible explanation of the recent increases in alligator counts is the choice of nesting locations by female alligators. Two 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** exhibited no long-term trend but did experience a significant decrease during the hydrilla management period followed by a significant increase in abundance during the post-hydrilla management period. The **snowy egret** exhibited a significant long-term decrease in abundance as well as a significant decreasing trend during the hydrilla management period. The decline began in 2005, midway through that period, after high variability earlier in the period of record (see Appendix E). The snowy egret levelled off at an annual mean of one in 2009 and has recorded annual means of zero in two years since then (2014 and 2015). The cormorant feeds predominantly on fish while the snowy egret 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 declines in these species. However, numbers for the cormorant and snowy egret are generally small throughout the period of record with annual means between 1994 and 2018 ranging from one to five for the cormorant and zero to four for the snowy egret. Thus, some of the observed changes over time may be artifacts of random fluctuations in these small populations. The cormorant has nested in a colony along the second mile of the river during several recent summers resulting in some higher counts in late summer and early fall (personal observation). This may account for the significant increasing trend during the post-hydrilla management period. Compilation of data from the park's biannual Wakulla River survey may provide more precise information.[19]

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) and 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 on the upper river in counts per survey over the period of record, 1992-2018 (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. 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 visible nests along the river tour route are used every year, while others are used irregularly (personal observation).

<u>Four species exhibited significant increases in abundance during the hydrilla management period</u>: cattle egret, hooded merganser, manatee, and pied-billed grebe. The **pied-billed grebe** is discussed above. As shown in Table 3, the **cattle egret** has experienced a long-term increasing trend 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. Breeding season monthly means were zero to three from 1994 to 2011. Cattle egrets then established breeding colonies on the upper river in 2012, 2013, and 2014 which pulled the long-term trend up with breeding seasonal monthly means of 45 to 59 (see Appendix E). The high counts in 2012 account for the significant increasing trend during the hydrilla management period. Since 2014 breeding season monthly means have dropped from 16 to a range of one to four, hence the significant decrease for the post-2012 period.

The **hooded merganser** experienced a significant increase over the period of record 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, with an upswing beginning in 2011-12 capped by very high abundance in 2016-17 and 2017-18. The increasing trend in winter counts per survey remains statistically significant (99.9% level or better) even if those two most recent winters are removed from the data series. 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 did result in a crayfish kill. A second dip in winter monthly means in 2008-09 and 2009-10 (5 and 3 respectively) follows a second smaller crayfish kill after the April 2008 Aquathol treatment. However, the merganser exhibits statistically significant increasing trends during both the hydrilla management and post-hydrilla management periods. No local ecosystem changes appear to be related to the most recent increases in 2016-17 and 2017-18. However, the long-term increasing trend is consistent with increases in summer breeding populations in eastern North America between 2005 and 2015 (Sauer et al., 2017) and a

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[19] 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.

southward trend in the centers of abundance and occurrence of wintering populations between 1975 and 2004 (La Sorte and Thompson, 2007).

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.[20] They over-wintered at the spring for the first time in 2007-2008. As shown in Appendix E, 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 treatment in 2002 opened a passageway through shallow water at the park boundary just north of the Route CR 365 (Shadeville Road) bridge that had previously been largely impassable because of dense hydrilla. Sediments remain largely bare in that area today facilitating regular manatee movement into the upper river. Winter monthly means peaked 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 have since plateaued at four to six animals suggesting that a new carrying capacity may have been reached for this species.

Post-Hydrilla Management Period (2012-2018)

Table 3 indicates that <u>seven species have experienced significant increases in annual mean abundance in the post-hydrilla management period</u>: American alligator, anhinga, double-crested cormorant, great egret, hooded merganser, pied-billed grebe, and yellow-crowned night-heron. The alligator, cormorant, merganser, grebe, and yellow-crowned night-heron 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), they underwent a steep decline in 2001 during the second year of intense hydrilla mechanical harvesting efforts from which they have not fully recovered. 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 12 and 16 to 17 since 2004, most recently exhibiting a significant increasing trend in abundance since 2012. However, their annual mean dropped again in 2018 from 16 to 11, comparable to lows of 10 and 11 in 2013, 2010, and 2005 (see Appendix E).

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 Appendix E). 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). A steady increase in annual mean abundance from 2003 to 2007 was followed by a steep decline in 2010 and generally staple annual mean abundance thereafter. However, analysis of individual survey count data yields a significant trend of increasing abundance during the current post-hydrilla management period albeit at a very slow rate of 0.11 animals per year.

<u>Eight species have exhibited significant decreases over the past six years</u>: American coot, American wigeon, cattle egret, common gallinule, great blue heron, manatee, osprey, and wood duck. Trends for the coot, wigeon, cattle egret, common gallinule, manatee, osprey, and wood duck are discussed above. **Great blue herons** are year-round residents of the upper Wakulla River that sometimes breed along the

[20] 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.

upper river 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 Appendix E). The occasional higher counts, may, therefore, reflect local breeding. Higher 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 was evident throughout the period of record, but they did exhibit a significant decreasing trend during the post-hydrilla management period despite nesting during some of those years. They 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.

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APPENDIX A
Current Survey Form

Routing of Completed Surveys: **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 (2018); Van Dyke (2019)

APPENDIX D
Wakulla Springs Nitrogen Trends

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

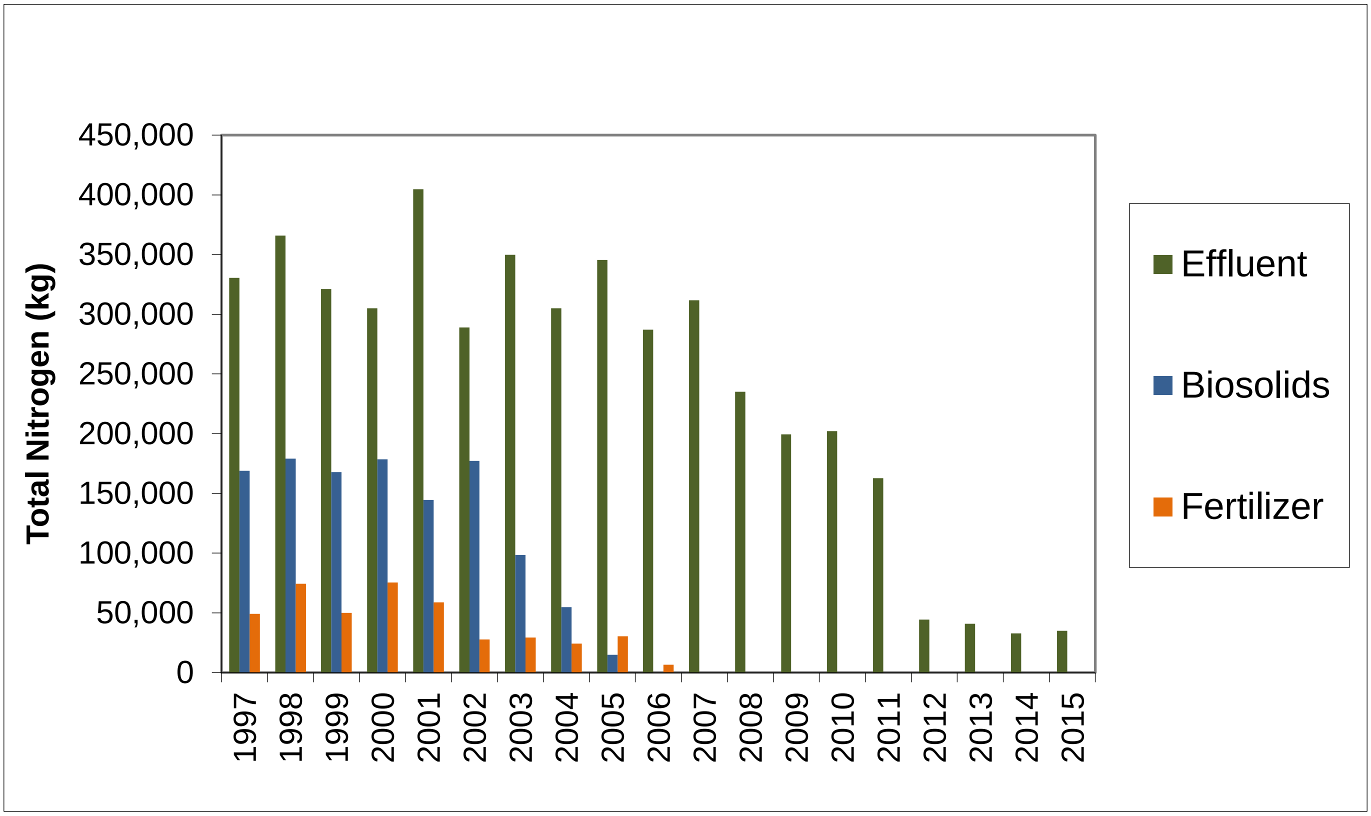
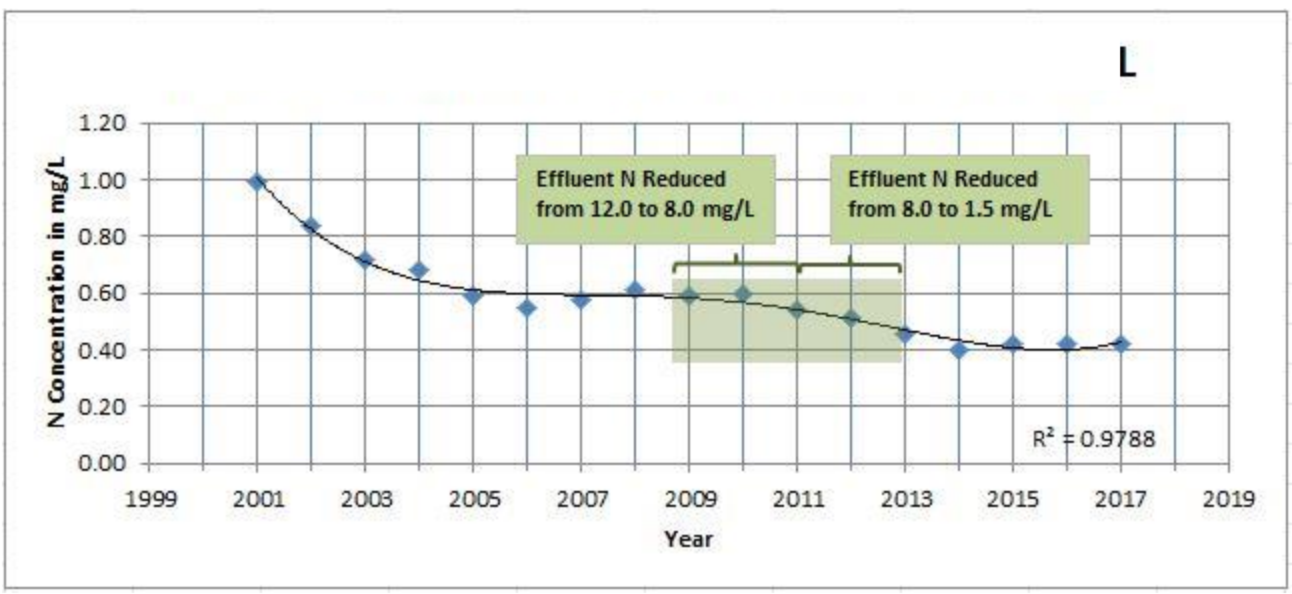


Figure D-2. Wakulla Spring Annual Nitrate Concentration



Source: Doug Barr (2018)

APPENDIX E
Wildlife Abundance Plots and Trends

This appendix presents plots of counts-per-survey and annual means for total animal abundance, i.e. the total numbers of animals counted per survey. It also presents average monthly mean count histograms, counts-per-survey plots, and annual means for each wildlife species monitored plus short explanatory narratives. Plots are included for the entire period of record, 1992-2018, and for three perturbation periods described above: hydrilla invasion (1992-2000), hydrilla management (2000-2012), and post-hydrilla management (2012-2018).[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) ≤ 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 means are presented as annual seasonal monthly means. Because of the seasonal gaps, the counts-per-survey data are presented as scatter plots without lines connecting the data points where seasonal data are analyzed.

<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

Regression statistics:

1. 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 than by a model with no predictor variables.
2. 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*: $m = (y_2 - y_1)/(x_2 - x_1)$.
3. 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 2018, the predictor variable, date, explains 30% of the observed variation in the counts-per-survey of the species.

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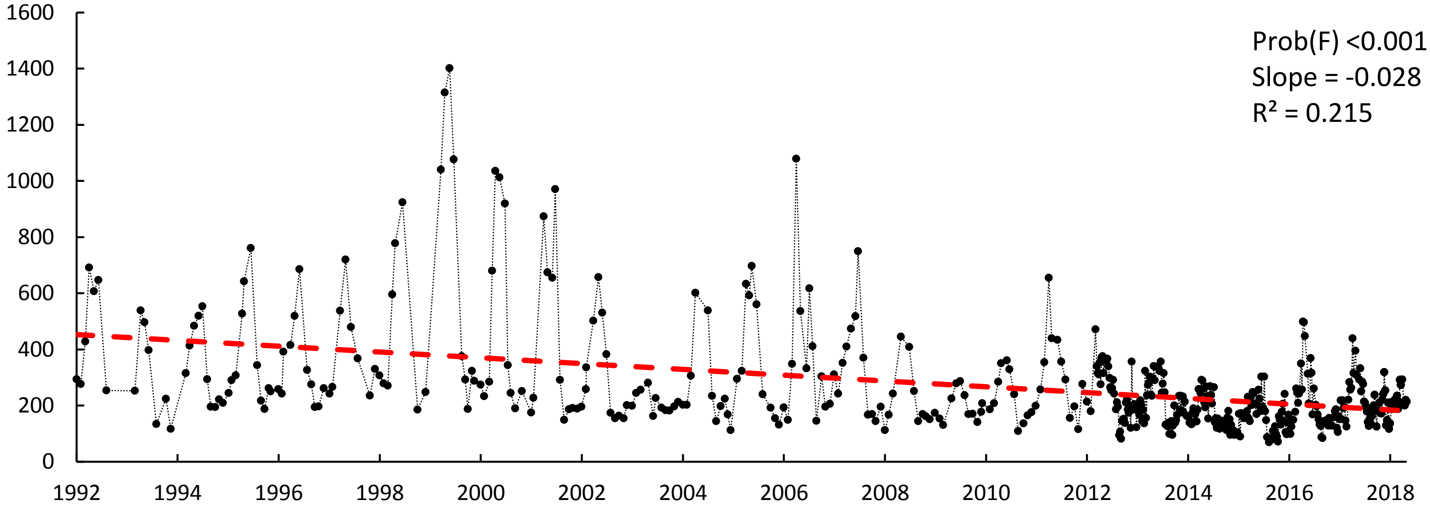
[1] Park staff conducted wildlife surveys monthly beginning in fall 1992. Volunteers began weekly monitoring in fall 2012 resulting in a higher density of data points between 2012 and 2018 on the counts per survey plots.

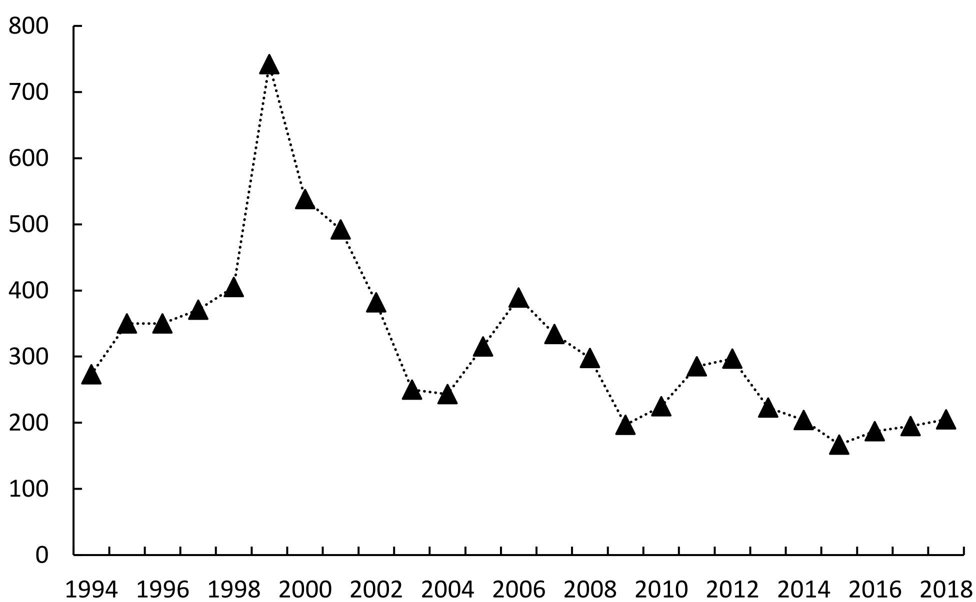
TOTAL WILDLIFE ABUNDANCE

27-year (1992-2018) Total Abundance (counts per survey)



Total wildlife counts per survey on the upper Wakulla River exhibit a significant (99.9% level or better) decreasing abundance trend of -0.028 animals counted per day or 10.22 counts per year[2] over the period of record, 9/1/92 – 12/29/18. Survey date explains 21.5% of the observed variation in counts per survey.

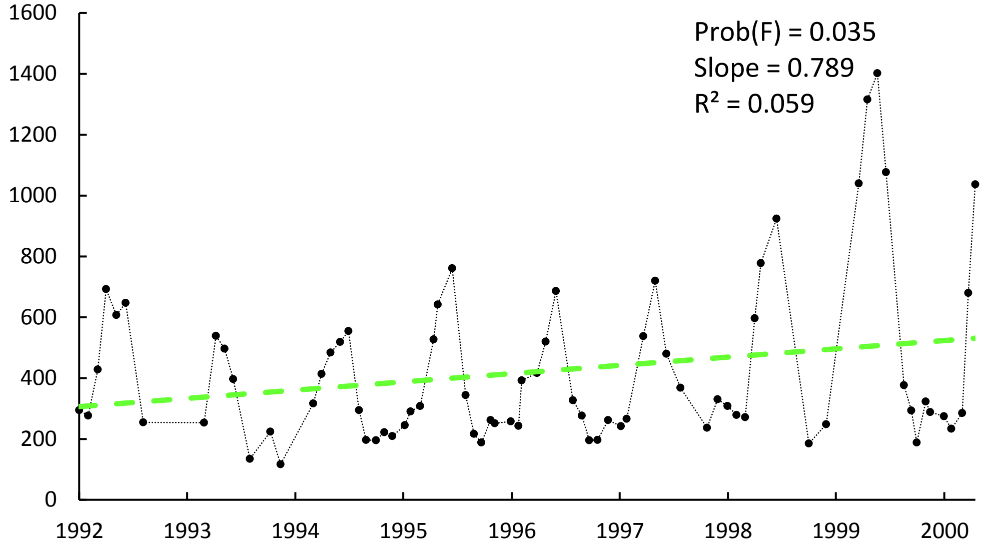
25-year (1994-2018) Total Abundance (annual means)



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.

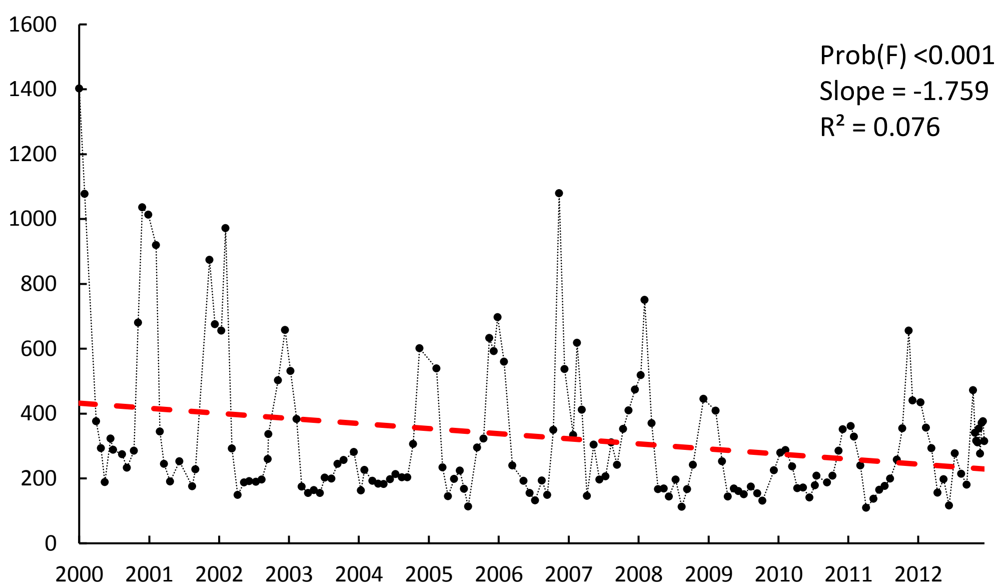
[2] Calculated from 6-digit values in regression output rather than rounded slope values displayed in figure.

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



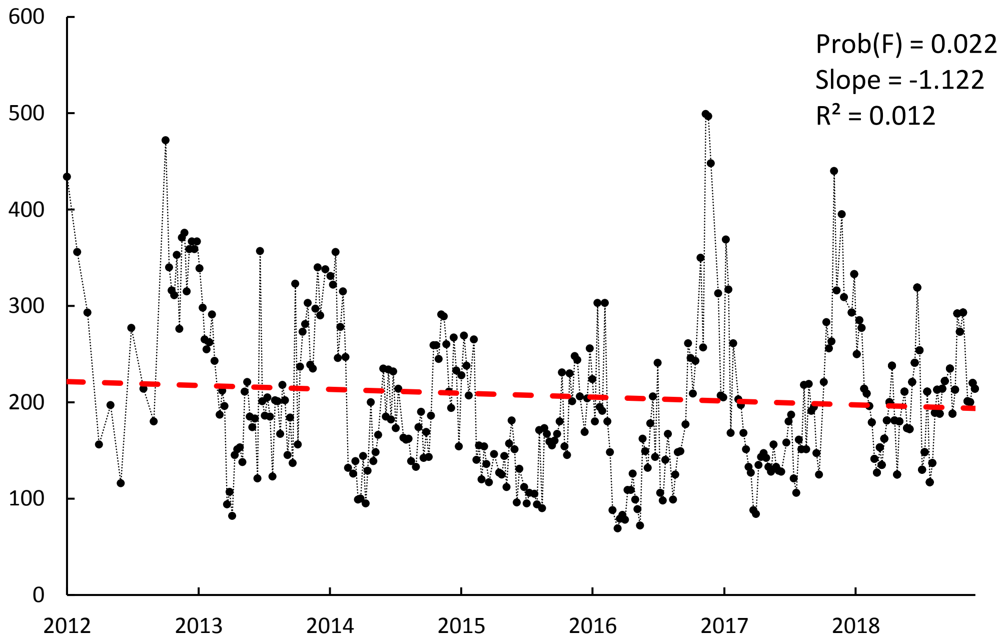
Total animal abundance increased significantly (96.5% level) during the 1992-2000 hydrilla invasion period with a trend that explains 5.9% of the observed variation.

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



Total animal abundance decreased significantly (99.9% level or better) during the 2000-2012 period of intense hydrilla management efforts with a trend that explains 7.6% of the observed variation.

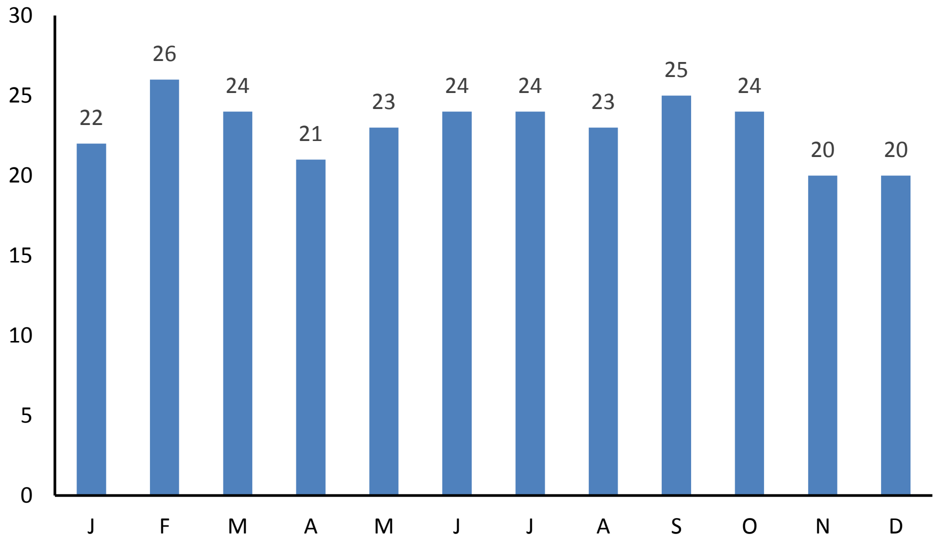
Abundance Post- Hydrilla Management: 2012-2018 (counts per survey)



Total animal abundance continued to decrease significantly (97.8% level) during the 2012-2018 post hydrilla management period with a trend that explains 1.2% of the observed variation.

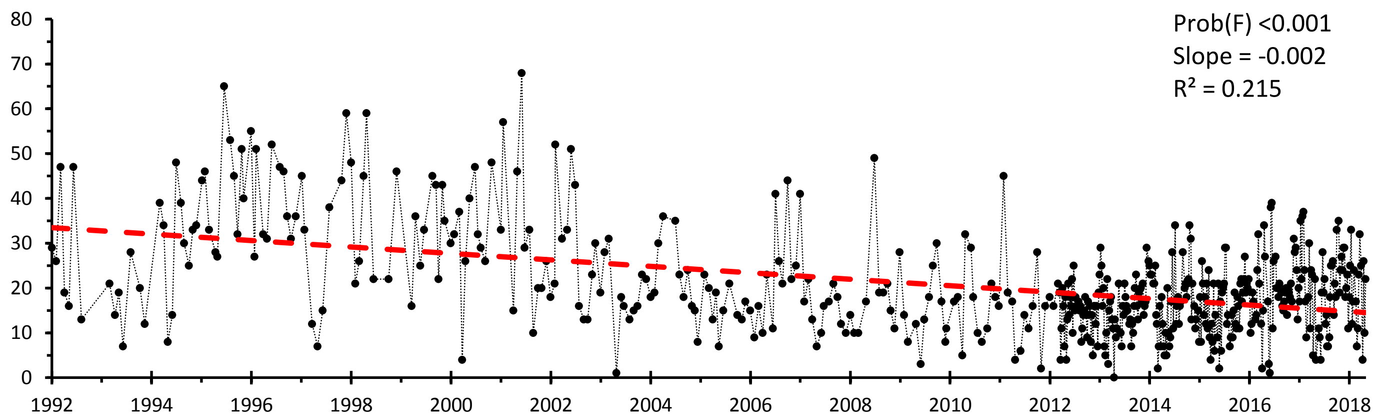
AMERICAN ALLIGATOR

Seasonal Abundance 1992-2018 (average monthly means)



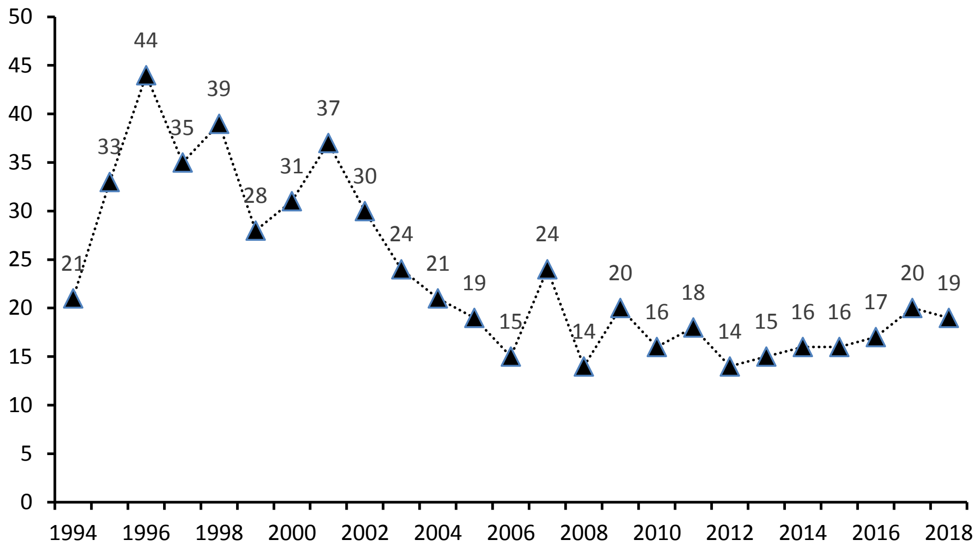
The American alligator is a year-round breeding resident of the upper Wakulla River. Abundance is fairly constant throughout the year.

Abundance 1992-2018 (counts per survey)



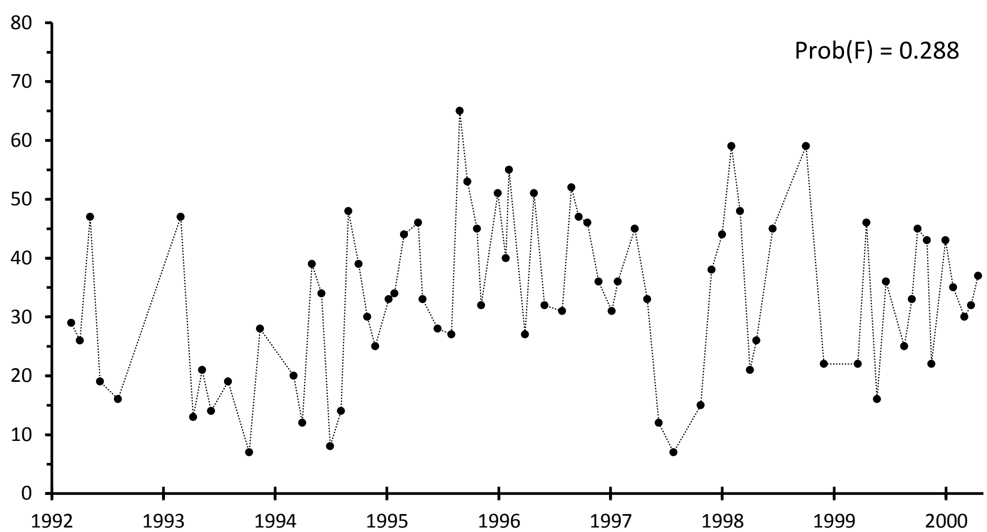
The alligator exhibited a significant (99.9% level or better) decreasing abundance trend of -0.002 animals counted per day or -0.72 counts per year over the period of record, 9/1/92 – 12/29/18. Survey date explains 21.5% of the observed variation in counts per survey.

Abundance 1994-2018 (annual means)



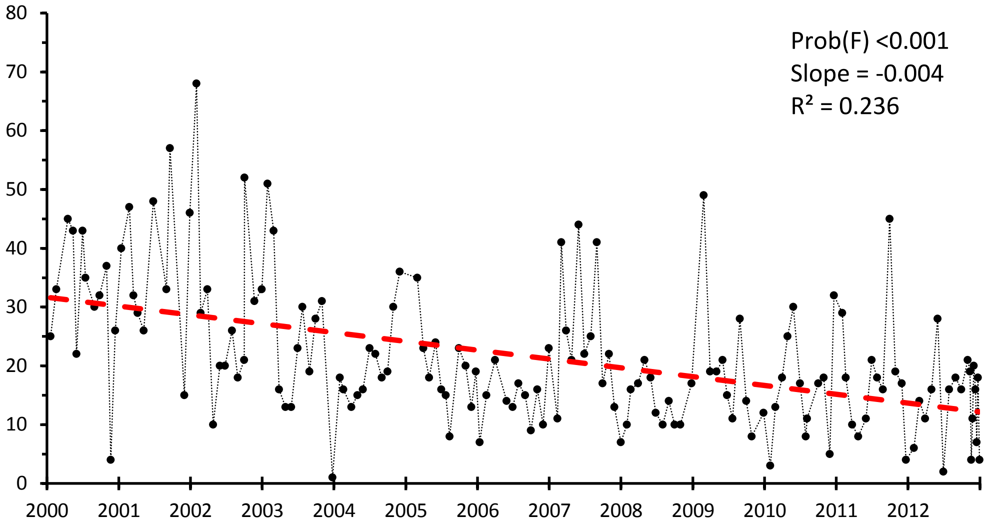
Annual means reveal the decreasing abundance trend. Peak abundance occurred in 1996, while a sharp decline began in 2001 and continued to 2006. Annual means began a steady increase in 2013.

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



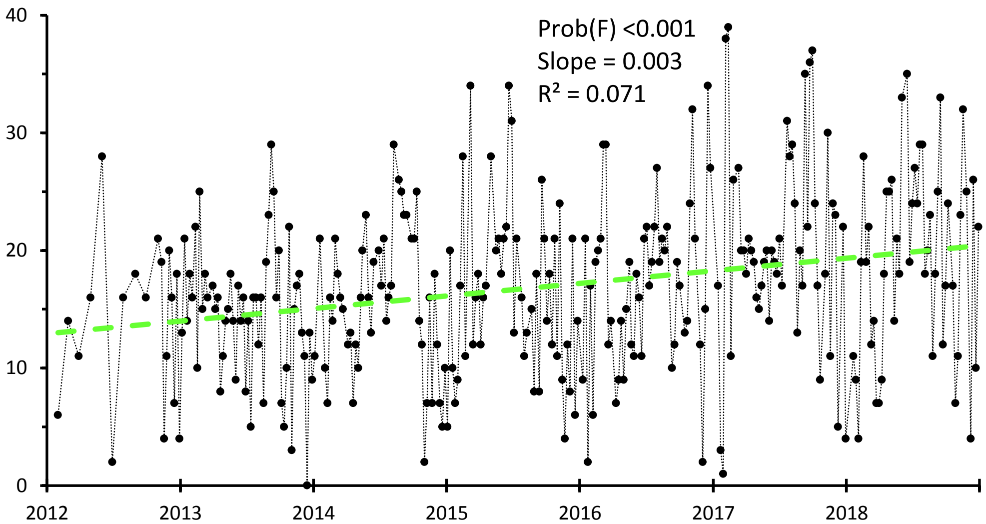
Alligator abundance exhibited no statistically significant trend during the 1992-2000 hydrilla invasion period. Counts per survey ranged from 7 to 65 and averaged 33 alligators.

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



Alligator abundance decreased significantly (99.9% level or better) during the 2000-2012 period of intense hydrilla management efforts with a trend that explains 23.6% of the observed variation.

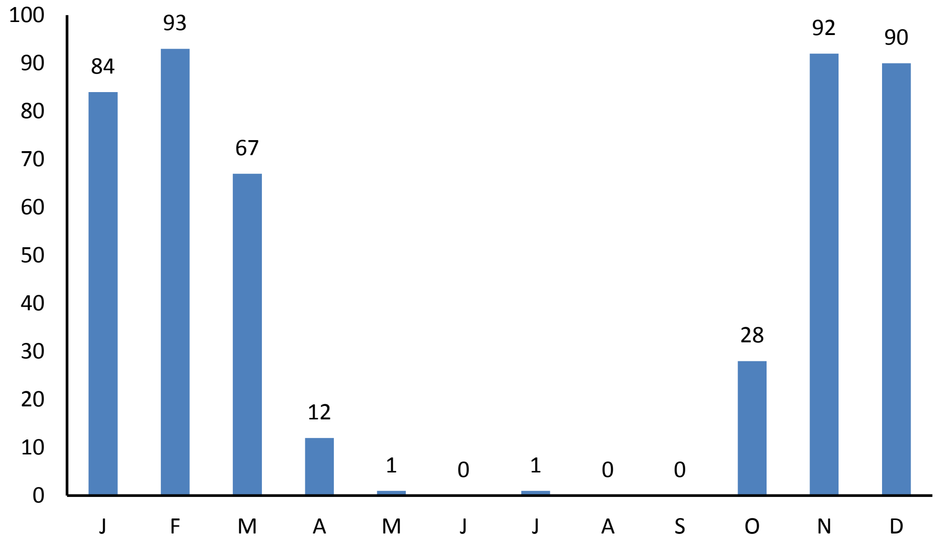
Abundance Post- Hydrilla Management: 2012-2018 (counts per survey)



Alligator abundance began to increase in 2013. The significant positive trend (99.9% level or better) explains 7.1% of the observed variation in alligator counts per survey.

