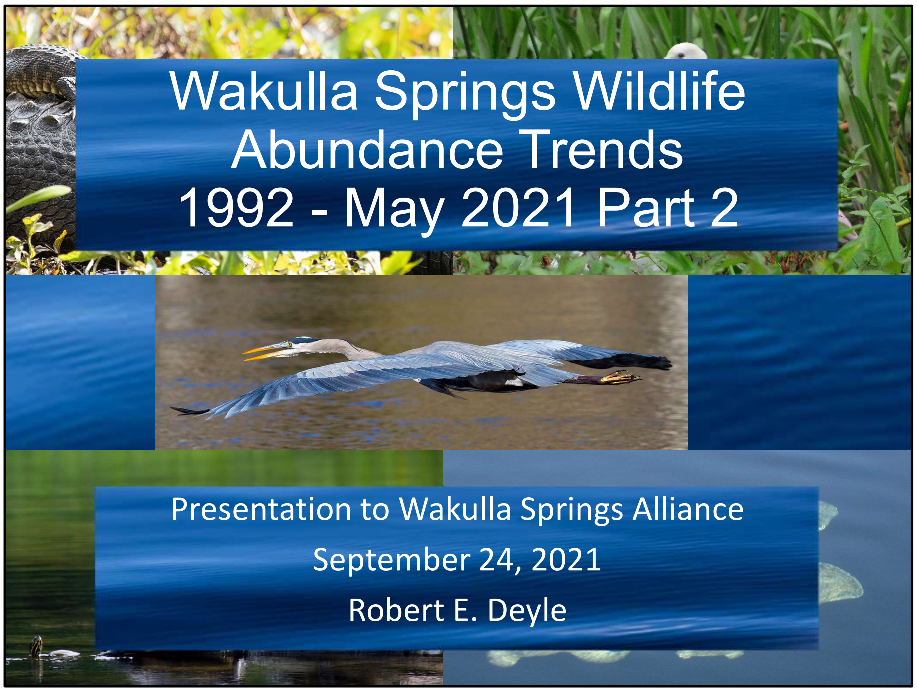
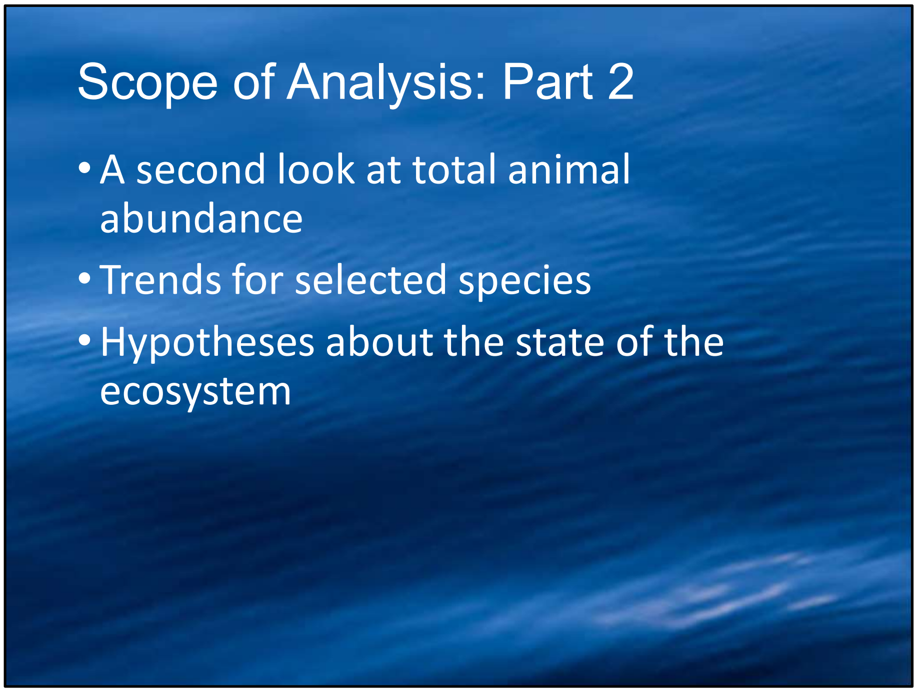
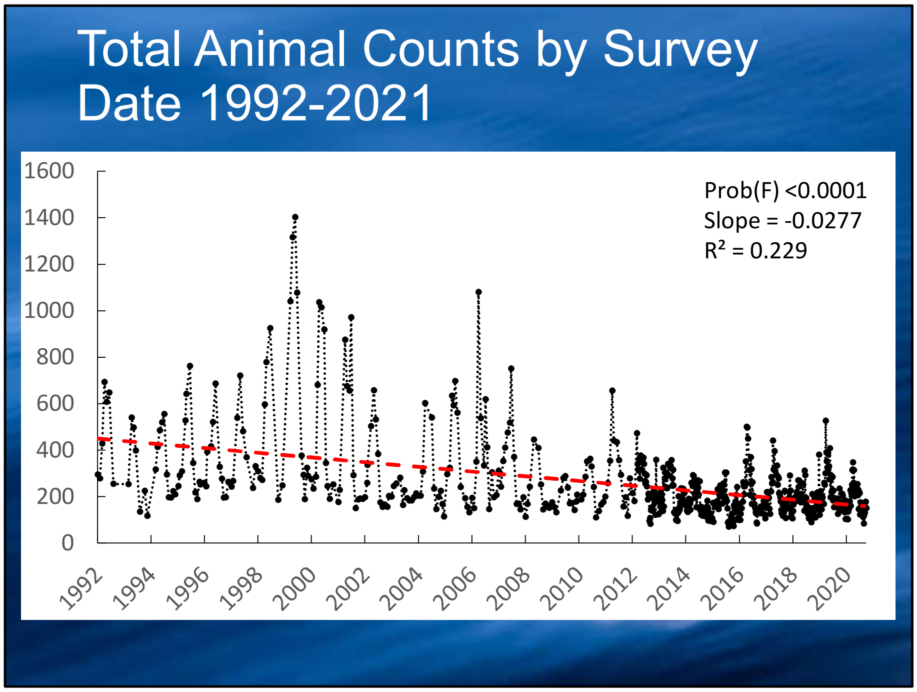


- Because of the other important business on our agenda in August, I split my presentation on Wakulla Springs wildlife abundance trends into two parts.
    - In Part 1, I shared aggregate trends over the 29.5 years the park has been monitoring wildlife along the 2-mile river boat tour route
        - And we looked at trends during three perturbation periods
    - **[click]** to next slide

Photo credits:
- Upper left – Bob Thompson
- Upper right – Doug Alderson
- Center – Bob Thompson
- Bottom left – Bob Thompson
- Bottom right – Bob Deyle



- Today I’d like to take a second look at the measure of total animal abundance as a proxy for ecosystem productivity
- Then explore the details of some selected species.
- Conclude with some speculation about the state of the ecosystem



- As you may recall I have suggested that trends in total animal counts per survey can be viewed as an indication of the total productivity of the upper Wakulla River ecosystem
- Regression analyses of these data for the period of record reveals a statistically significant decreasing trend from September 1992 through May 2021
- As indicated by the R-squared statistic, the linear regression model explains 22.9% of the observed variation in total counts per survey
    - The Prob(F) value indicates the relationship is significant at a confidence level of greater than 99.99%,
        - i.e. we can be 99.99% certain that there is a true statistical correlation between total animal counts per survey and the passage of time
    - The slope of -0.0277 animals counted per day translates into a decrease of 10 animals counted per year
- During my presentation last month, Kathleen Coates pointed out that the measure of total animal abundance is not solely a function of the conditions of the Wakulla River ecosystem,
    - Some of the species surveyed migrate seasonally
    - Others are present more or less year-round but only occasionally breed along the tour boat route

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

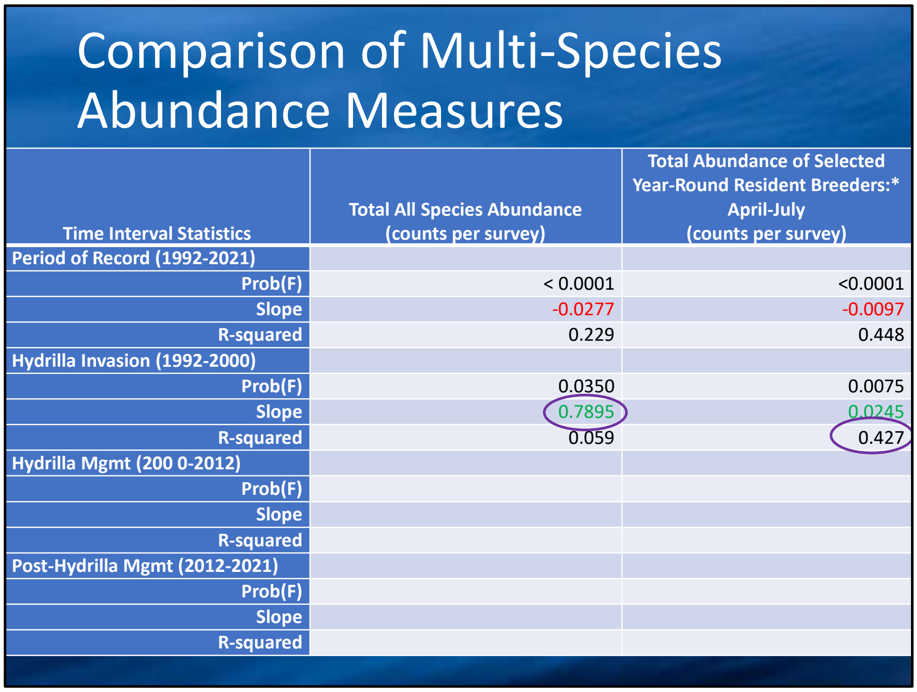
*Year-round breeding populations probably supplemented by winter migrants.
**Occasionally nest along the tour boat route; frequently nest in sanctuary.

- I have, therefore, created a separate measure of multi-species abundance that is limited to six species that are year-round resident breeders:
  - American alligator
  - Anhinga
  - Common gallinule
  - Green heron
  - Pied-billed grebe
  - Yellow-crowned night-heron
- I have excluded cooter turtles because counts are substantially influenced by water visibility depth for which we do not have a reliable statistical control
- I also only analyzed data for the summer breeding season, i.e. the months of April through July, to avoid the confounding by in-migration of common gallinule and pied-billed grebes in late summer
- So lets see how this alternative measure of multi-species abundance compares to the one based on all 24 species surveyed

Comparison of Multi-Species Abundance Measures

Time Interval Statistics	Total All Species Abundance (counts per survey)	Total Abundance of Selected Year-Round Resident Breeders:* April-July (counts per survey)
Period of Record (1992-2021)		
Prob(F)	< 0.0001	<0.0001
Slope	-0.0277	-0.0097
R-squared	0.229	0.448
Hydrilla Invasion (1992-2000)		
Prob(F)		
Slope		
R-squared		
Hydrilla Mgmt (200 0-2012)		
Prob(F)		
Slope		
R-squared		
Post-Hydrilla Mgmt (2012-2021)		
Prob(F)		
Slope		
R-squared		

- This table compares the regression statistics for the two multi-species abundance measures for the period of record and each of the perturbation periods
- Both exhibit statistically significant decreasing trends over the period of record from 1992-2001
    - The slope is steeper for the all-species model: -0.0277 counts per survey versus -0.0097
    - But the passage of time explains a higher proportion of the observed abundance for the year-round resident breeders based on the R-squared values: **[click]** 44.8% for year-round resident breeders versus 22.9% for all-species



Comparison of Multi-Species Abundance Measures

Time Interval Statistics	Total All Species Abundance (counts per survey)	Total Abundance of Selected Year-Round Resident Breeders:* April-July (counts per survey)
Period of Record (1992-2021)		
Prob(F)	< 0.0001	<0.0001
Slope	-0.0277	-0.0097
R-squared	0.229	0.448
Hydrilla Invasion (1992-2000)		
Prob(F)	0.0350	0.0075
Slope	0.7895	0.0245
R-squared	0.059	0.427
Hydrilla Mgmt (200 0-2012)		
Prob(F)		
Slope		
R-squared		
Post-Hydrilla Mgmt (2012-2021)		
Prob(F)		
Slope		
R-squared		

- During the hydrilla invasion period, both exhibit statistically significant increasing trends
    - **[click]** Again the slope is steeper for the all-species model
    - **[click]** But, the passage of time explains a higher proportion of the observed abundance for the year-round resident breeders, i.e. 42.7% versus 5.9%

Comparison of Multi-Species Abundance Measures

Time Interval Statistics	Total All Species Abundance (counts per survey)	Total Abundance of Selected Year-Round Resident Breeders:* April-July (counts per survey)
Period of Record (1992-2021)		
Prob(F)	< 0.0001	<0.0001
Slope	-0.0277	-0.0097
R-squared	0.229	0.448
Hydrilla Invasion (1992-2000)		
Prob(F)	0.0350	0.0075
Slope	0.7895	0.0245
R-squared	0.059	0.427
Hydrilla Mgmt (200 0-2012)		
Prob(F)	0.0006	<0.0001
Slope	-1.7593	-0.0152
R-squared	0.076	0.348
Post-Hydrilla Mgmt (2012-2021)		
Prob(F)		
Slope		
R-squared		

- During the hydrilla management period, both exhibit statistically significant decreasing trends
    - **[click]** Again the slope is steeper for the all-species model
    - **[click]** But, the passage of time explains a higher proportion of the observed abundance for the year-round resident breeders, i.e. 34.8% versus 7.6%

