

Specimen-based modeling,  
stopping rules, and the  
extinction of the the ivory-billed  
woodpecker *Campephilus  
principalis*

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Connecticut

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# Estimation of Extinction Dates

Temporal Sequence of Species Occurrences

↓  
...111111111111100000000000.....

“Contaminated” Sequence of Species Occurrences  
(False Negatives, False Positives)

↓ ?  
...1111111111111001001000000.....

# Reasons For Estimating Extinction Dates

- Missing Species
  - Optimizing search efforts and maximizing allocation of limited conservation resources
- Invasive or Pest Species
  - Optimizing termination of extirpation programs

*Caprimulgus vociferans*, Gmel.  
*Caprimulgus vociferans*, Gmel.  
Willow Oak.

*Caprimulgus vociferans*, Gmel.  
Largest White Bill'd Woodpecker.  
T. 18.



# Ivory-billed Woodpecker

## Life History & Ecology

- Largest North American bird (wingspan 80 cm)
- Geographic range southeastern US (+ Cuba)
- Preferred bottom land forest, decayed trees
- Fed on insects and grubs beneath bark
- Home-range ~ several km<sup>2</sup>
- Annual reproduction clutch size 2-4 years
- Lifespan > 10 years
- “Common” in 1900s
- Last specimen collected in 1932
- Last confirmed sighting in 1944

# Reasons For Ivory-billed Woodpecker Decline

- Hunting (American Indians, European settlers)
- Habitat Change (Agriculture, Forestry)
- Demand by Collectors (Economic Pressures)



*Caprimulgus vociferans*, Gmel. *Caprimulgus vociferans*  
*Willow Oak.*

*Caprimulgus vociferans*, Gmel. *Caprimulgus vociferans*  
Largest White Bill'd Woodpecker.  
T. 18.



Extinct

scope access. We also thank J. Fountain and K. Padian for editorial advice. The ground section of MOR 1125 was provided by Quality Thin Sections, and the laying hen demineralized thin sections were provided by J. Barnes (NCSU College of Veterinary Medicine). Site access was provided by the Charles M. Russell

National Wildlife Refuge. The research was funded by NCSU as well as by grants from N. Myhrvold (J.R.H.) and NSF (M.H.S.).

#### Supporting Online Material

[www.sciencemag.org/cgi/content/full/308/5727/1456/](http://www.sciencemag.org/cgi/content/full/308/5727/1456/)