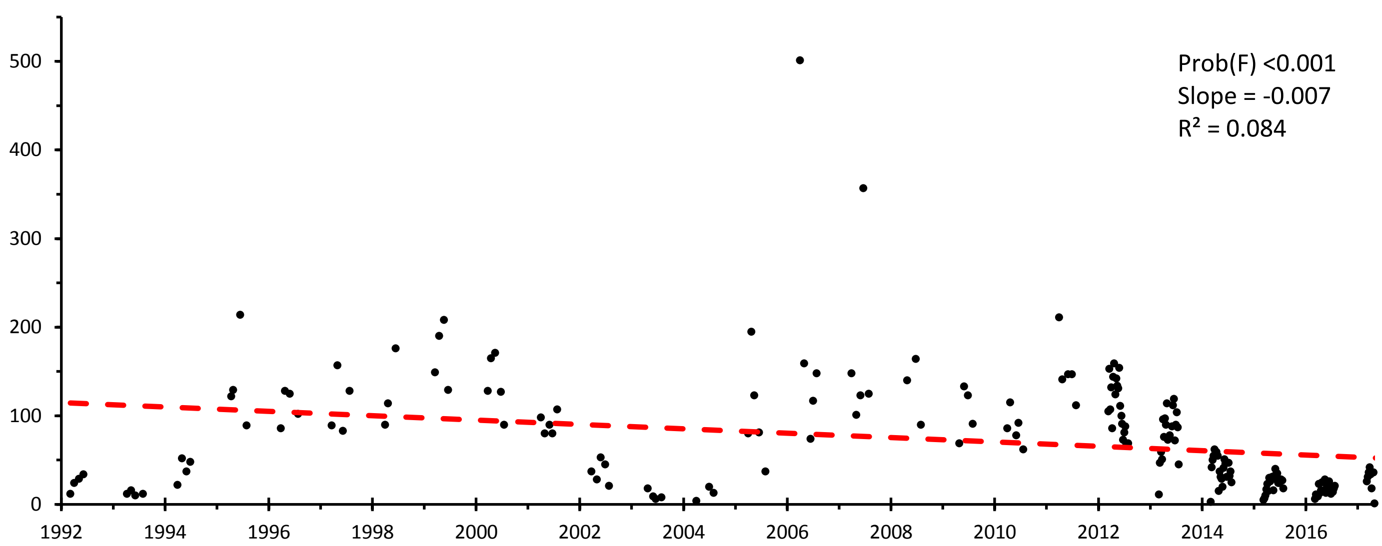
AMERICAN COOT

Seasonal Abundance 1992-2018 (average monthly means)



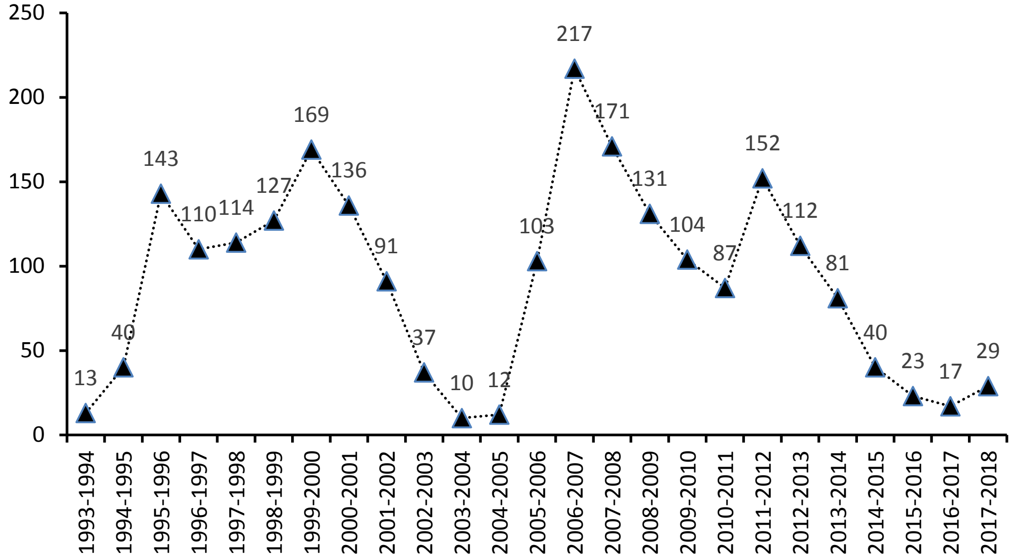
The American coot is a winter migrant to the upper Wakulla River. Abundance peaks during the months of November through March.

Seasonal Abundance Nov-Mar 1992-93 – 2017-18 (counts per survey)



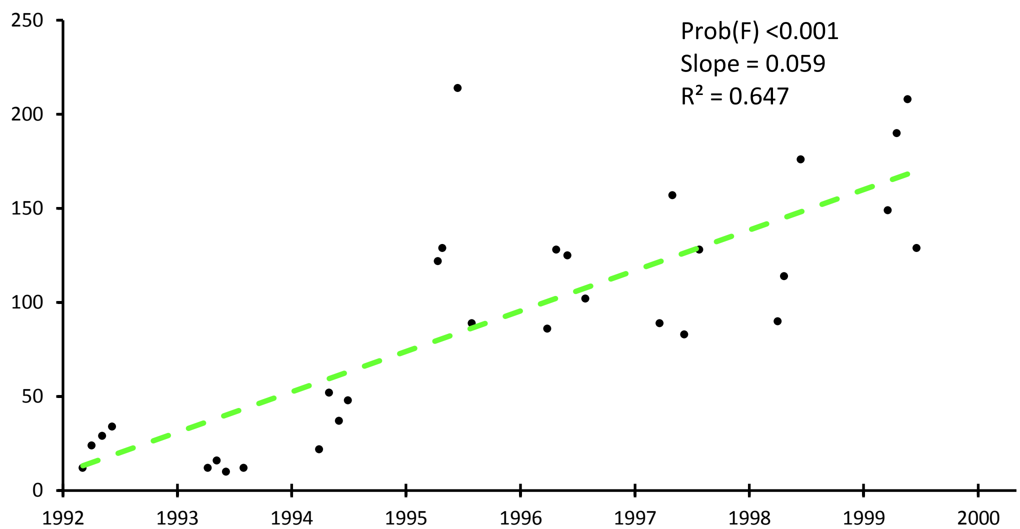
The American coot exhibited a significant (99.9% level or better) decreasing seasonal abundance trend of -0.007 animals counted per day or -1.46 counts per year over the period of record, 9/1/92 – 12/29/18. Survey date explains 8.4% of the observed variation in counts per survey.

Seasonal Abundance Nov-Mar 1993-94 – 2017-18 (winter monthly means)



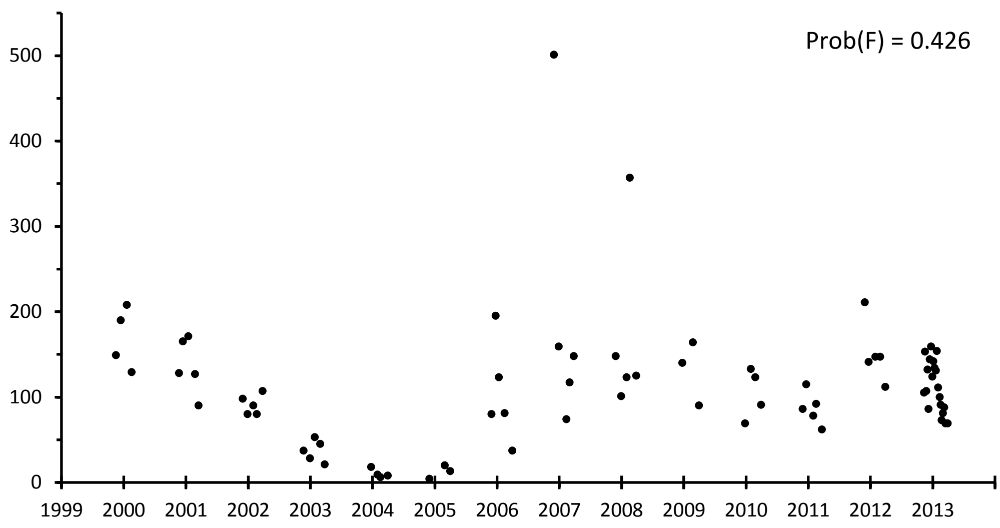
Winter monthly means reveal multiple peaks and valleys with an initial decline beginning in 2000-2001. Secondary peaks occurred in 2006-07 and 2011-12 after which winter monthly means declined until 2017-18 when a slight increase occurred.

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



American coot seasonal abundance exhibited a significant increase (99.9% level or better) 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)



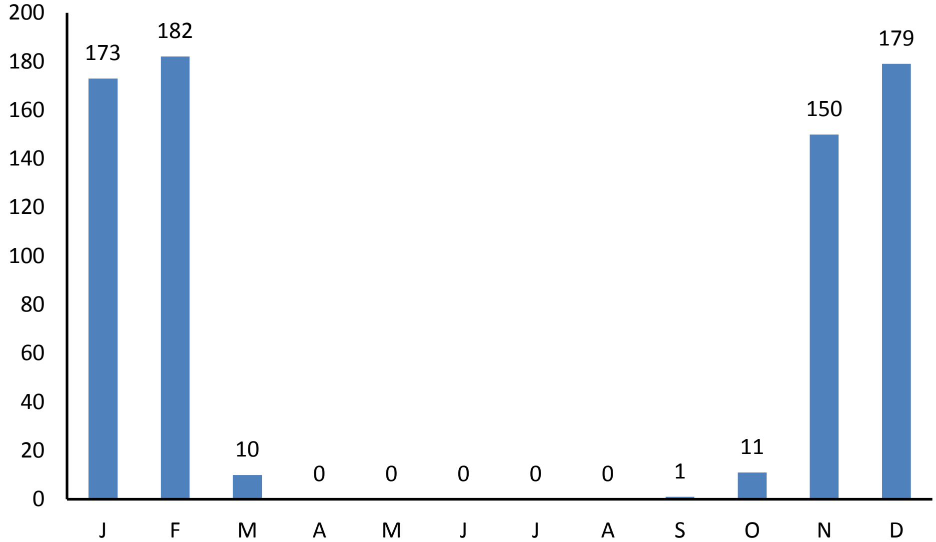
The American coot exhibited no significant trend in seasonal abundance during the hydrilla management period. Counts per survey ranged from 4 to 501 and averaged 112 coots.

Seasonal Abundance Post- Hydrilla Management: Nov-Mar 2012-13 – 2017-18 (counts per survey)

American coot seasonal abundance decreased significantly (99.9% level or better) during the post-hydrilla management period with a trend that explains 60.8% of the observed variation.

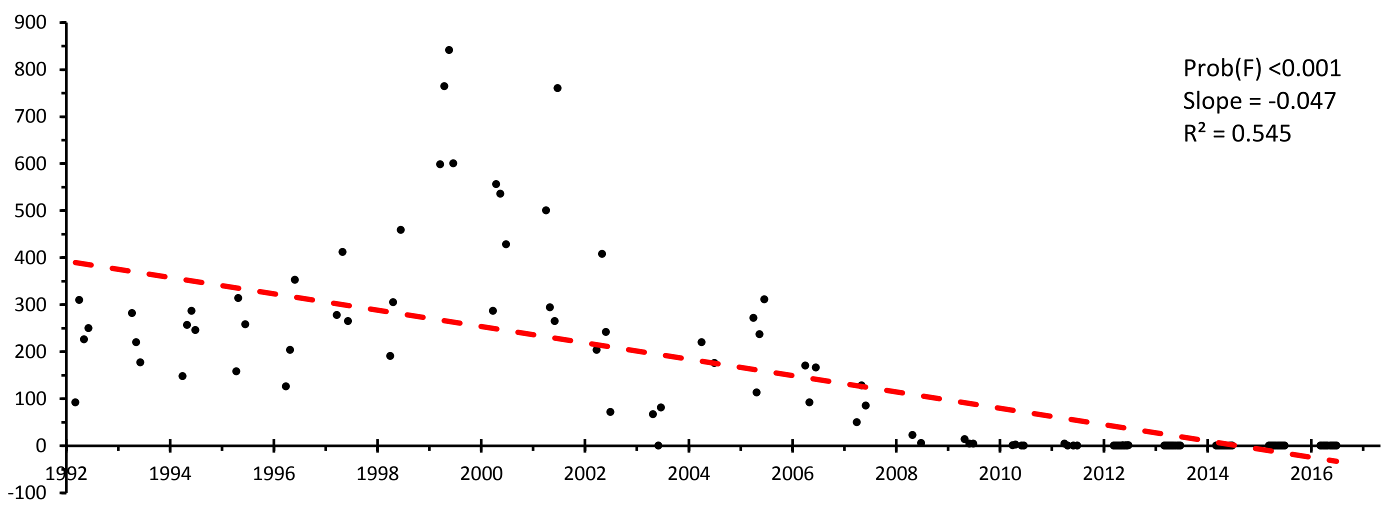
AMERICAN WIGEON

Seasonal Abundance 1992-2017 (average monthly means)[3]



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.

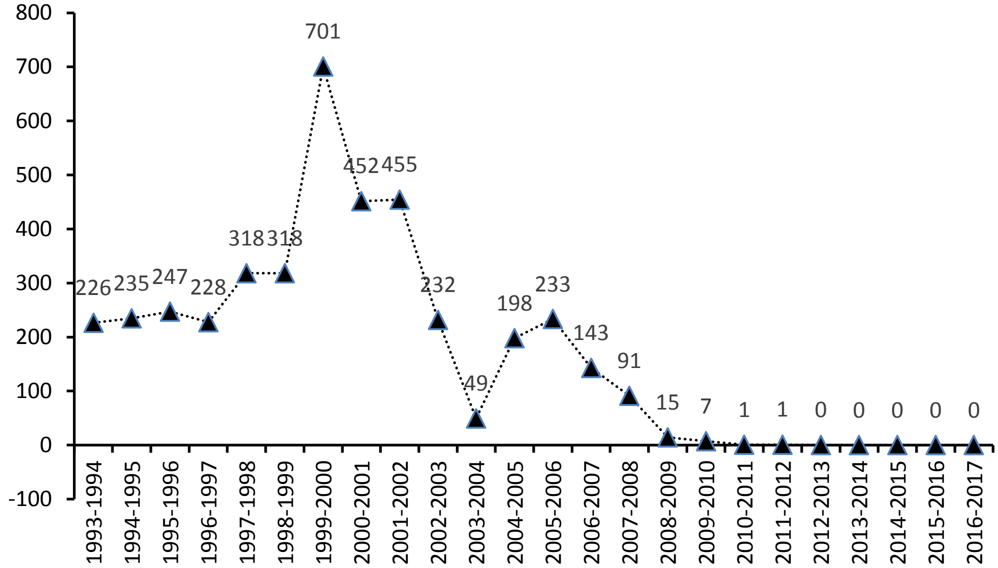
Seasonal Abundance Nov-Feb 1992-93 – 2016-17 (counts per survey)



The American wigeon exhibited a significant (99.9% level or better) decreasing seasonal abundance trend of -0.047 animals counted per day or -17.37 counts per year over the period of record, 9/1/92 – 12/29/18. Survey date explains 54.5% of the observed variation in counts per survey.

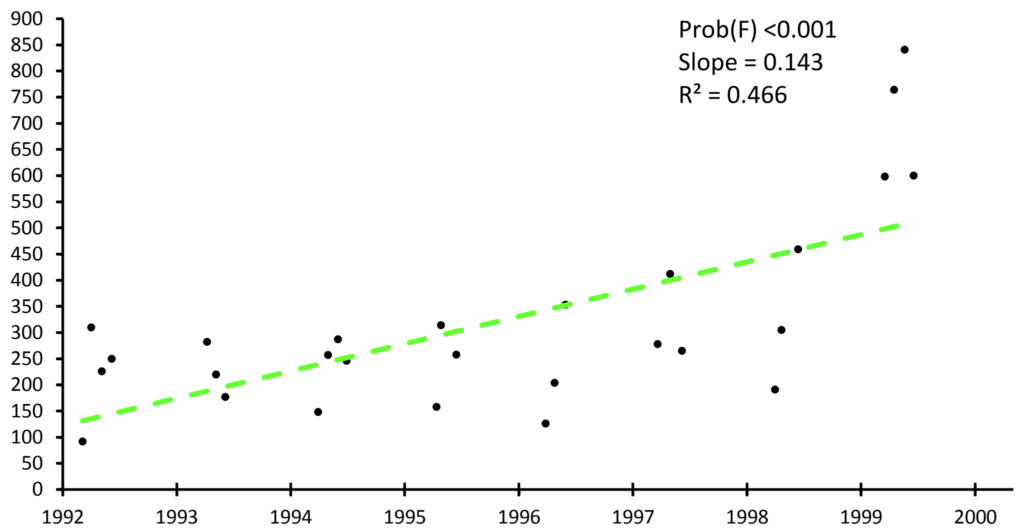
[3] The American wigeon was dropped from the survey form in 2018.

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



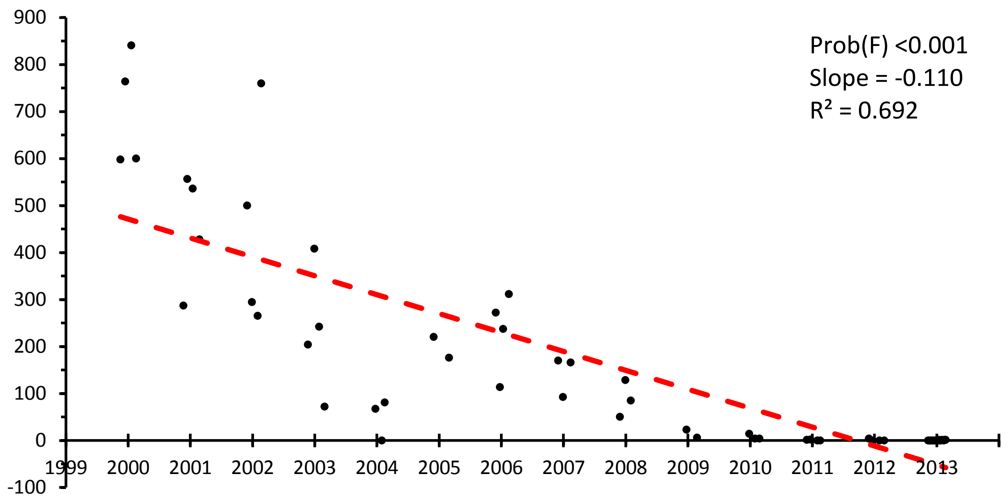
Winter monthly means reveal a prominent peak in 1999-2000 followed by a small secondary peak in 2005-06 after which winter monthly mean abundance declined to 1 in 2010-2011 and 0 by 2012-13.

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



American wigeon seasonal abundance exhibited a significant increase (99.9% level or better) 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)



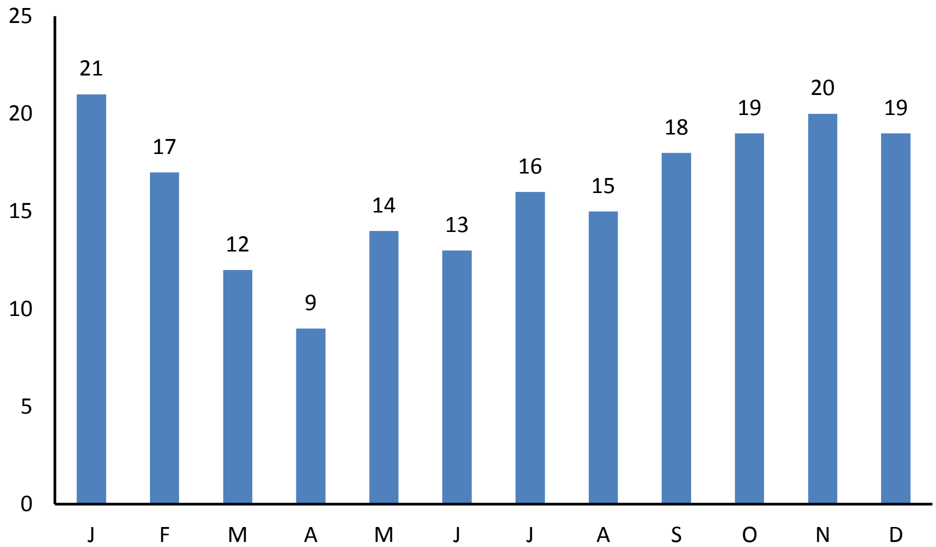
The trend in seasonal abundance reversed during the hydrilla management period exhibiting a significant decrease (99.9% level or better) that explains 69.2% of the observed variation in winter counts per survey.

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 (98.7% level) decrease with a trend that explains 7.8% of the observed variation.

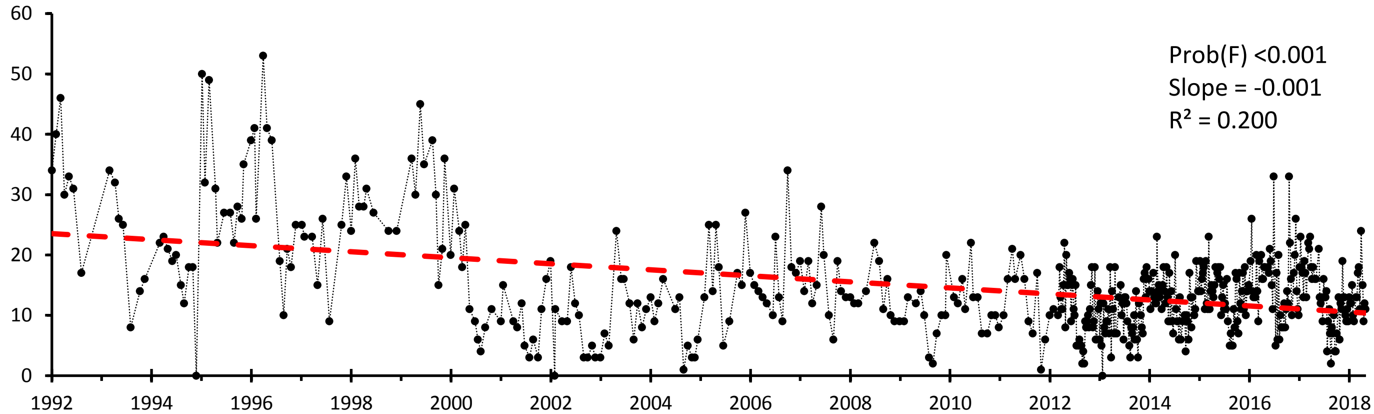
ANHINGA

Seasonal Abundance 1992-2018 (average monthly means)



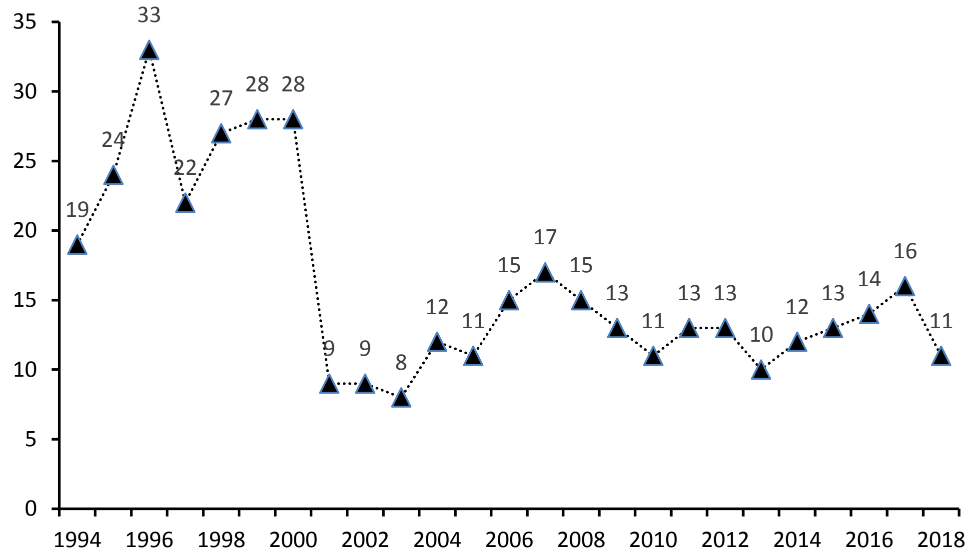
The anhinga is a year-round breeding resident of the upper Wakulla River. Abundance peaks during fall and early winter and is lowest leading into the late spring/early summer breeding period.

Abundance 1992-2018 (counts per survey)



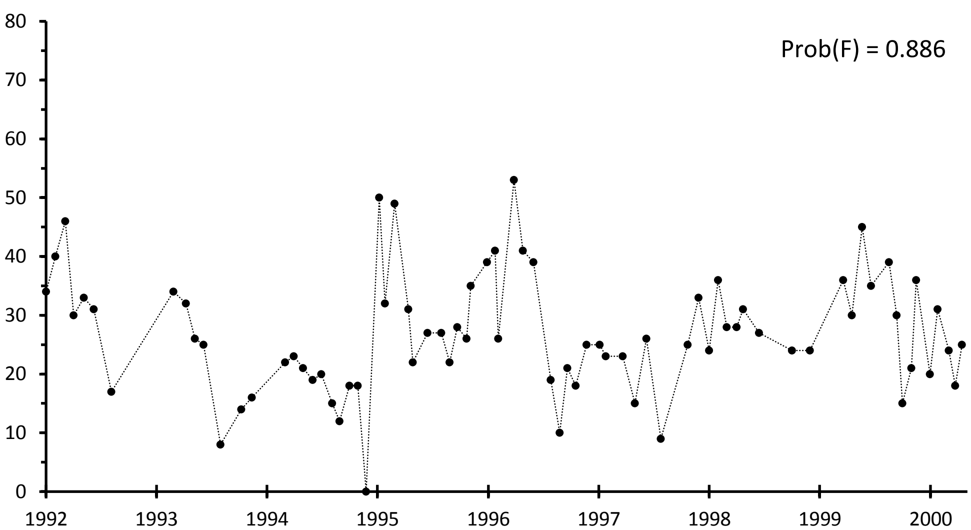
The anhinga exhibited a significant (99.9% level or better) decreasing abundance trend of -0.001 animals counted per day or -0.50 counts per year over the period of record, 9/1/92 – 12/29/18. Survey date explains 20.0% of the observed variation in counts per survey.

Abundance 1994-2018 (annual means)



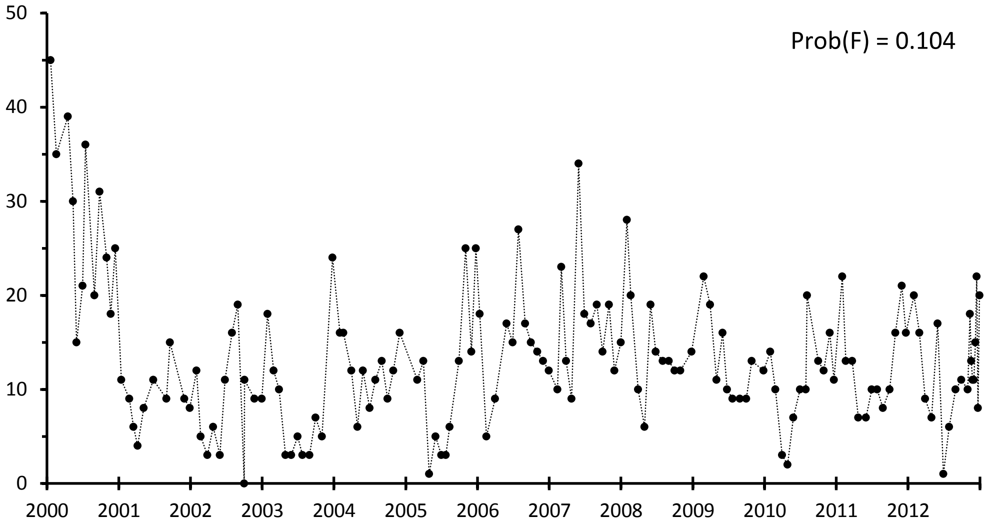
Annual means reveal a steep decrease in 2001 from which the species has not fully recovered exhibiting a fairly steady oscillation since 2005.

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



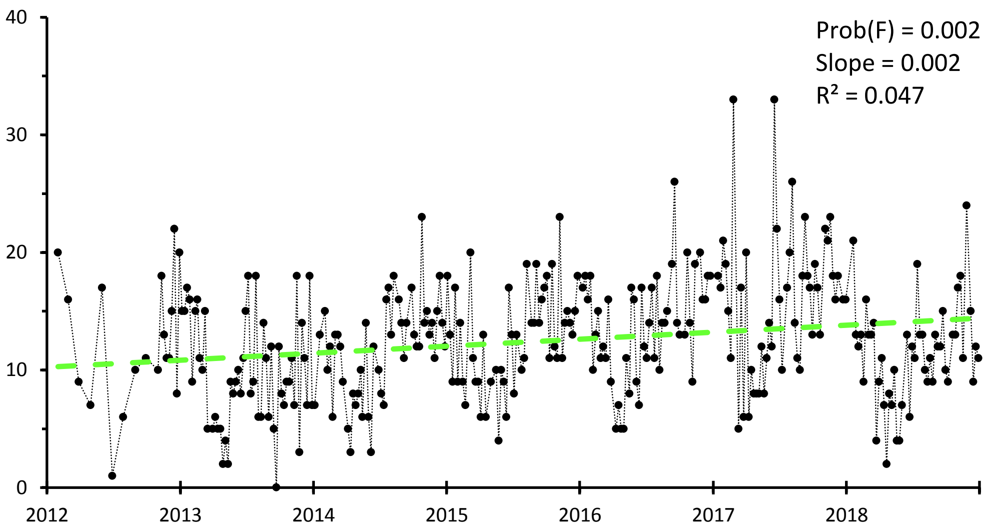
The anhinga exhibited no statistically significant trend in abundance during the 1992-2000 hydrilla invasion period. Counts per survey ranged from 0 to 53 and averaged 27 animals.

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.

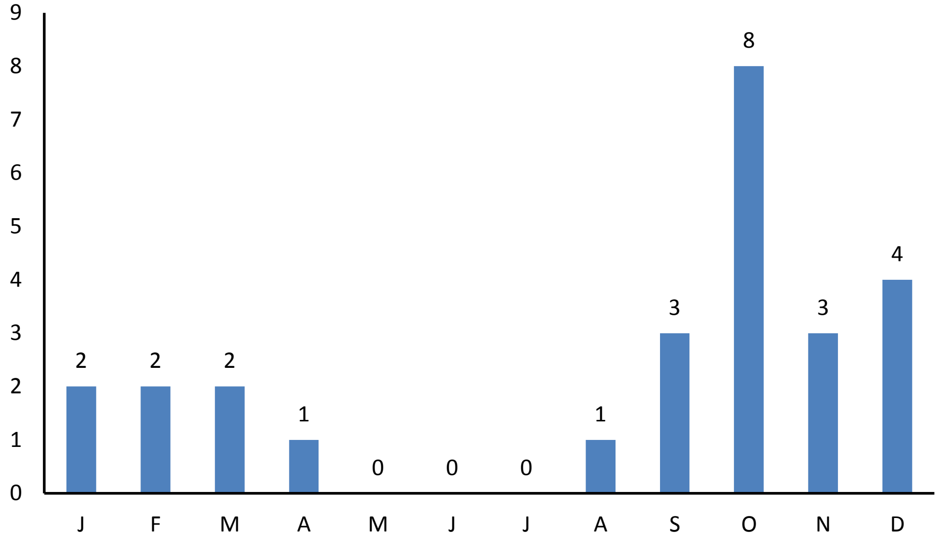
Abundance Post- Hydrilla Management: 2012-2018 (counts per survey)



A significant (99.8% level) positive trend emerged during the post-hydrilla management period that explained 4.7% of the observed variation in counts per survey.

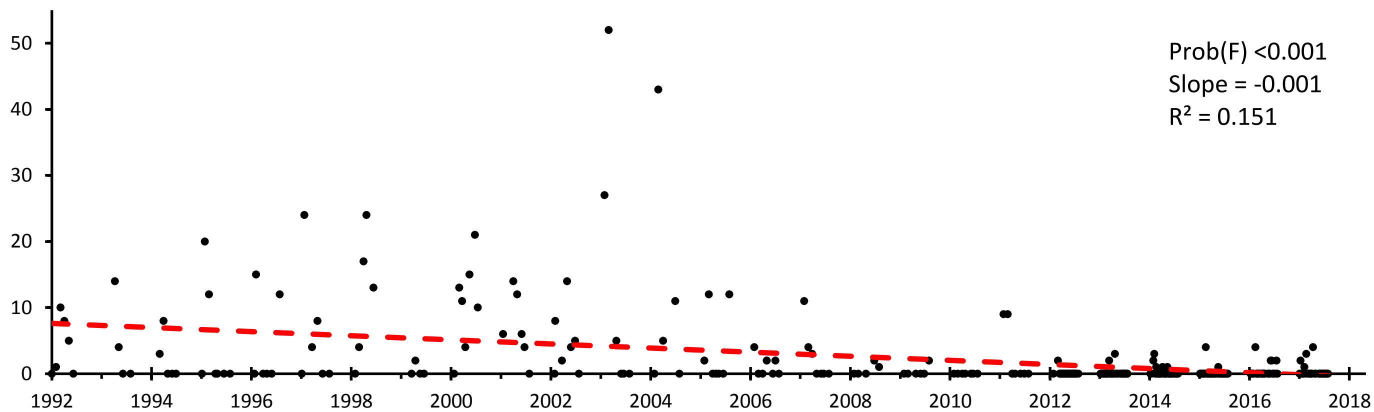
BLUE-WINGED TEAL

Seasonal Abundance 1992-2018 (average monthly means)



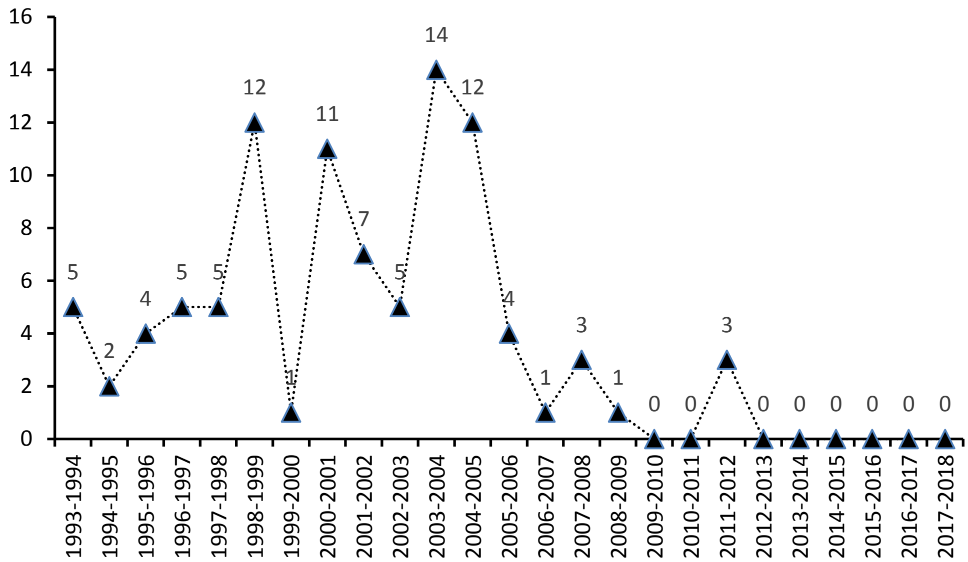
The blue-winged teal is a winter migrant to the upper Wakulla River that has not been present in large numbers since the early 2000s. It is most commonly seen in the fall and early winter (Sept-Mar).

Seasonal Abundance Sep-Mar 1992-93 – 2017-18 (counts per survey)



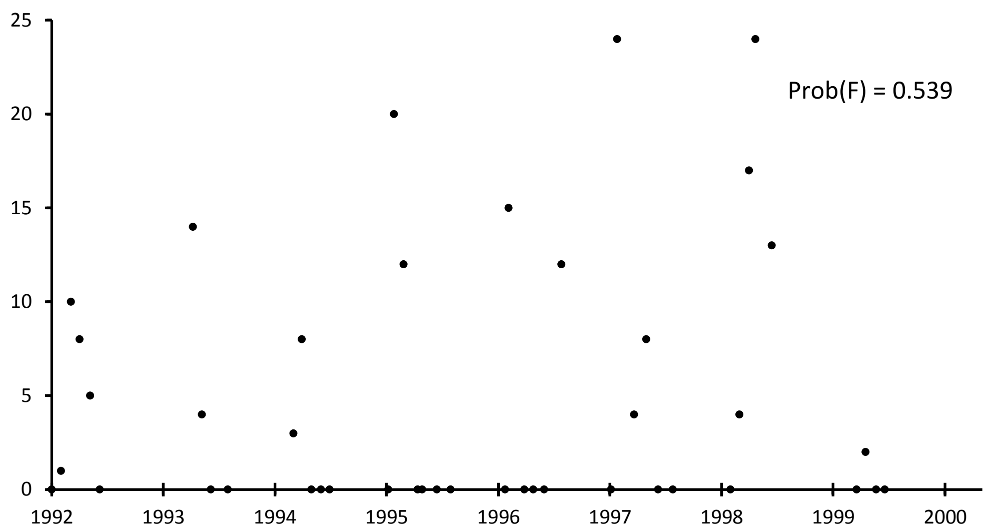
The blue-winged teal exhibited a significant (99.9% level or better) decreasing seasonal abundance trend of -0.001 animals counted per day or -0.31 counts per year over the period of record, 9/1/92 – 12/29/18. Survey date explains 15.1% of the observed variation in counts per survey.