Comparison of Multi-Species Abundance Measures

Time Interval Statistics	Total All Species Abundance (counts per survey)	Total Abundance of Selected Year-Round Resident Breeders:* April-July (counts per survey)
Period of Record (1992-2021)		
Prob(F)	< 0.0001	<0.0001
Slope	-0.0277	-0.0097
R-squared	0.229	0.448
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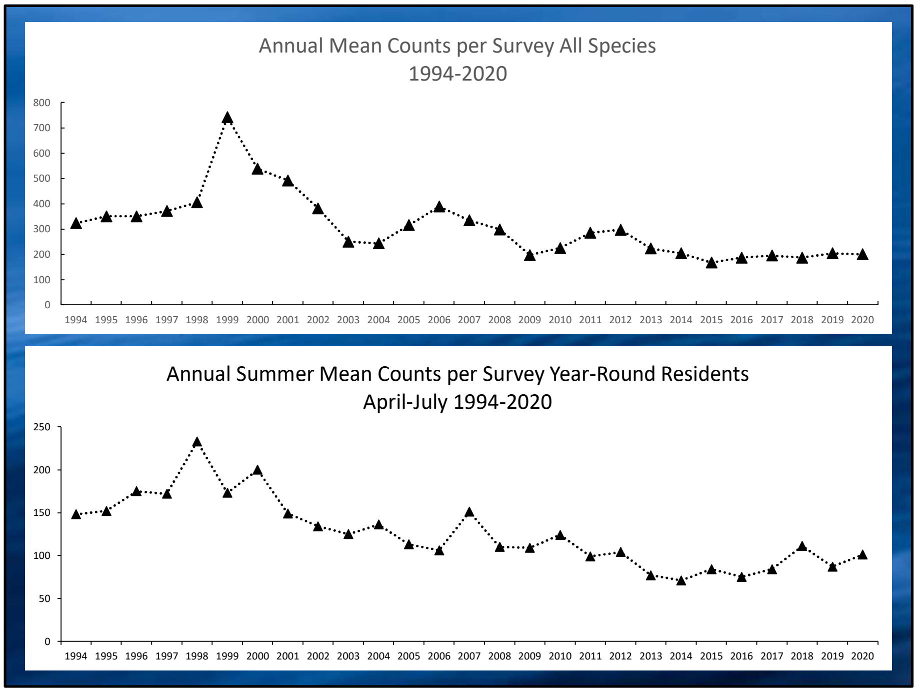
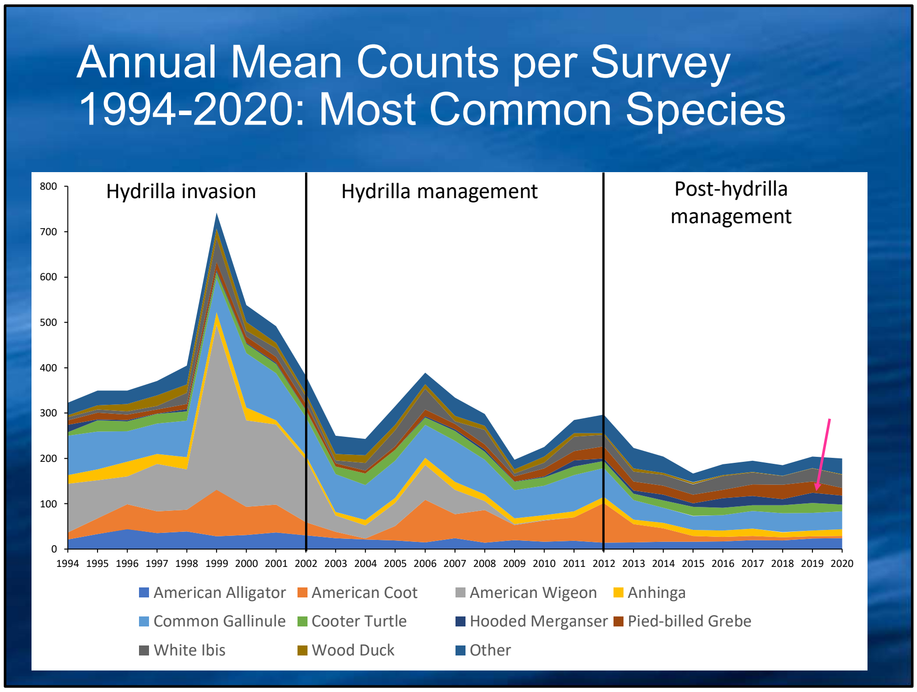
R-squared	0.059	0.427
Hydrilla Mgmt (200 0-2012)		
Prob(F)	0.0006	<0.0001
Slope	-1.7593	-0.0152
R-squared	0.076	0.348
Post-Hydrilla Mgmt (2012-2021)		
Prob(F)	0.0014	0.0001
Slope	-0.0117	0.0071
R-squared	0.019	0.081

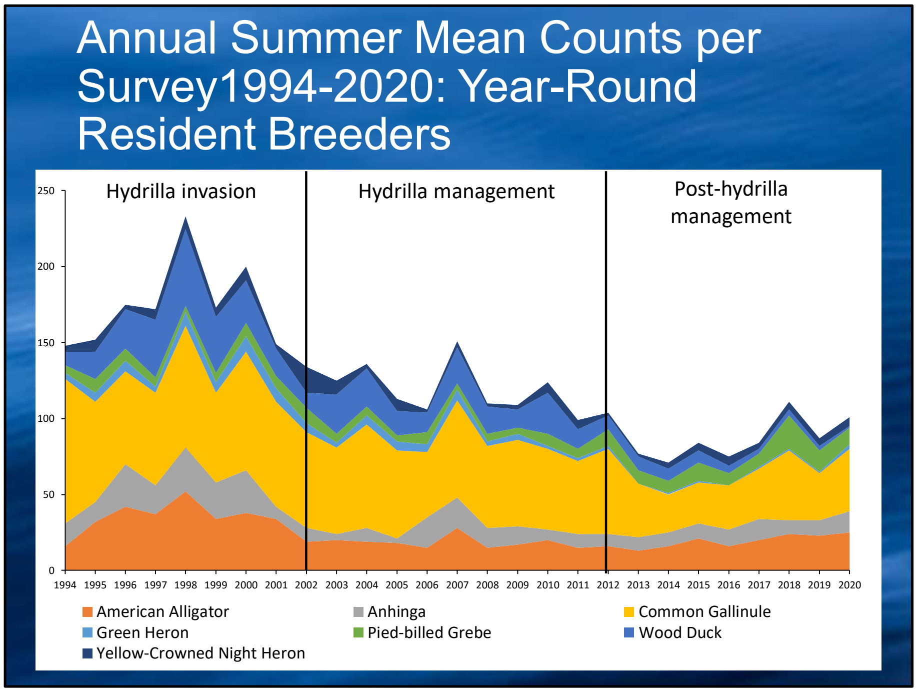
- During the post-hydrilla management period, the two measures diverge
  - The all-species metric exhibits a significant decreasing trend while the year-round breeders metric has a significant increasing trend
  - **[click]** As for the other time periods, the slope is steeper for the all-species model
  - **[click]** But, the passage of time explains a higher proportion of the observed abundance for the year-round resident breeders, i.e. 8.1% versus 1.9%
- It appears therefore that the year-round resident breeder measure of multi-species abundance may be a better reflection of ecosystem trends on the river since the passage of time explains substantially more the observed variation in abundance of that suite of species than of all 24 species surveyed
- We also can be more confident that the observed rates of change, as defined by the slopes, are more likely a reflection of upper river ecosystem conditions
- **4 minutes to here**



- I'd like to transition into talking about individual species by examining the relative proportions of these abundance measures attributable to the most common species
- **[click]** Here we see the annual mean number of animals counted per survey for all 24 species surveyed from 1994-2020
    - Smoothing the data in this manner makes it easier to discern year-to-year changes.
- **[click]** And here we see the Annual Summer Mean Counts per Survey Year-Round Residents



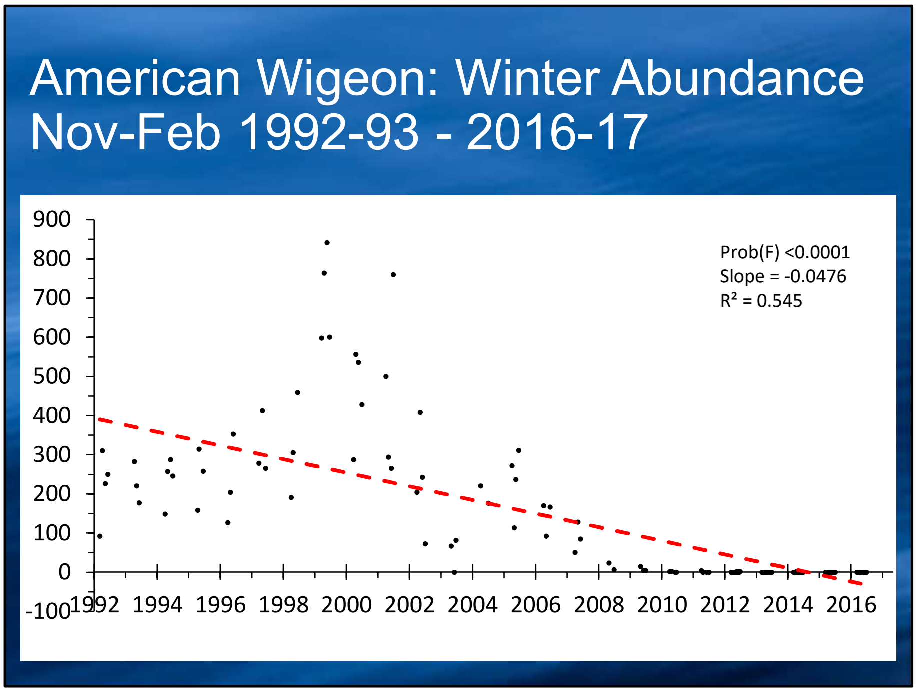
- This is a stacked graph of the annual mean number of animals counted per survey that breaks out the most common species among the 24 surveyed
- Reading from the bottom layer to the top we see that
    - The species contributing the most to annual mean counts per survey during the hydrilla invasion period included
        - American coot – orange
        - America wigeon – gray
        - And common gallinule – light blue
    - As we move into the hydrilla management period, the contribution from American wigeon declines, while American coot and common gallinule comprise greater proportions of total abundance
    - By the onset of the post-hydrilla management period, the wigeon has disappeared altogether and coot abundance begins to decline
        - Total abundance is primarily driven by common gallinule, pied-billed grebe, white ibis (dark gray), and “other”
        - Note also the increasing prevalence of hooded merganser (dark blue) **[click]**



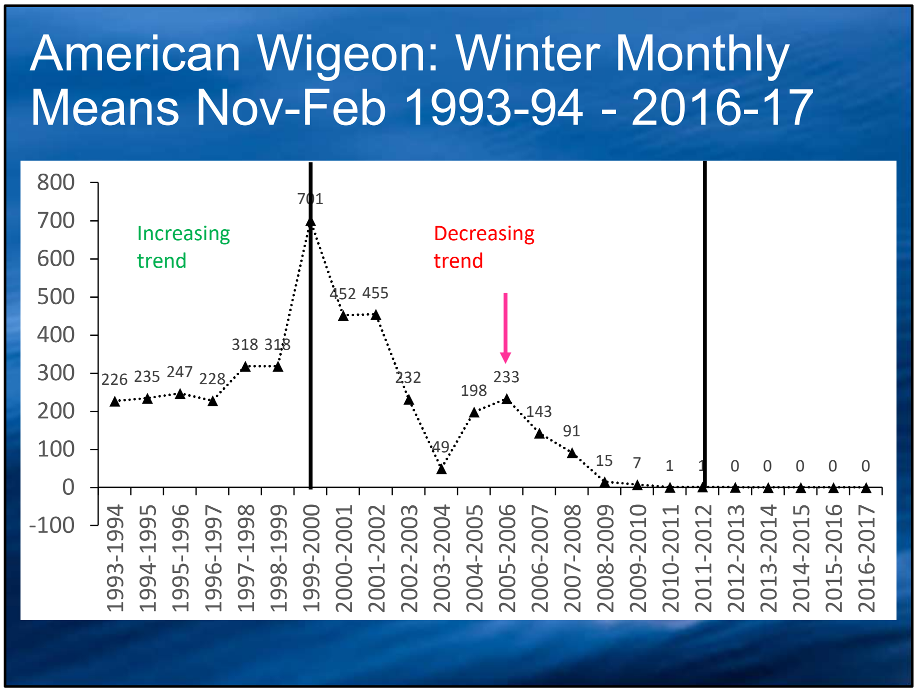
- Shifting to the 7 year-round resident breeders during the summer months of April through July
    - we see that the multi-species abundance measure is influenced predominantly by three species during both the hydrilla invasion and hydrilla management periods:
        - American alligator (orange)
        - Common gallinule (yellow)
        - Wood duck (blue)
- However, with the decline of the wood duck during the post-hydrilla management period the predominant species are
    - Alligator
    - Gallinule
    - Pied-billed grebe (green)
- The anhinga (gray) comprises the fourth most prevalent species throughout the period of record
- **5 minutes to here**

- So let’s look at the trends of the species driving these multi-species abundance patterns
- **[click]** I’ve selected the five most prevalent from the all-species measure: wigeon, coot, common gallinule, hooded merganser, pied-billed grebe, and white ibis

- The American wigeon was a winter migrant with peak abundance between November and February
- It mostly eats plants, feeding on land as well as eating emergent and submerged plants in shallow water
- Photo: https://www.audubon.org/field-guide/bird/american-wigeon



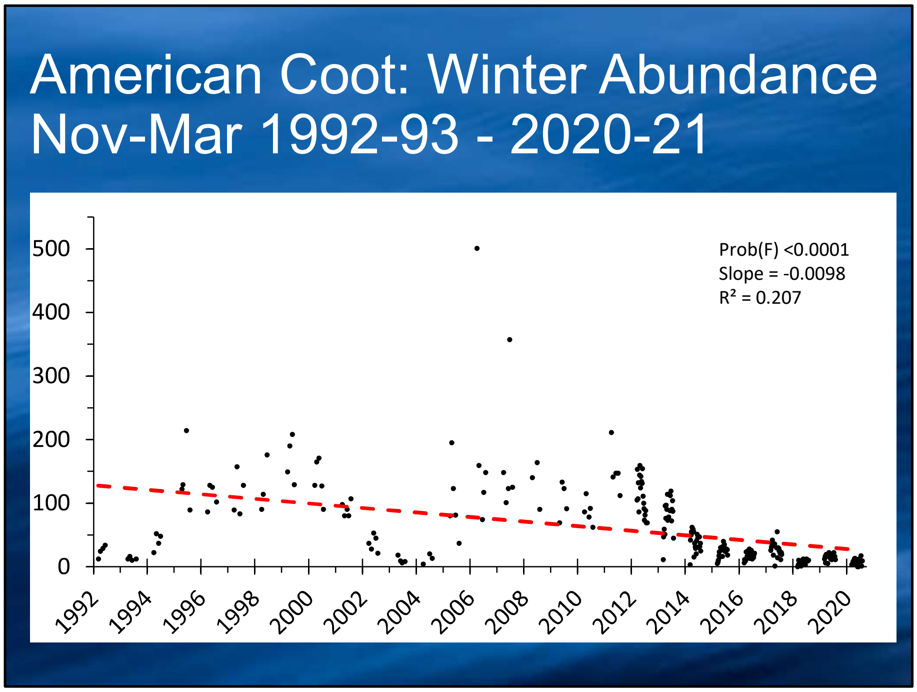
- The wigeon experienced a statistically significant long-term decline and was essentially gone by 2011.
- We removed it from our survey in 2018.