DC1  
Materials and  
Figs. S1 to S3

11 March 2009  
10.1126/scien

# Ivory-billed Woodpecker (*Campephilus principalis*) Persists in Continental North America

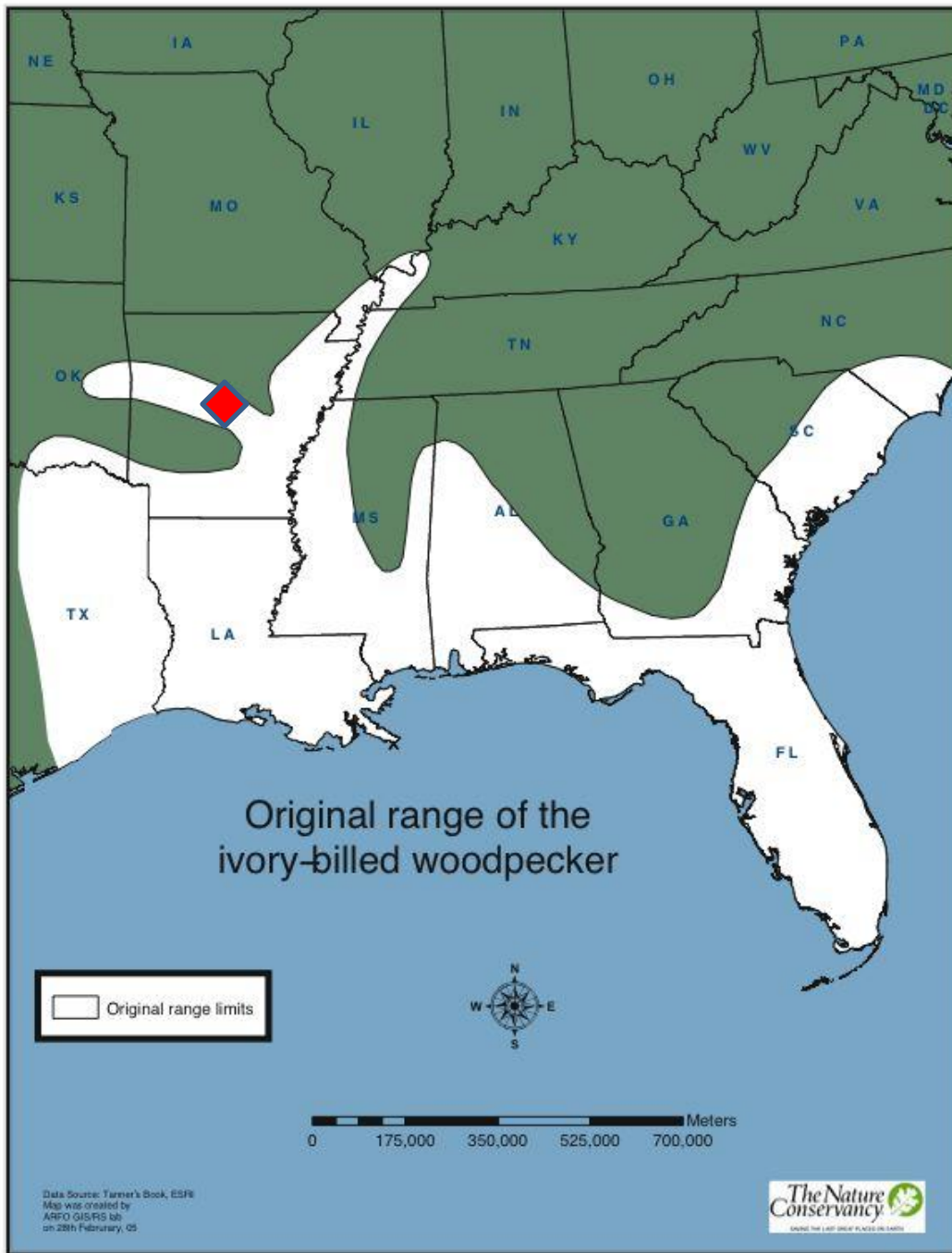
John W. Fitzpatrick,<sup>1\*</sup> Martjan Lammertink,<sup>1,2</sup>  
M. David Luneau Jr.,<sup>3</sup> Tim W. Gallagher,<sup>1</sup> Bobby R. Harrison,<sup>4</sup>  
Gene M. Sparling,<sup>5</sup> Kenneth V. Rosenberg,<sup>1</sup>  
Ronald W. Rohrbaugh,<sup>1</sup> Elliott C. H. Swarthout,<sup>1</sup> Peter H. Wrege,<sup>1</sup>  
Sara Barker Swarthout,<sup>1</sup> Marc S. Dantzker,<sup>1</sup> Russell A. Charif,<sup>1</sup>  
Timothy R. Barksdale,<sup>6</sup> J. V. Remsen Jr.,<sup>7</sup> Scott D. Simon,<sup>8</sup>  
Douglas Zollner<sup>8</sup>

The ivory-billed woodpecker (*Campephilus principalis*), long suspected to be extinct, has been rediscovered in the Big Woods region of eastern Arkansas. Visual encounters during 2004 and 2005, and analysis of a video clip from April 2004, confirm the existence of at least one male. Acoustic signatures consistent with *Campephilus* display drums also have been heard from the region. Extensive efforts to find birds away from the primary encounter site remain unsuccessful, but potential habitat for a thinly distributed source population is vast (over 220,000 hectares).

The ivory-billed woodpecker is one of seven North American bird species that are suspected or known to have become extinct since

Singer Tract) during the late 1930s (3–6). That population disappeared as the Singer Tract was logged amid cries for protection

Arkansas, large red-c him and lar 20 m away that the bir pecker (SO sighting on Harrison v thenticity c guided thro 13:15 CST km of the woodpecke front of the of landing fully reveal bird instead landed brief from the o flew off (S locate the failed, but experience of five add 5 April 20 text). All s within 3 km At 15:4



## The Ivory-Bill Returns

**T**he announcement on *Science Online* (28 April 2005) of the persistence of the ivory-billed woodpecker has received more press attention than any bird news in my lifetime, and perhaps in all of history. In the hope that all the fuss has not exhausted our appetite for rejoicing over this development, we publish herewith the paper in print, along with an appropriate cover, and the following appreciation from your editor, a birder since boyhood.