Seasonal Abundance Sep-Mar 1993-94 – 2017-18 (winter monthly means)



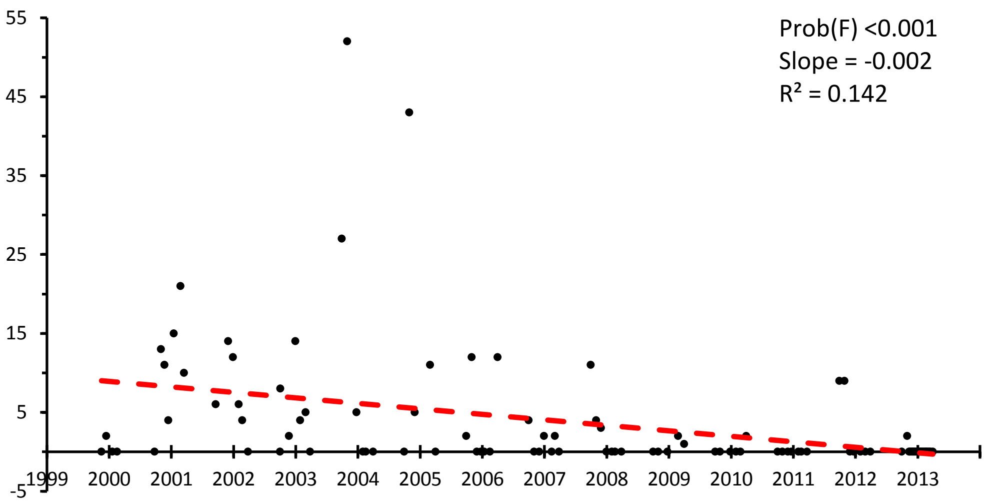
Winter monthly means reveal large oscillations between 1997-98 and 2003-04 followed by a steep decline from which the species has not recovered.

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



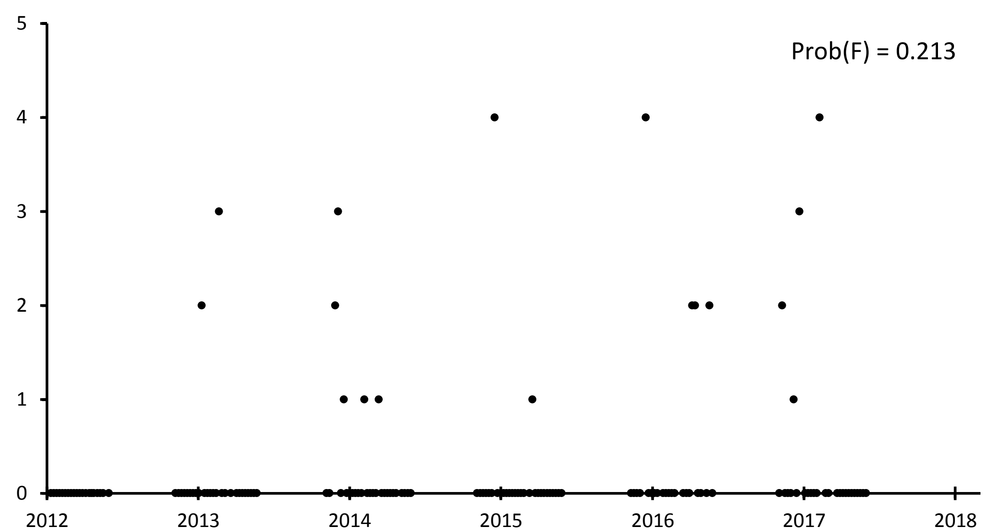
Blue-winged teal exhibited no statistically significant trend in abundance during the 1992-2000 hydrilla invasion period. Counts per survey ranged from 0 to 24 and averaged 5 animals.

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



A significant decreasing abundance trend (99.9% level or better) emerged during the hydrilla management period. It explains 14.2% of the observed variation in winter counts per survey.

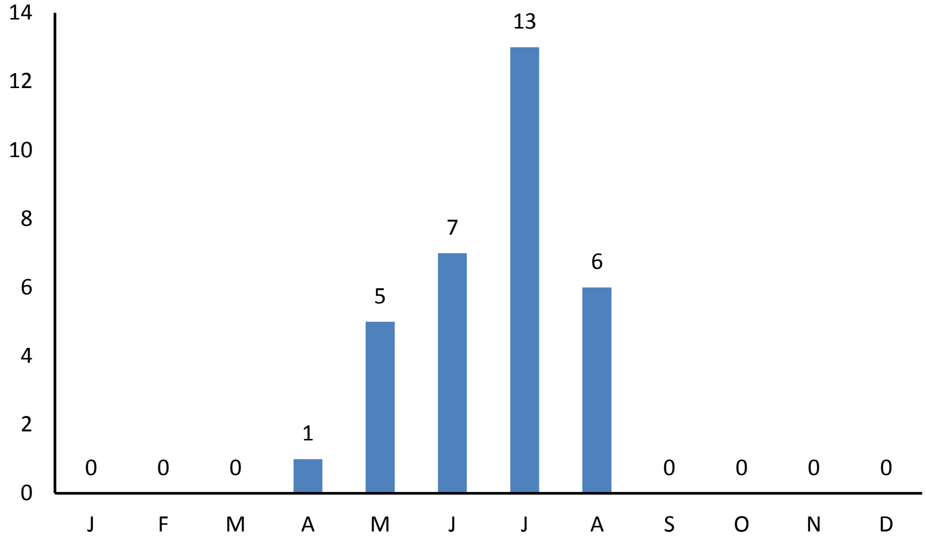
Seasonal Abundance Post- Hydrilla Management: Sep-Mar 2012-13 – 2017-18 (counts per survey)



The blue-winged teal exhibited no significant trend during the post-hydrilla management period as the average count per survey dropped to 0.25 with a range of 0 to 4 animals.

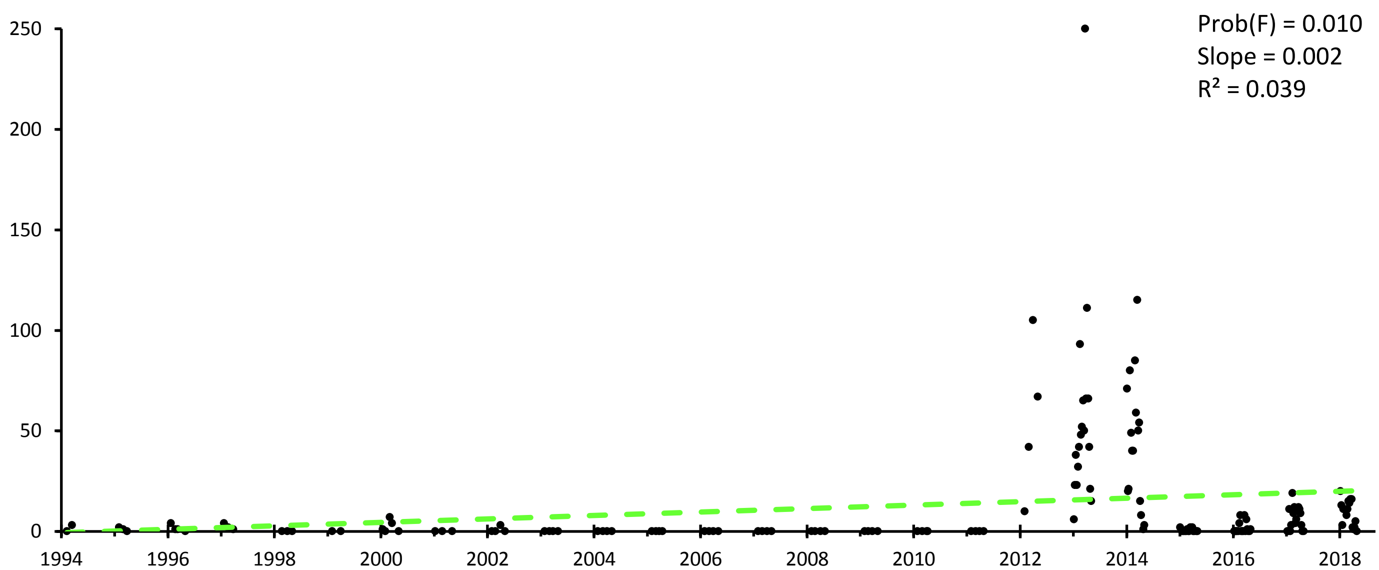
CATTLE EGRET

Seasonal Abundance 1992-2018 (average monthly means)



The cattle egret is an occasional 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. Nesting colonies were established both along the river boat tour route and further down the river in 2012, 2013, and 2014.

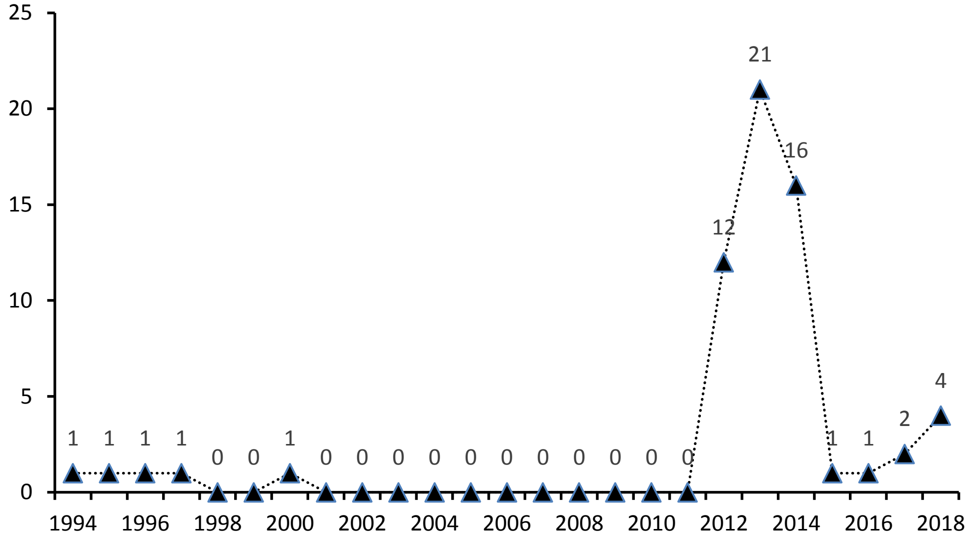
Seasonal Abundance May-Aug 1994-2018 (counts per survey) [4]



The cattle egret exhibited a significant (99.0% level) increasing seasonal abundance trend of 0.002 animals counted per day or 0.86 counts per year over the period analyzed, 6/8/94 – 8/25/18. Survey date explains 3.9% of the observed variation in counts per survey.

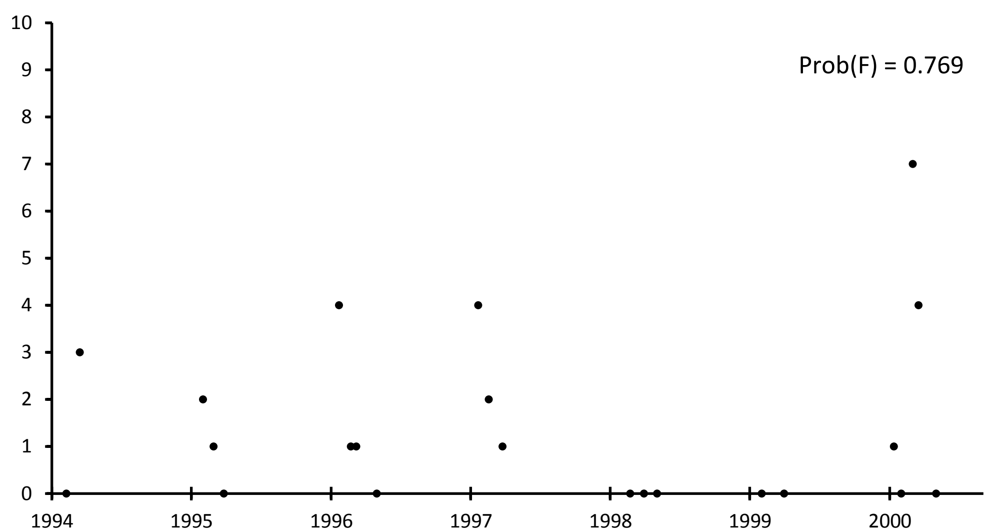
[4] No data were recorded for this species during its breeding season in 1992 or 1993.

Seasonal Abundance May-Aug 1994-2018 (summer monthly means)



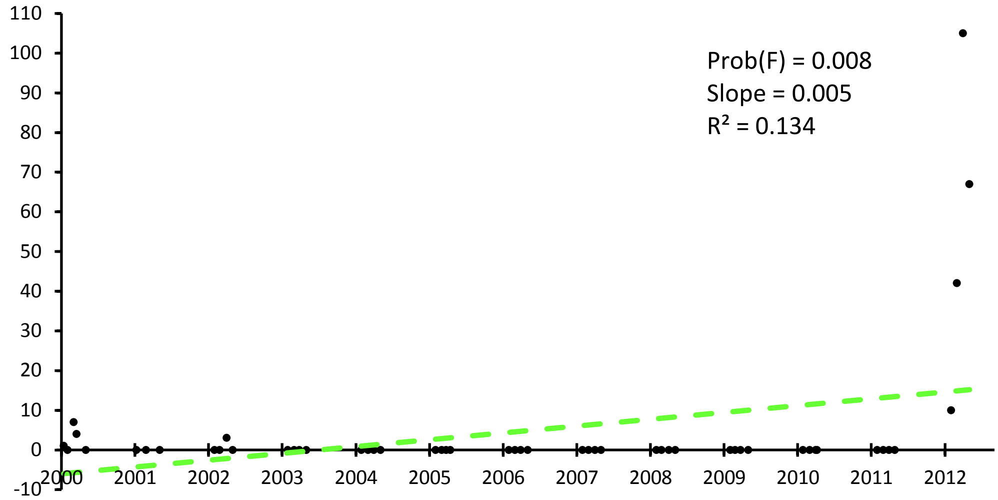
Summer monthly means reveal the peak cattle egret abundances associated with nesting on the upper river in 2012-2014.

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



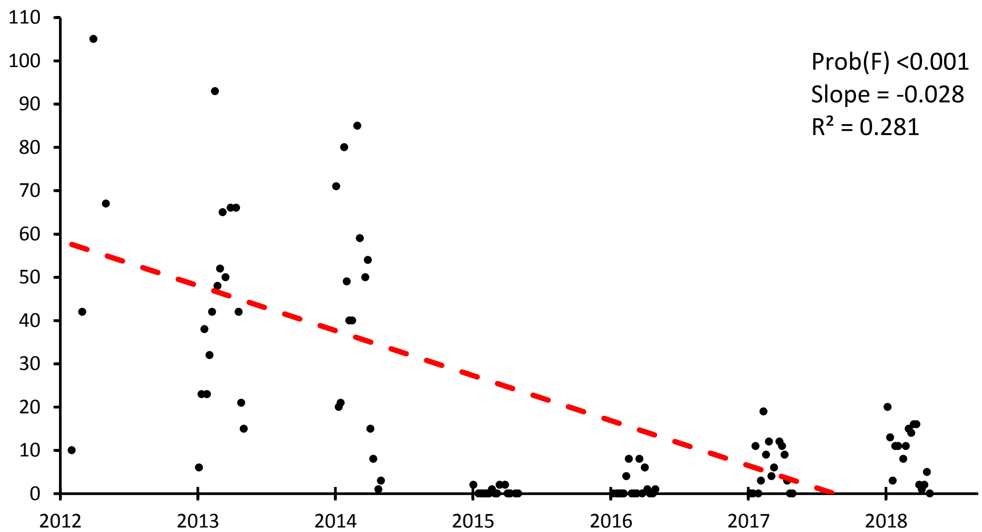
The cattle egret exhibited no statistically significant trend in abundance during the 1994-2000 hydrilla invasion period. Counts per survey ranged from 0 to 7 and averaged 1.4 animals.

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



A significant increasing abundance trend (99.2% 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.

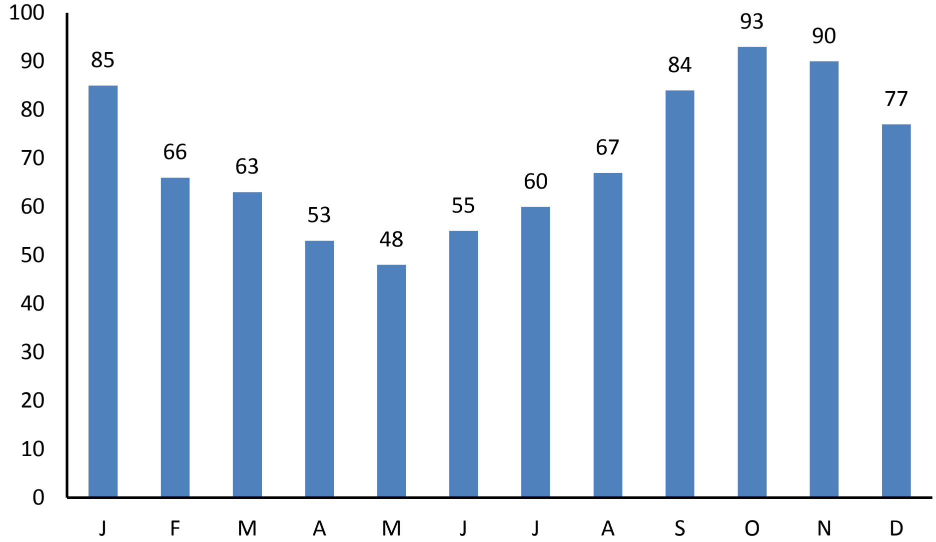
Seasonal Abundance Post- Hydrilla Management: May-Aug 2012-2018 (counts per survey)



The cessation of nesting along the upper river resulted in a significant (99.9% level or better) decrease in summer breeding season abundance during the post-hydrilla management period with a trend that explains 28.1% of the observed variation in counts per survey.

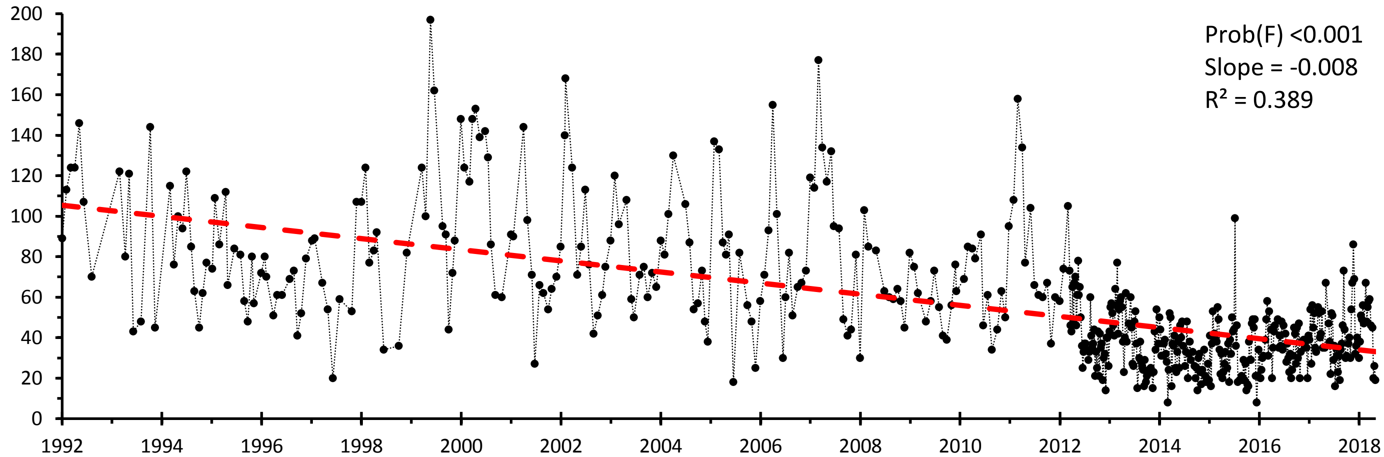
COMMON GALLINULE (COMMON MOORHEN)

Seasonal Abundance 1992-2018 (average monthly means)



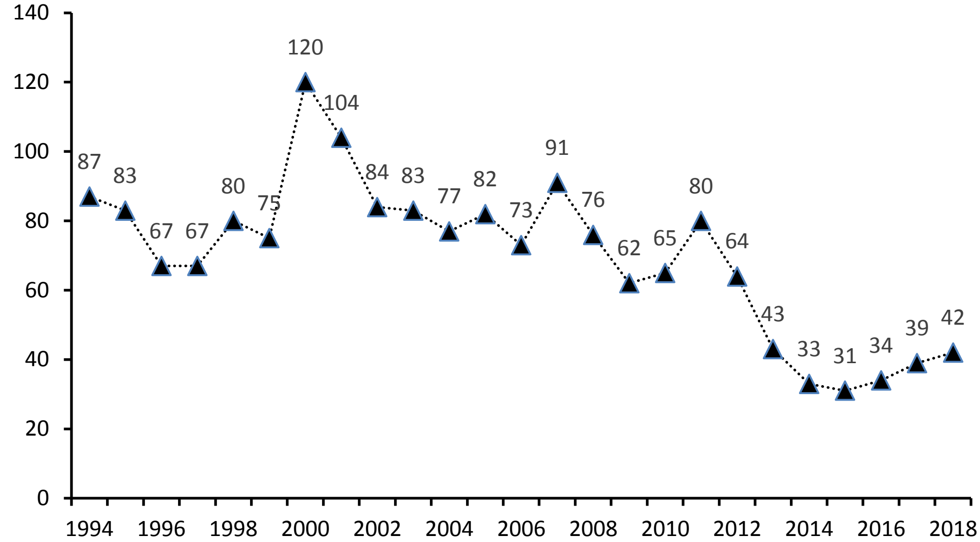
The common gallinule is a year-round breeding resident of the upper Wakulla River with a seasonal pattern of abundance which likely reflects both a summer breeding season with 2-3 broods per pair coupled with an influx of winter migrants joining the resident population (Bannor and Kiviat, 2002).

Abundance 1992-2018 (counts per survey)



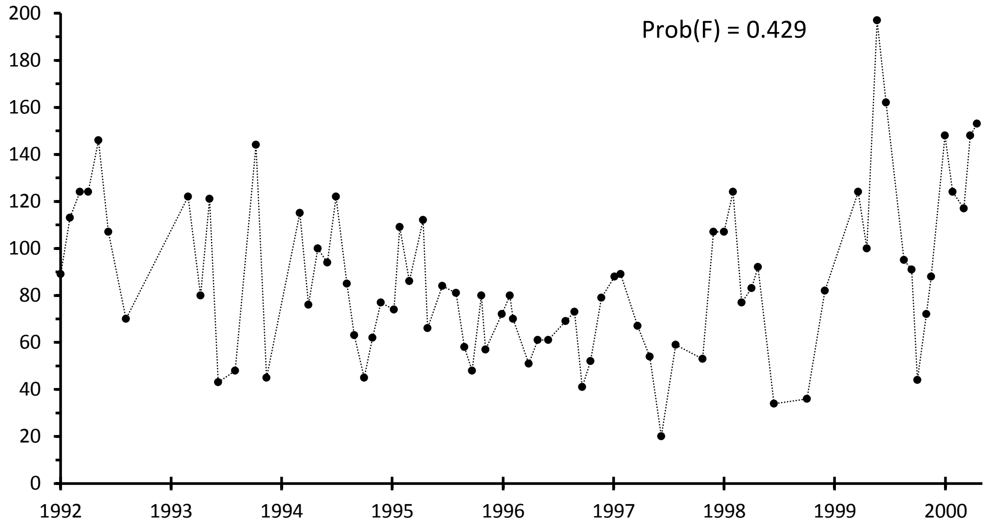
The common gallinule exhibited a significant (99.9% level or better) decreasing abundance trend of -0.008 animals counted per day or -2.92 counts per year over the period of record, 9/1/92 – 12/29/18. Survey date explains 38.9% of the observed variation in counts per survey.

Abundance 1994-2018 (annual means)



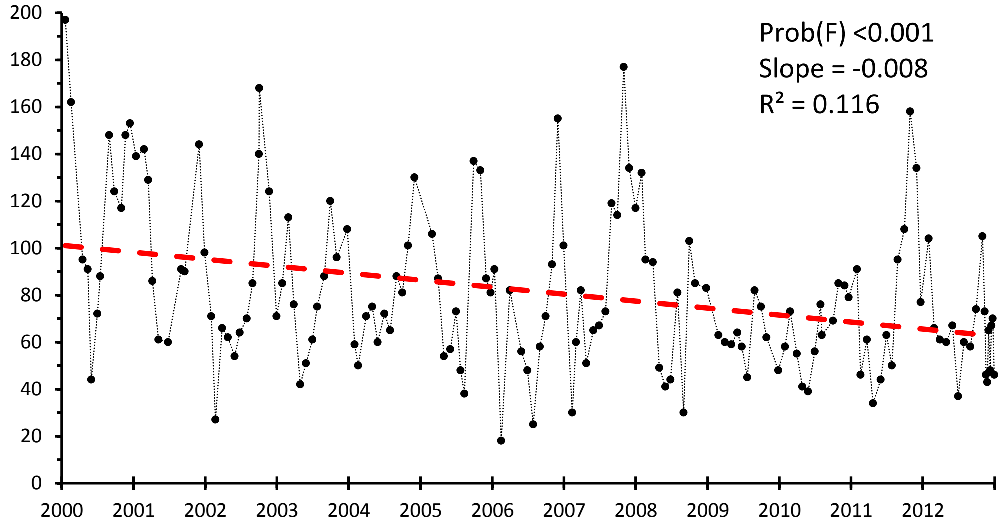
Annual means reveal a generally declining pattern since a peak in 2000. A second steep decline began in 2012 following an oscillating but slowly declining pattern between 2000 and 2011. Most recently, annual means have increased since 2015.

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



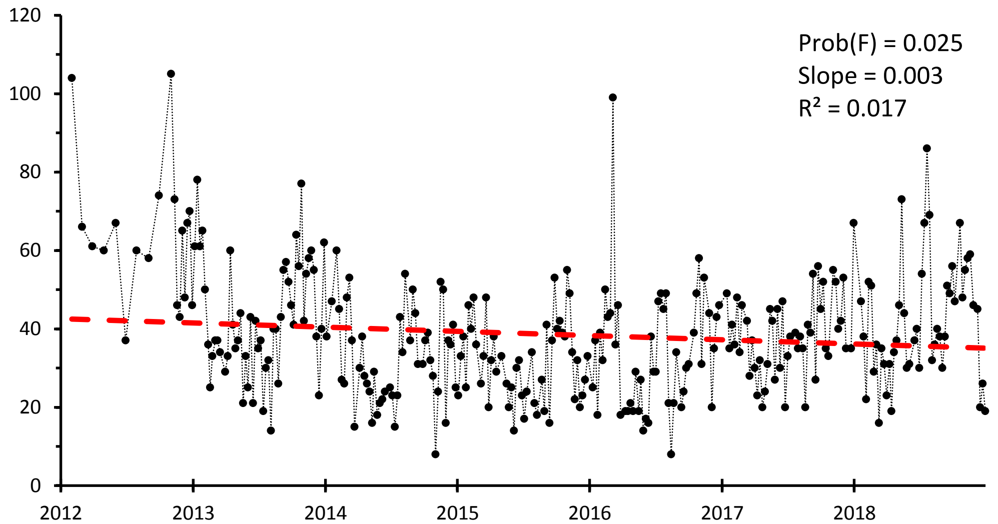
The common gallinule exhibited no statistically significant trend in abundance during the hydrilla invasion period. Counts per survey ranged from 20 to 197 and averaged 87 animals.

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



A significant (99.9% level or better) decline in abundance emerged during the hydrilla management period with a trend that explains 11.6% of the observed variation in counts per survey.

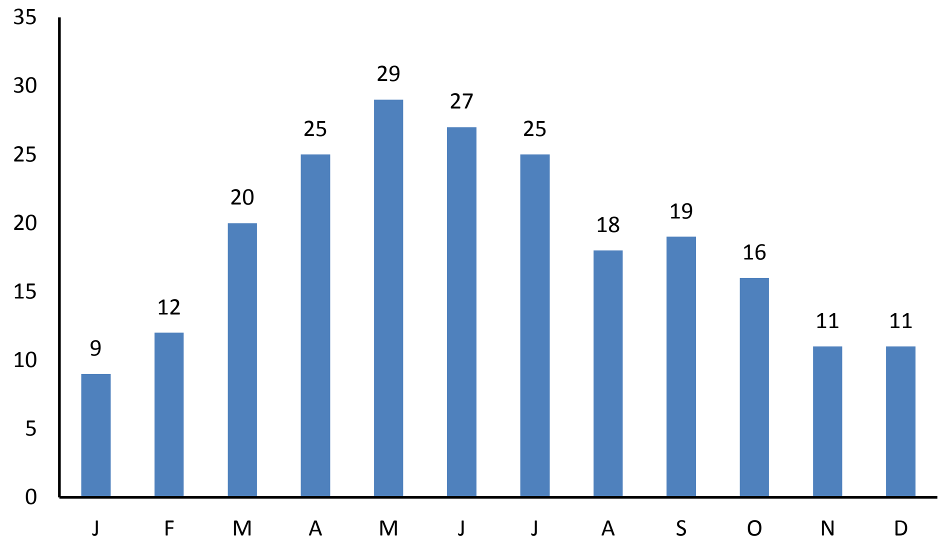
Abundance Post- Hydrilla Management: 2012-2018 (counts per survey)



The decline continued through the post-hydrilla management period with a significant (97.5% level) negative trend that explained 1.7% of the observed variation in counts per survey.

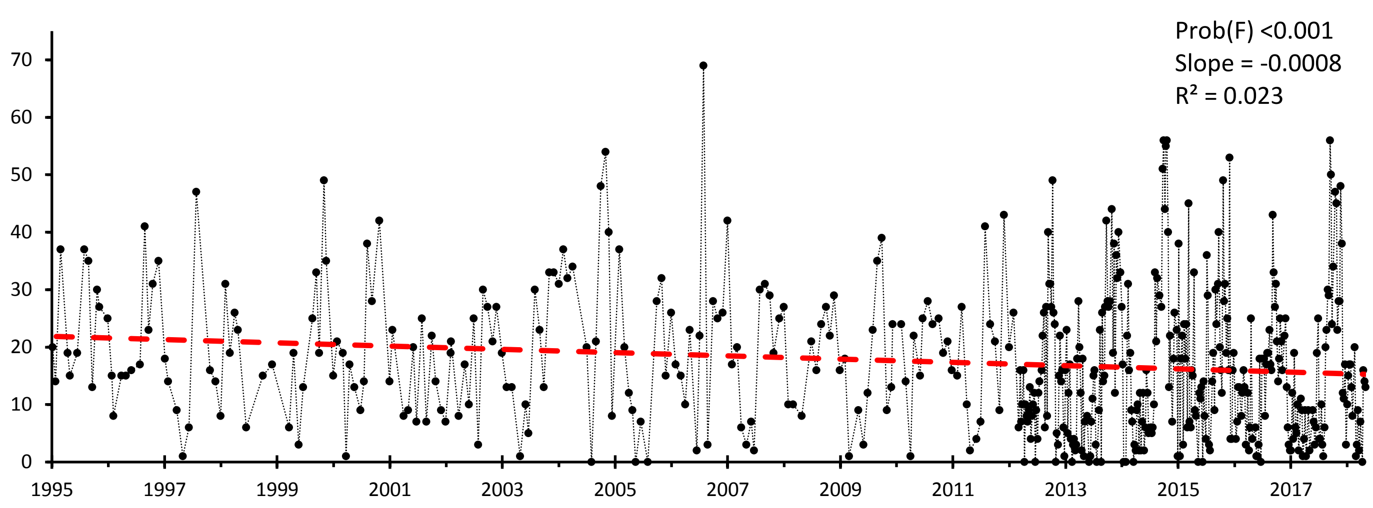
COOTER TURTLE

Seasonal Abundance 1995-2018 (average monthly means)[5]



The cooter turtle, which is likely to be almost exclusively the Suwannee cooter (*Pseudemys concinna suwanniensis*) (Krysko et al., 2019),[6] is a year-round breeding resident of the upper Wakulla River with a distinctive seasonal pattern of abundance that peaks in May. This may be due in part to the turtle's reproductive cycle with multiple clutches laid from late March to early August, peaking in May and June (p. 262).

Abundance 1995-2018 (counts per survey)



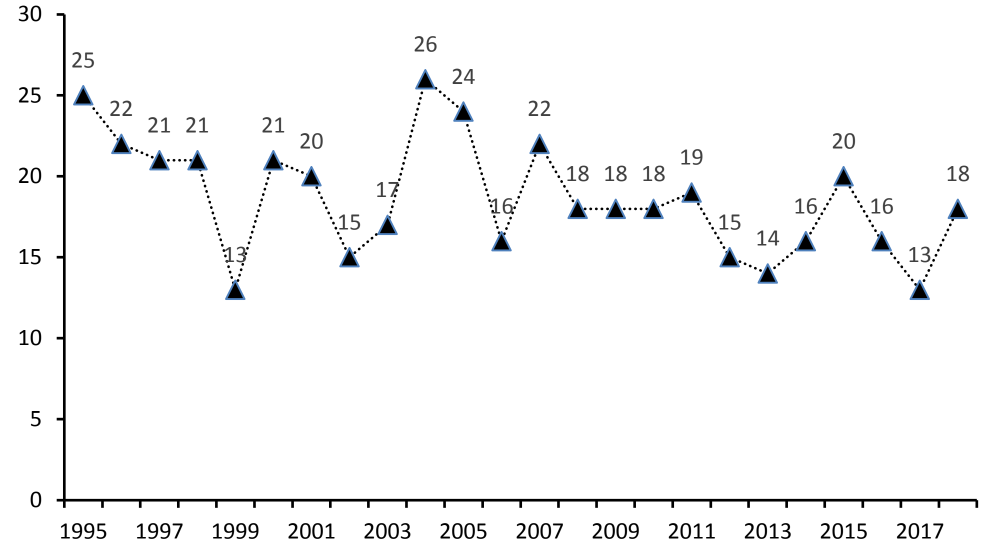
The cooter turtle exhibited a significant (99.9% level or better) decreasing abundance trend of -0.0008 animals counted per day or -0.28 counts per year over the period analyzed, 1/30/95 – 12/29/18. Survey date explains 2.3% of the observed

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

[6] Krysko et al. (2019) show the Wakulla/St. Marks system as the furthest west extent of the range of the Suwannee cooter. However, they also report two catalogued vouchers since 1980 for the Florida red-bellied cooter (*Pseudemys nelson*) in the St. Marks basin. The range map is drawn to exclude the Wakulla River, but it is possible red-bellied cooters have found their way up to Wakulla Spring.

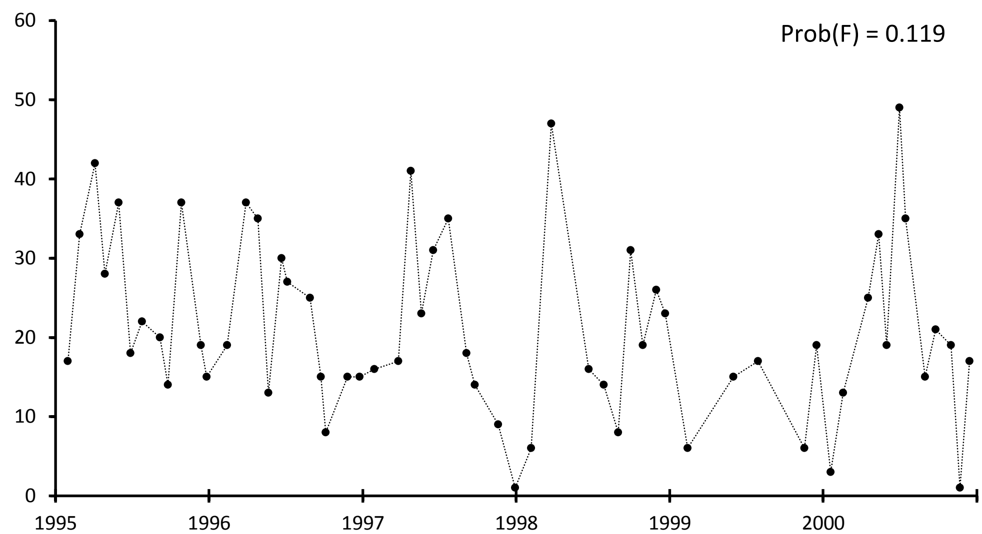
variation in counts per survey. High variation between surveys likely reflects the effects of air temperature and cloud cover on basking behavior and the effects of varying water visibility depth on observing turtles.

Abundance 1995-2018 (annual means)



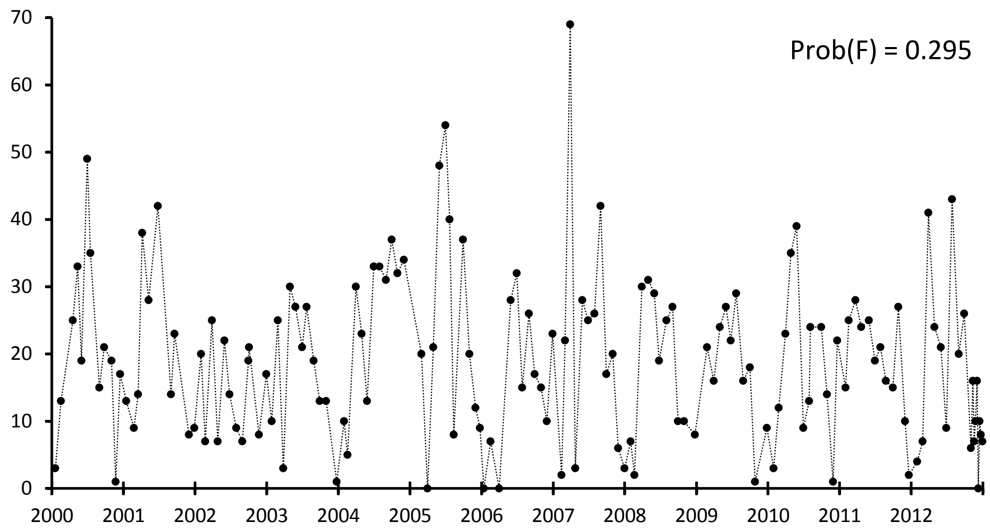
Annual means reveal an abundance pattern with multiple peaks and valleys.