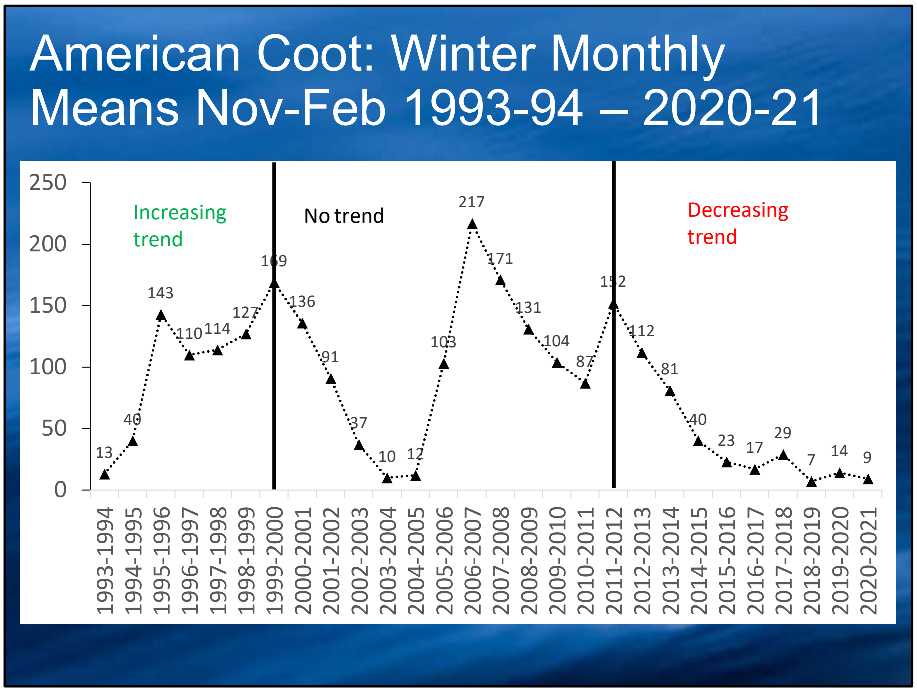
- American wigeon exhibited an increasing trend during the hydrilla invasion period **[click]**, peaking in the winter of 1999-2000
    - Followed by a steep decline during the hydrilla management period **[click]**
    - Both of these apparent trends are statistically significant when analyzed for counts per survey
- The wigeon's long-term decline after 2005-06 **[click]** may have resulted in part from the net decrease in SAV biomass that resulted from the mechanical harvesting and herbicide treatments of hydrilla and accompanying impacts.
    - However, the southern boundary of the wigeon's winter range has been shifting northward, consistent with hypothesized effects of climate change (La Sorte and Thompson, 2007)
    - And wigeon breeding populations in Ontario and Manitoba from whence Florida winter migrants originate exhibited statistically significant declines of about -2 percent per year between 1993 and 2019 (Sauer et al., 2020)
- 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

6 minutes to here

- Like the wigeon, the American coot is a primarily herbivorous winter migrant with peak numbers between November and March

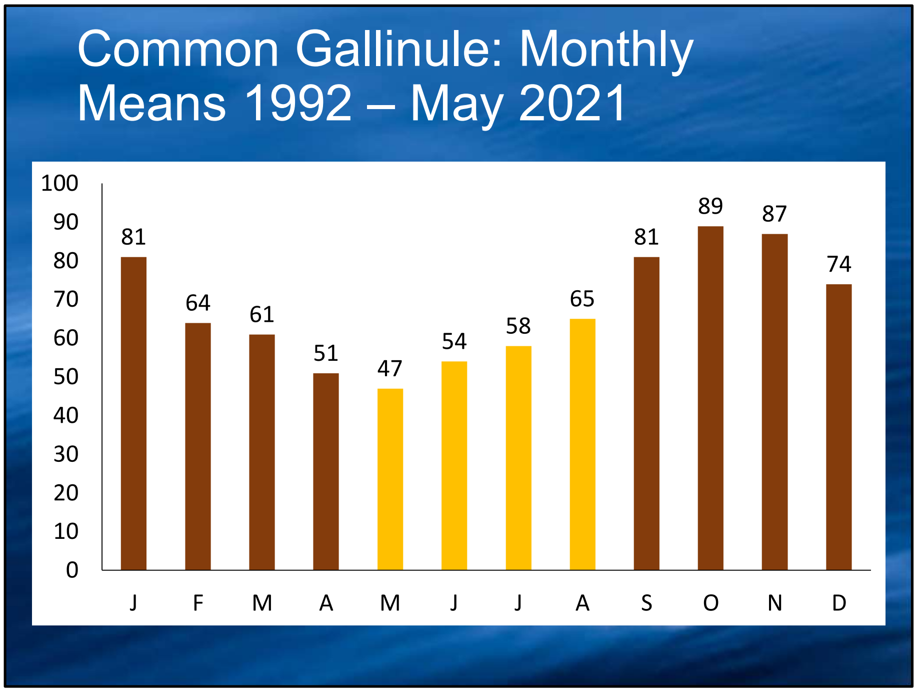


- It also has experienced a significant decline over the period of record

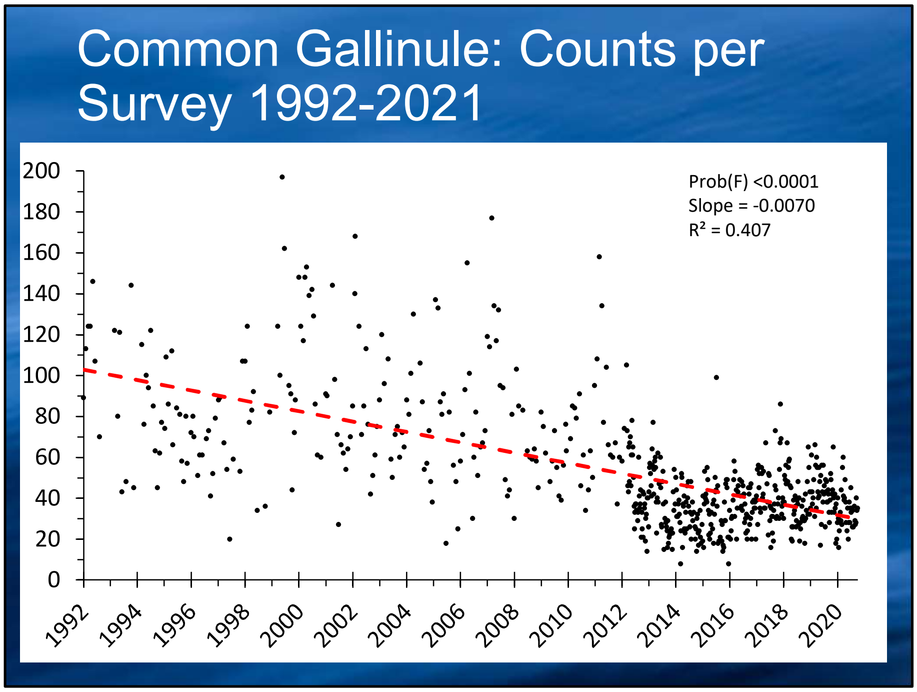


- Again, like the wigeon, the coot experienced a significant increase in abundance during the hydrilla invasion
- **[click]** However, during the hydrilla management period its numbers varied widely, yielding no significant statistical trend
- It has declined steadily, however, since the beginning of the post-hydrilla management period in the winter of 2011-2012
- The wide swings in annual winter monthly means suggest that variables beyond the Wakulla River ecosystem may be primarily responsible for the shifting patterns of its abundance, as well as its apparent long-term decline
- Similar to the wigeon, its long-term decline is consistent with documented decreases in breeding populations in most of the areas from which it probably migrates in the mid west and eastern North America (Sauer et al., 2020) as well as a northward shifting of its winter range

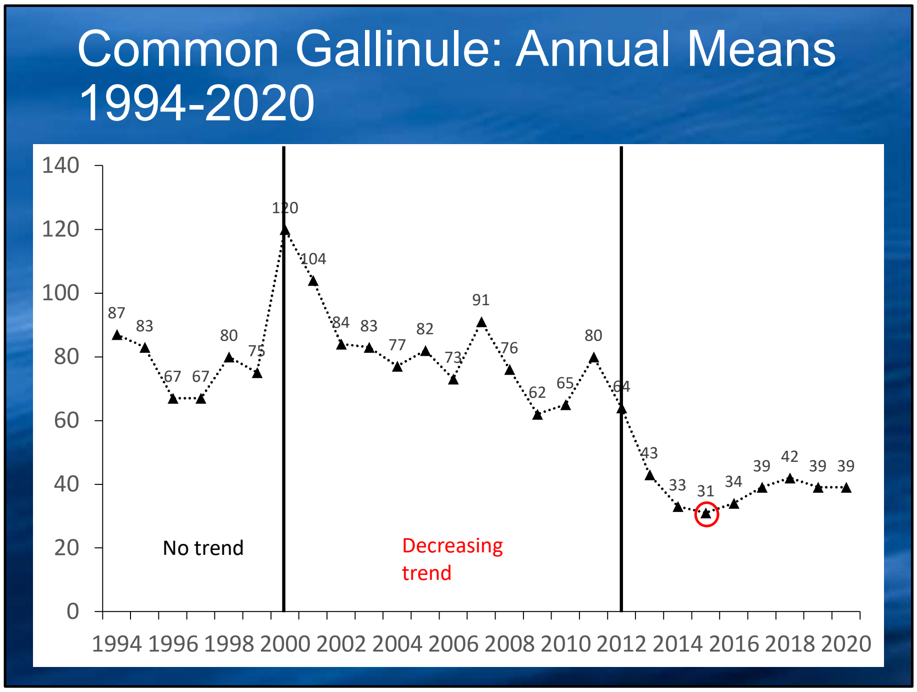
- Like the wigeon and coot, the common gallinule is predominantly herbivorous, feeding on floating and submerged plants
    - According to the Cornell Lab of Ornithology's Birds of the World, the common gallinule predominantly eats seeds of aquatic and terrestrial grasses and some snails.
- It is a year-round resident breeder whose population is supplemented by winter migrants from the Midwest, New England, and the Mid-Atlantic **[click to next slide]**



- Based on monthly means distributions shown here and data on migration tower kills in Florida (Stevenson and Anderson's 1994 reference, *The Birdlife of Florida)* I have divided the year into
    - **[click]** a summer season: May through August and
    - **[click]** a winter season: September through April
- The difference in average monthly means between the two seasons is noticeable but not huge
    - The summer average monthly mean is 56.0
    - The winter average monthly mean is 73.5; 1.3 times greater



- Based on year-round counts per survey, the common gallinule experienced a long-term decline over the period of record,

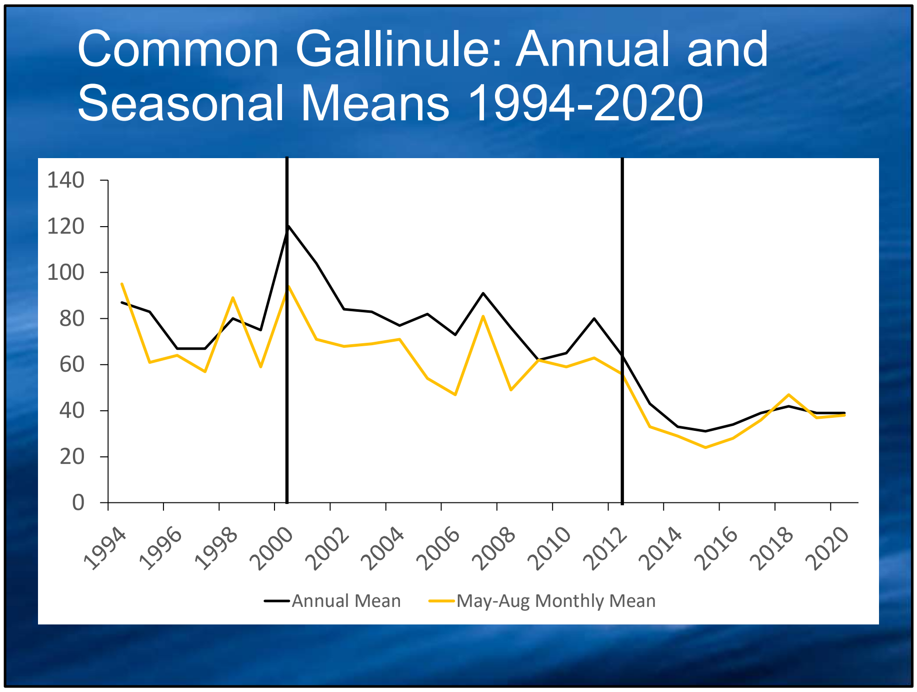


- Looking at annual means, while the gallinule did attain a peak level of abundance in 2000 during the hydrilla invasion, the trend in counts per survey during that period was not significant
- They are known to eat hydrilla, so this increase may have been occasioned by increased food supply
- A statistically significant decline in year-round counts per survey did occur during the hydrilla management period of 2000-2012
- It began in 2001, one year before the first large-scale herbicide treatment that caused the massive *Hydrilla* die off,
    - perhaps as a result of disruptions from the aggressive hydrilla harvesting
- That decline continued into the post-hydrilla management period until 2015 **[see red circle]**
- As of 2018, it appeared that a rebound might be in the making
    - However, annual means levelled out in 2019 and 2020
    - It is not clear what may be behind the increases between 2015 and 2018 and the subsequent levelling off.
- The decline in hydrilla biomass resulting from the herbicide treatment and associated impacts, including the ascendance of blue-green algae, which offer low food value, are plausible contributing causes for this species's long-term decline.
    - While the Cornell Birds of the World reports they rarely eat algae, that is what I

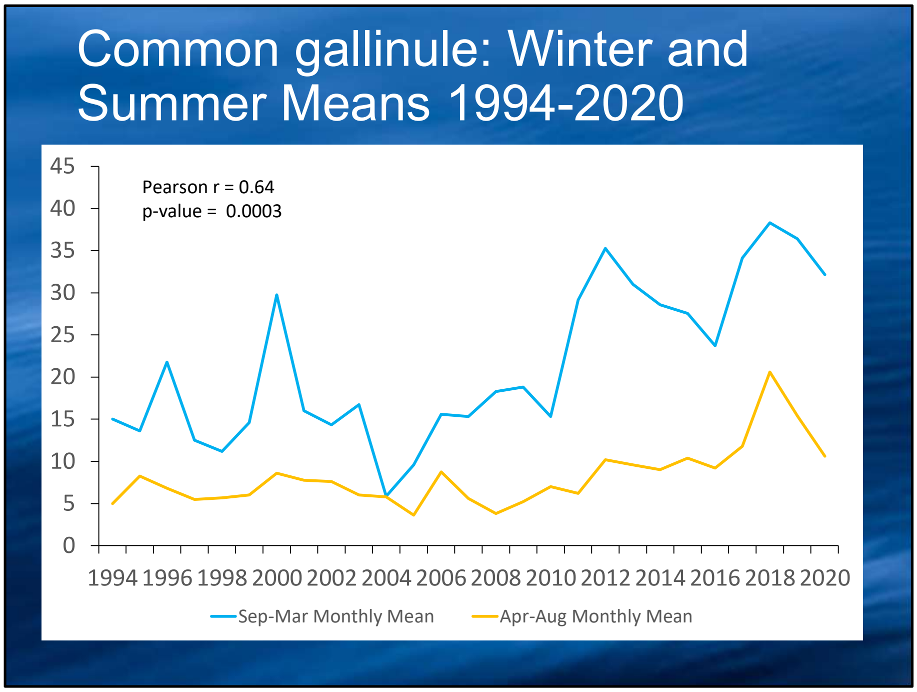
see them eating most often as in the photo **[click to next slide]**

Common Gallinule

Photo Bob Thompson



- Comparing summer seasonal means with the annual means, we see a fairly good fit to the annual mean pattern



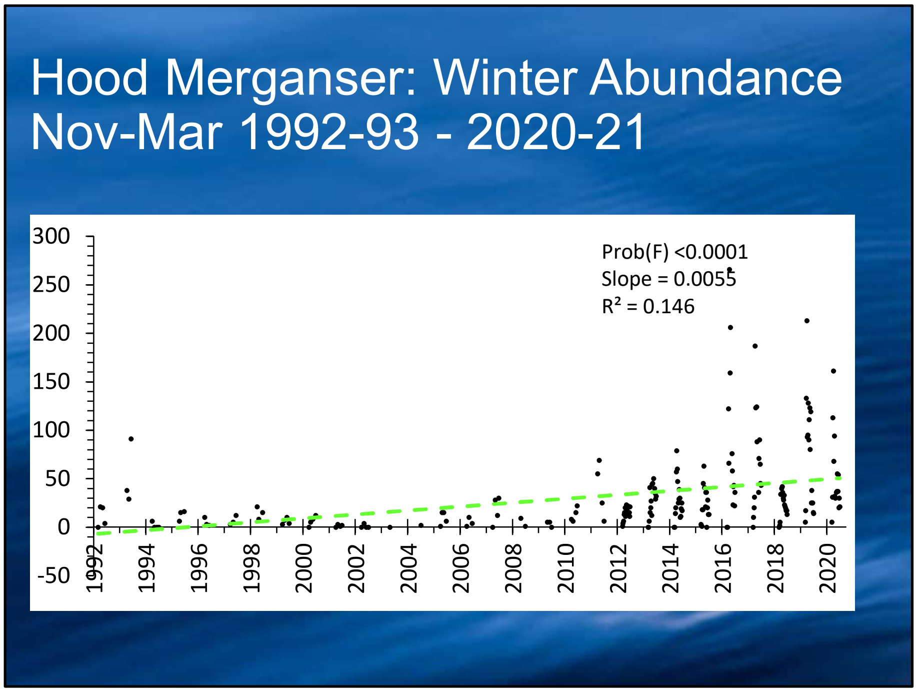
- While the winter mean pattern is at times out of phase with the summer trend, the overall patterns are fairly similar
- A Pearson r correlation analysis yields a moderately strong significant positive correlation of 0.64
- Thus, while forces outside the upper Wakulla River ecosystem are likely contributing to fluctuations in winter counts and, therefore, annual means, the long-term trend appears consistent

Common Gallinule Abundance Trends – Annual, Summer, and Winter

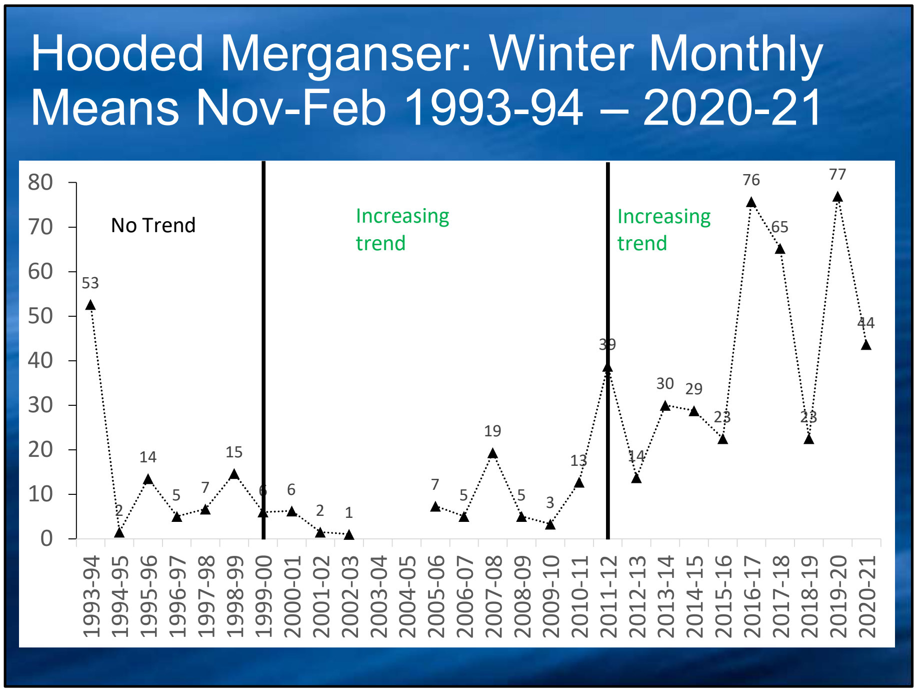
Season	Statistics	Period of record 1992-2021	Hydrilla Invasion 1992-2000	Hydrilla Management 2000-2012	Post-Hydrilla Management 2012-2021
Annual	Prob(F)	< 0.0001	0.4291	<0.0001	0.0417
	Slope	-0.0070	n/s	-0.0081	-0.0015
	R-squared	0.407	n/s	0.116	0.010
Summer (May-August)	Prob(F)	<0.0001	0.4565	0.0236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

- In fact, if we look at the regression statistics for the three different seasonal patterns, annual, summer, and winter,
- we see consistent patterns over most time periods:
  - **[click]** The long-term trends are all significantly decreasing
  - **[click]** The hydrilla invasion period trends are all non-significant
  - **[click]** The hydrilla management trends are all significantly decreasing
- **[click]** Only in the post-hydrilla management period do the seasonal trends diverge
  - The trend for the summer season is significantly increasing,
  - while the annual and winter trends are decreasing
- The slopes are steeper for the winter trends and the R-squared values are higher suggesting that
  - more substantial change is happening to winter migrants than to the resident breeding population
  - Thus, summer trends may be a better indicator of the state of the upper Wakulla River ecosystem
- **10 minutes to here**

- The hooded merganser is a winter migrant that begins arriving in November and heads back north in March
- A diving duck, it feeds primarily on crayfish on the upper Wakulla River



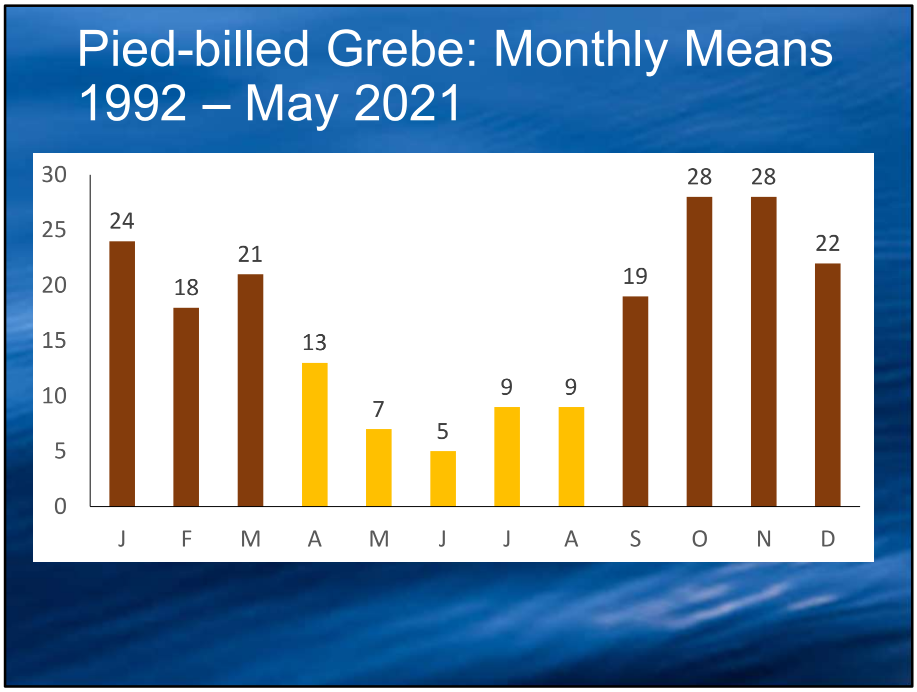
- It has experienced a significant increase over the period of record



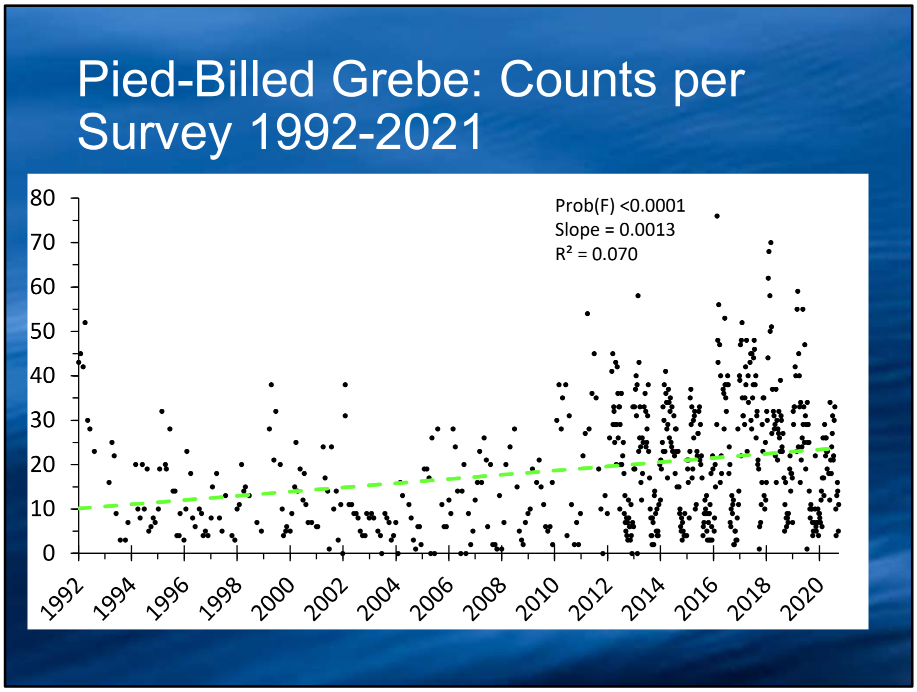
- Winter monthly means were low for many years after an initial peak in 1993-94, exhibiting no significant trend in counts per survey during the hydrilla invasion period **[click]**
- A gradual increase beginning in the mid-2000s yielded an significant increase during the hydrilla management period **[click]**
- An upswing beginning in 2011-12 and large swings between 2016-17 and 2020-21 comprise a continuing significant increase during the post-hydrilla management period **[click]** .
- Very low winter monthly means of two and one in 2001-02 and 2002-03 may reflect some negative impacts from the most intense hydrilla management initiatives,
    - including the April 2002 initial Aquathol treatment which resulted in a crayfish kill.
    - A second dip in winter monthly means in 2008-09 and 2009-10 (five and three respectively) followed a second crayfish kill
- The substantial vacillations likely reflect dynamics in summer breeding success and, perhaps, weather influence on migrating behavior from one winter to another
- The general increasing trend since the mid-2000s is consistent with
    - USGS Breeding Bird Survey data which show strong increasing trends in areas from which Florida migrants originate in eastern Canada and northeastern US
    - And a southward trend in the centers of abundance and occurrence of wintering

populations documented between 1975 and 2004 (La Sorte and Thompson, 2007).

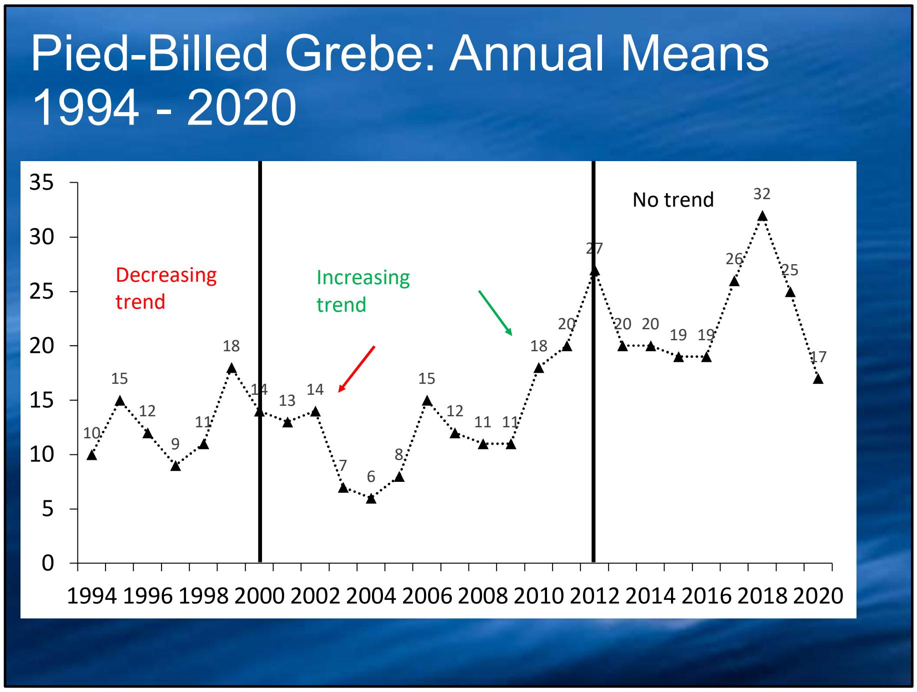
- The pied-billed grebe feeds by diving for small fish and crustaceans. On the upper Wakulla River, it eats mainly crayfish **[click]**
- Like the common gallinule, it is a year-round resident breeder whose population is supplemented by winter migrants from the upper Midwest and Mid-Atlantic states from September through March or early April.