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



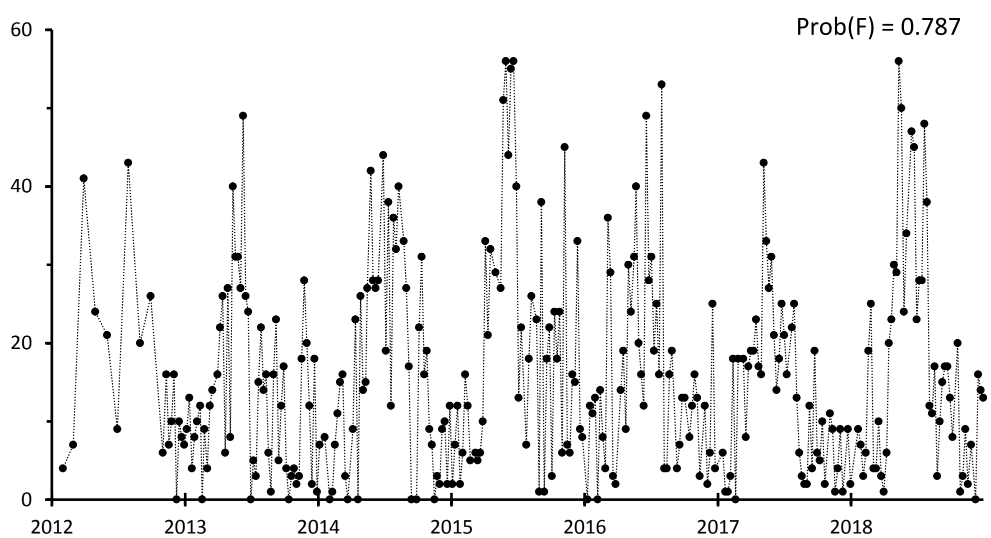
Cooter turtles exhibited no statistically significant trend in abundance during the hydrilla invasion between 1995 and 2000. Counts per survey ranged from 1 to 49 and averaged 21 animals.

Abundance 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.

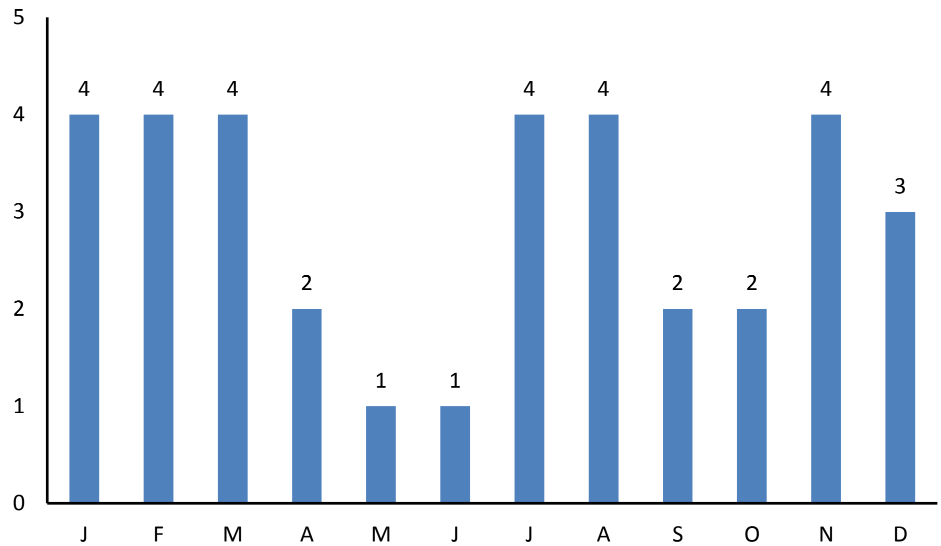
Abundance Post- Hydrilla Management: 2012-2018 (counts per survey)



The absence of a significant trend continued through the post-hydrilla management period with counts per survey ranging from 0 to 56 and averaging 16, a further decline from the preceding period.

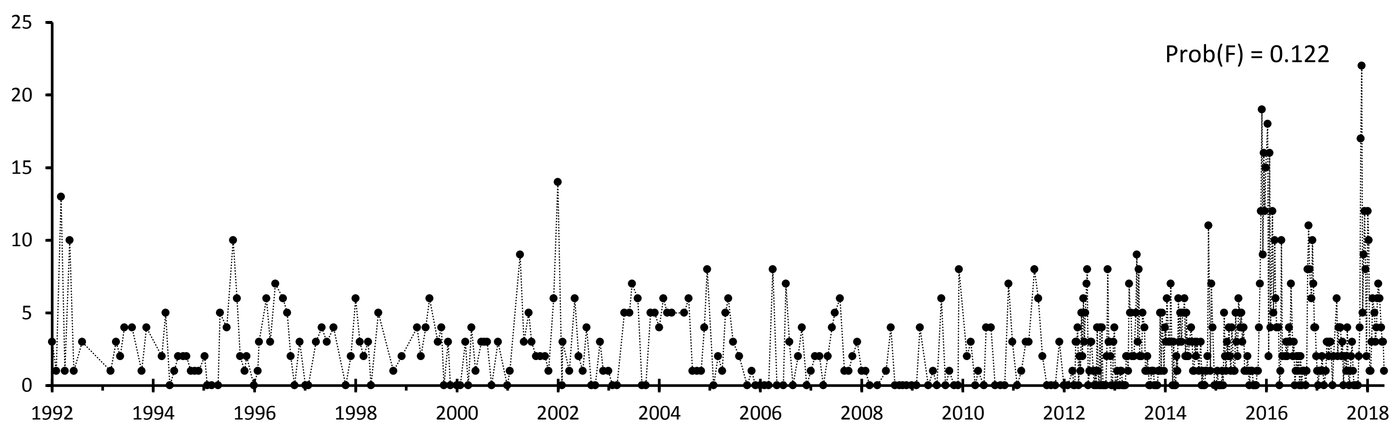
DOUBLE-CRESTED CORMORANT

Seasonal Abundance 1992-2018 (average monthly means)



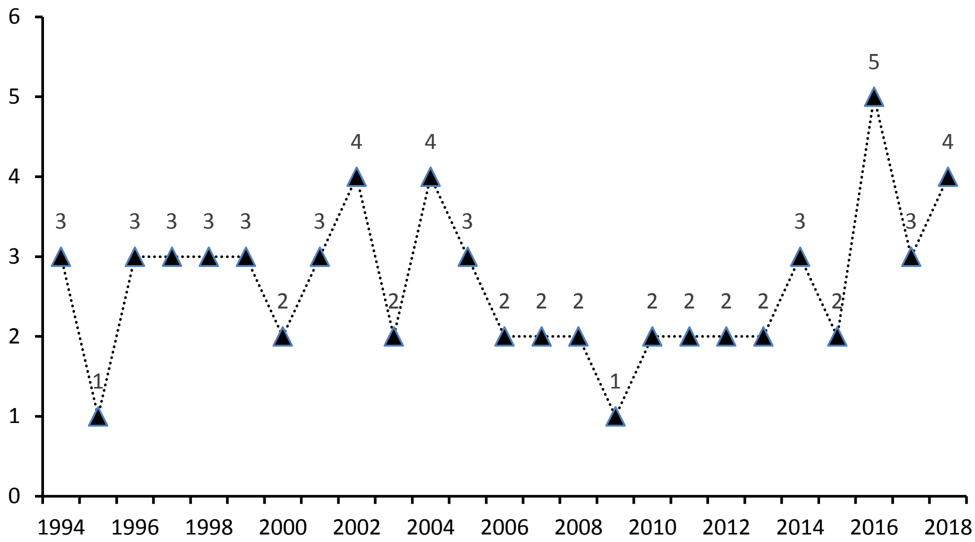
The double-crested cormorant is a year-round resident of the upper Wakulla River that sometimes breeds in colonies in the second mile of the river below the spring (personal observation). Local breeding may explain the high monthly means in July and August while higher means in November through March may reflect an influx of winter migrants from northern breeding territories (Dorr, Hatch, and Weseloh, 2014).

Abundance 1992-2018 (counts per survey)



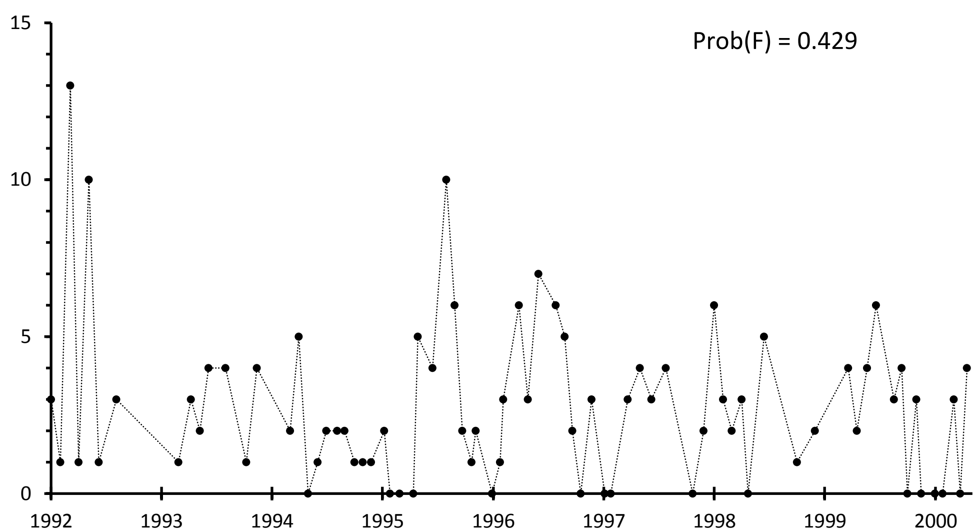
The double-crested cormorant exhibited no significant long-term abundance trend over the period of record, 9/1/92 – 12/29/18. Counts per survey range from 0 to 22 with a mean of 3. Recent highs may be due to nesting colonies in the second mile of the river.

Abundance 1994-2018 (annual means)



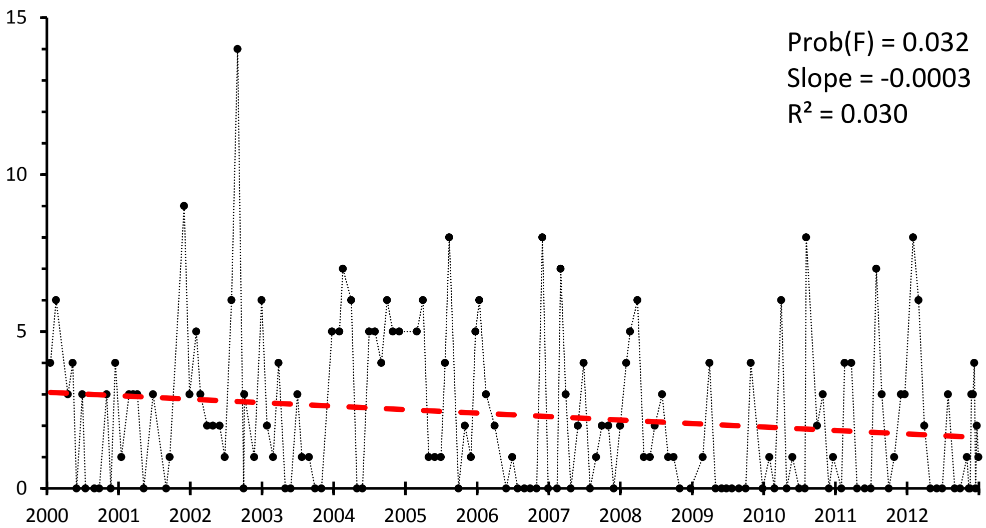
Annual mean counts per survey are low, ranging from 1 to 5. They also show highs in 2016 and 2018 that likely reflect local breeding colonies. No patterns are evident that suggest impacts from ecosystem perturbations analyzed here.

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



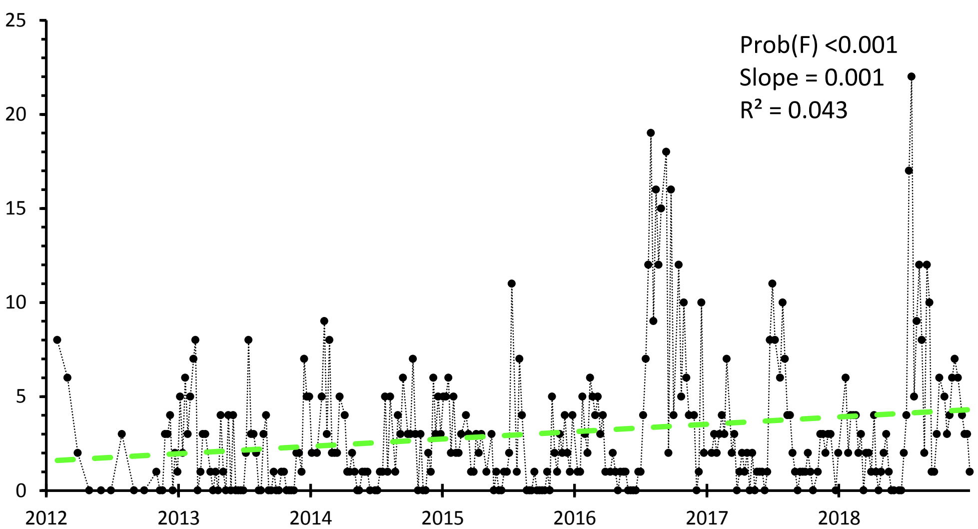
Double-crested cormorants exhibited no statistically significant trend in abundance during the hydrilla invasion. Counts per survey ranged from 0 to 13 and averaged 3 animals.

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



A significant (96.8% 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.

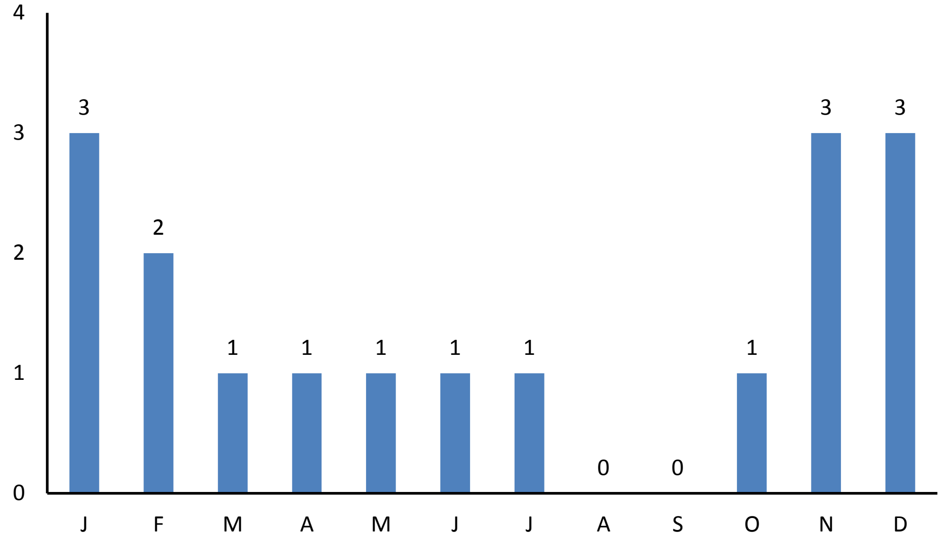
Abundance Post- Hydrilla Management: 2012-2018 (counts per survey)



The cormorant abundance trend reversed during the post-hydrilla management period with a positive trend significant at the 99.9% level or better. The trend explains 4.3% of the observed variation in counts per survey during this period.

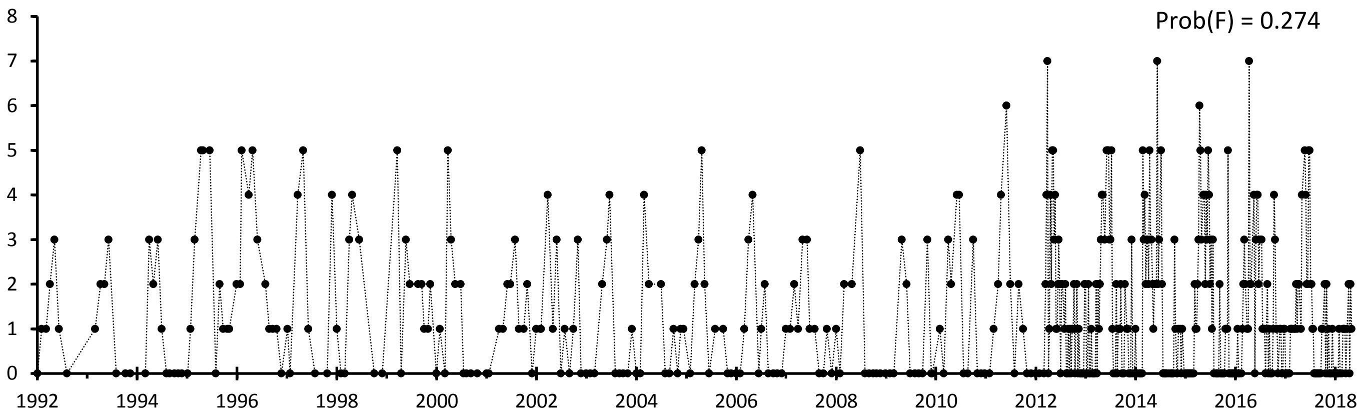
GREAT BLUE HERON

Seasonal Abundance 1992-2018 (average monthly means)



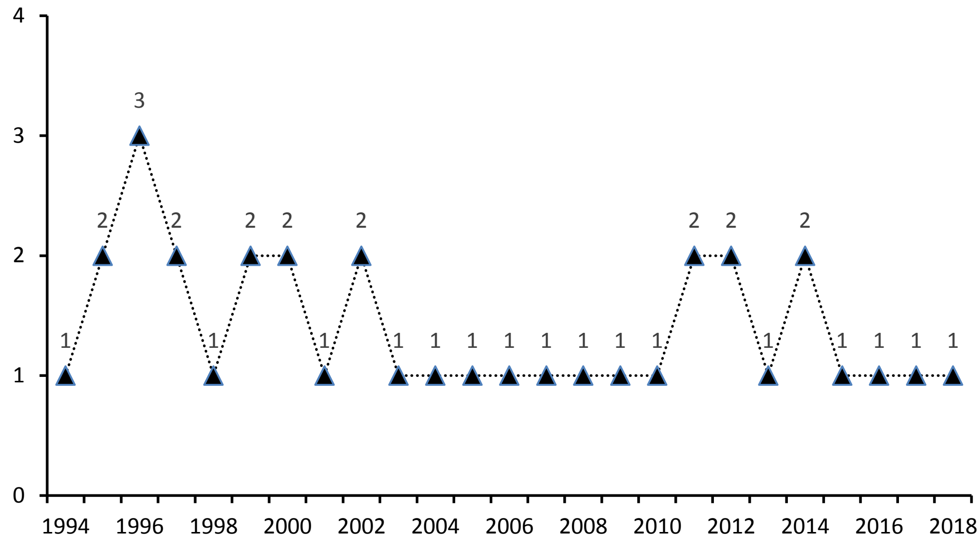
The great blue heron is a year-round resident of the upper Wakulla River that sometimes breeds along the river boat tour route (personal observation). Numbers are small throughout the year likely reflecting relatively large feeding territories. Higher means in November through February may reflect an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

Abundance 1992-2018 (counts per survey)



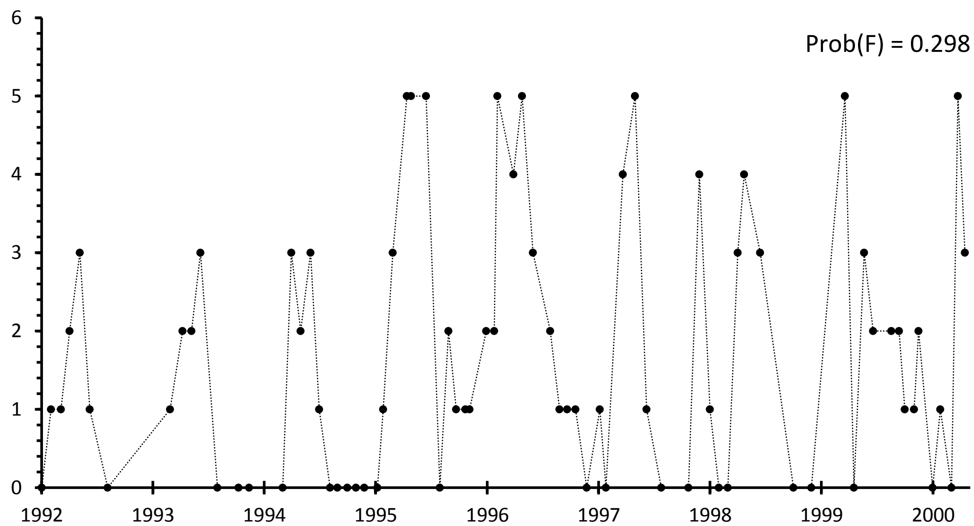
The great blue heron has been present in small numbers and exhibited no significant long-term abundance trend over the period of record, 9/1/92 – 12/29/18. Counts per survey ranged from 0 to 7 with an average of 1. Higher counts occurred during winter months when the local population may have been augmented by winter migrants.

Abundance 1994-2018 (annual means)



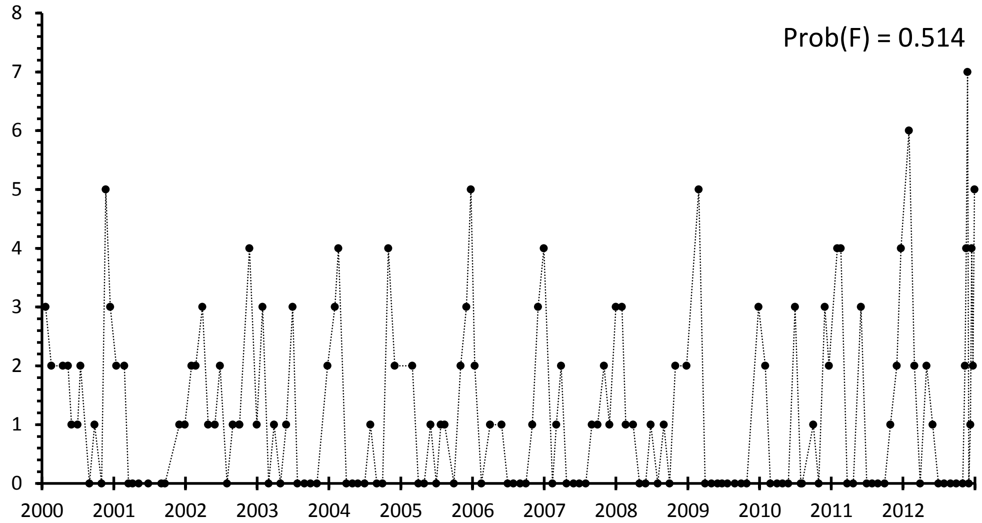
Annual mean counts per survey are very low ranging from 1 to 3. With such low numbers, no trends are apparent.

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



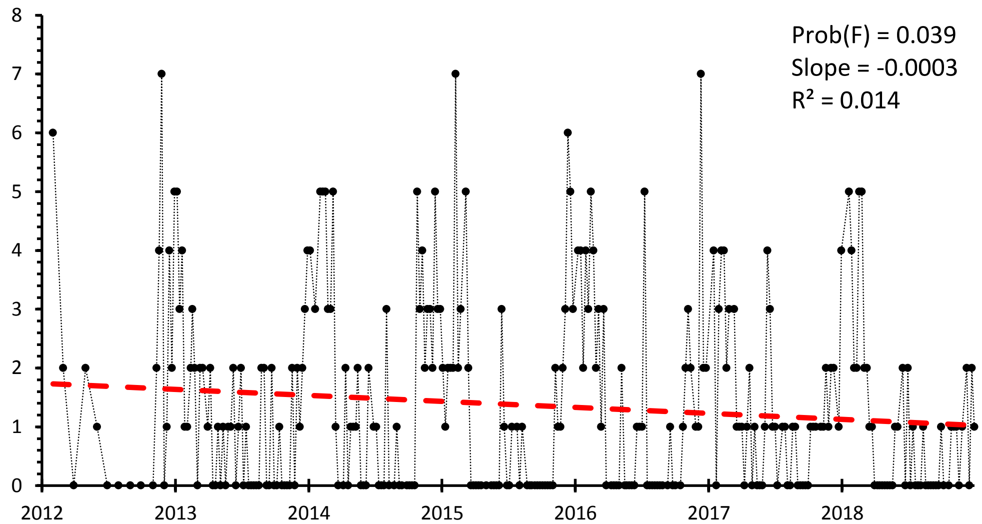
Great blue herons exhibited no statistically significant trend in abundance during the hydrilla invasion between 1992 and 2000. Counts per survey ranged from 0 to 5 and averaged 2 animals.

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.

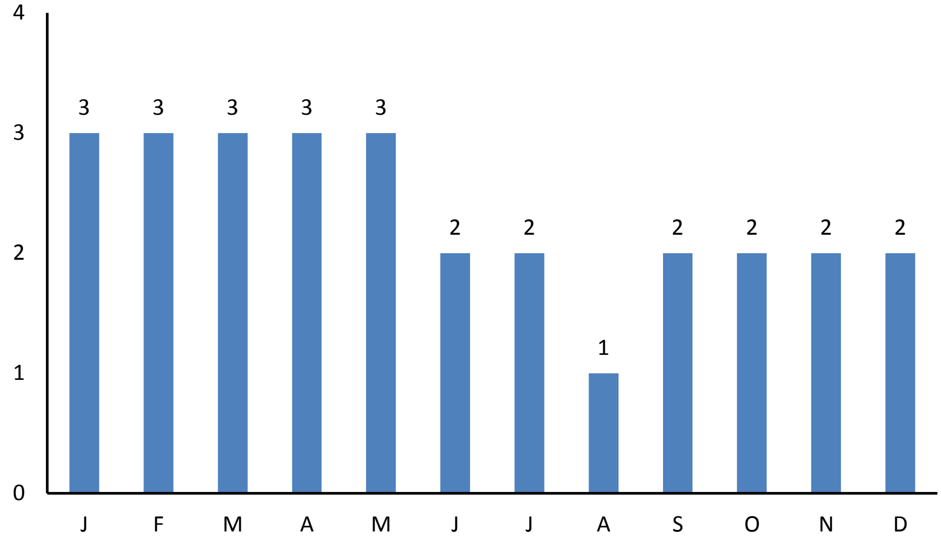
Abundance Post- Hydrilla Management: 2012-2018 (counts per survey)



The great blue heron did exhibit a significant decrease in abundance (96.1% level) during the post-hydrilla period with a trend that explains 1.4% of the observed variation in counts per survey.

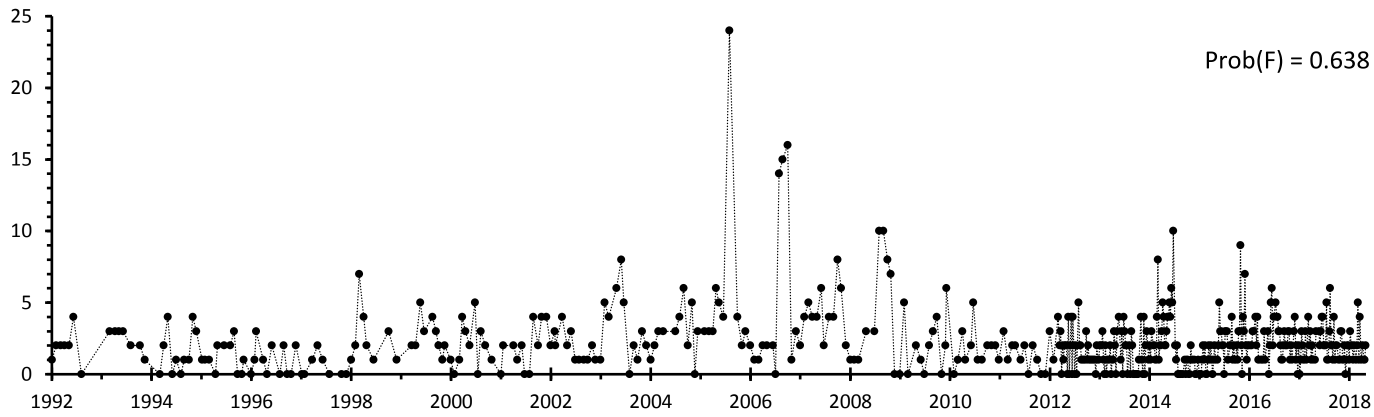
GREAT EGRET

Seasonal Abundance 1992-2018 (average monthly means)



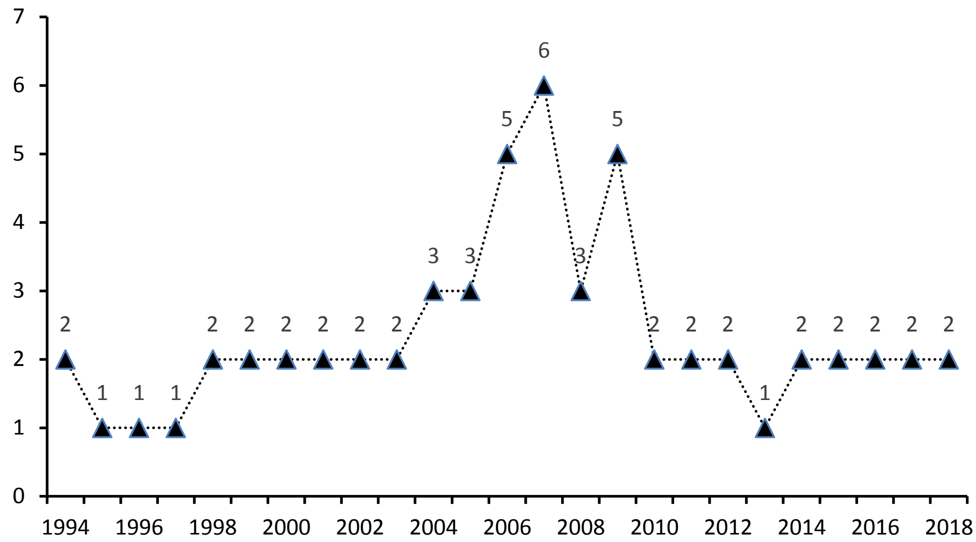
The great egret is a year-round resident of the upper Wakulla River that sometimes breeds along the upper river (Bob Thompson, personal communication). Numbers are small throughout the year likely reflecting relatively large feeding territories.

Abundance 1992-2018 (counts per survey)



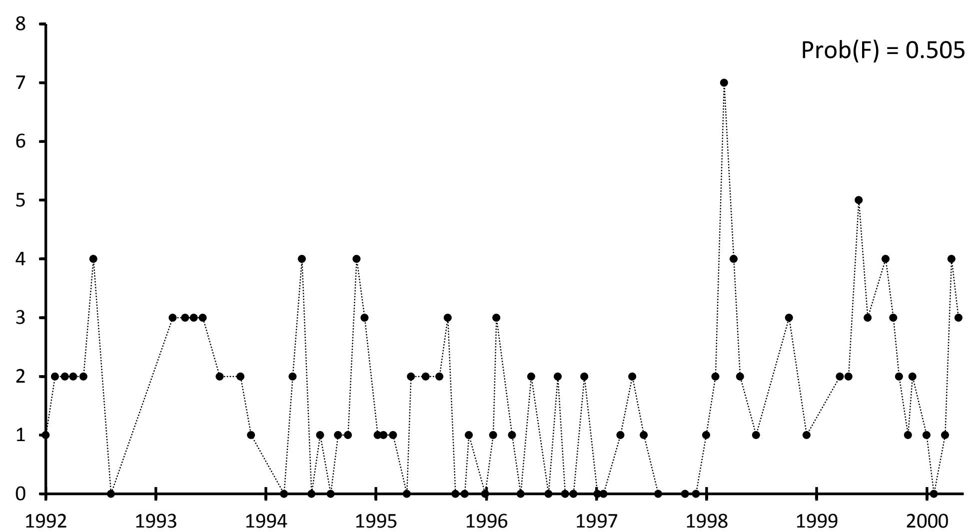
The great egret has been present in small numbers and exhibited no significant long-term abundance trend over the period of record, 9/1/92 – 12/29/18. Counts per survey ranged from 0 to 24 with an average of 2.

Abundance 1994-2018 (annual means)



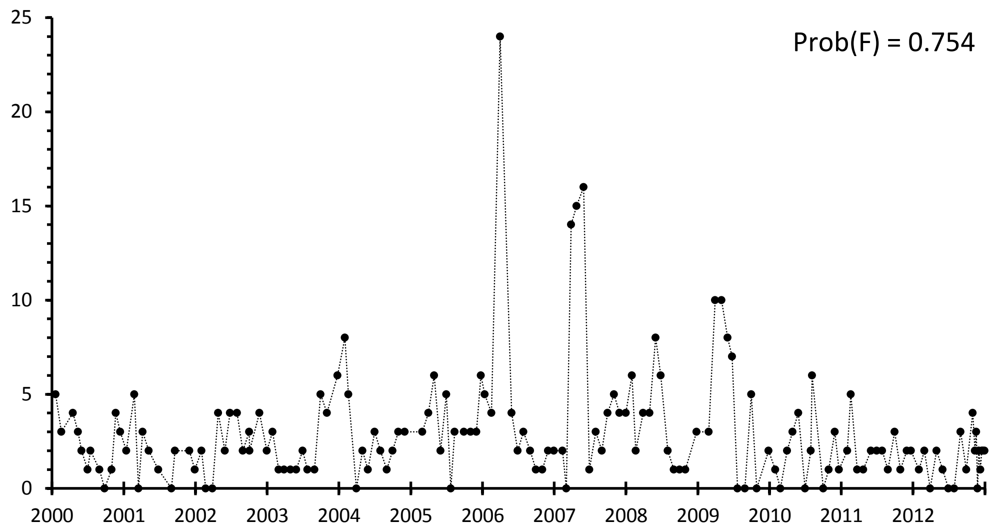
Annual mean counts per survey are very low ranging from 1 to 6. A steady increase from 2003 to 2007 was followed by a steep decline in 2010 and generally stable annual mean abundance thereafter. Bob Thompson documented nesting along the river boat tour route in 2009 and 2010.

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



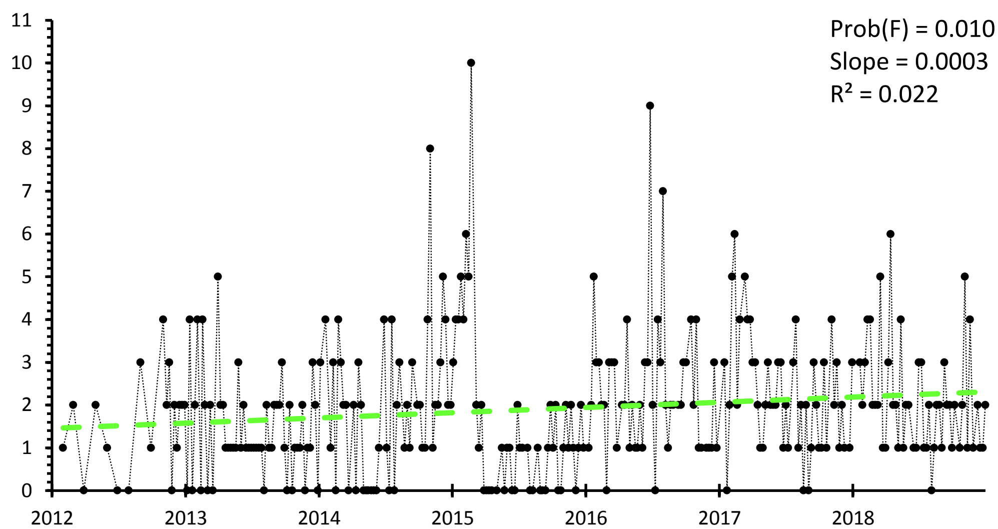
Great egrets exhibited no statistically significant trend in abundance during the hydrilla invasion between 1992 and 2000. Counts per survey ranged from 0 to 7 and averaged 2 animals.

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.