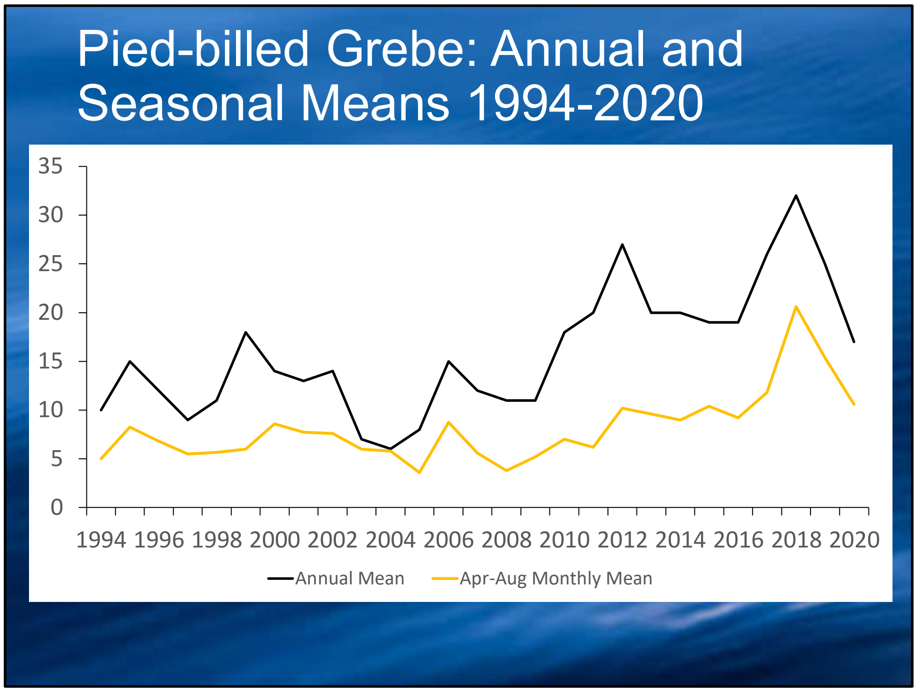
- Based on monthly means distributions shown here I divided the year into
    - **[click]** a summer season: April through August and
    - **[click]** a winter season: September through March
- The difference in average monthly means between the two seasons is more pronounced for the grebe than the common gallinule:
    - The summer average monthly mean is 8.6
    - The winter average monthly mean is 22.9
        - 2.7 times greater



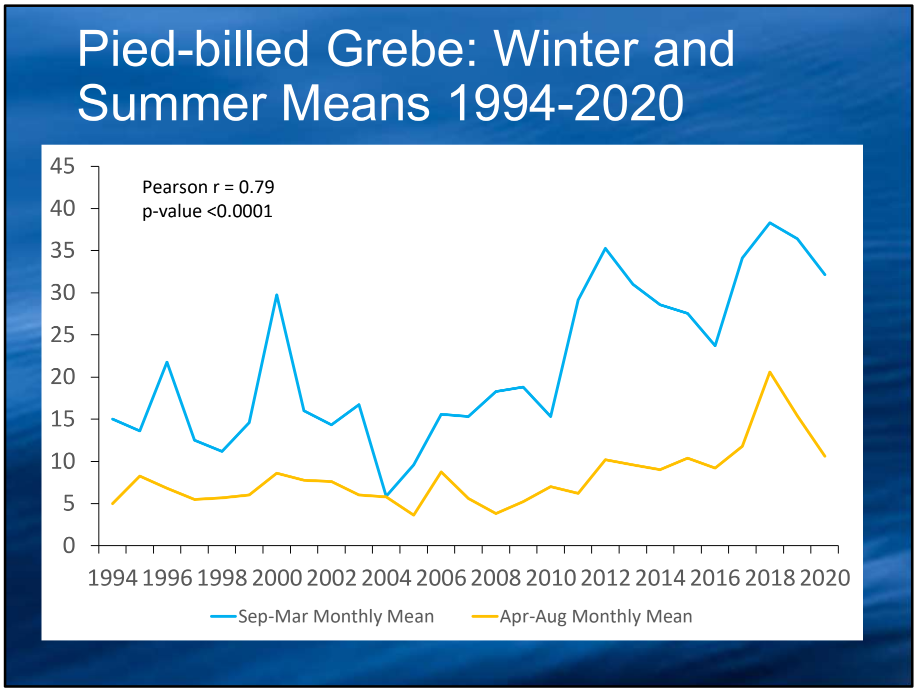
- Unlike the predominantly herbivorous species we've looked at so far,
- the pied-billed grebe has experienced a significant long-term trend of increasing abundance over the period of record,



- Looking at a graph of annual means, there is no apparent trend during the hydrilla invasion period
- However, analysis of year-round counts per survey reveals a significant decrease
- Trends in year-round counts per survey turned around during the hydrilla management period resulting in a significant increase.
  - However, annual means show a decline between 2000 and 2004 during the intensive mechanical harvesting and herbicide treatment of the hydrilla **[click]**
    - By-catch from the mechanical harvesting, and a crayfish kill following the initial April 2002 Aquathol treatment, may have contributed to this decline.
  - Annual means generally increased after 2004 with a couple of plateaus. **[click]**
- Annual means have vacillated during the post-hydrilla management period resulting in no significant trend



- Comparing summer seasonal means with annual means, we see a fairly good fit to the annual mean pattern as we did with the common gallinule



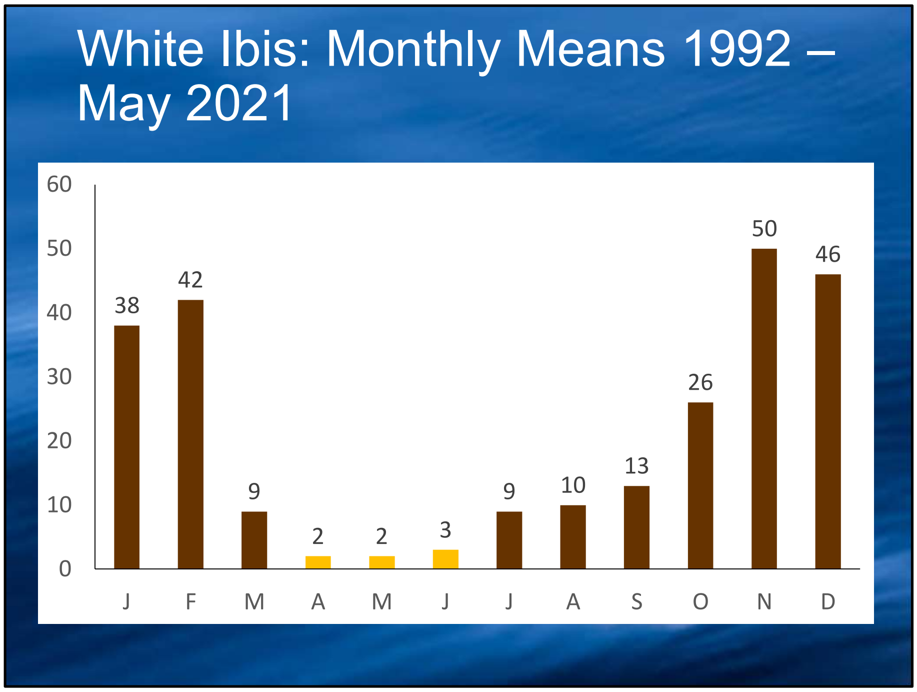
- The winter mean pattern exhibits greater variability than the summer trend;
  - however, they do exhibit fairly similar patterns
- In fact, a Pearson r correlation analysis yields a strong significant positive correlation
- Thus, while forces outside the upper Wakulla River ecosystem are likely contributing to fluctuations in winter counts and, therefore, annual means, the long-term trend appears consistent

Pied-billed Grebe Abundance Trends – Annual, Summer, and Winter

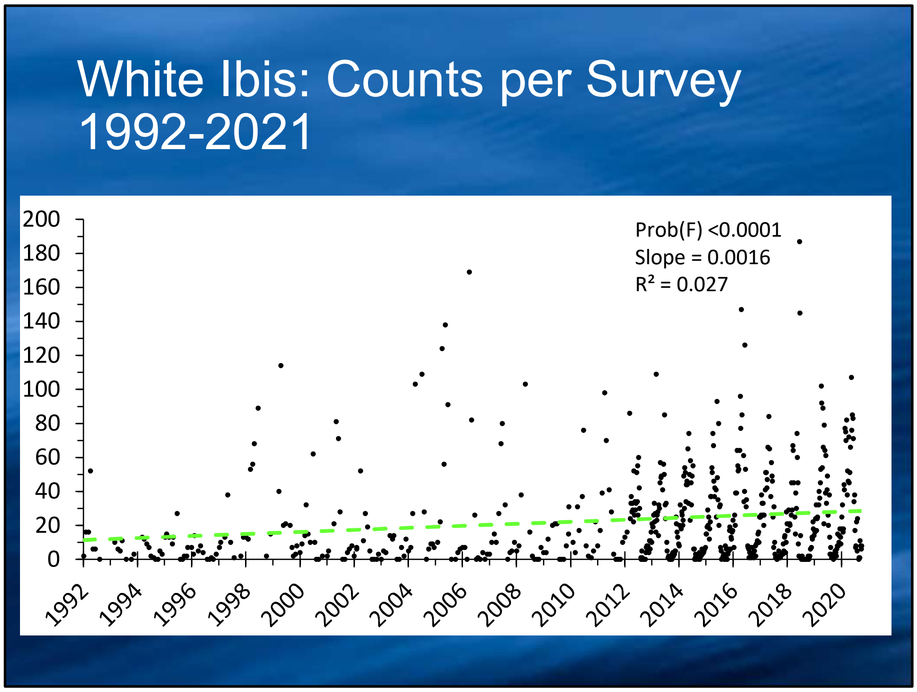
Season	Statistics	Period of record 1992-2021	Hydrilla Invasion 1992-2000	Hydrilla Management 2000-2012	Post-Hydrilla Management 2012-2021
Year-round	Prob(F)	<0.0001	0.0037	<0.0001	0.4632
	Slope	0.0013	-0.0042	0.0028	n/s
	R-squared	0.070	0.108	0.124	n/s
Summer (April-August)	Prob(F)	<0.0001	0.2863	0.8614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

- That surmise is supported by comparing regression models of counts per survey for the period of record
    - The trends are significant and positive for all three seasons
    - The winter season trend has a slightly steeper slope, suggesting that winter migrant trends may be having somewhat greater influence on the observed year-round trend
- **[click]** Year-round counts per survey show a significant decrease during the hydrilla invasion
    - But increase during the hydrilla management period
    - And then level off during the post-hydrilla management period
- **[click]** Winter counts per survey follow a similar pattern
- **[click]** Meanwhile, summer counts per survey show no trend during the hydrilla invasion and hydrilla management periods
    - But an increase during the post-hydrilla management period
- Taken together the pattern suggests that pied-billed grebes are doing well despite perturbations to the river ecosystem
- **12 minutes to here**

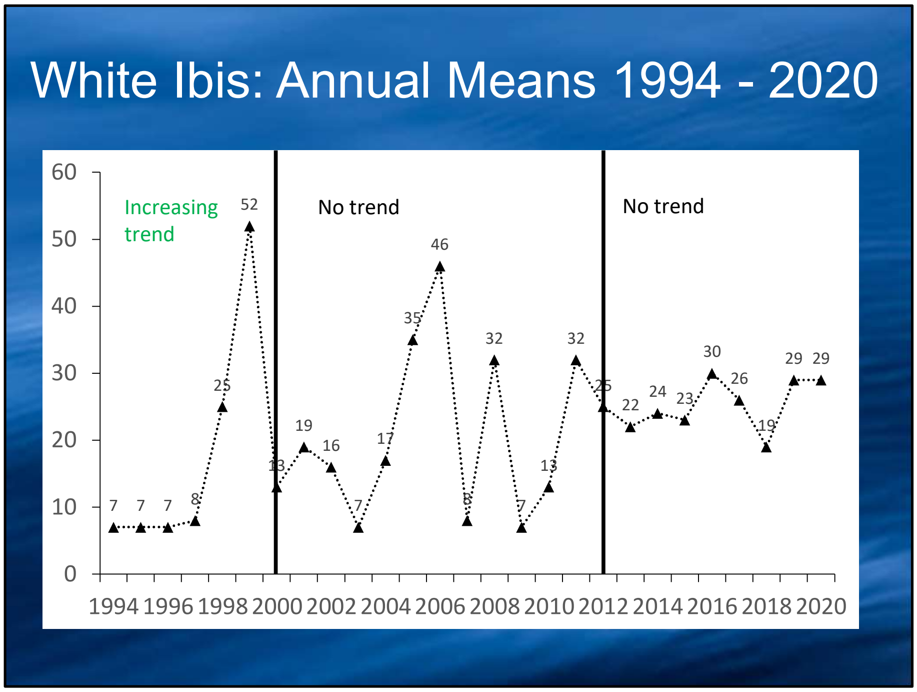
- The white ibis is the fifth most abundant species when we look at the period of record stacked graph of annual means
- They eat small aquatic and semiaquatic organisms, especially crustaceans and aquatic insects, in particular crayfish
- While this photo by Bob Thompsons captures a pair in a mating dance, white ibis do not breed along the upper river
    - Adults are most prevalent in the winter, while smaller numbers of juveniles predominate during summer months



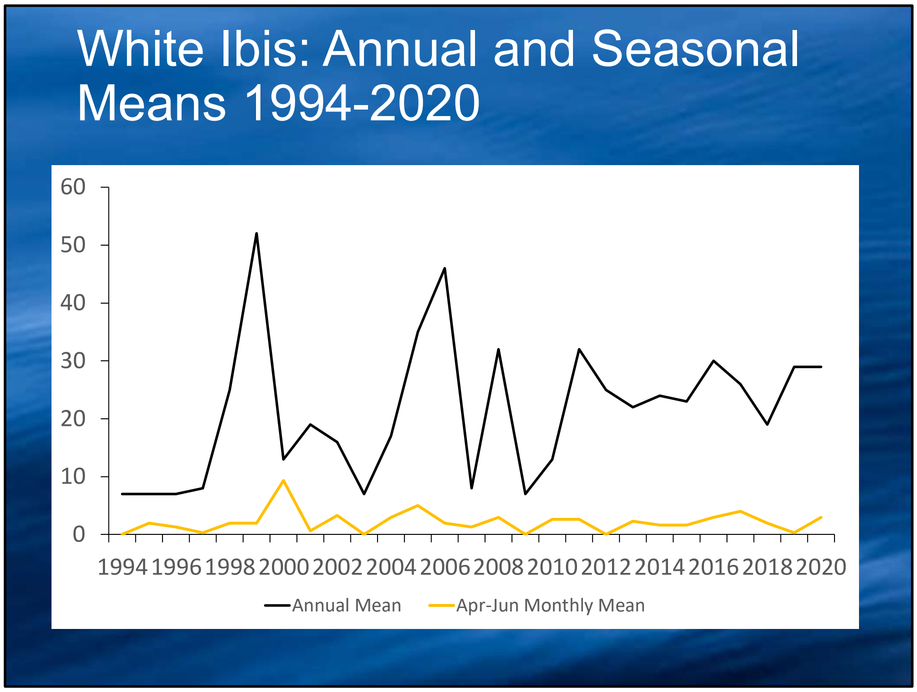
- This is evident from the distribution of monthly means based upon which I divided the year into
  - **[click]** a breeding season: April through Jun and
  - **[click]** a non-breeding season: July through March
- The difference in average monthly means between the two seasons is dramatic
  - The breeding season average monthly mean is 2.3
  - The non-breeding season average monthly mean is 27
    - 12 times greater