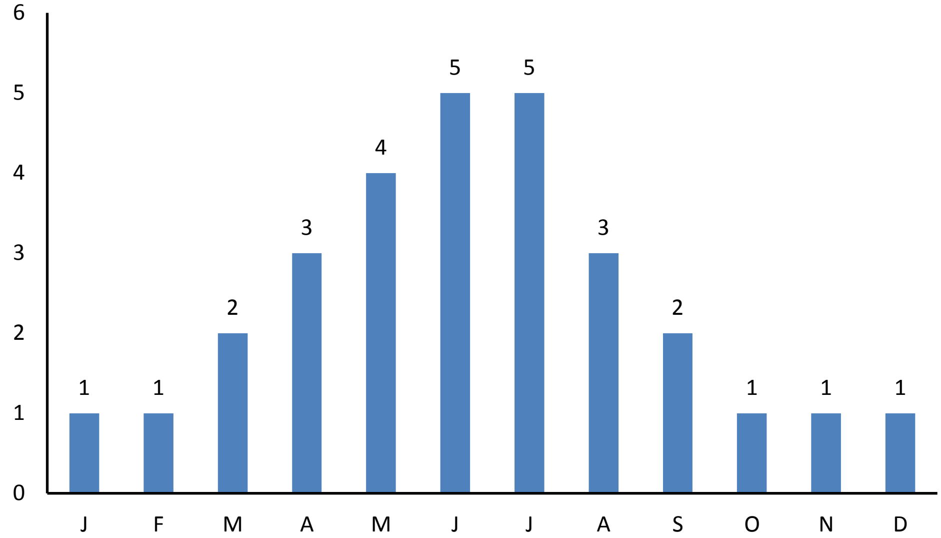
Abundance Post- Hydrilla Management: 2012-2018 (counts per survey)



The great egret did exhibit a significant increase in abundance (99.0% level) during the post-hydrilla period with a trend that explains 2.2% of the observed variation in counts per survey.

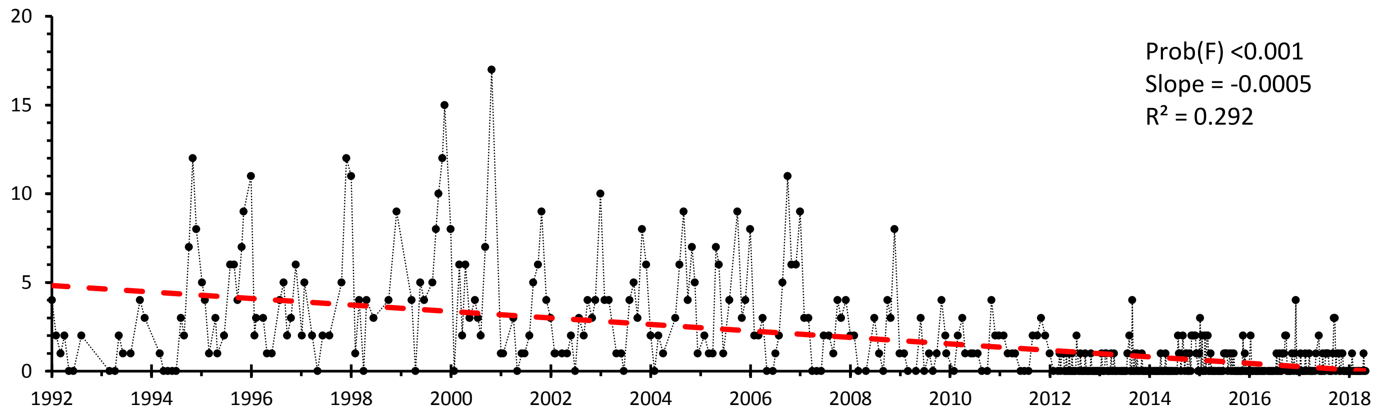
GREEN HERON

Seasonal Abundance 1992-2018 (average monthly means)



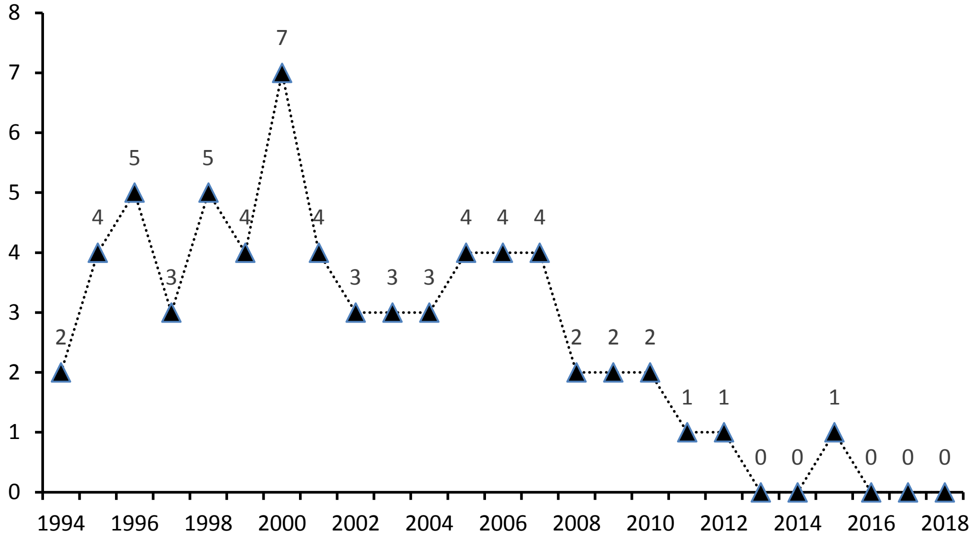
The green heron is a secretive year-round resident breeder on the upper Wakulla River. Peak abundance in May through July may reflect the breeding cycle and/or their propensity for wandering after the breeding season (The Cornell Lab of Ornithology, 2019). Small numbers throughout the year likely reflect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

Abundance 1992-2018 (counts per survey)



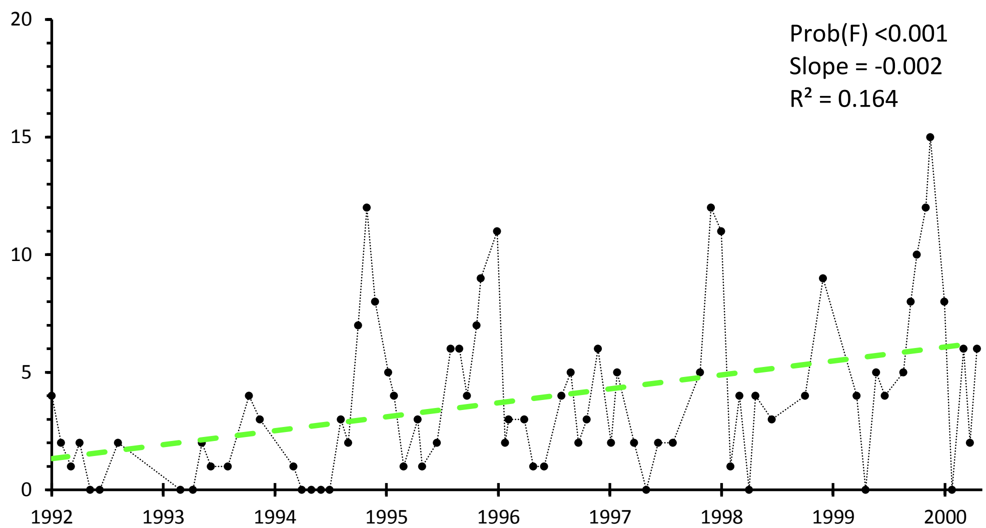
The green heron exhibited a significant (99.9% level or better) decreasing abundance trend of -0.0005 animals counted per day or -0.18 counts per year over the period analyzed, 9/1/92 – 12/29/18. Survey date explains 29.2% of the observed variation in counts per survey.

Abundance 1994-2018 (annual means)



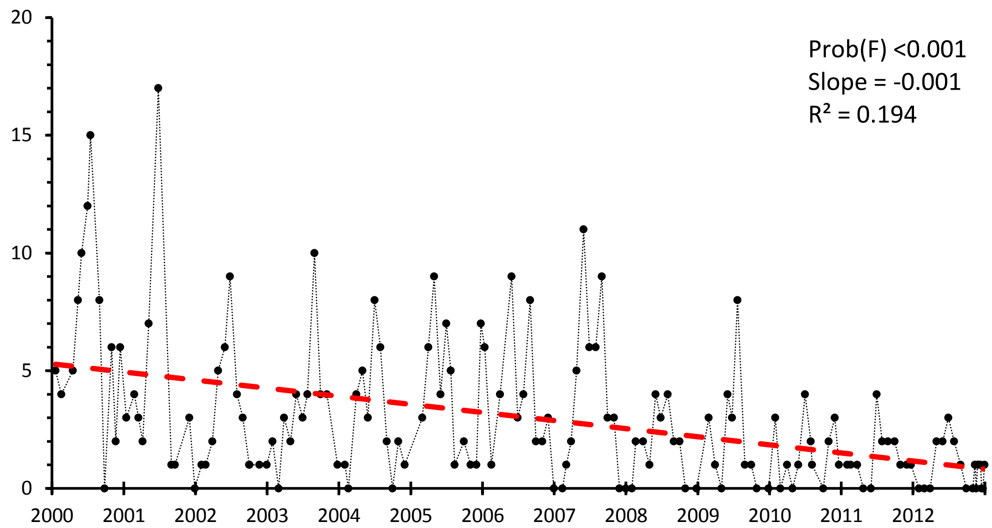
Annual mean counts per survey of the green heron peaked in 2000 near the onset of intensive hydrilla management and have generally declined since.

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



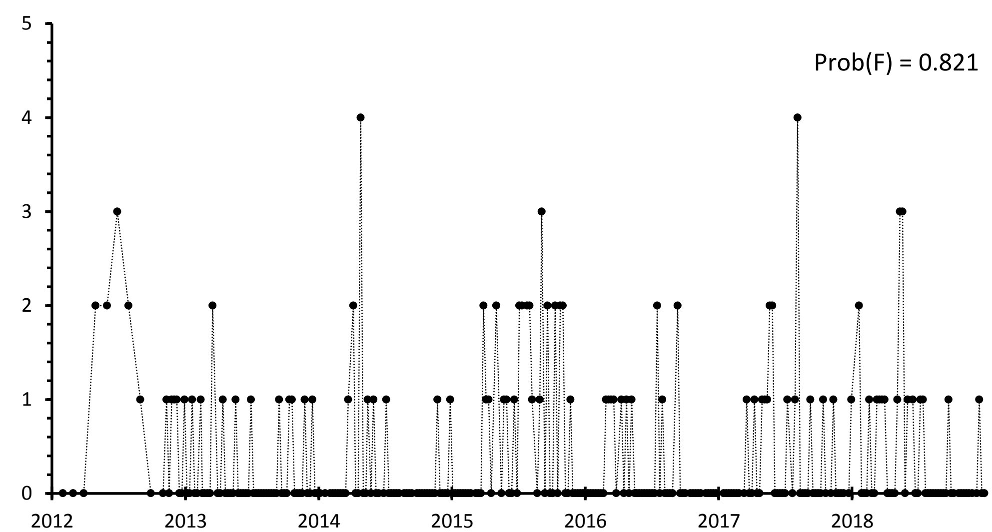
Great herons exhibited a significant increasing trend in abundance during the hydrilla invasion between 1992 and 2000 that explains 16.4% of the observed variation in counts per survey.

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



The green heron exhibited a significant (99.9% level or better) decreasing trend in abundance during the hydrilla management period which explains 19.4% of the observed variation in survey counts per day.

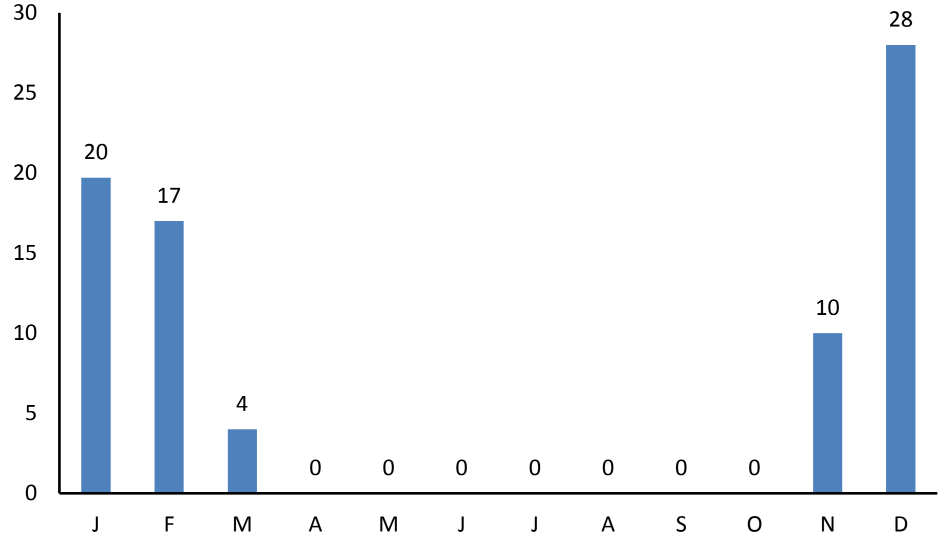
Abundance Post- Hydrilla Management: 2012-2018 (counts per survey)



Green heron abundance leveled off during the post-hydrilla management period with no significant trend. Counts per survey ranged from 0 to 4 with an average of 0.4 animals per survey.

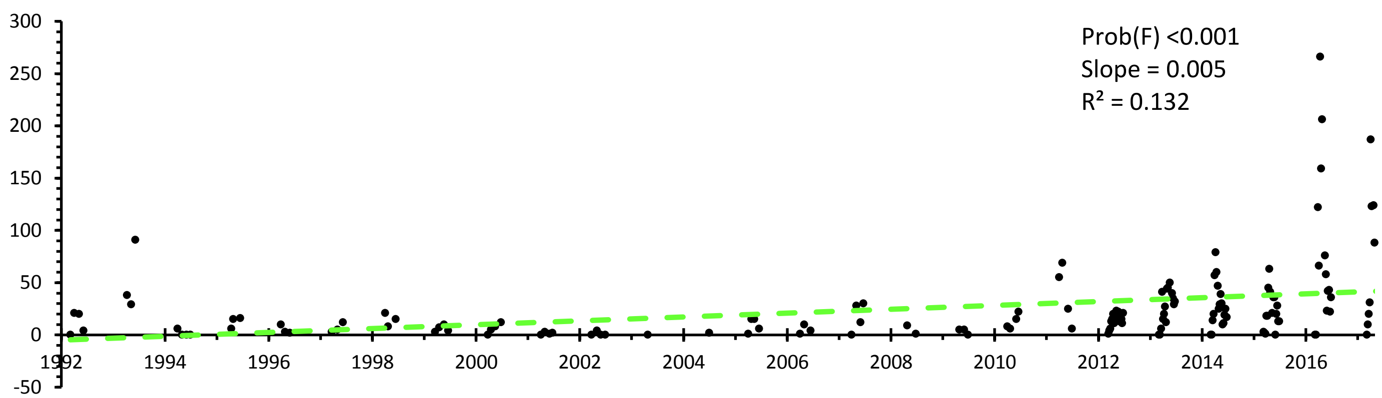
HOODED MERGANSER

Seasonal Abundance 1992-2018 (average monthly means)



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

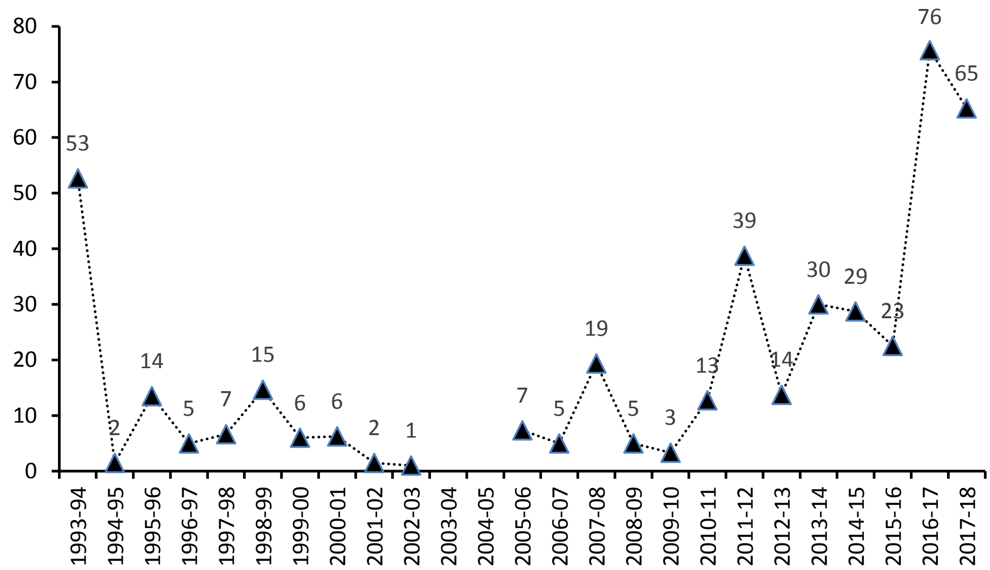
Seasonal Abundance Nov-Feb 1992-93 – 2017-18 (counts per survey)[7]



The hooded merganser exhibited a significant (99.9% level or better) increasing abundance trend of 0.005 animals counted per day or 1.84 counts per year over the period analyzed, 9/1/92 – 12/29/18. Survey date explains 13.2% of the observed variation in counts per survey.

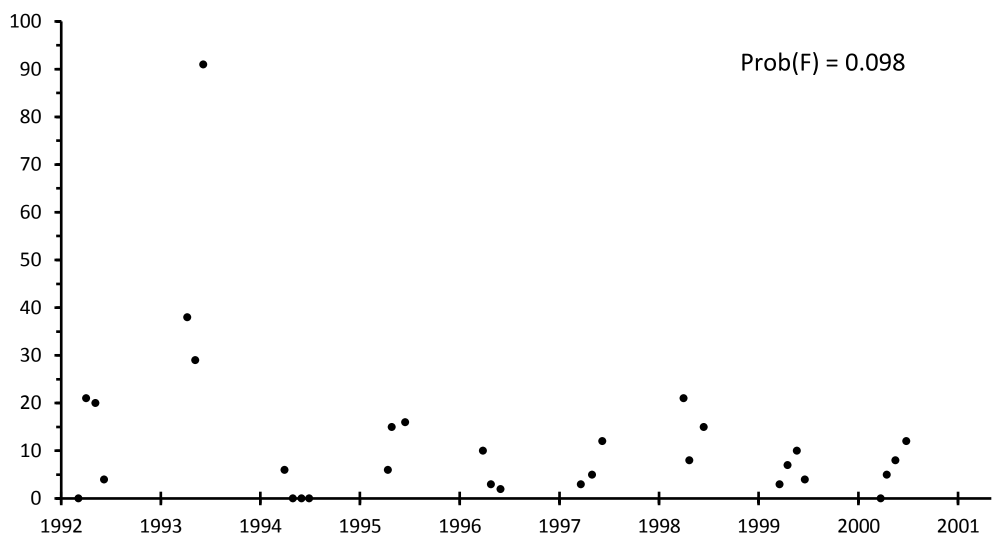
[7] No data available for 2004.

Seasonal Abundance Nov-Feb 1993-94 – 2017-18 (winter monthly means)



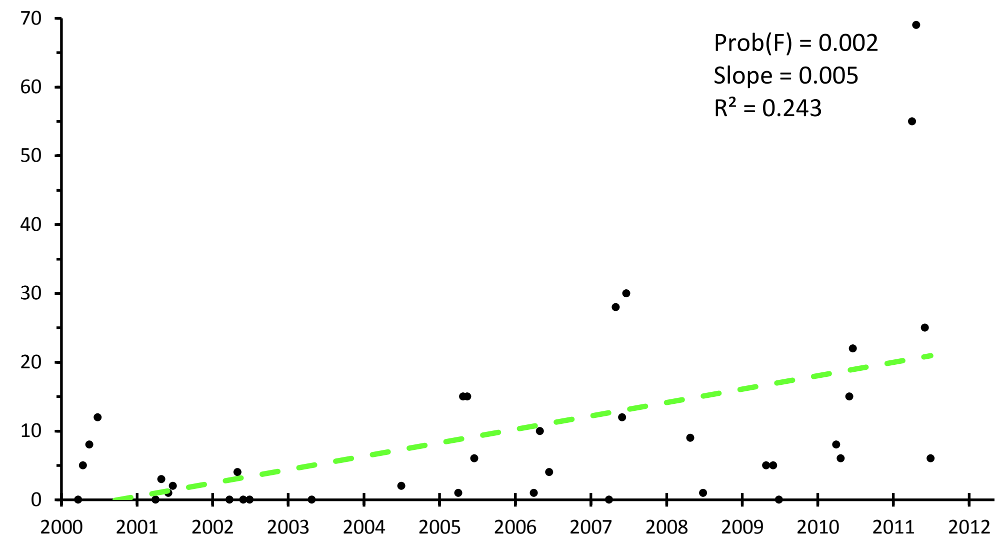
Annual winter monthly mean counts per survey of the hooded merganser began with a high in 1993-94, then settled into relatively low numbers before beginning a two-stage ascent in 2011-12.

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



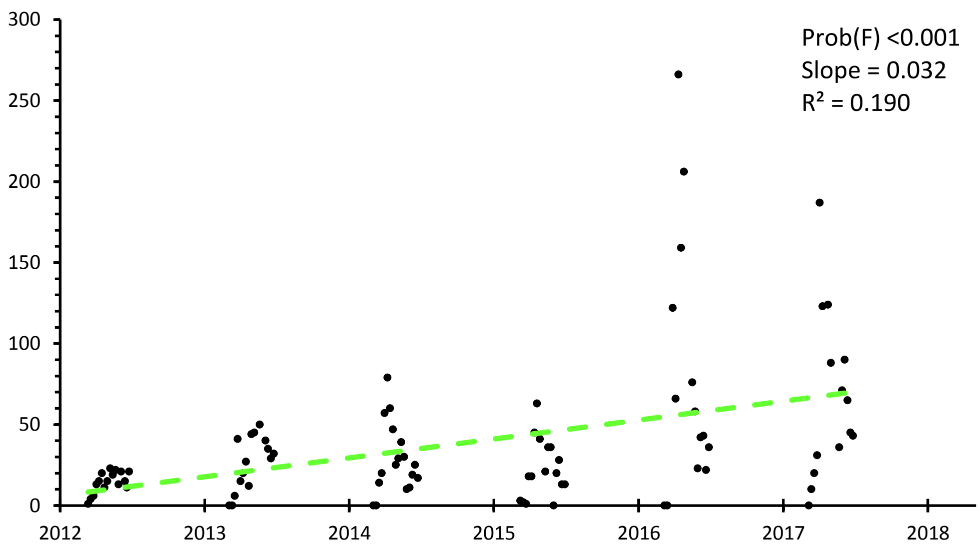
Hooded mergansers exhibited no significant winter seasonal abundance trend during the hydrilla invasion. Counts per survey ranged from 0 to 91 with an average of 12.

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



The hooded merganser exhibited a significant (99.8% 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.

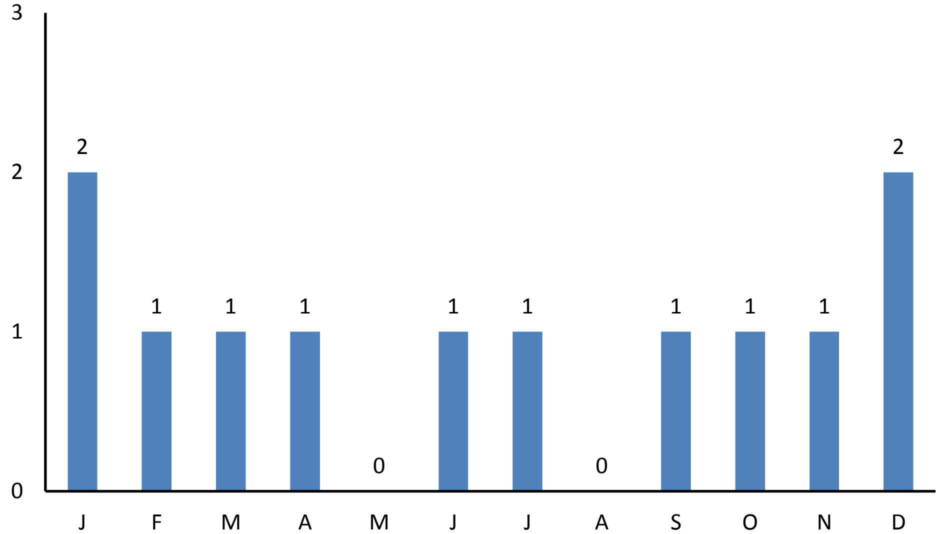
Seasonal Abundance Post- Hydrilla Management: Nov-Feb 2011-12 – 2017-18 (counts per survey)



Hooded merganser winter seasonal abundance continued to increase with a significant trend (99.9% level or better) during the post-hydrilla management period. The trend explains 19.0% of the observed variation in survey counts per day.

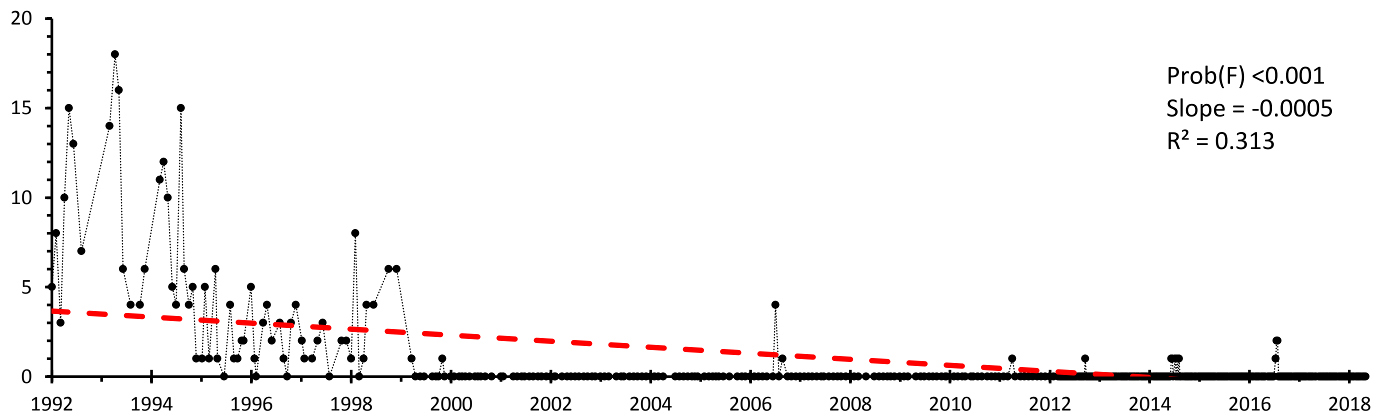
LIMPKIN

Seasonal Abundance 1992-2018 (average monthly means)



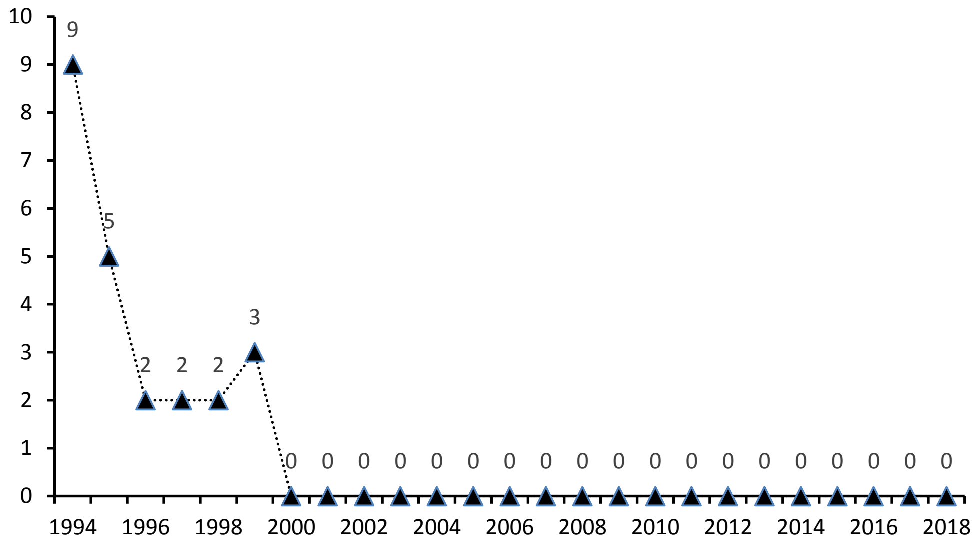
The limpkin was a year-round breeding resident of the upper Wakulla River until its near complete disappearance in 2000. It is now an occasional visitor. Low average monthly means reflect this dramatic shift in population levels.

Abundance 1992-2018 (counts per survey)



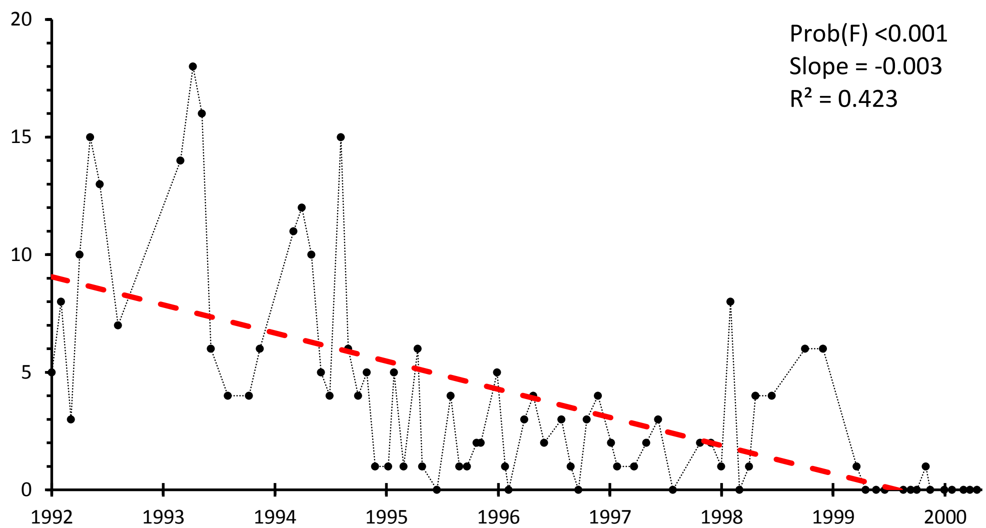
The limpkin exhibited a significant (99.9% level or better) decreasing abundance trend of -0.0005 animals counted per day or -0.17 counts per year over the period of record, 9/1/92 – 12/29/18. Survey date explains 31.3% of the observed variation in counts per survey.

Abundance 1994-2018 (annual means)



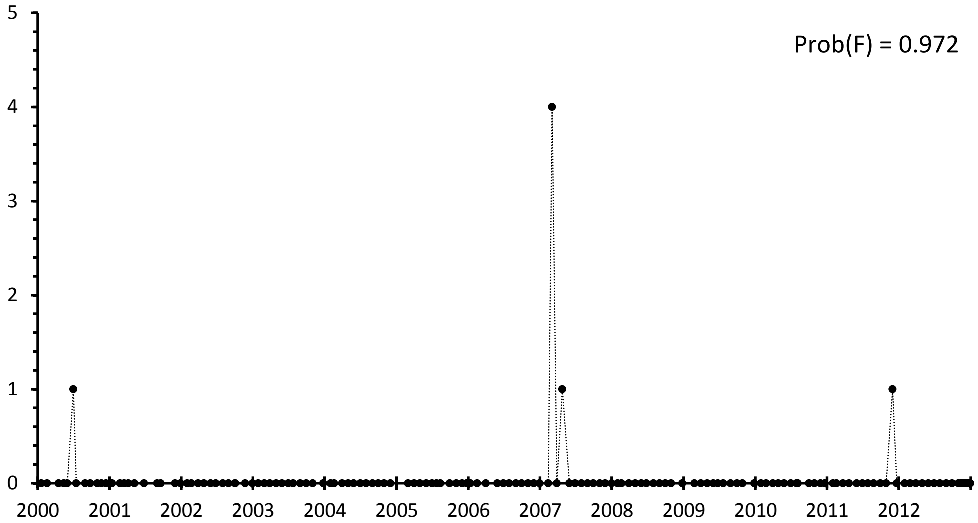
Annual mean counts per survey of the limpkin dropped immediately after 1994 and bottomed out at 0 in 2000.

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



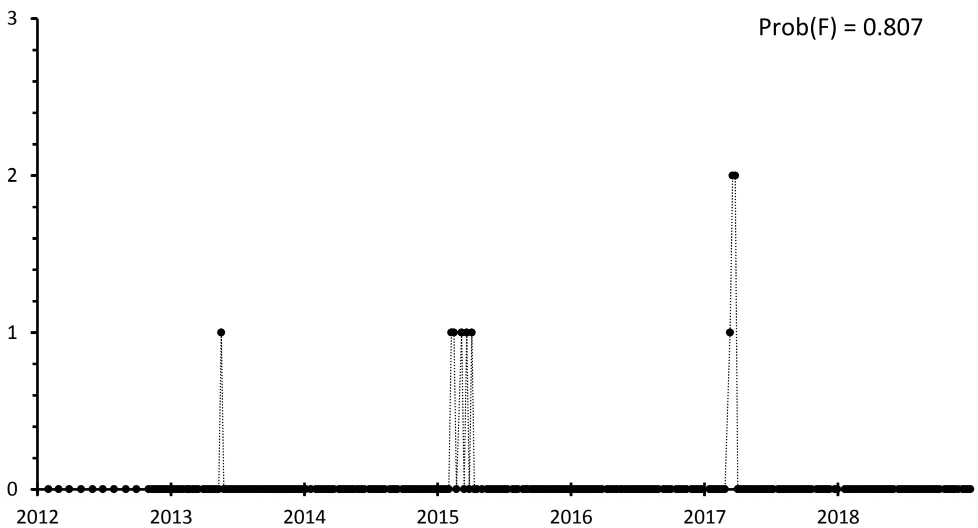
The limpkin exhibited a significant decreasing trend in abundance during the hydrilla invasion period that explains 42.3% of the observed variation in counts per survey.

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.

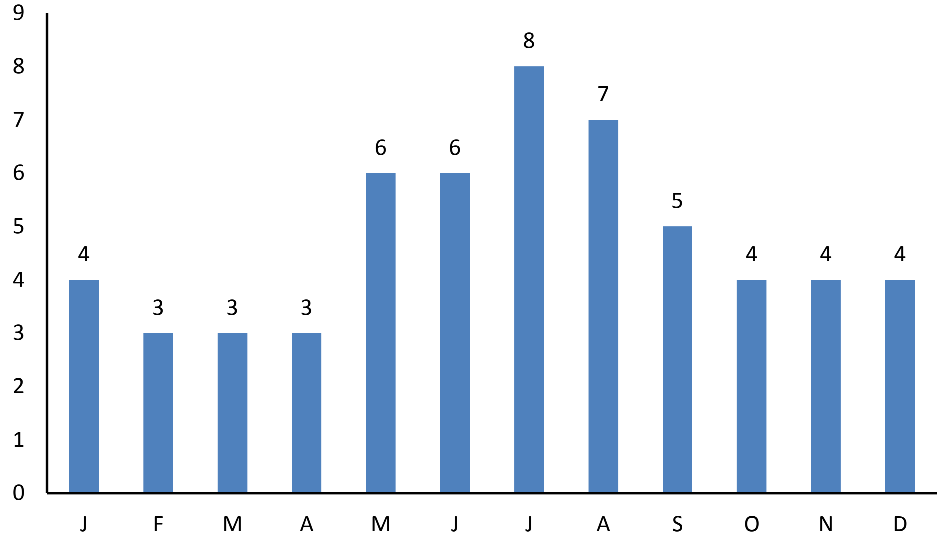
Abundance Post- Hydrilla Management: 2012-2018 (counts per survey)



The lack of a significant abundance trend for the limpkin continued during the post-hydrilla management period with average counts per survey at 0 and a range of 0 to 2.

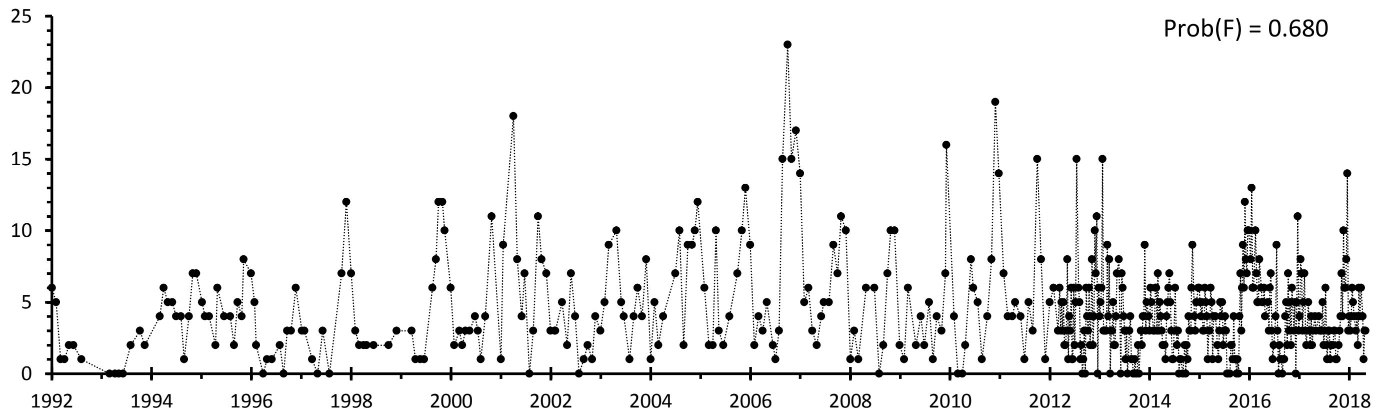
LITTLE BLUE HERON

Seasonal Abundance 1992-2018 (average monthly means)



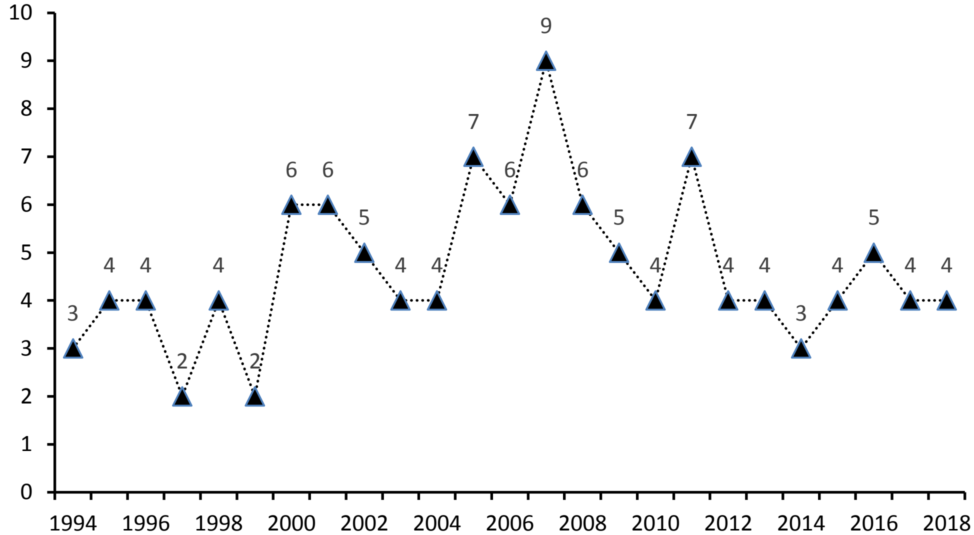
The little blue heron is a year-round resident that occasionally breeds in a nesting colony along the second mile of the upper Wakulla River. Lower monthly means from October through April likely reflect this species's tendency to wander after the breeding season (Audubon, 2019).

Abundance 1992-2018 (counts per survey)



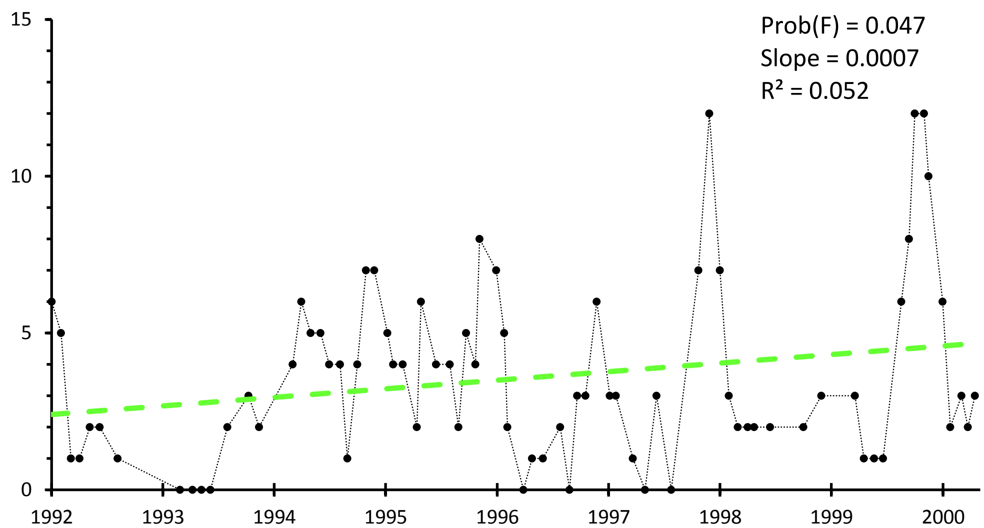
While little blue heron counts per survey during the period of record, 9/1/92 – 12/29/18, have ranged from 0 to 23, they exhibited no significant long-term trend, averaging 4 birds counted per survey.

Abundance 1994-2018 (annual means)



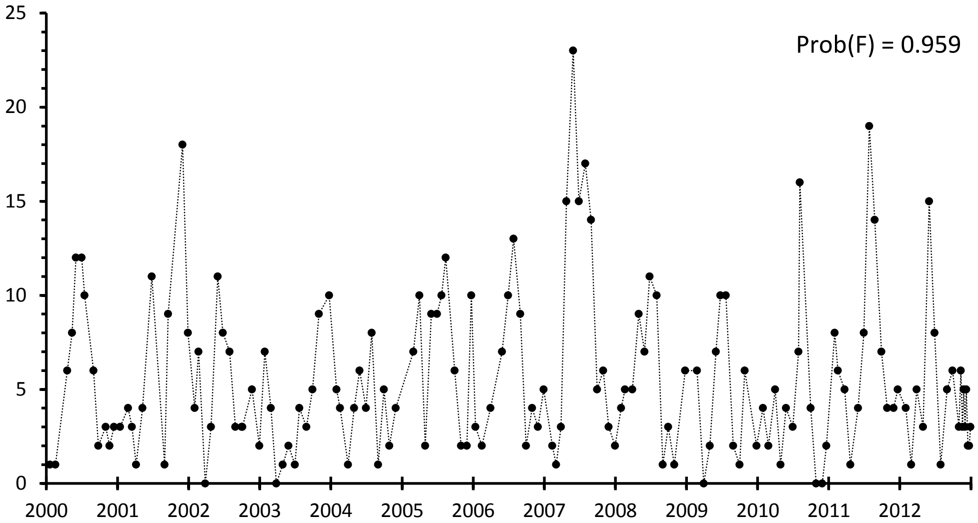
Annual mean counts per survey of the little blue heron have exhibited substantial variation with a peak in 2007. Annual means since 2012 have been comparable to those between 1994 and 1999.

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



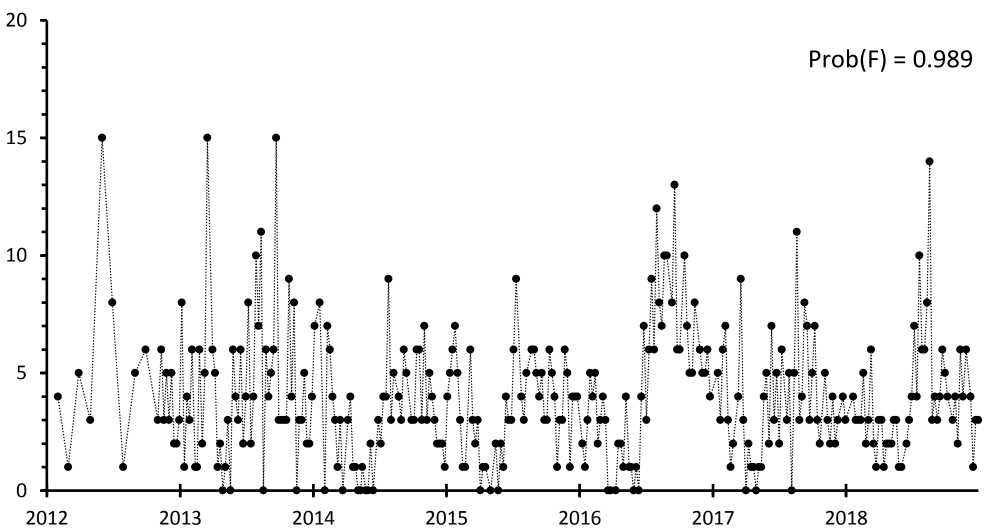
The little blue heron exhibited a significant increasing trend in abundance during the hydrilla invasion between 1992 and 2000 that explains 5.2% of the observed variation in counts per survey.

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.

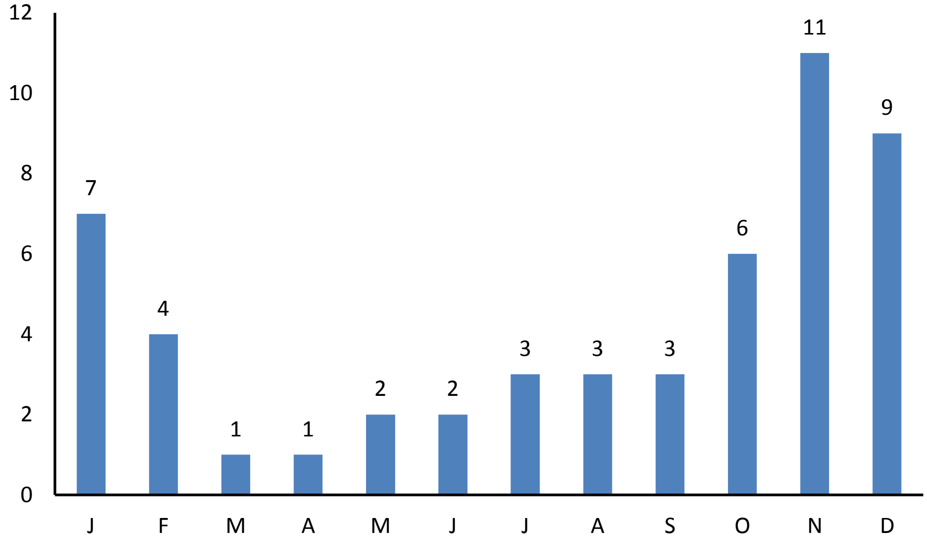
Abundance Post- Hydrilla Management: 2012-2018 (counts per survey)



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 and a range of 0 to 15.

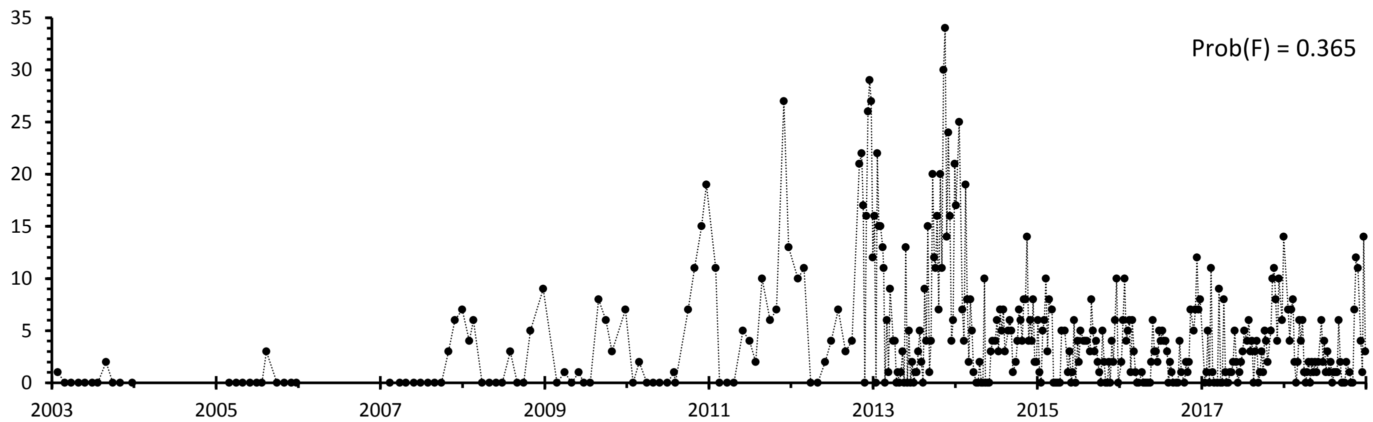
MANATEE

Seasonal Abundance 2003-2018 (average monthly means)[8]



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 69-70º F (21 C º) spring.

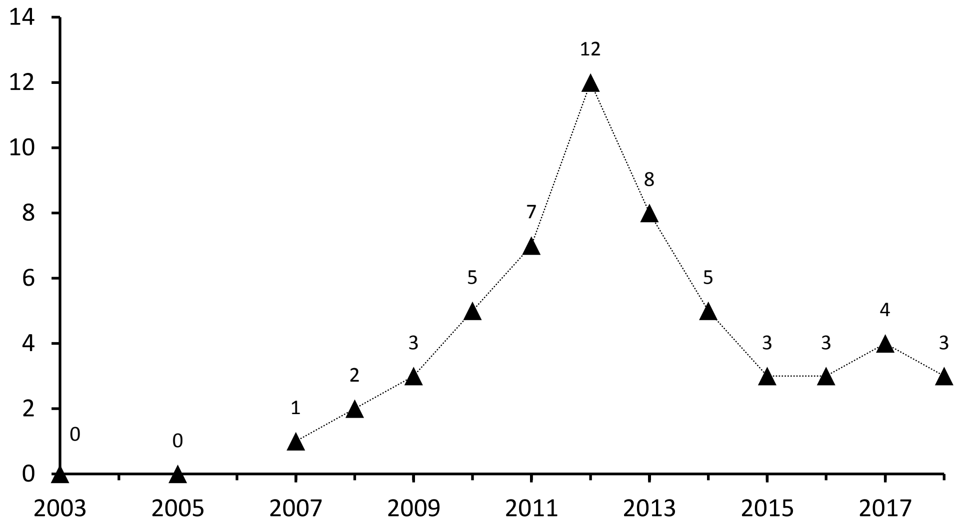
Abundance 2003-2018 (counts per survey)



Manatee exhibited no significant long-term trend, with counts per survey ranging from 0 to 34 and averaging 4 animals over the shorter 15-year period of record, 1/27/30 – 12/29/18.

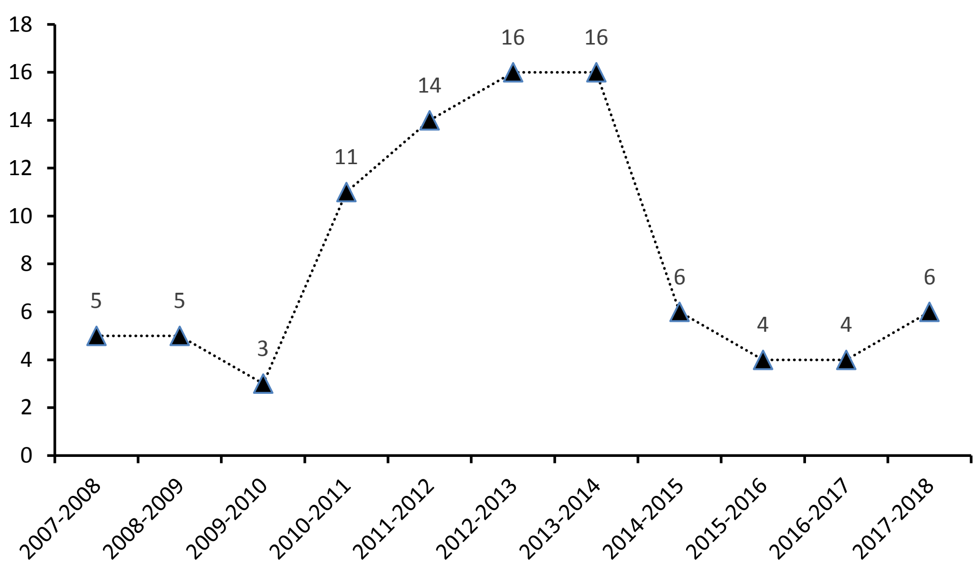
[8] Manatee were not included on the survey form until 2007. Data prior to 2007 are likely incomplete. Observations recorded in 2003 and 2005 are from the open-ended "Comments" section at the bottom of the survey form. None were recorded for 2004 or 2006.

Abundance 2003-2018 (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 2018.

Seasonal Abundance Oct-Feb 2007-08 - 2017-18 (winter monthly means)

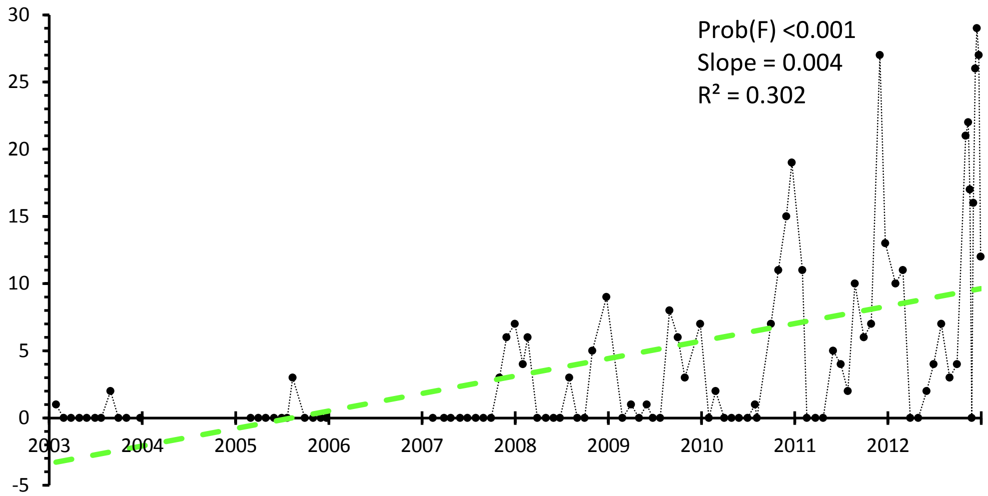


Examination of winter monthly means reveals a more gradual increase peaking in the winter of 2012-13 and 2013-14.

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

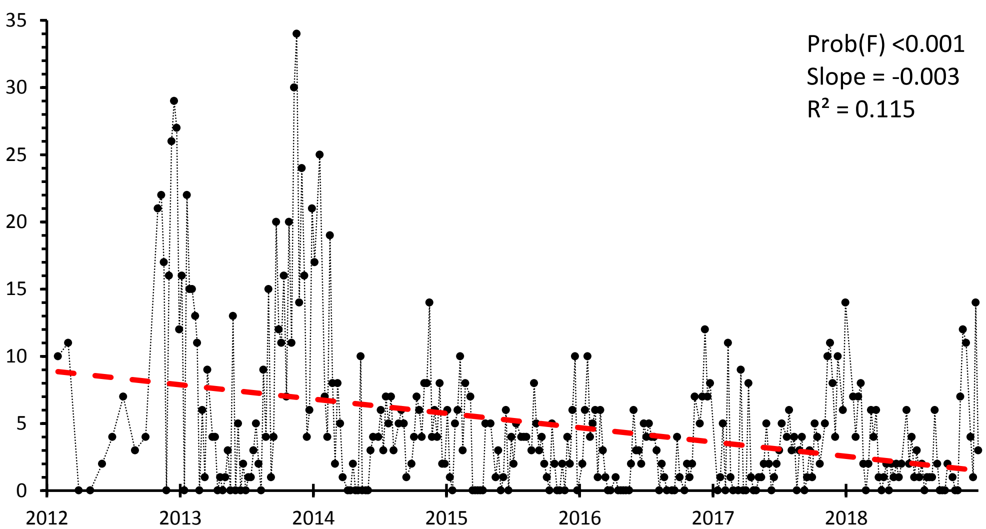
Manatee were not counted during this time.

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



Manatee were not counted during the first three years of this time period. They exhibited an overall significant increasing trend (99.9% level or better) that explains 30.2% of the observed variation in counts per survey.

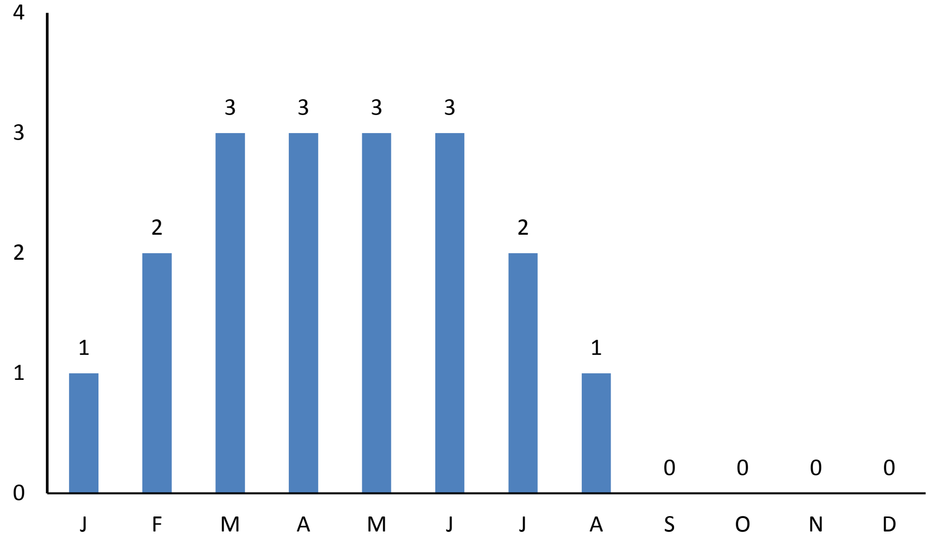
Abundance Post- Hydrilla Management: 2012-2018 (counts per survey)



The decline in manatee abundance following the peak winters of 2012-13 and 2013-14 resulted in a significant decrease (99.9% level or better) in abundance overall for the post-hydrilla management period with the trend explaining 11.5% in the observed variation in counts per survey.

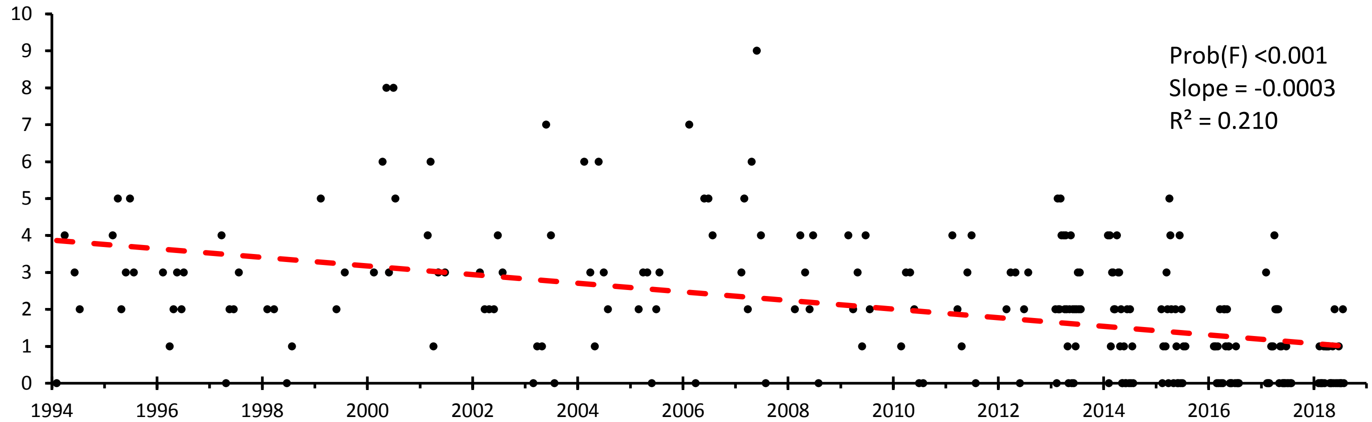
OSPREY

Seasonal Abundance 1992-2018 (average monthly means)



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

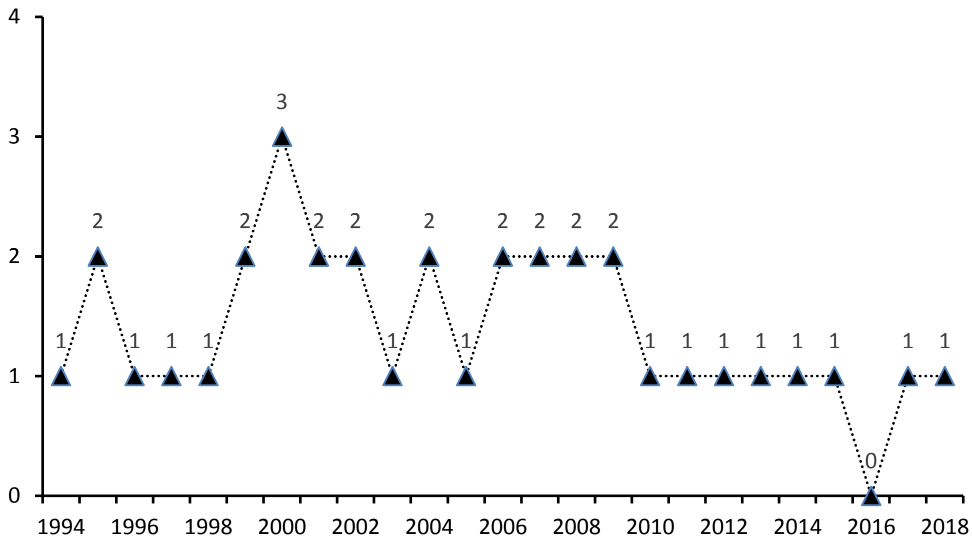
Seasonal Abundance Feb-Jul 1994 – 2018 (counts per survey)



The osprey exhibited a significant (99.9% level or better) decreasing seasonal abundance trend of -0.0003 animals counted per day or -0.12 counts per year over the period analyzed, 2/3/94 – 7/28/18.[9] Survey date explains 2.1% of the observed variation in counts per survey.

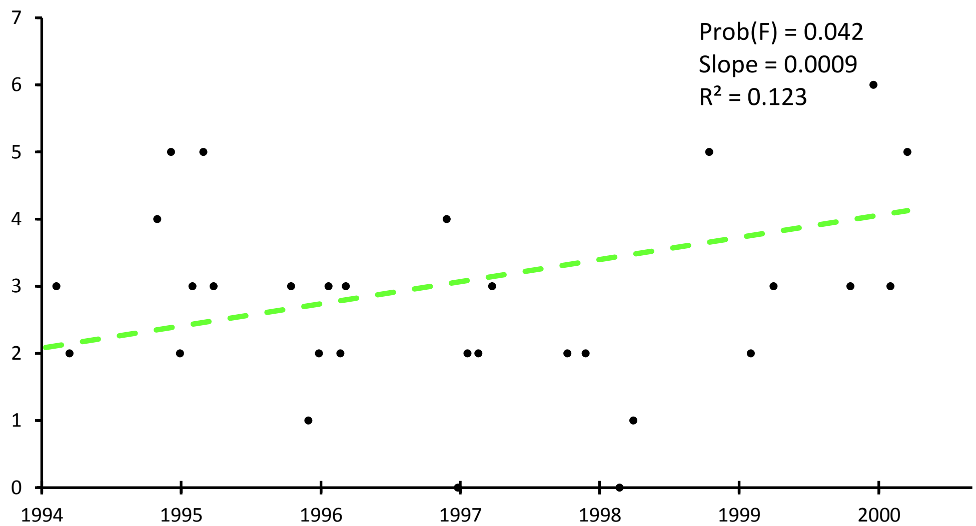
[9] The period of analysis begins 2/3/94 because of incomplete seasonal data in 1992 and 1993.

Seasonal Abundance Feb-Jul 1994 – 2018 (breeding season monthly means)



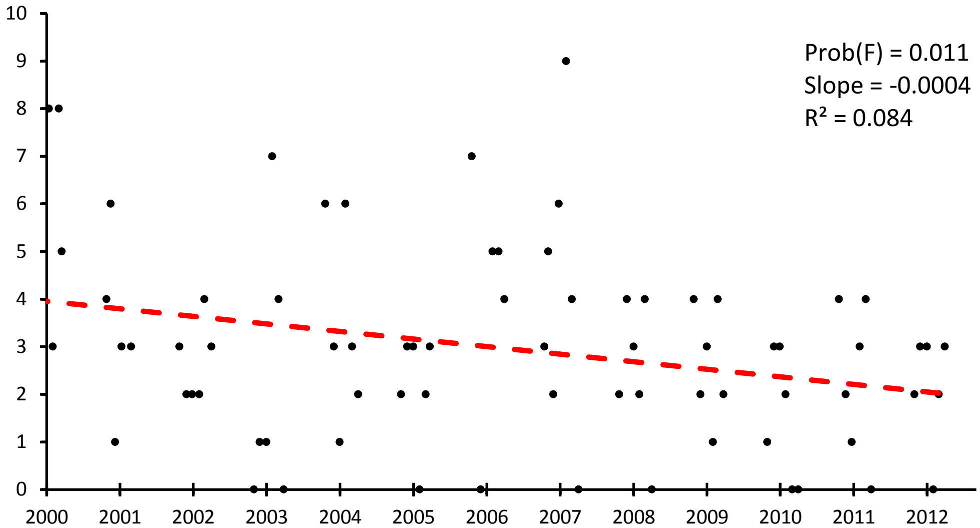
Breeding season monthly means have been very low ranging from 0 in 2016 to a peak of 3 in 2000.

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



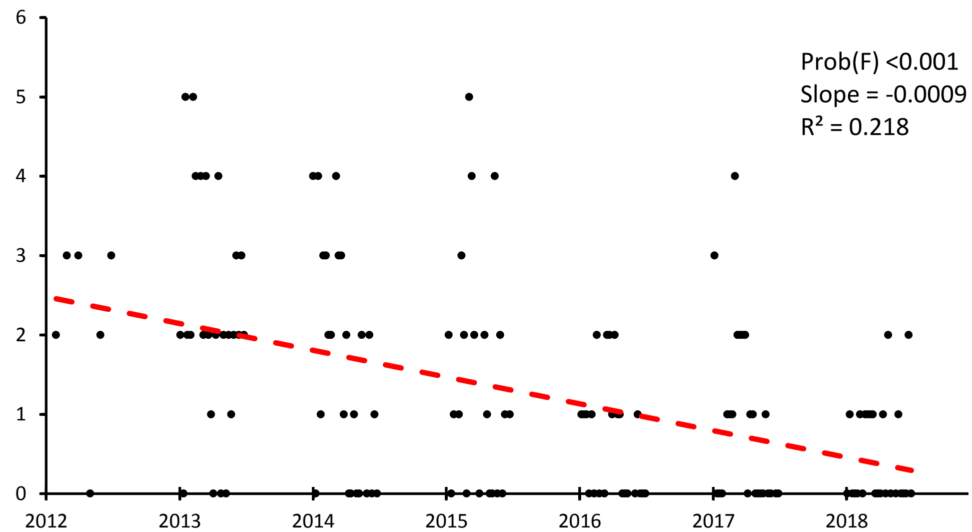
The osprey exhibited a significant increasing trend in breeding season abundance from 1994 to 2000 during the hydrilla invasion period. The trend explained 12.3% of the observed variation in counts per survey.

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 (98.9% level) that explains 8.4% of the observed variation in counts per survey.

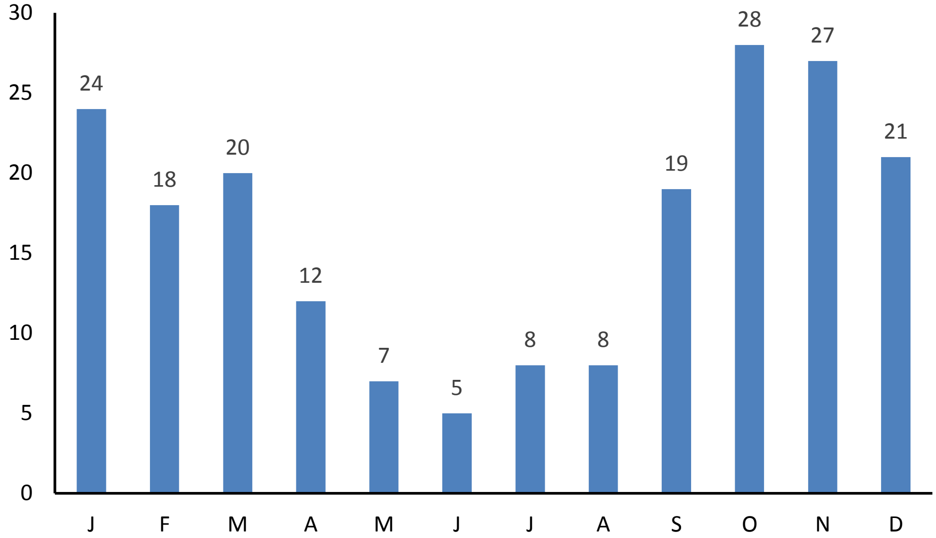
Seasonal Abundance Post- Hydrilla Management: Feb-Jul 2012-2018 (counts per survey)



A significant (99.9% level or better) trend of decreasing breeding season abundance emerged during the post-hydrilla management period that explains 21.8% of the observed variation in counts per survey.

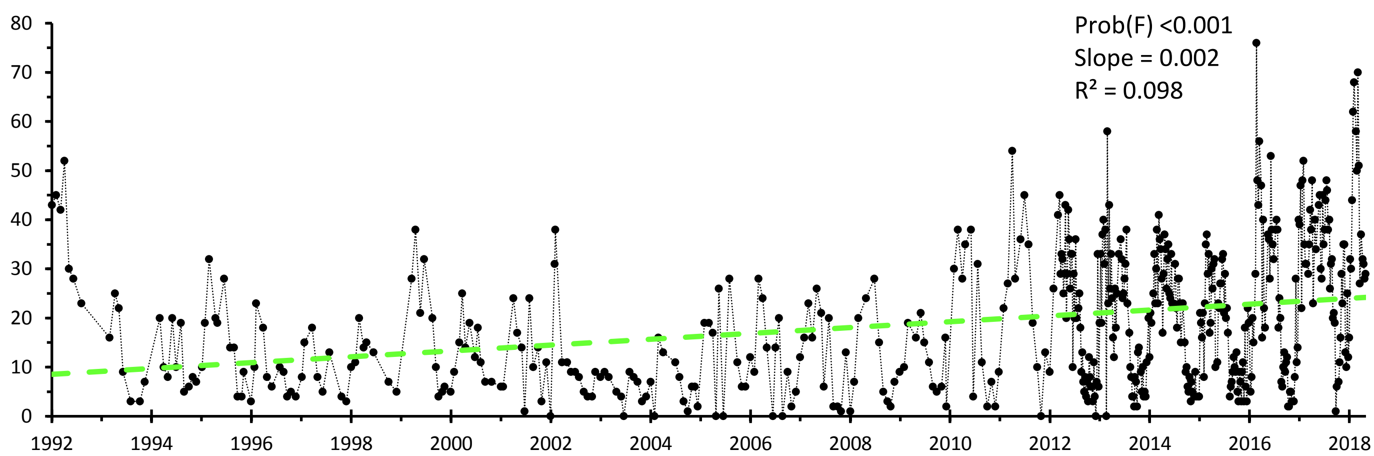
PIED-BILLED GREBE

Seasonal Abundance 1992-2018 (average monthly means)



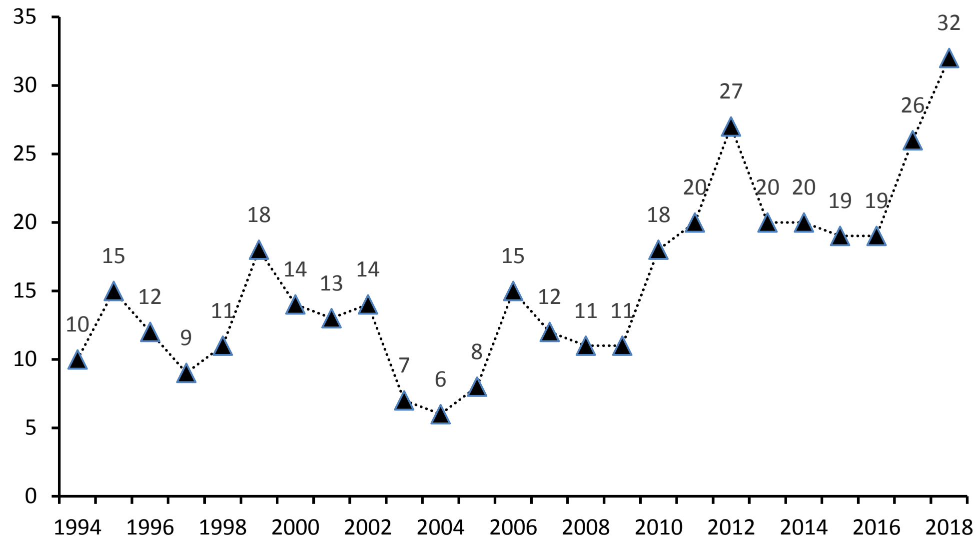
The pied-billed grebe is a year-round breeding resident whose numbers are augmented by winter migrants from September through March (Muller Storer, 1999).

Abundance 1992-2018 (counts per survey)



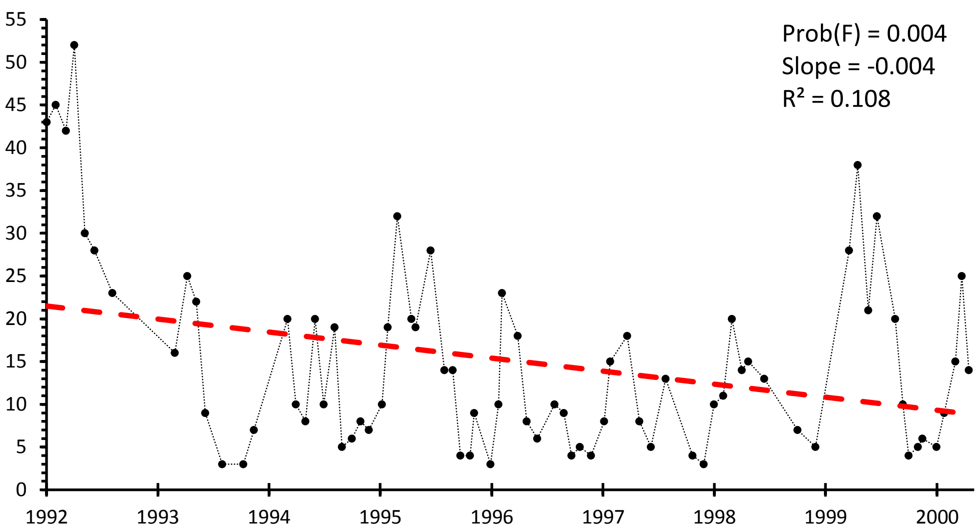
The pied-billed grebe exhibited a significant (99.9% level or better) increasing trend of 0.002 animals counted per day or 0.59 counts per year over the period of record, 9/1/92 – 12/29/18. Survey date explains 9.8% of the observed variation in counts per survey.