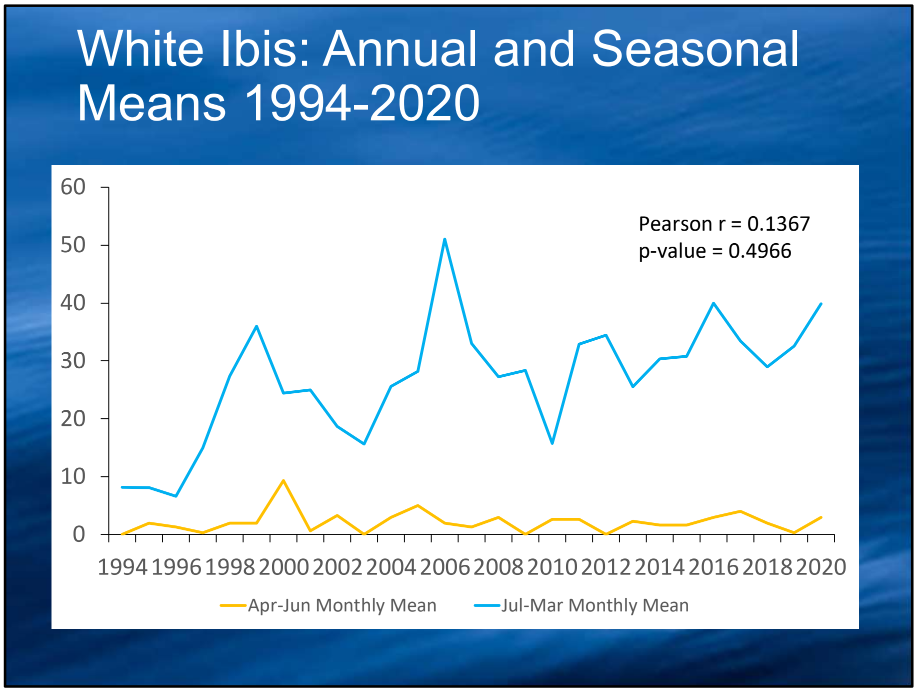
- Based on year-round counts per survey, the white ibis has experienced a significant long-term trend of increasing abundance over the period of record,



- Looking at a graph of annual means, there are large vacillations, especially during the hydrilla invasion and hydrilla management periods
- Analysis of counts per survey yields
    - **[click]** a significant positive trend during the hydrilla invasion
    - **[click]** and no significant trends during the hydrilla management and post-hydrilla management periods



- Comparing summer breeding season means with annual means, we see little similarity

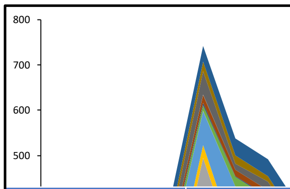


- And there is no apparent correlation between summer breeding season trend and winter non-breeding season trend
- This is borne out by the non-significant Pearson r statistic
- Thus, in this case, the winter season counts are likely the better measure of carrying capacity for this species,
    - but we must recognize that those counts are influenced by out-of-ecosystem factors that affect breeding success
- **14 minutes to here**

White Ibis Abundance Trends – Annual, Summer, and Winter

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

- Comparing regression models of counts per survey for the period of record and three perturbation periods yields a mixed set of increasing trend patterns
- Peculiarly, the post-hydrilla management trend is not significant for the year-round season, but significant for both the summer and winter seasons
- Nonetheless, as with the pied-billed grebe, the overall pattern suggests that white ibis are doing well despite perturbations to the river ecosystem



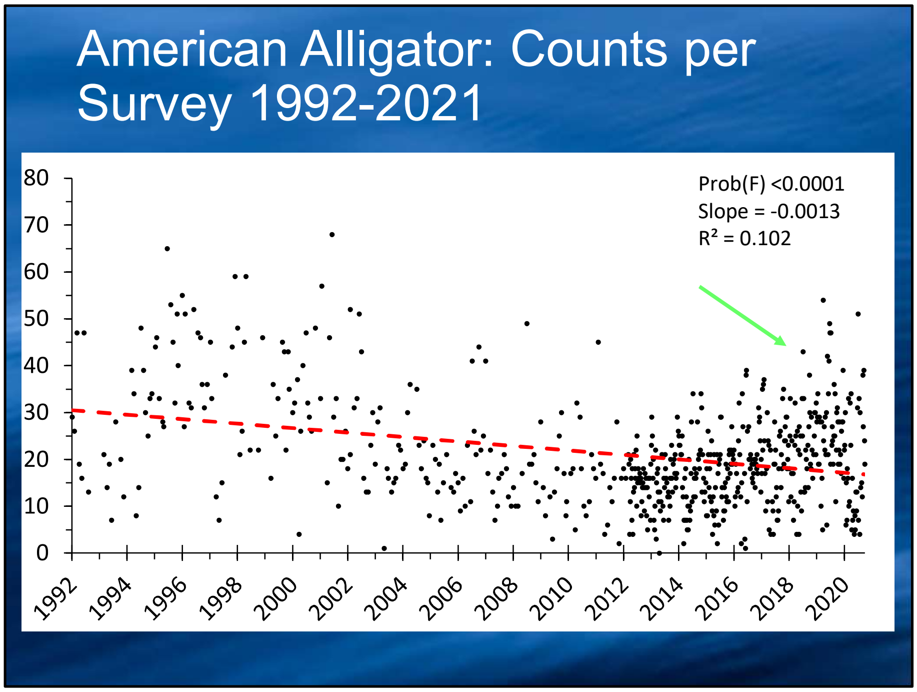
Annual Means: 1992-2020
Most Common Species

Species	Seasonal Pattern	Long-term Trend	2012-2021 Trend	Possible Confounding Factors
American coot	Winter migrant	Decreasing	Decreasing	↓ breeding population; winter range → N
America wigeon	Winter migrant	Decreasing	Extirpated	↓ breeding population; winter range → N
Common gallinule	Year-round resident breeder + winter migrant	Decreasing	Decreasing	↓ migrant breeding population; ↑ regional breeding population
Hooded merganser	Winter migrant	Increasing	Increasing	↑ breeding population; winter range → S
Pied-billed grebe	Year-round resident breeder + winter migrant	Increasing	No trend	No coincident changes in migrant breeding or range or regional breeding
White ibis	Winter peak non-breeder	Increasing	No trend	Available breeding habitat?

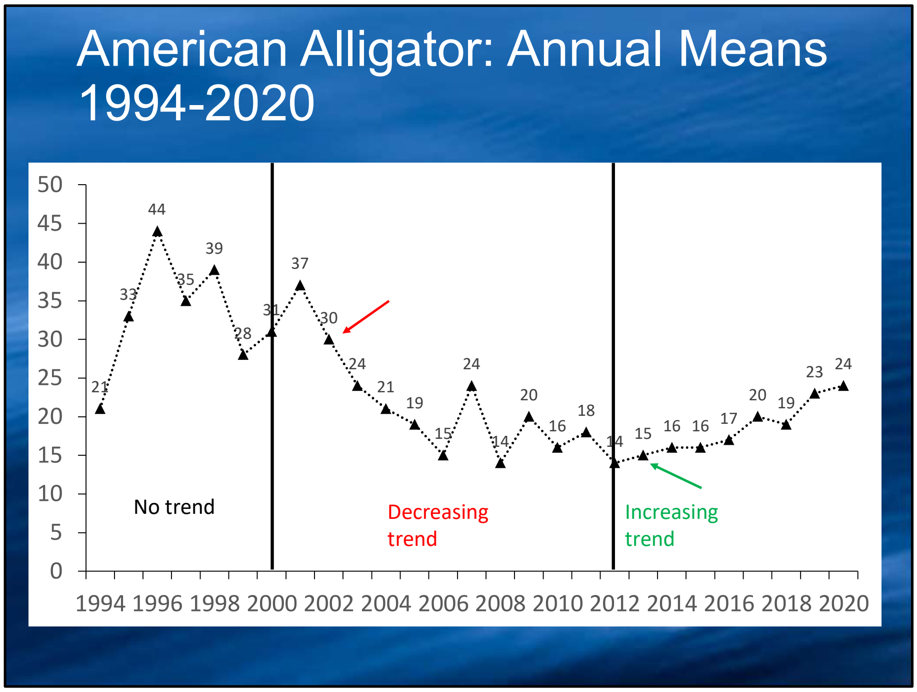
- Summarizing the status of the six most common species over the period of record from 1992-2021 we see
    - Three exhibiting significant decreases: American coot, American wigeon, and common gallinule
    - Three showing significant increases: hooded merganser, pied-billed grebe and white ibis
- Since 2012
    - Two have continued to decrease: coot and gallinule
    - The wigeon has been extirpated,
    - The hooded merganser has increased, and
    - Two have levelled off exhibiting no significant trends: grebe and ibis
- Changes in out-of-ecosystem breeding conditions of migrants likely influence the observed winter abundance of all but the grebe
- Northward shifts of winter ranges of both the wigeon and coot also are consistent with observed decreasing trends in their abundance
- **15 minutes to here**

- Now we turn to the year-round resident breeders
- The common gallinule and pied-billed grebe are in both groups so I will now focus on the American alligator, anhinga, wood duck, and yellow-crowned night heron

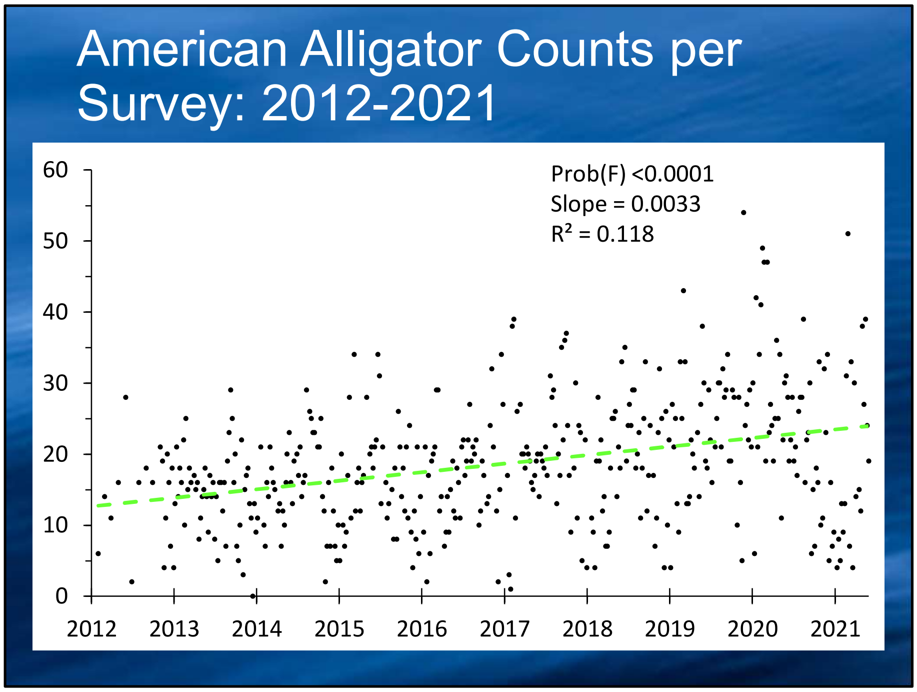
- The alligator is a generalist top predator in the aquatic food web, eating everything from snails to deer,
    - As such, trends in the American alligator’s abundance may be indicative of aggregate changes in the productivity of the ecosystem.



- Counts per survey data over the period of record show that It has experienced a long-term decline
- However, there has been an apparent shift upward more recently **[click]**



- Looking at annual mean counts per survey reveals fluctuating alligator abundance during the hydrilla invasion period **[click]**
    - With no statistically significant trend in counts per survey **[click]**
- Alligator abundance began a protracted significant decline in 2002 at the onset of intensive Aquathol treatment **[click]**
    - Yielding a significantly negative trend **[click]**
- However, its abundance numbers turned around beginning in 2013 **[click]**
    - yielding a significant increasing trend in counts per survey since 2012. **[click]**



- While the significant positive trend in alligator abundance since 2012 is encouraging, it may not necessarily signal an improvement in ecosystem productivity
- Other factors might be at work:
  - Anecdotal information from park rangers suggests that there may have been more nesting along the tour boat route recently, so that total counts have been enhanced by larger numbers of juveniles
  - To the extent that such an increase reflects improved habitat, it would be a bona fide signal of an improving ecosystem
  - On the other hand, there may be some randomness to where female alligators choose to nest
- Another possible confounder is the trend of declining river stage
  - This may result in basking alligators, both adults and juveniles, being more visible from the river and/or also affect where females are nesting
- A warming climate also might be at work, as well as changes in average cloud cover

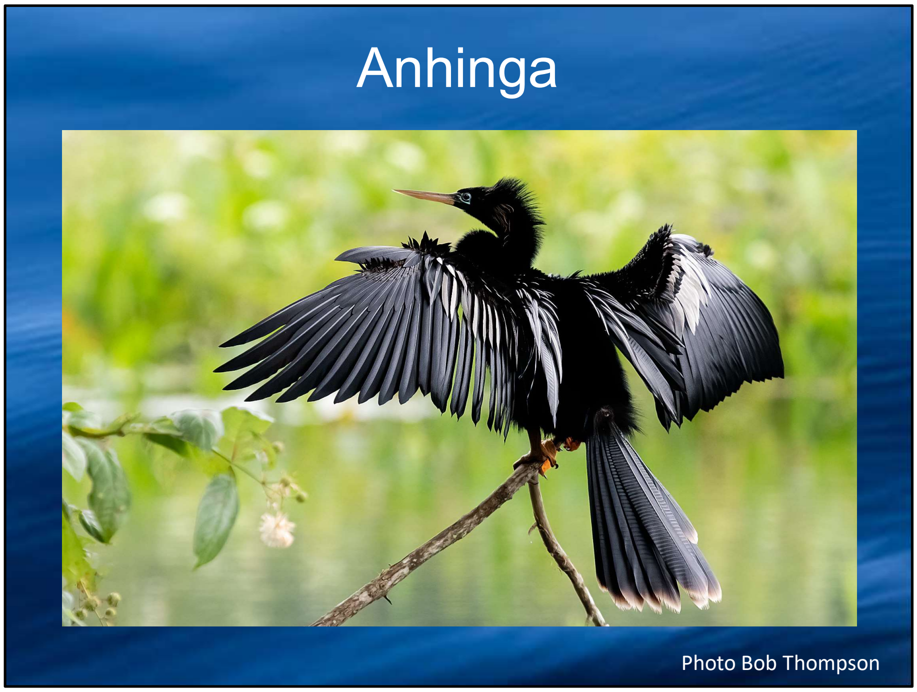
American Alligator Counts per Survey Multiple Regression: 2012-2021