Abundance 1994-2018 (annual means)



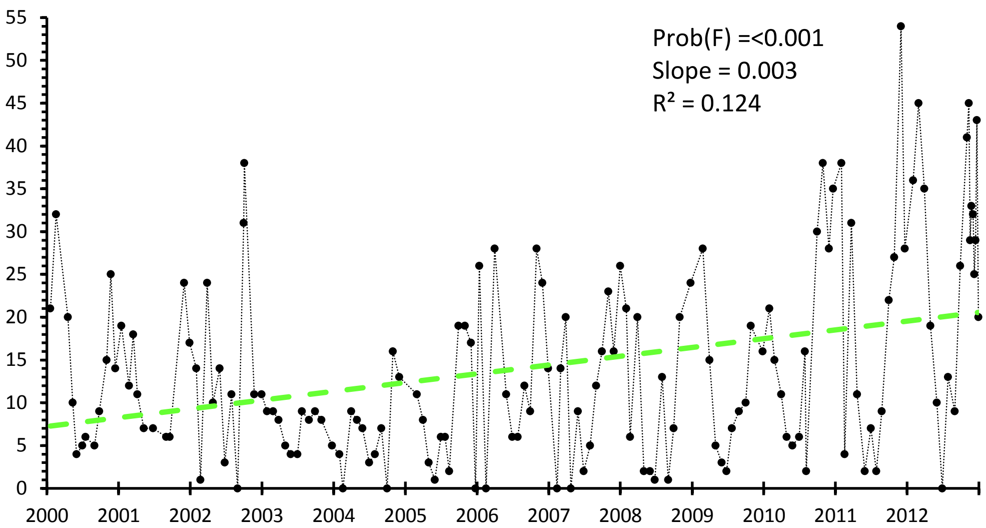
Annual mean counts per survey of the pied-billed grebe also suggest a long-term increase with several ups and downs including a decline beginning in 2000 that continued to 2004 during the hydrilla management period.

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



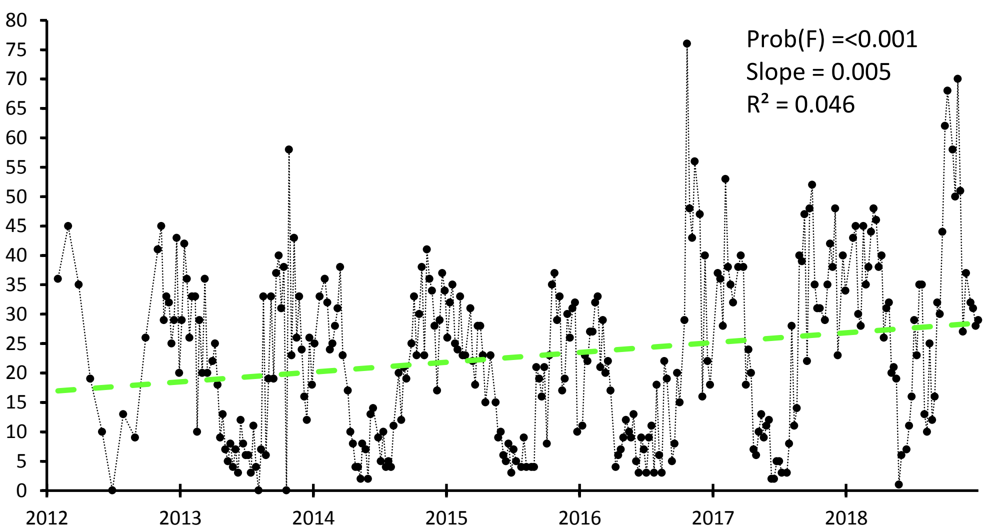
Despite its long-term trend of increasing abundance, the pied-billed grebe experienced a significant decreasing trend (99.6% level) during the hydrilla invasion that explains 10.8 % of the observed variation in counts per survey.

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



Pied-billed grebe abundance turned around during the hydrilla management period exhibiting a significant increase (99.9% level or better) that explains 12.4% of the observed variation in counts per survey.

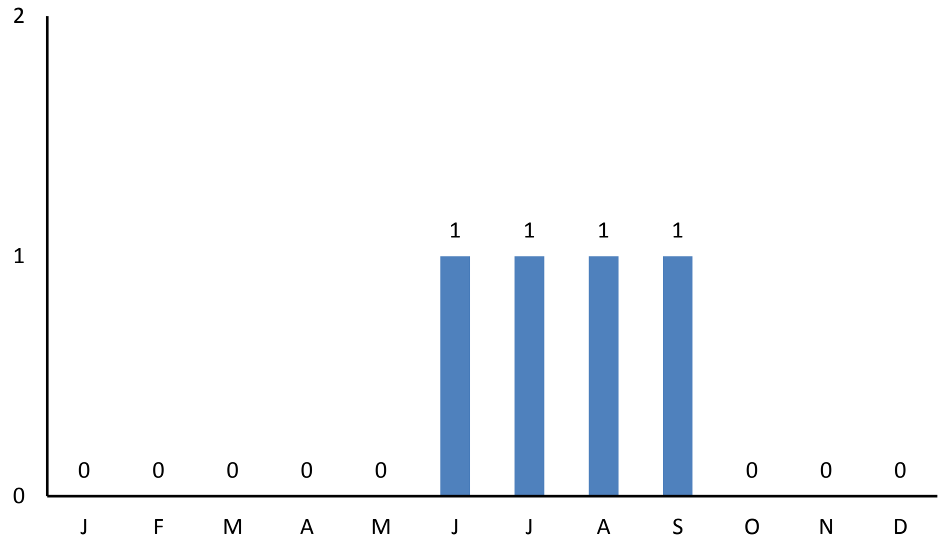
Abundance Post- Hydrilla Management: 2012-2018 (counts per survey)



The significant increasing abundance trend continued during the post-hydrilla management period explaining 4.6% of the observed variation in counts per survey.

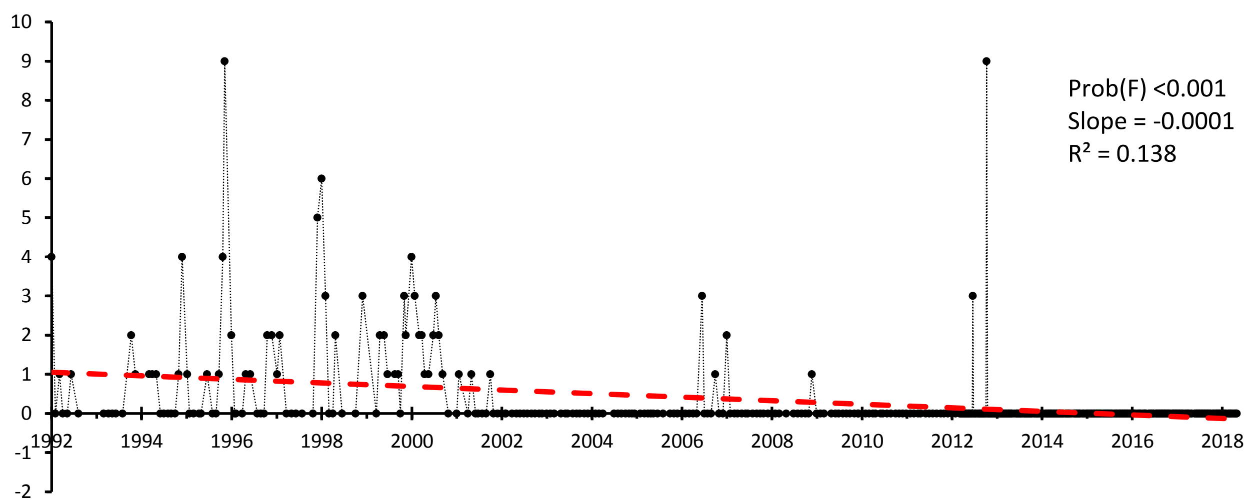
PURPLE GALLINULE

<u>Seasonal Abundance 1992-2018 (average monthly means)</u>



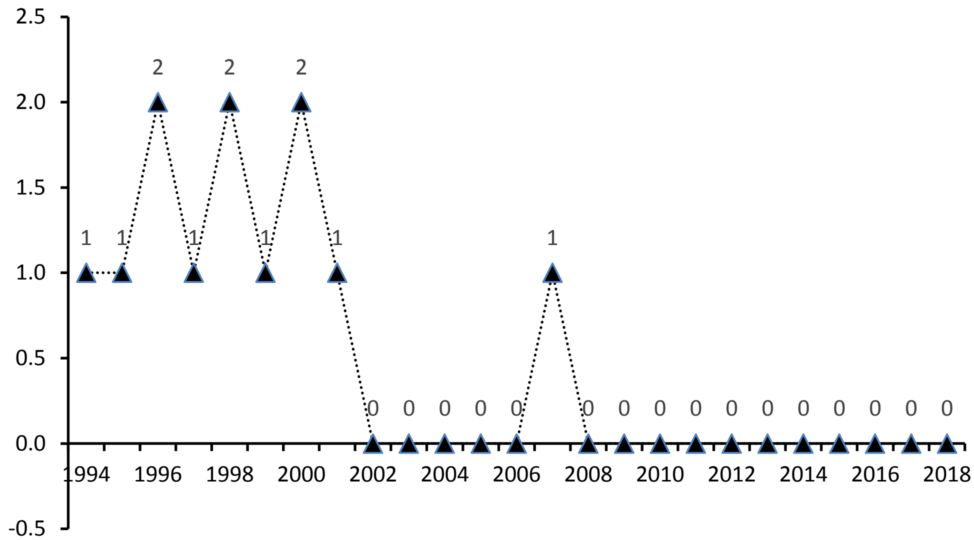
The purple gallinule is uncommon on the upper Wakulla River, most often seen during summer months of June through September. Monthly means range from 0 to 1.

<u>Abundance 1992-2018 (counts per survey)</u>



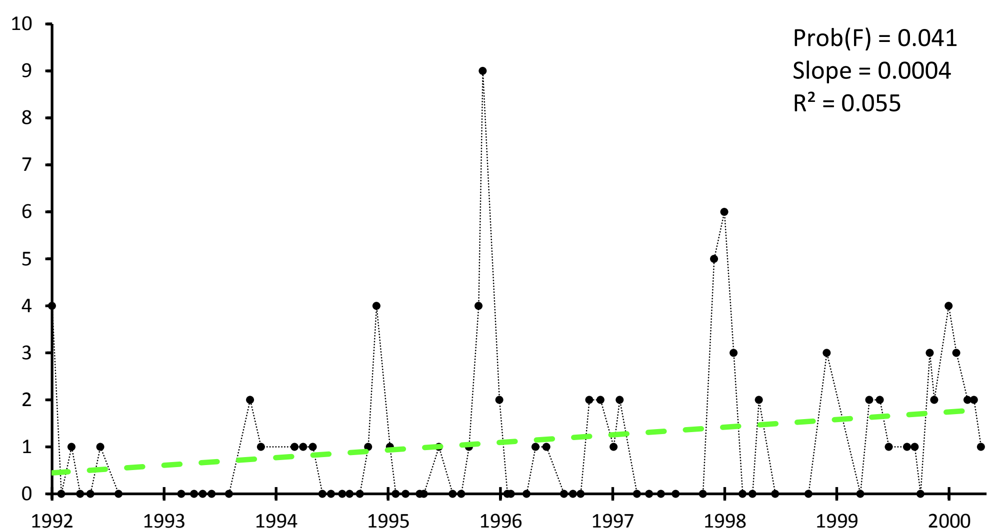
The purple gallinule exhibited a significant (99.9% level or better) but very slowly decreasing trend of -0.0001 animals counted per day or -0.05 counts per year over the period of record, 9/1/92 – 12/29/18. Survey date explains 13.8% of the observed variation in counts per survey.

Abundance 1994-2018 (annual means)



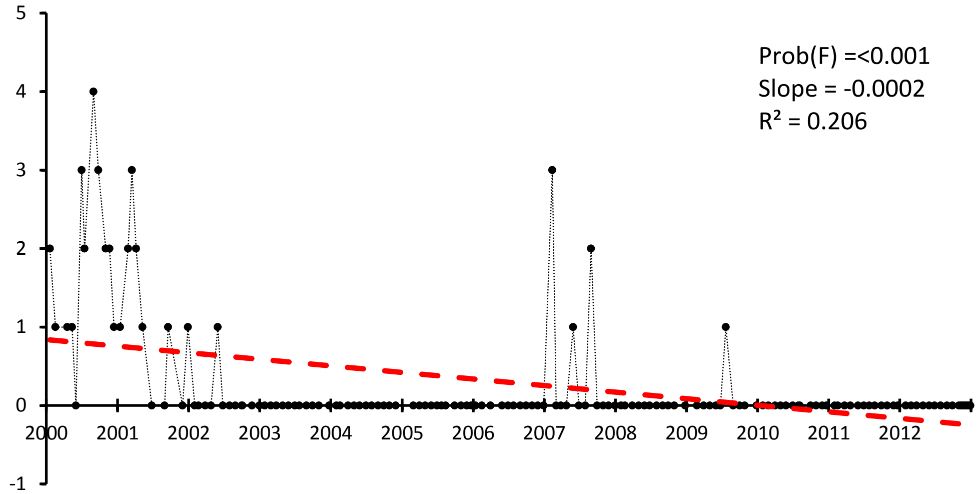
Annual mean counts per survey of the purple gallinule are very low ranging from 0 to 2. Nonetheless they suggest a dramatic decline in 2002 after which the species has been virtually absent.

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



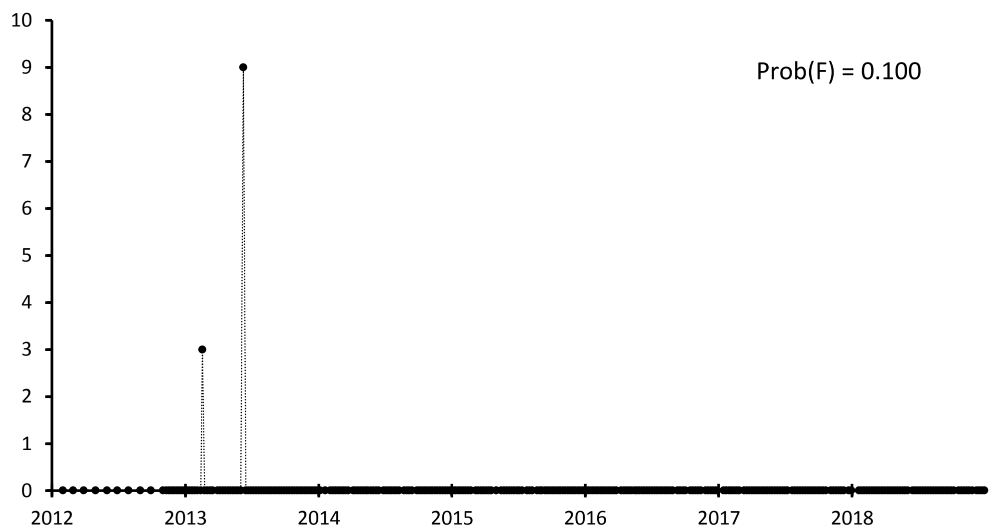
Despite its long-term trend of decreasing abundance, the purple gallinule experienced a significant increasing trend (95.9% level) during the hydrilla invasion that explains 5.5 % of the observed variation in counts per survey. While the hydrilla mat likely provided suitable habitat, the increases began before the mat became established.

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



Purple gallinule abundance turned around during the hydrilla management period exhibiting a significant decrease (99.9% level or better) that explains 20.6% of the observed variation in counts per survey.

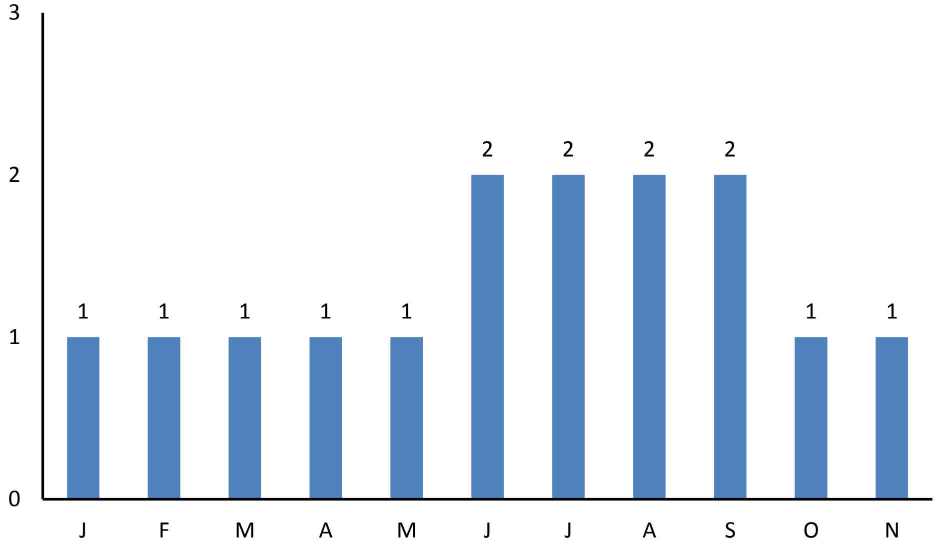
Abundance Post- Hydrilla Management: 2012-2018 (counts per survey)



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.

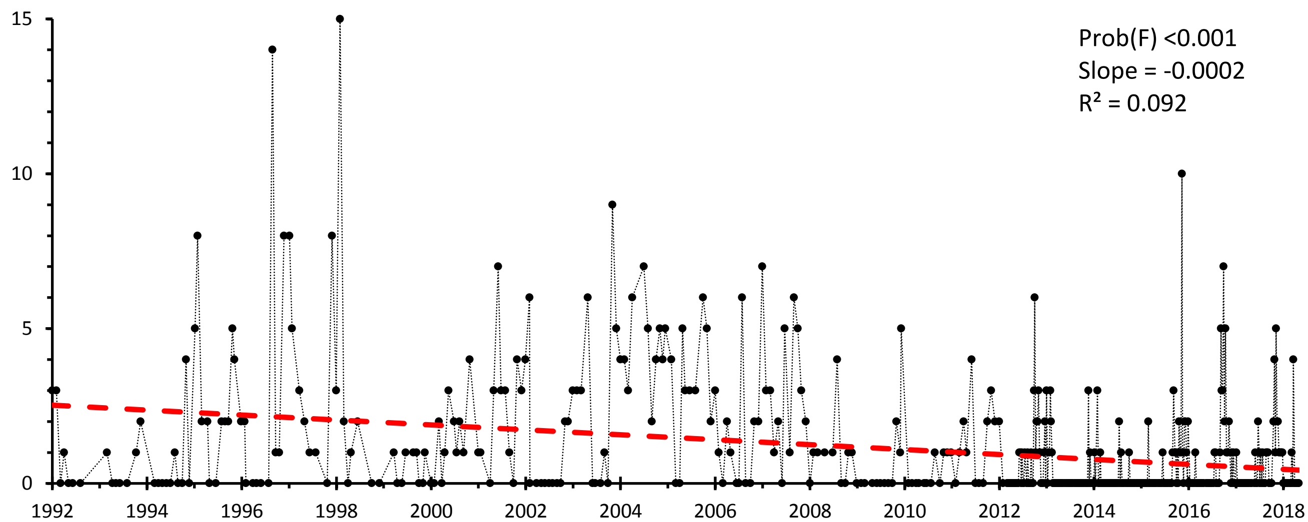
SNOWY EGRET

Seasonal Abundance 1992-2018 (average monthly means)



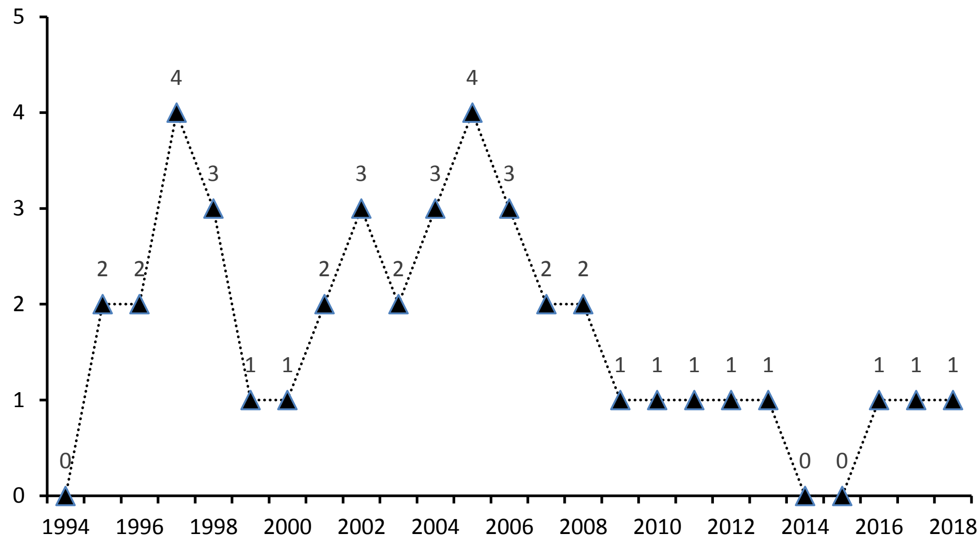
The snowy egret occurs in small numbers on the upper Wakulla River. It is somewhat more common during the summer months of June through September. Monthly means range from 1 to 2.

Abundance 1992-2018 (counts per survey)



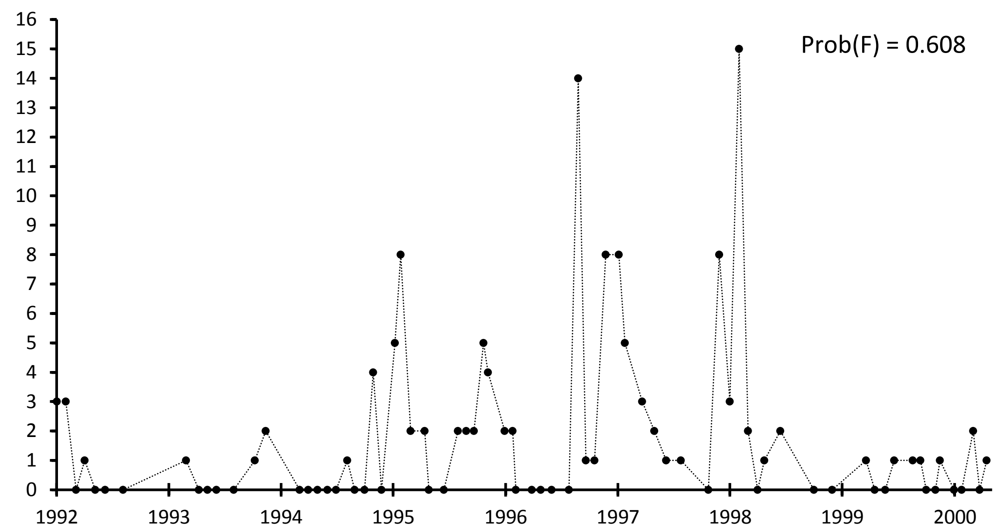
The snowy exhibited a significant (99.9% level or better) but very slowly decreasing trend of -0.0002 animals counted per day or -0.08 counts per year over the period of record, 9/1/92 – 12/29/18. Survey date explains 9.2% of the observed variation in counts per survey.

Abundance 1994-2018 (annual means)



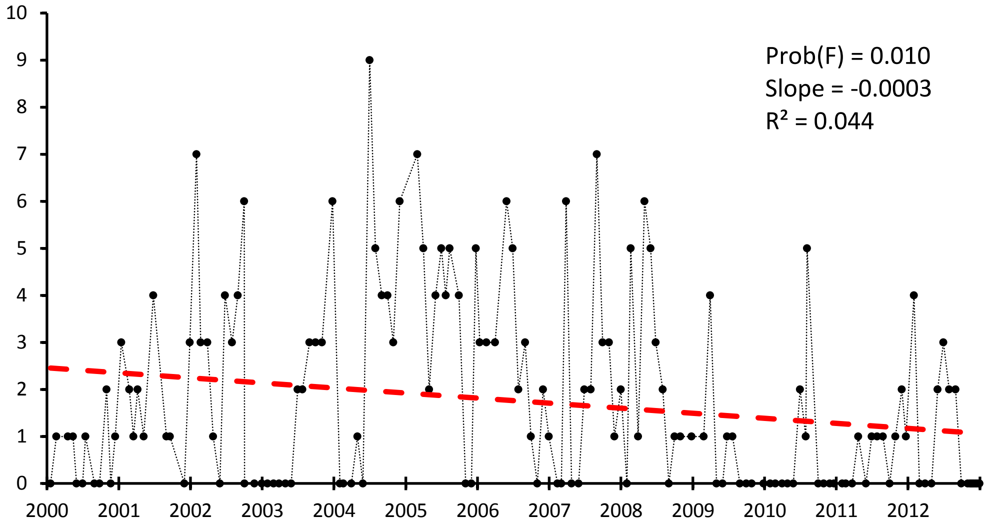
Annual mean counts per survey of the snowy egret are quite variable ranging from 0 to 4 with multiple peaks and valleys that do not appear to be directly related to any of the ecosystem perturbations on the upper Wakulla River.

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



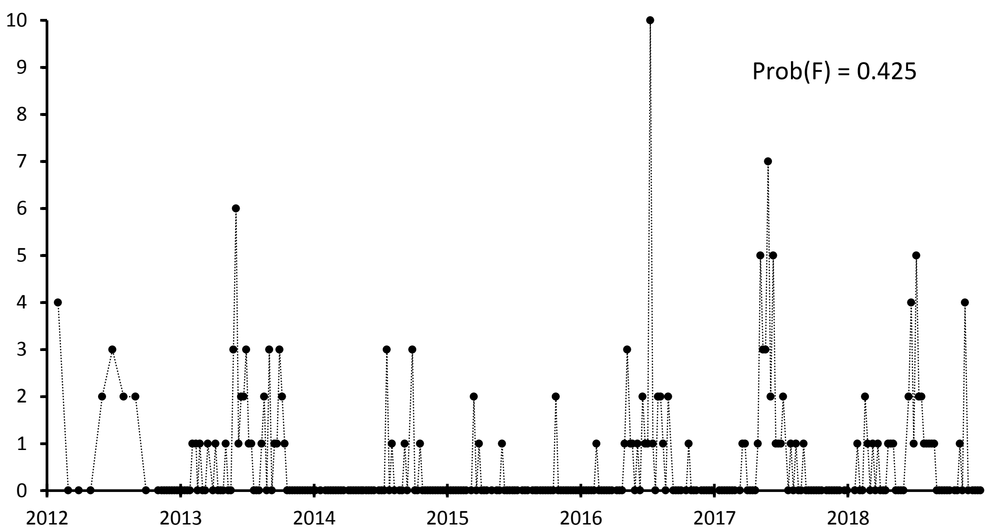
The snowy egret exhibited no significant trend in abundance during the hydrilla invasion with counts per survey ranging from 0 to 15 and an average of 2.

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



Snowy egrets exhibited a significant (99.0% level) decreasing trend of abundance during the hydrilla management period that explains 4.4% of the observed variation in counts per survey.

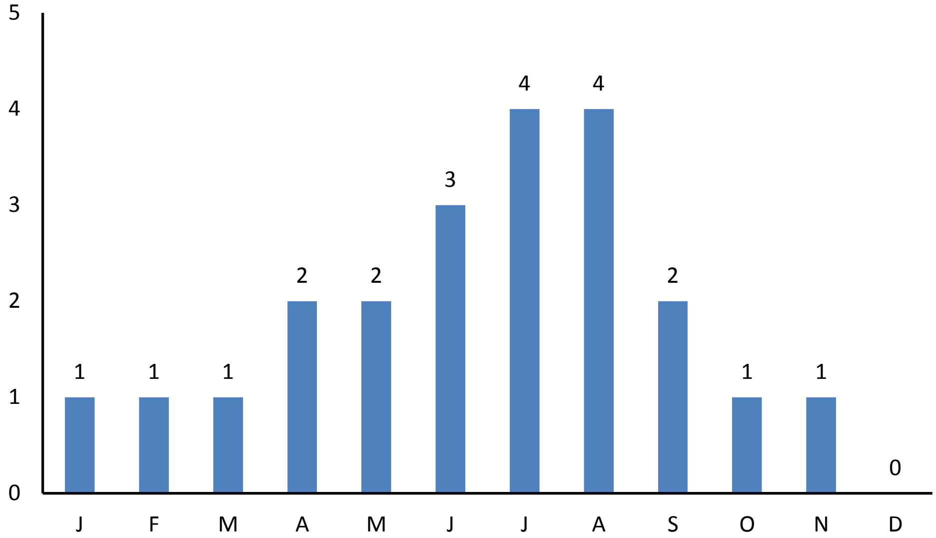
Abundance Post- Hydrilla Management: 2012-2018 (counts per survey)



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 0.6.

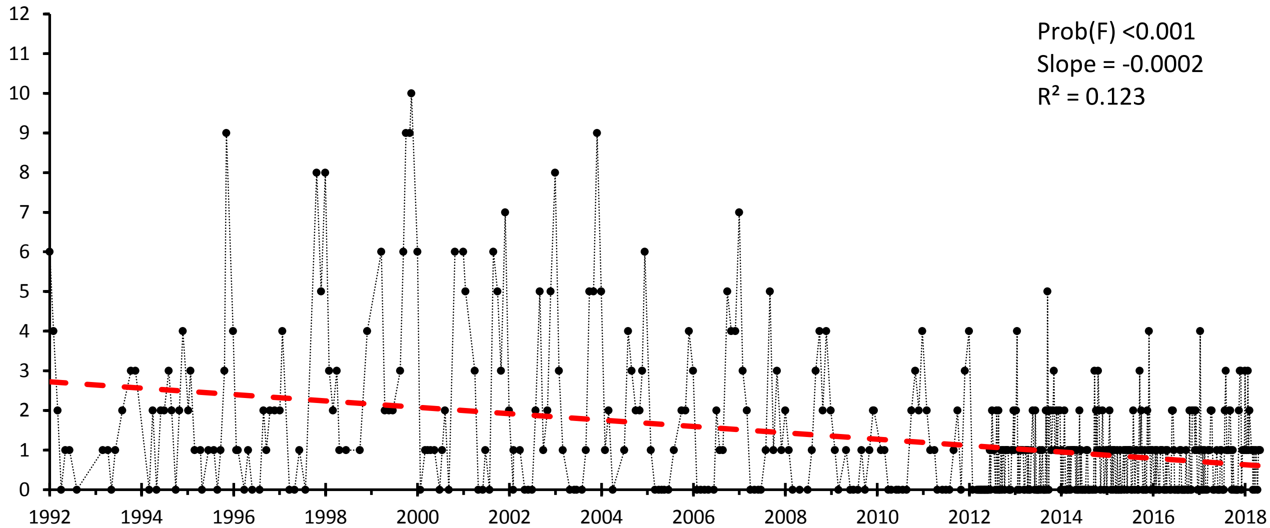
TRICOLORED HERON

Seasonal Abundance 1992-2018 (average monthly means)



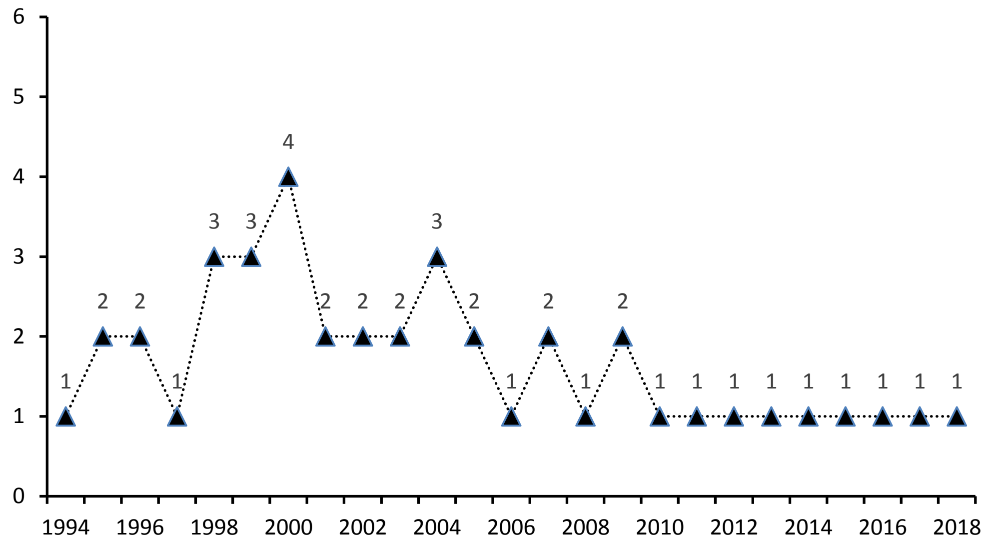
The tricolored heron also occurs in relatively small numbers on the upper Wakulla River and is somewhat more common during the summer months of June through August. Monthly means range from 0 to 4.

Abundance 1992-2018 (counts per survey)



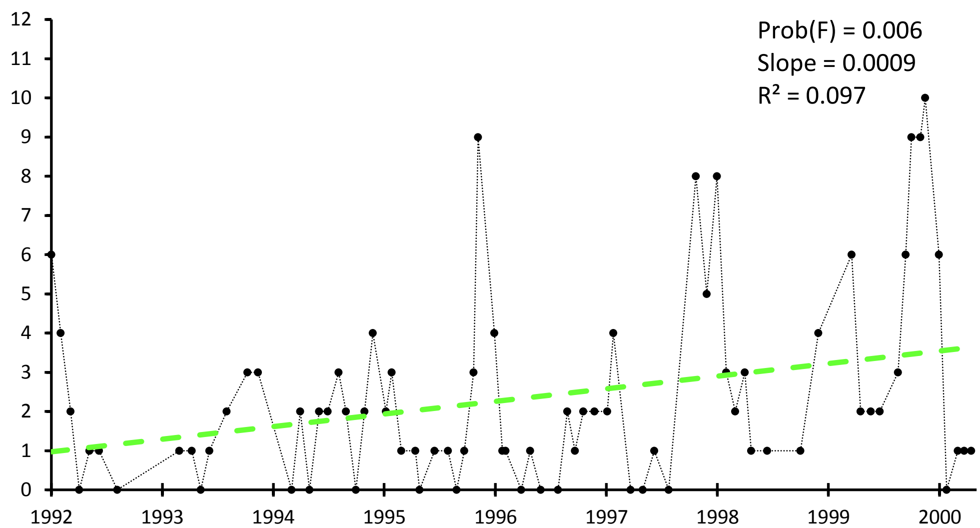
The tricolored heron exhibited a significant (99.9% level or better) but very slowly decreasing trend of -0.0002 animals counted per day or -0.08 counts per year over the period of record, 9/1/92 – 12/29/18. Survey date explains 12.3% of the observed variation in counts per survey.

Abundance 1994-2018 (annual means)



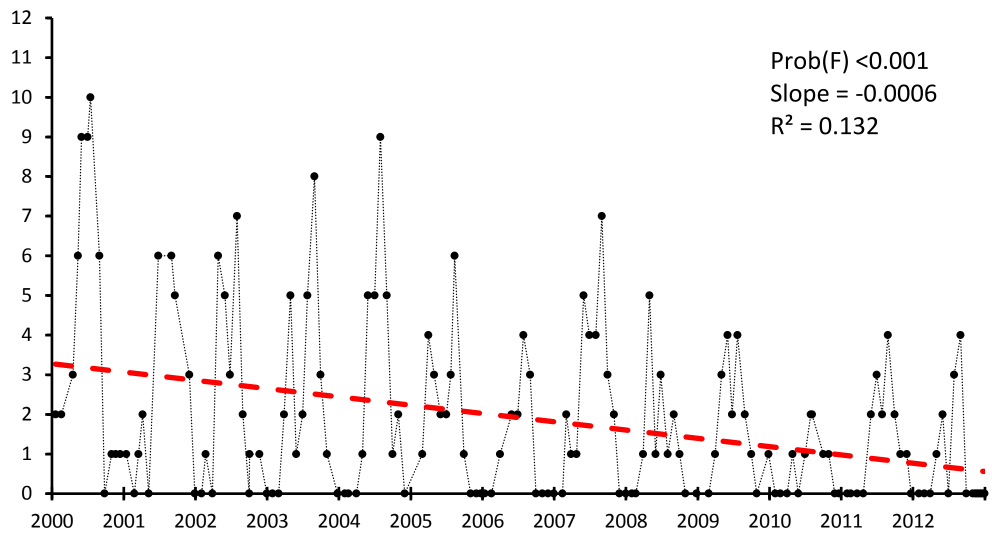
Annual mean counts per survey of the tricolored heron are quite variable from 1994 to 2005 after which there is a general decline flattening out to a mean annual count of 1 from 2010 through 2018.