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

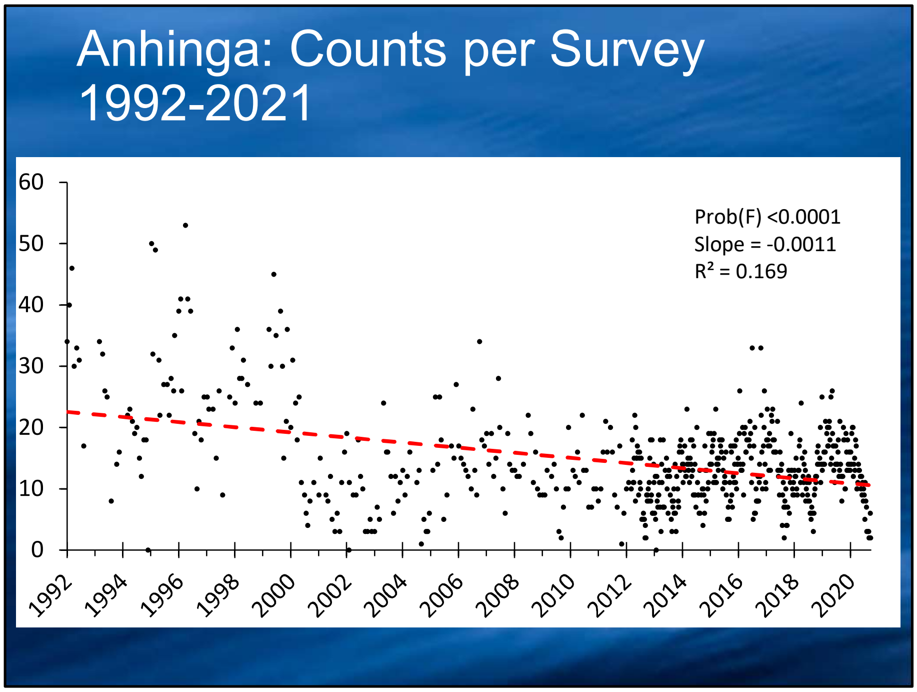
- To test for the influence of some of these possible confounders I recruited survey volunteer Nico Wiender to digitize river stage, air temperature, and cloud cover data from the survey sheets for the period during which weekly data have been collected: November 10, 2012, through May 29, 2021.
- Running a multivariate regression yielded these findings **[click]**:
  - **[click]** The apparent positive trend in alligator abundance remains statistically significant as shown by the probability value for the Date coefficient.
    - It indicates that the coefficient is significant at better than the 99.99% confidence level.
  - Each of the control variables also is significant at the 99.99% level or better:
    - **[click]** Alligator counts are higher when the river stage is lower as I have hypothesized (coefficient is negative: -3.141)
    - **[click]** Alligator counts also are higher when air temperature is higher
    - **[click]** And counts are higher when sunshine is greater, i.e. cloud cover is lower
      - Sunshine was coded as a dummy/categorical variable based on cloud cover categories included on the survey form: coded 1 for “clear” and “some clouds”; coded 0 for “fog,” “overcast,’ and “rain.”
- We can, therefore, be reasonably confident that the recent increasing trend is genuine

absent the possibility that increased nesting is unrelated to ecosystem conditions

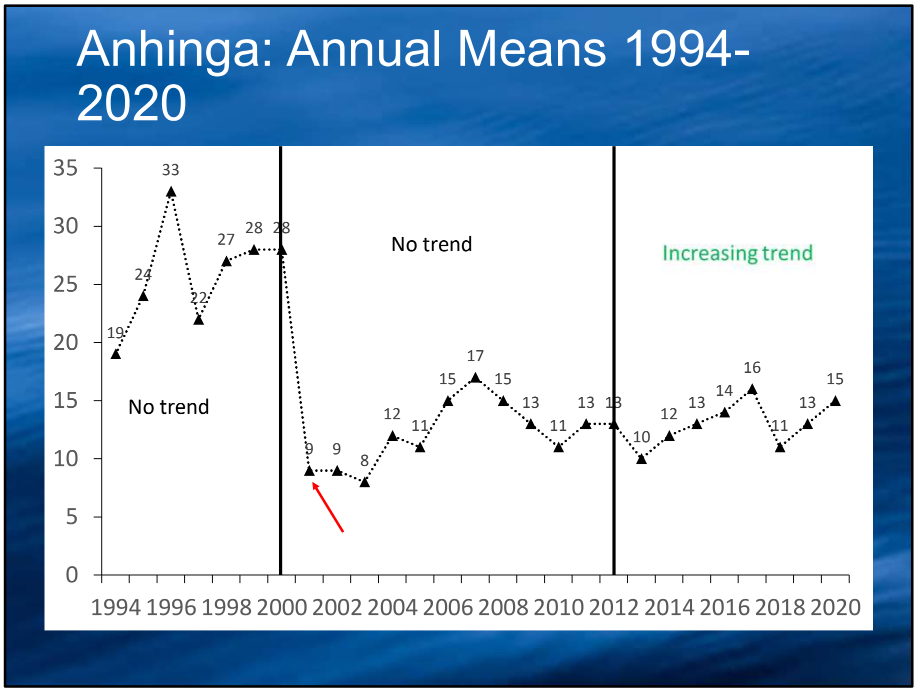
- **17 minutes to here**



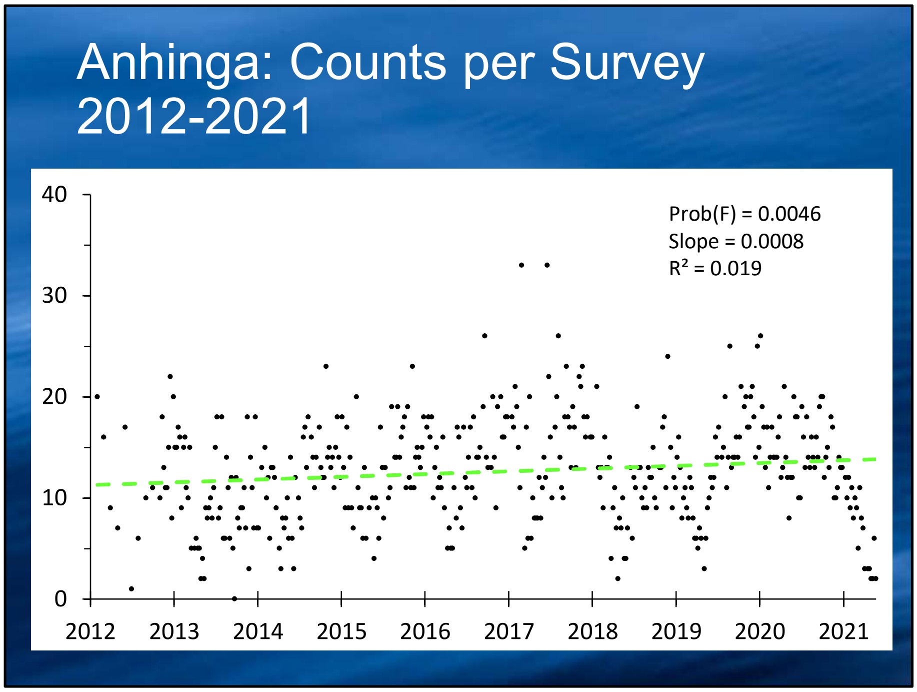
- Anhinga are year-round breeders that almost exclusively eat small to medium-size fish.



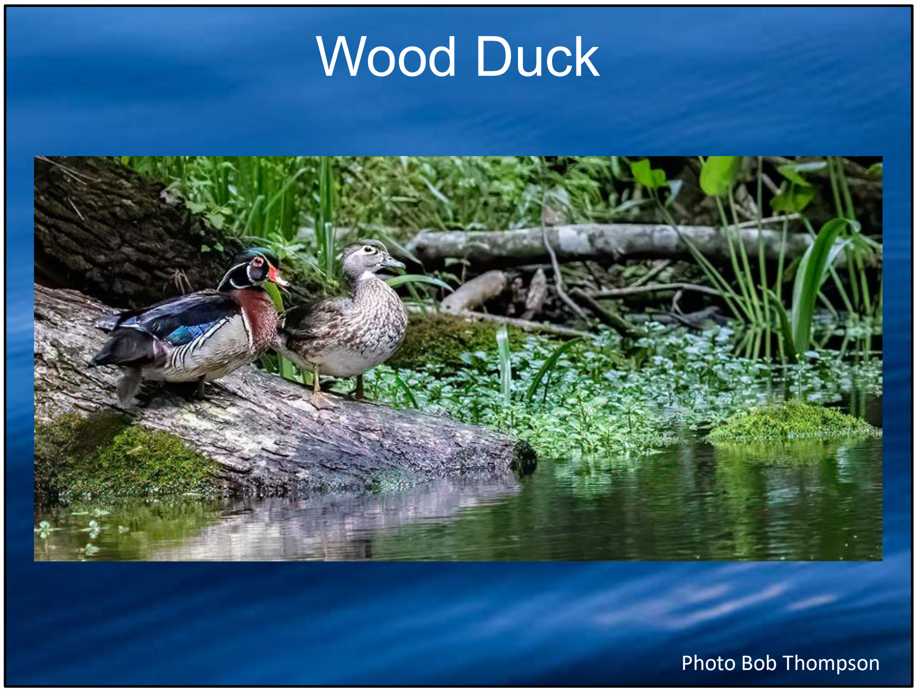
- Counts per survey data over the period of record show a long-term decline for the anhinga as well



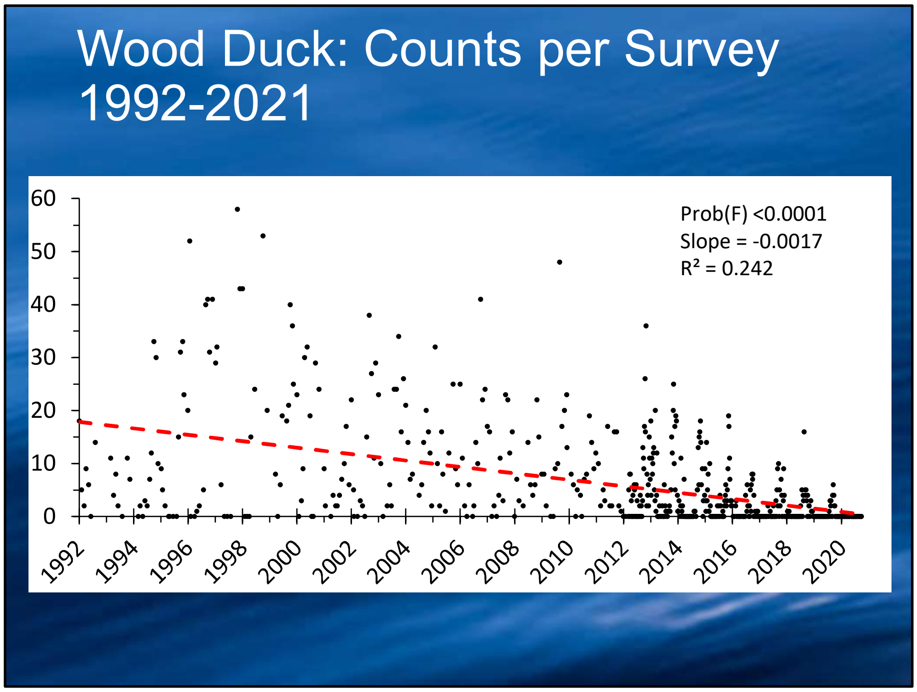
- Although they exhibited no statistically significant trends during the hydrilla invasion or the hydrilla management period,
    - The anhinga's annual mean underwent a steep decline between 2000 and 2001 **[click]** prior to the initial large-scale herbicide treatment in April 2002
    - The decline began in early 2000 , the year that the hydrilla spread downriver of the tour boat turnaround
    - The decline may have been because the dense floating mats hydrilla interfered with fishing,
- Their annual means have fluctuated between 9 and 17 ever since 2001
- **[click]** During the post-hydrilla management period, anhinga counts per survey have shown a significant increase



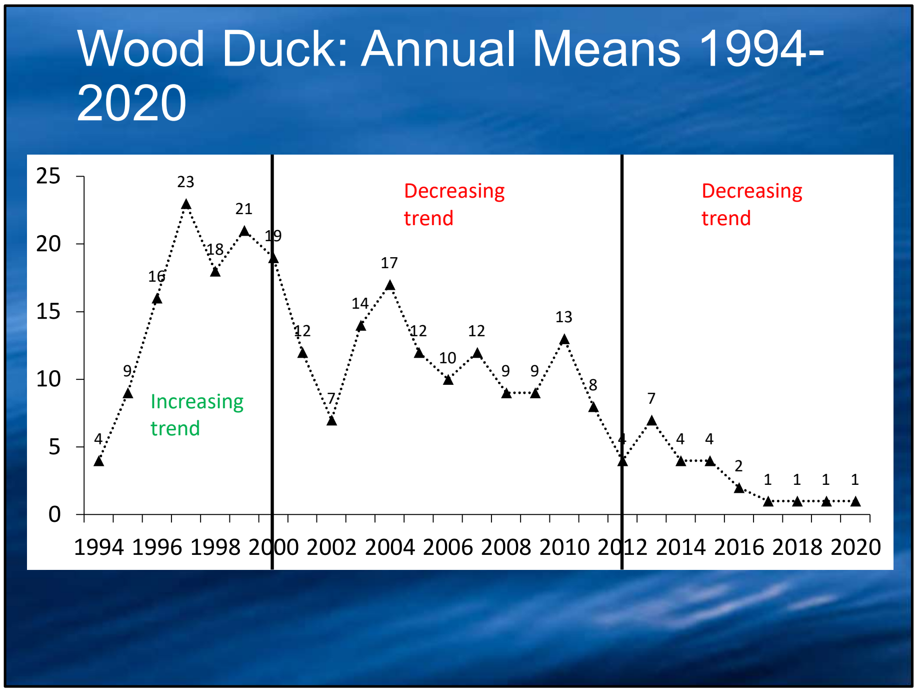
- The increase is modest, however
  - With a slope of only 0.0008 count per survey
- Perversely, this may be an artifact of reduced nesting.
  - Anhinga males are highly territorial during the nesting season ()
  - While there were as many as five active nests along the tour route as recently as 2015, there have only been one or two since 2017 (personal observation)
  - With fewer defended nesting territories, breeding season counts would be higher
- However, a steep decline that began in November 2020 raised concerns among park staff and volunteers.
  - The data graphed show that abundance typically declines each spring, but the 2020-21 decline began earlier.
- **18 minutes to here**



- Wood ducks are the only ducks that breed on the upper Wakulla River
- They nest in hollow trees in the adjoining woodlands, most often in cavities that develop when branches break and permit subsequent heart rot of the trunk (Soulliere 1990b).
- They feed on a wide array of terrestrial and aquatic fruits, seeds, and invertebrates