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



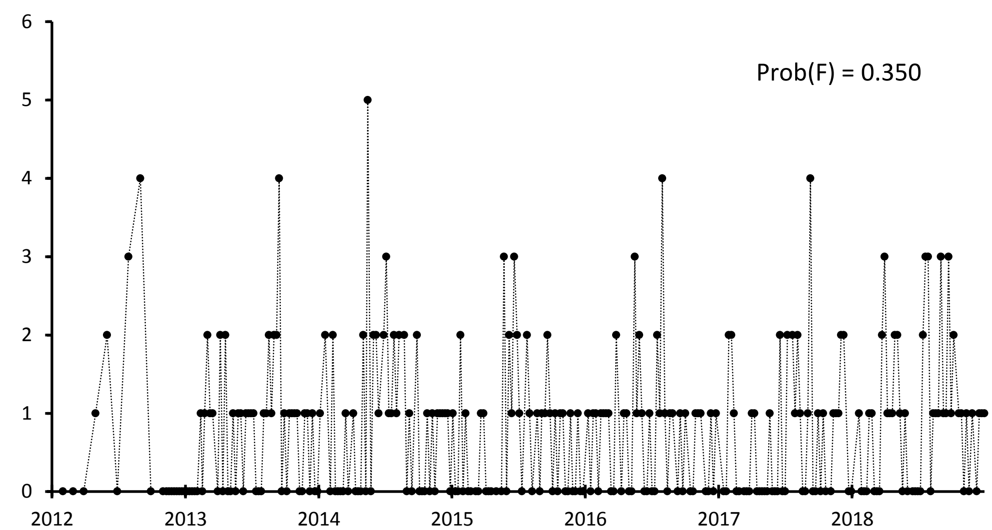
The tricolored heron exhibited a significant trend (99.4%) of increasing abundance during the hydrilla invasion that explains 9.7% of the observed variation in counts per survey.

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 (99.9% level or better) that explains 13.2% of the observed variation in counts per survey.

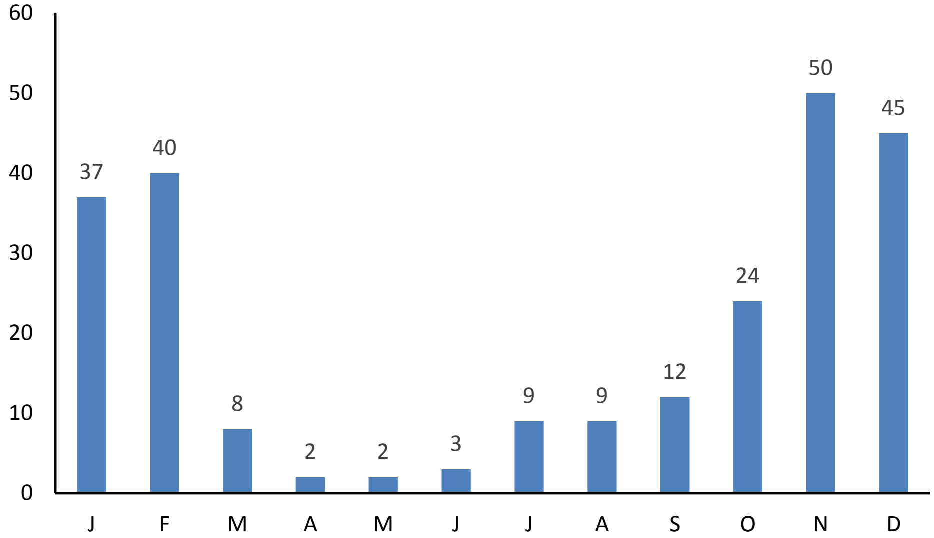
Abundance Post- Hydrilla Management: 2012-2018 (counts per survey)



The tricolored heron exhibited no significant abundance trend during the post-hydrilla management period with counts ranging from 0 to 5 and an average of 0.8.

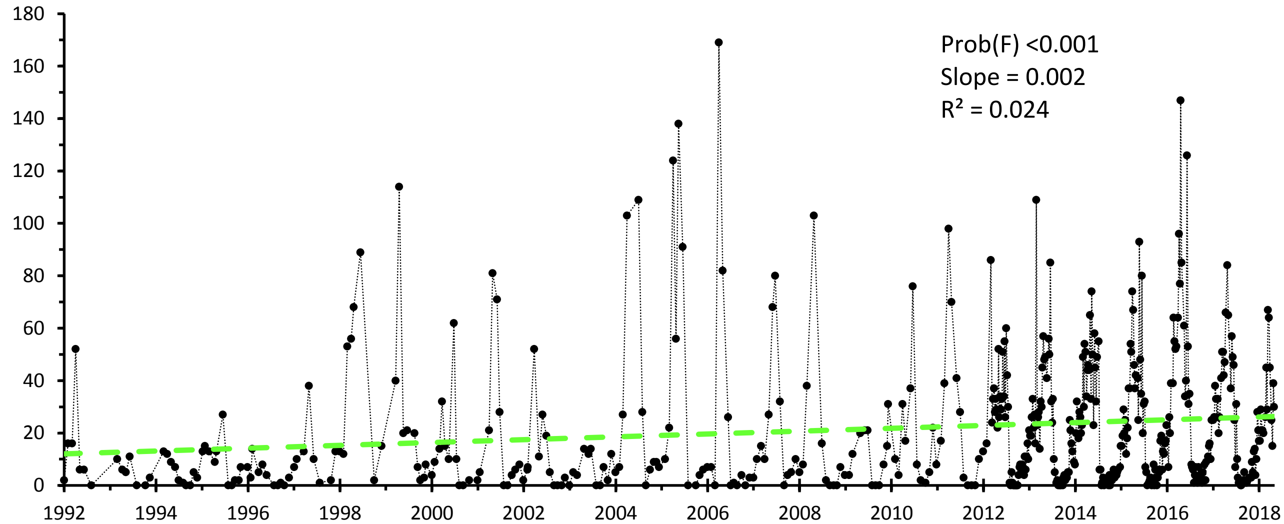
WHITE IBIS

Seasonal Abundance 1992-2018 (average monthly means)



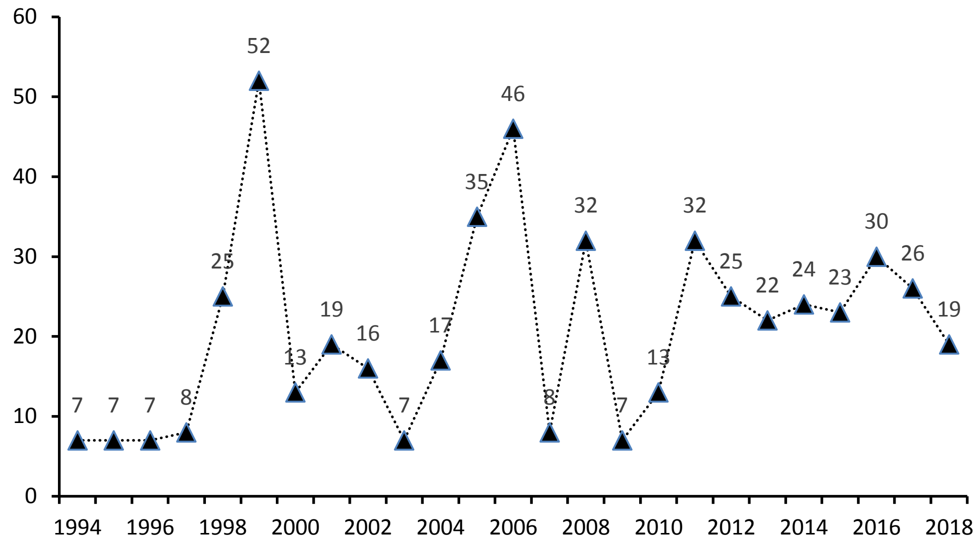
The white ibis does not breed on the upper Wakulla River. However, adults congregate there outside the breeding season beginning in July. Summer populations are comprised primarily of juveniles (personal observation).

Abundance 1992-2018 (counts per survey)



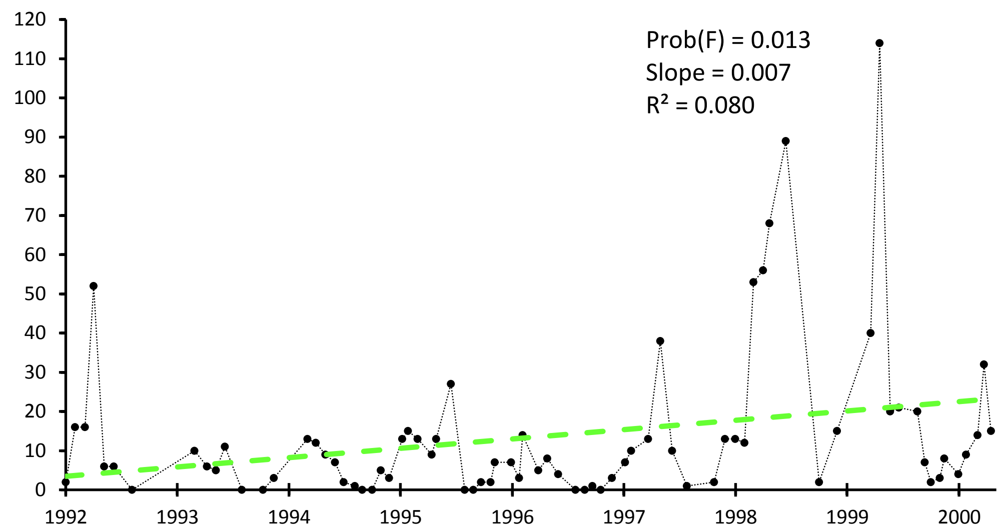
White ibis exhibited a significant (99.9% level or better) increasing abundance trend of 0.002 animals counted per day or 0.55 counts per year over the period of record, 9/1/92 – 12/29/18. Survey date explains 2.4% of the observed variation in counts per survey.

Abundance 1994-2018 (annual means)



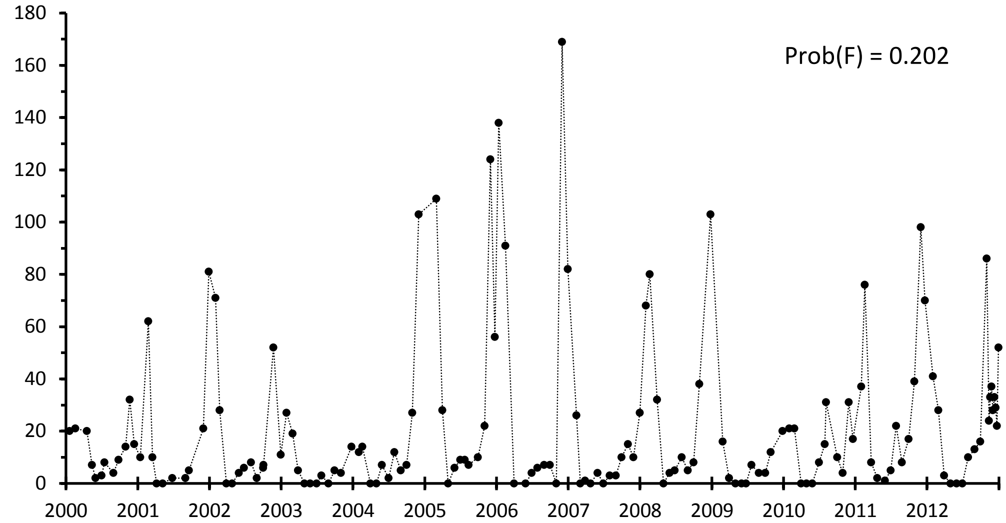
Annual mean counts per survey of the white ibis vary substantially with high peaks and valleys, particularly between 1997 and 2011.

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



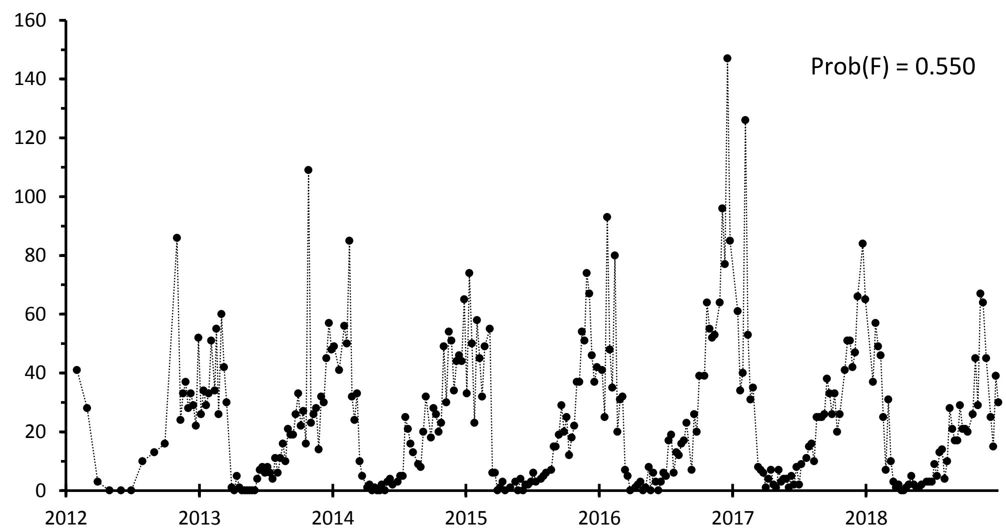
The white ibis exhibited a significant trend (98.7%) of increasing abundance during the hydrilla invasion that explains 8.0% of the observed variation in counts per survey.

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.

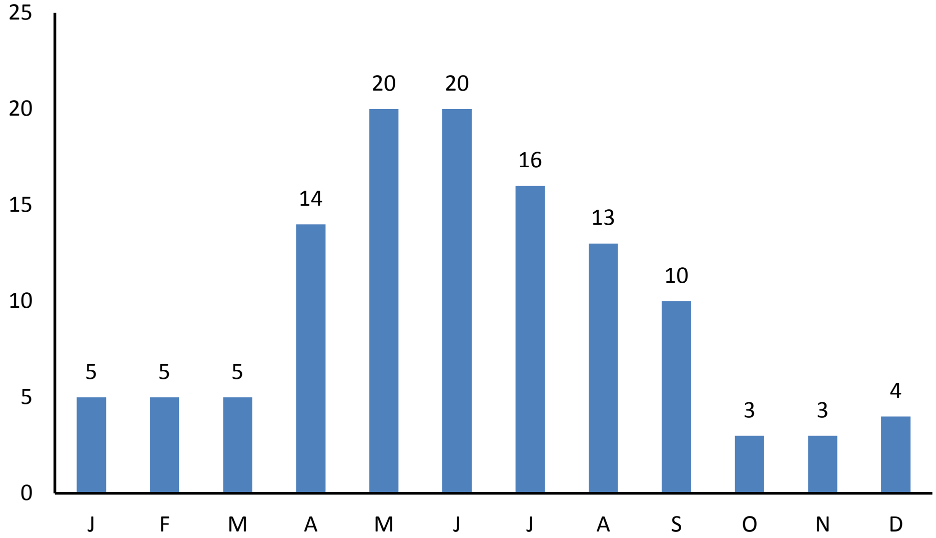
Abundance Post- Hydrilla Management: 2012-2018 (counts per survey)



No significant abundance trend occurred during the post-hydrilla management period either. Counts per survey ranged from 0 to 147 with an average of 24. The seasonal abundance pattern is evident in these denser data.

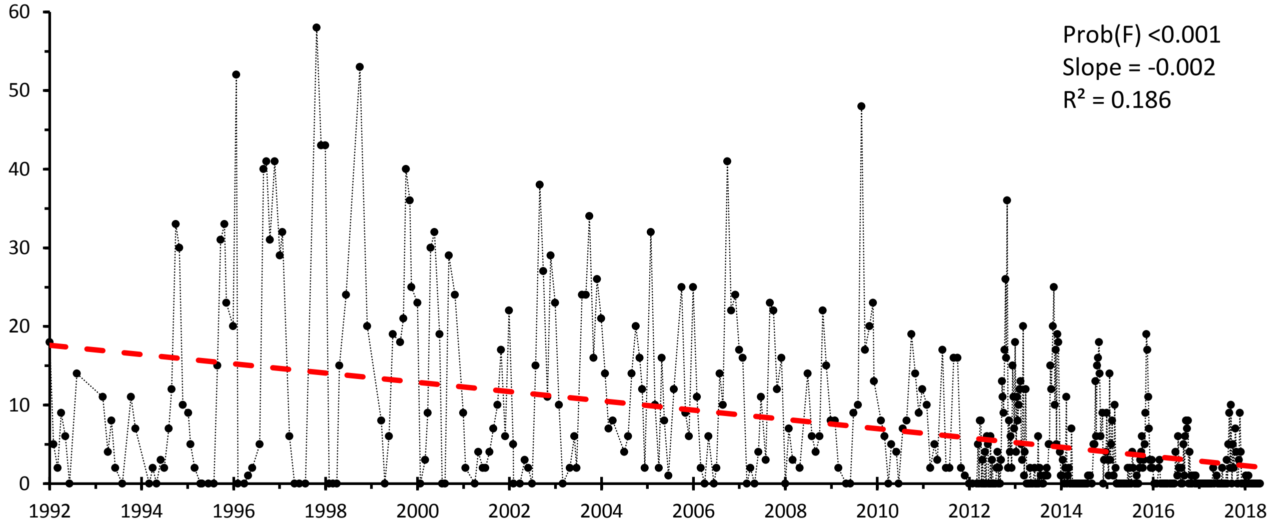
WOOD DUCK

Seasonal Abundance 1992-2018 (average monthly means)



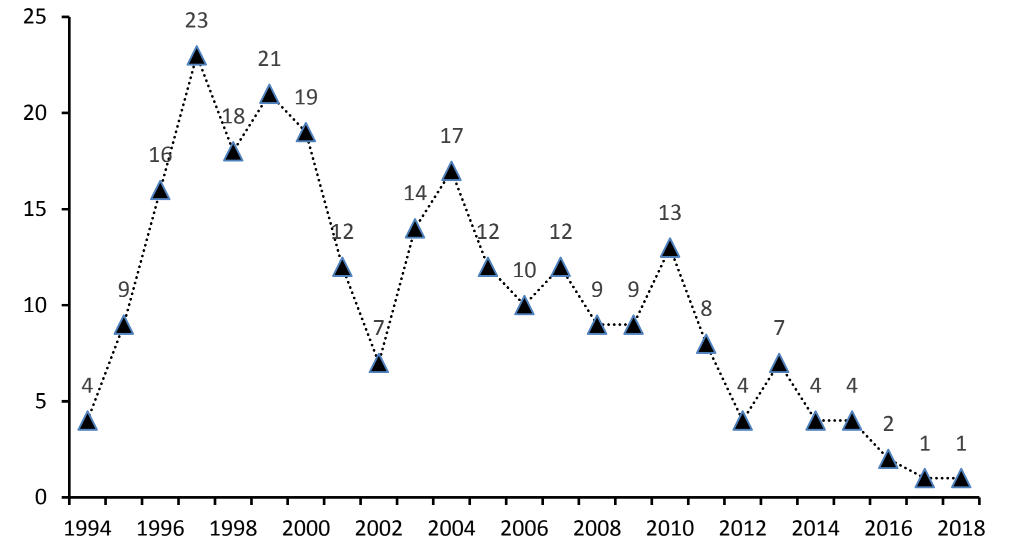
The wood duck is a year-round breeding resident that may have two broods per year. Females are permanent residents while males are not (Kaufman, 2019b), which may account in part for lower numbers outside the summer breeding season.

Abundance 1992-2018 (counts per survey)



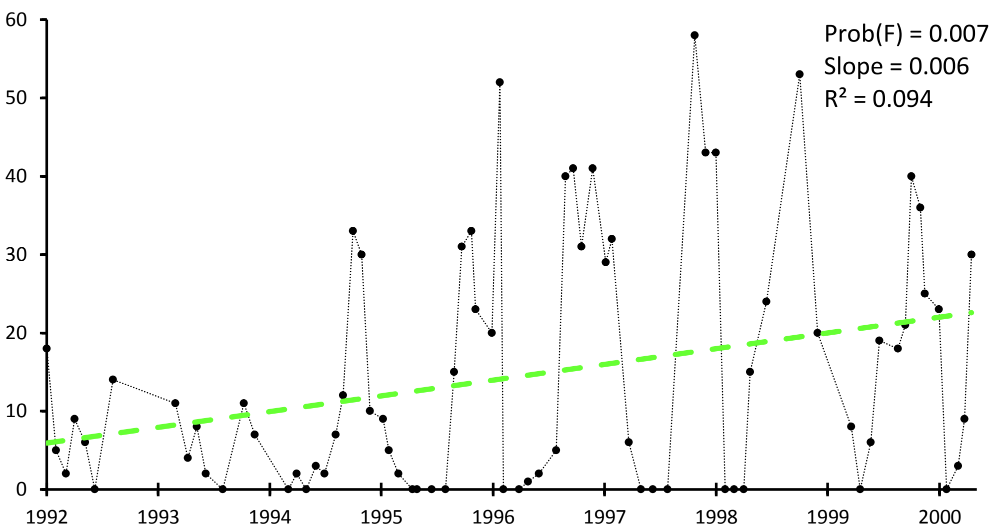
The wood duck exhibited a significant (99.9% level or better) decreasing abundance trend of -0.002 animals counted per day or -0.59 counts per year over the period of record, 9/1/92 – 12/29/18. Survey date explains 18.6% of the observed variation in counts per survey.

Abundance 1994-2018 (annual means)



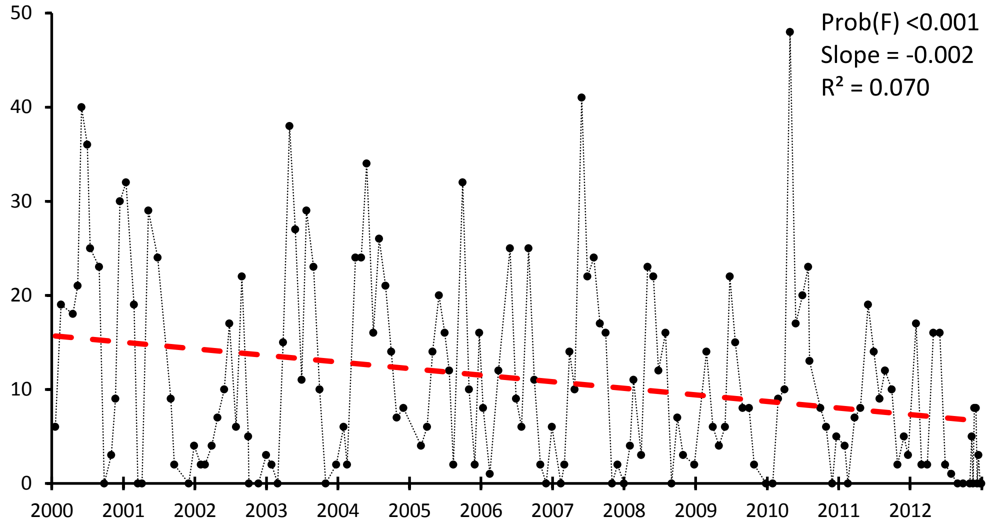
Wood duck annual mean counts per survey peak between 1997 and 1999, decline steeply to 2002, rebound to 2004, and then generally decline to very low values in 2016-2018.

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



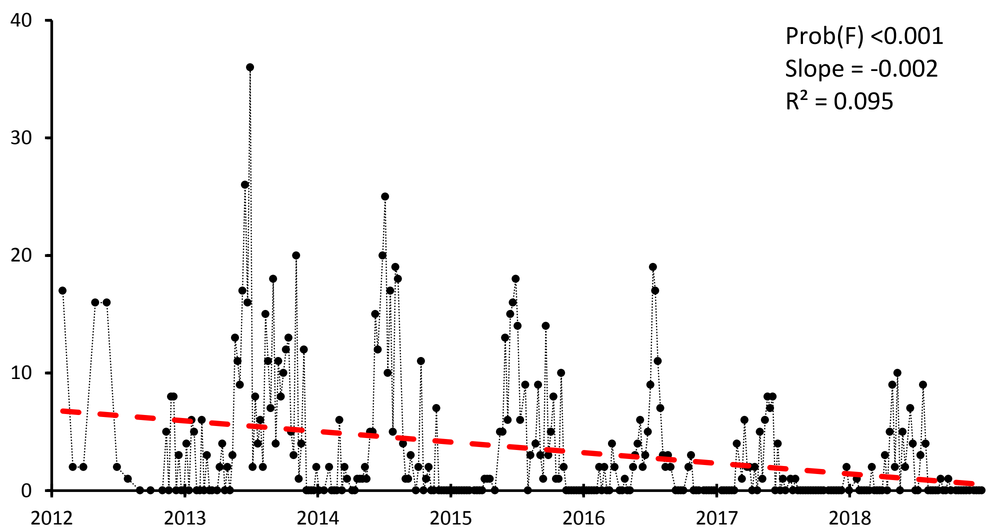
The wood duck exhibited a significant trend (99.3%) of increasing abundance during the hydrilla invasion that explains 9.4% of the observed variation in counts per survey.

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



The wood duck began a significant decreasing trend (99.9% level or better) in abundance during the hydrilla management period that explains 7.0% of the observed variation in counts per survey.

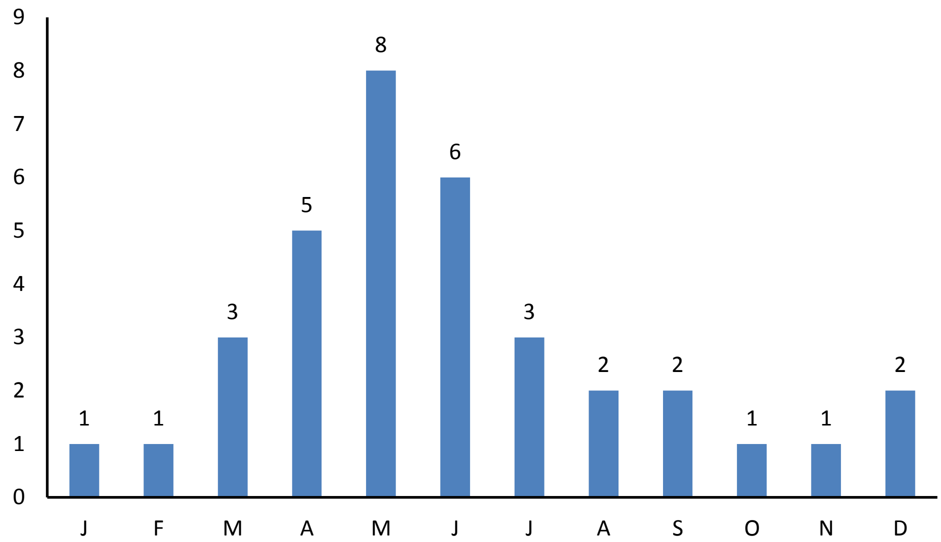
Abundance Post- Hydrilla Management: 2012-2018 (counts per survey)



The significant decrease (99.9% level or better) in wood duck abundance continued through the post-hydrilla management period with a trend that explains 9.5% of the observed variance in counts per survey.

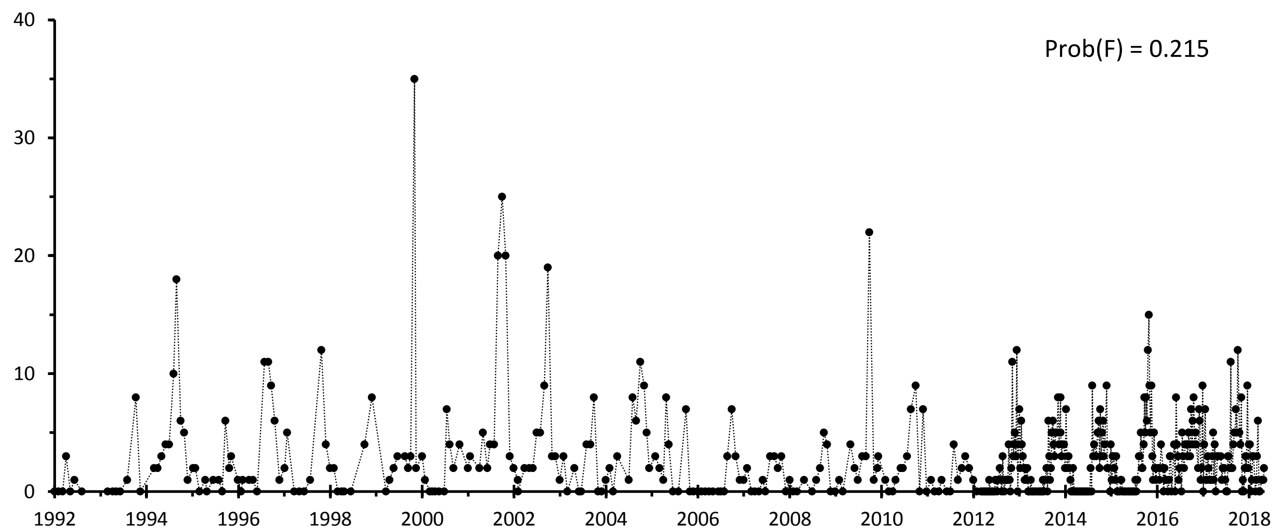
YELLOW-CROWNED NIGHT-HERON

Seasonal Abundance 1992-2018 (average monthly means)



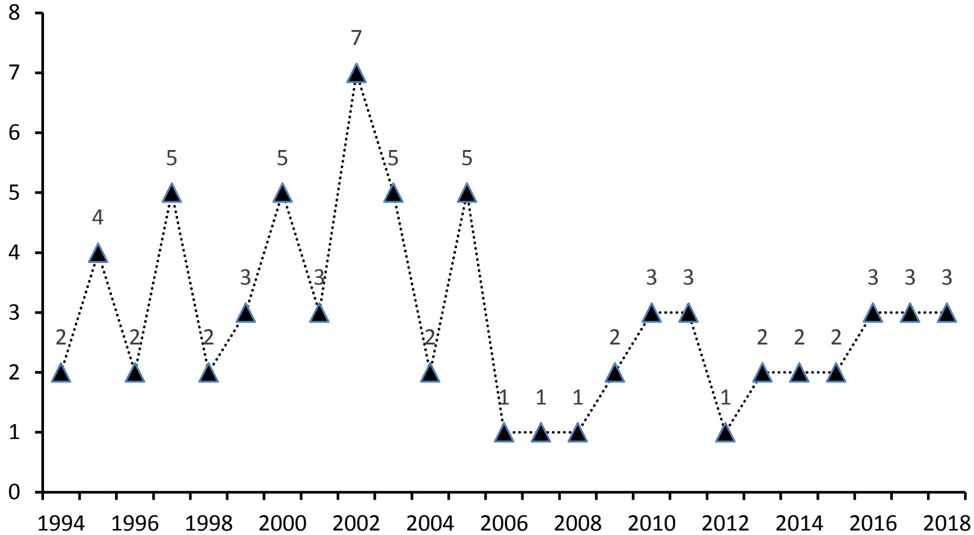
The yellow-crowned night-heron is a year-round resident that breeds in the summer. However, most individuals migrate to south Florida or beyond in the winter (Watts, 2011).

Abundance 1992-2018 (counts per survey)



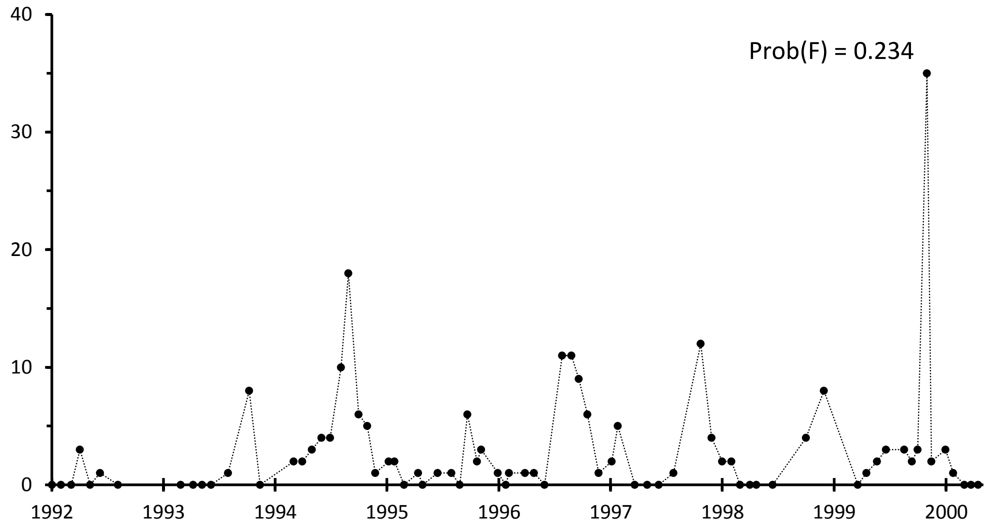
The yellow-crowned night-heron exhibited no significant abundance trend over the period of record, 9/1/92 – 12/29/18. Counts per survey ranged from 0 to 35 with an average of 2.7.

Abundance 1994-2018 (annual means)



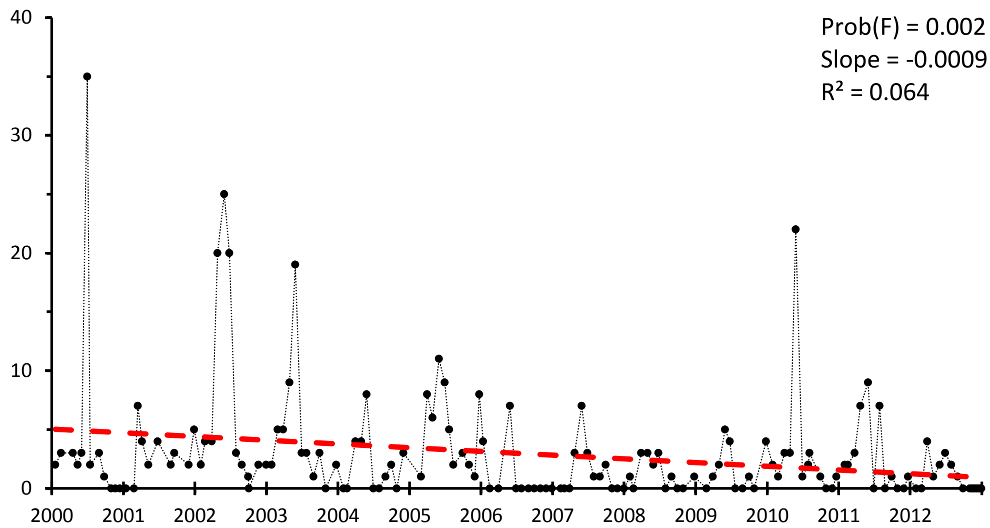
Despite the lack of a significant long-term trend in counts per survey, annual mean counts appear to have decreased with counts ranging from 2 to 7 between 1992 and 2005 decreasing to a range of 1 to 3 thereafter. Annual means peak at 7 in 2002 followed by a two-year decline to 2 in 2004.

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



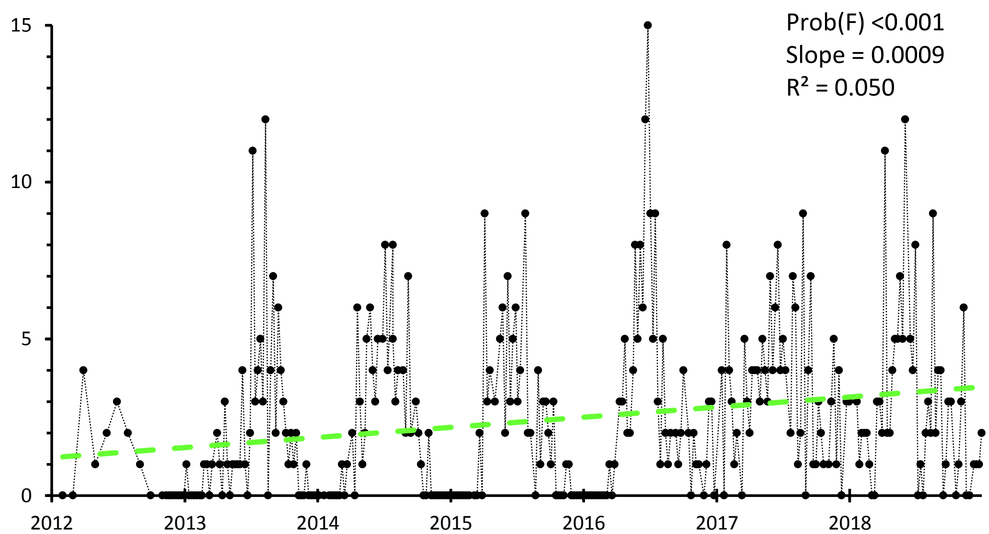
The yellow-crowned night-heron exhibited no significant abundance trend during the hydrilla invasion period. Counts per survey ranged from 0 to 35 with an average of 2.9.

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



The yellow-crowned night-heron exhibited a significant decreasing trend (99.8% level) in abundance during the hydrilla management period that explains 6.4% of the observed variation in counts per survey.

Abundance Post- Hydrilla Management: 2012-2018 (counts per survey)



The yellow-crowned night-heron abundance trend reversed during the post-hydrilla management period with a significant positive trend (99.9% level or better) that explains 5.0% of the observed variance in counts per survey.

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