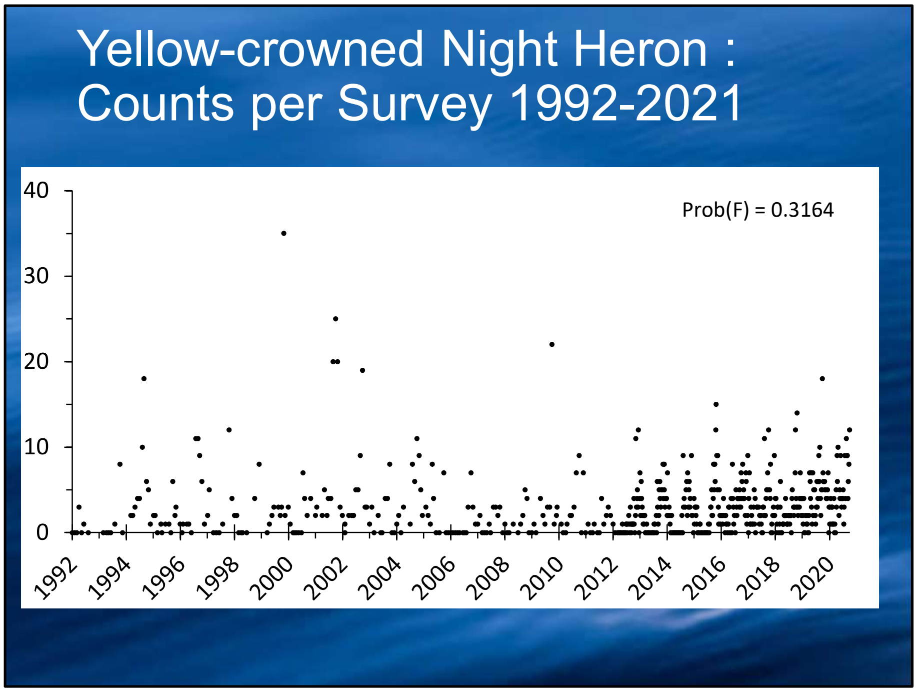


- This year-round breeder also has experienced a long-term decline in counts per survey

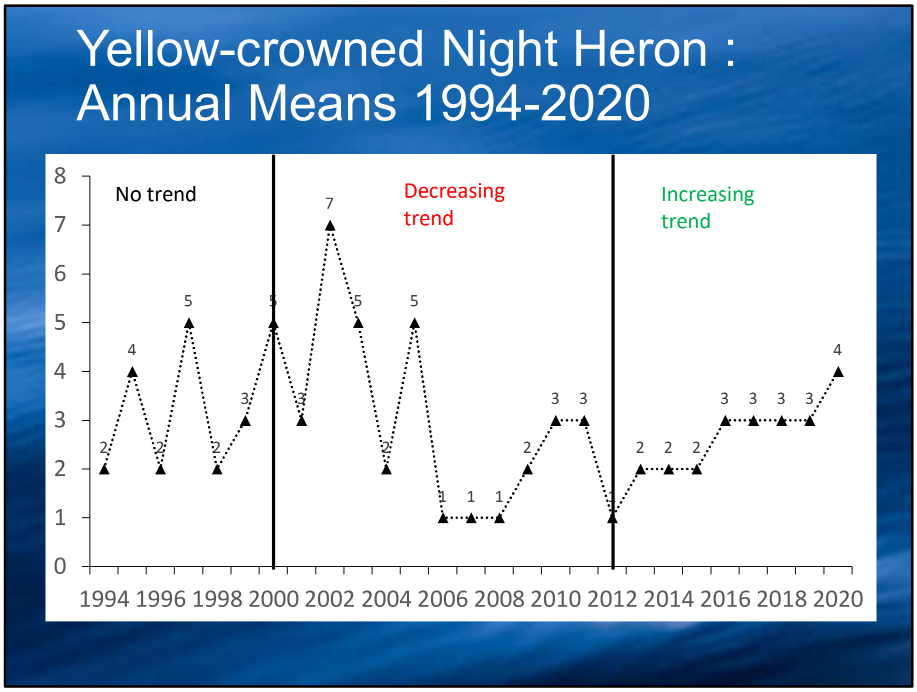


- Annual mean counts per survey reveal a steep increase during the hydrilla invasion **[click]**,
    - followed by a steep decline during the hydrilla management period that continued through the post-hydrilla management period **[click]**
    - The annual mean has been 1 since 2017 compared to a peak of 23 in 1997 at the outset of the hydrilla invasion
- 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 continued decline also may reflect a decrease in suitable nesting cavities proximate to the river; they typically nest within 2 km of water (Gary R. Hepp and Frank C. Bellrose. 2020. Wood Duck. Birds of the World. https://birdsoftheworld.org/bow/species/wooduc/cur/introduction)
- The USGS Breeding Bird Survey records a long-term decreasing trend of –3.34% per year in Florida between 1993 and 2019, possibly due to decreasing forested wetland habitat
- It might be worthwhile to try erecting nesting boxes
- **19 minutes to here**

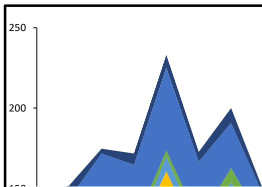
- The yellow-crowned night heron breeds on the upper Wakulla River during the summer. Some individuals remain over winter while others likely migrate south
- They feed primarily on crustaceans; mostly crayfish on the upper Wakulla River from what I have observed



- Unlike the other more common species we have examined, the yellow-crowned night heron exhibits no statistically significant trend over the period of record



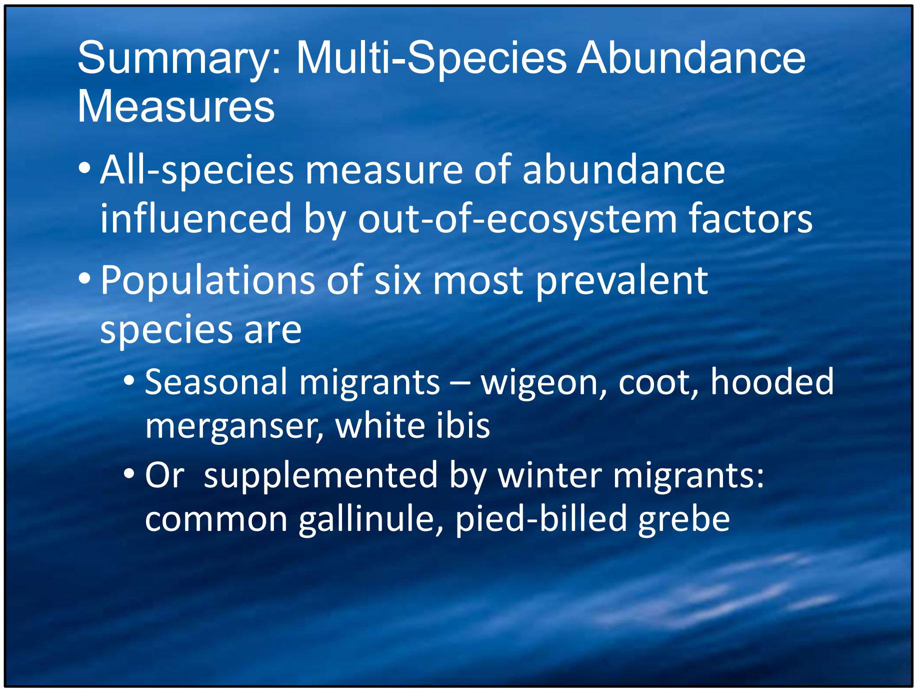
- Annual means are small ranging from 1 to 7
- **[click]** Counts per survey exhibited no significant trend during the hydrilla invasion
- **[click]** But a significant decreasing trend was observed during the hydrilla management period
- **[click]** Followed by a significant increasing trend since 2012



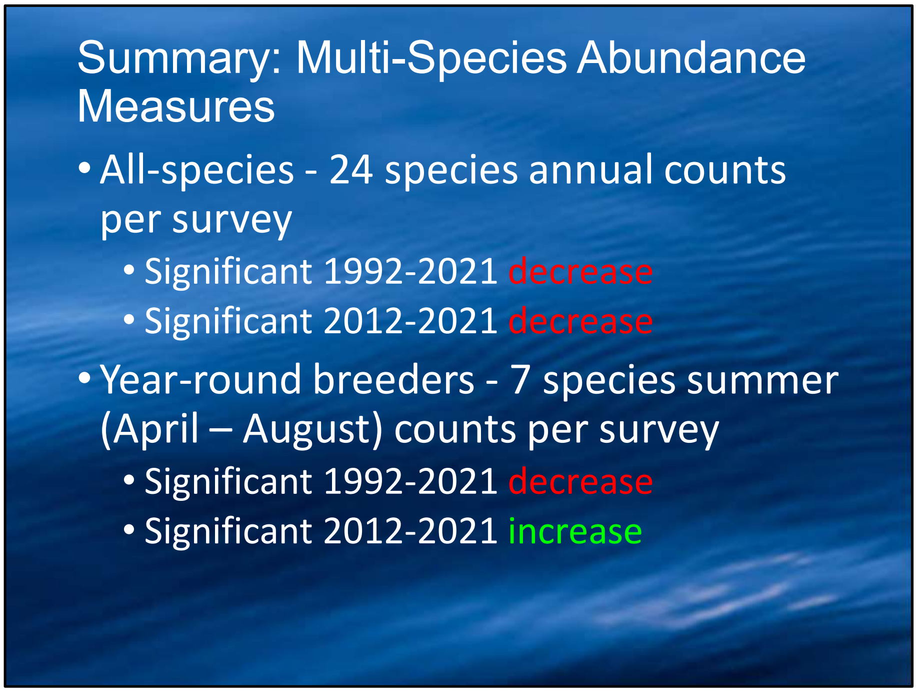
Annual Summer Means: 1992-2020 Year-Round Resident Breeders

Species	Seasonal Pattern	Long-term Trend	2012-2021 Trend	Possible Confounding Factors
American alligator	Year-round breeder	Decreasing	Increasing	Shifts in nesting locations?
Anhinga	Year-round breeder	Decreasing	Increasing	Decreased nesting → higher summer adult counts?
Common gallinule	Year-round resident breeder + winter migrant	Decreasing	Decreasing	↓ migrant breeding population; ↑ regional breeding population
Pied-billed grebe	Year-round resident breeder + winter migrant	Increasing	No trend	No coincident changes in migrant breeding or range or regional breeding
Wood duck	Year-round breeder	Decreasing	Decreasing	n/a
Yellow-crowned Night heron	Year-round breeder	No trend	Increasing	n/a

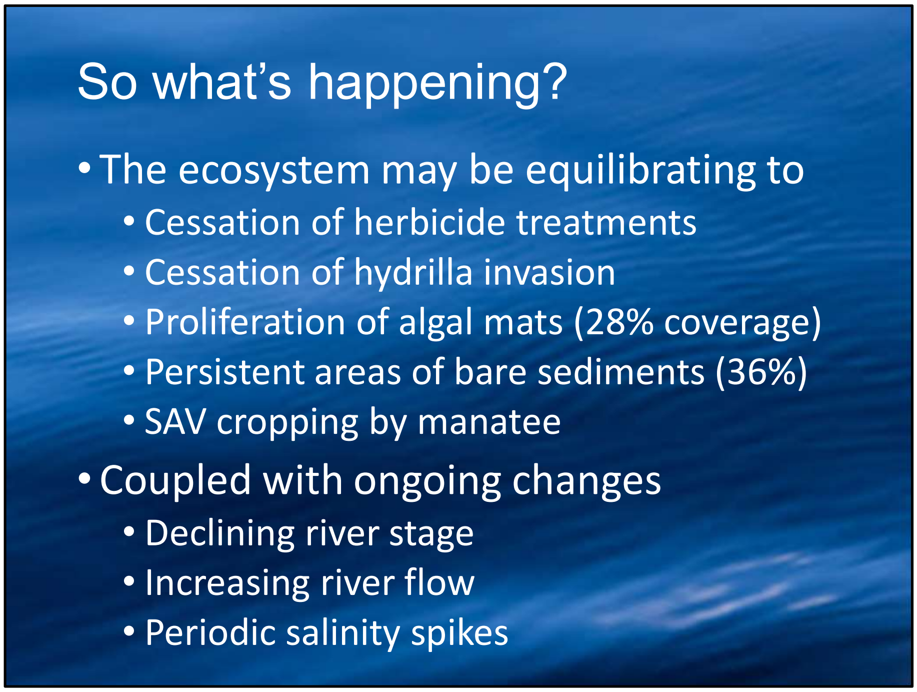
- Summarizing the status of the six year-round resident breeders we've examined for the period of record from 1992-2021 (did not look at green heron) we see
    - Four exhibiting significant decreases: American alligator, anhinga, common gallinule, and wood duck
    - Pied-billed grebe showing a significant increase
    - Yellow-crowned night heron experienced no significant trend
- Since 2012
    - Three are increasing: alligator and anhinga, and yellow-crowned night heron
    - Two are continuing to decrease: gallinule and wood duck
    - While the pied-billed grebe has levelled off exhibiting no significant trend:



- While the all-species measure of abundance reflects to some extent the biological productivity and carrying capacity of the upper Wakulla River ecosystem
- It also is influenced by out-of-ecosystem factors that affect such things as
  - Summer range breeding success and
  - Winter range geography
- Because the populations of the five most prevalent species among the 24 surveyed, are
  - Seasonal migrants – American wigeon, American coot, white ibis
  - Or supplemented by winter migrants: common gallinule, pied-billed grebe



- Thus, we should probably consider the year-round breeder measure as likely to be more representative of changes in overall biological productivity
- So, while the all-species metric indicates both long-term and recent declining trends in animal abundance **[click]**
- The year-round breeder metric offers a bit of hope that some improvement may be occurring **[click]**



- **[click]** The ecosystem may be equilibrating to
    - Cessation of herbicide treatments
    - Cessation of hydrilla invasion
    - Proliferation of algal mats
    - Persistent areas of bare sediments
    - SAV cropping by manatee
- **[click]** Coupled with ongoing changes
    - Declining river stage
    - Increasing river flow
    - Periodic salinity spikes

- **[click]** Herbivores in decline or extirpated
  - American wigeon - extirpated
  - American coot
  - Wood duck
  - Common gallinule – persisting on algae
- **[click]** Reduced nesting by some fish-eating predators
  - Osprey
  - Anhinga
- **[click]** Crayfish eating by some fish-eating birds
  - Anhinga
  - Double-crested cormorant

- **[click]** Increases in some generalist carnivores
    - American alligator
    - Great egret
    - Green heron
    - Tricolored heron
    - But the latter three are present in very small numbers
- **[click]** Increases or stable crayfish eaters
    - Hooded mergansers
    - Pied-billed grebes
    - White ibis
    - Yellow-crowned night herons

- **[click]** Emerging algal/detrital-based ecosystem dominated by generalists and crayfish eaters?