Why is there so much excitement about this discovery—enough to generate over 300,000 Google searches, an editorial in the *New York Times*, and an Internet traffic jam on the many sites that serve America's six million birders? It should bring a thrill to everyone who cares about nature and about the diversity of life on Earth. My use of the word "return" in the title reflects much of the mainstream commentary about the finding, but it's not an apt description. It only seems as though the ivory-bill has arisen from the ashes. In fact, it never went away, so it can hardly be said to have returned.

Some will say, "It's only one bird." Well, maybe and maybe not. At least we now know that a mated pair of ivory-bills existed in these Arkansas forests and laid the egg that hatched this bird at least 40 years after the last confirmed record of the species from North America. We must now recognize that previous claimed sightings, some of them by experienced observers, should probably not have been disregarded. We should encourage future naturalists and other watchers in likely habitats to report their observations carefully so that they can be evaluated. Most important, this surprising news underscores the need to conserve ecologically suitable habitats for vanishing species, even when hope seems to have been lost.

I must add a note about the personal excitement and pleasure this discovery has brought me. The sense of excitement began about 2 months ago when I received a somewhat cryptic e-mail from John Fitzpatrick, the head of Cornell's Laboratory of Ornithology (located in a nice piece of deciduous forest called Sapsucker Woods). Fitzpatrick's message inquired as to whether *Science* would be interested in reviewing a report confirming the persistence of a bird (I believe he said "iconic" bird) long thought to have been extinct. That was not a difficult code to break, and I got back to him in a New York second!

The pleasure came because the involvement of the Cornell laboratory closed a circle for me. As a boy in the 1930s, I was a faithful follower of *National Geographic* accounts of Cornell expeditions to Louisiana to record and photograph these magnificent birds. I even wrote a fan letter to the expedition's leader, the pioneer Cornell ornithologist Arthur Allen. My mother supervised my 7-year-old grammar and penmanship but failed to edit the sign-off that kids use for relatives. I signed it "Love, Donny." I was happily surprised when Professor Allen responded to my questions with an official-looking letter on Cornell stationery. To my mother's amused delight, he signed it "Love, Arthur." How pleased this generous man would have been by his successors' find.

Cornell and the Nature Conservancy, a partner in the venture, deserve all the credit they have been given. But it is only fair to single out Gene Sparling of Hot Springs, Arkansas, who first found the bird, made the identification, and then guided two members of the Cornell team into the right area. No one who heard the interview of these three on National Public Radio can be unaware of the thrill this amateur naturalist had from his discovery or of the excitement it brought to his two colleagues. It is fortunate for science that it attracts people who may lack special training or higher degrees but have found the knowledge and confidence to know that they can do real science. Generations of British parson naturalists have given us centuries of first-flowering dates for British plants, and a national brigade of observers who assist Cornell with the Partners in Flight program have expanded our knowledge of bird distribution and migration. For Gene Sparling, the Cornell team, and the partner organizations who have helped preserve the Arkansas habitat, an appropriate salutation would be the ancient Hebrew blessing: "Baruch Mechayei haMetim": "Blessed is the one who gives life to the dead."

**Donald Kennedy**  
Editor-in-Chief

10.1126/science.1115204





“I must add a note about the personal excitement and pleasure this discovery has brought me....Blessed is the one who gives life to the dead.”

Donald Kennedy, Editor, *Science*

“We have dedicated our time and our dreams to protecting and conserving this area. These woods are my church.”

John Fitzpatrick, Director, Lab of Ornithology, Cornell University

“It's like a funeral shroud has been pulled back, giving us a brief glimpse of a living bird, rising Lazarus-like from the grave. “

Tim Gallagher, Editor, *Living Bird*, Cornell Lab of Ornithology

*Castanea, arbutus, flos. Massachusetts  
Arbutus longo, angustis foliis: Sagittifolia.*  
Willow Oak.

*Cast. maximus rufus albus.*  
Largest White Bill'd Woodpecker.  
T. 18.



**Extant?**



0

woodpecker behind tree trunk



16.7

right wing begins to open



33.3

white secondaries, anterior black patch on wing



50

wing & tail visible as bird starts to fly



66.7

tail visible, body and wings obscured by tree



83.3

entire bird obscured by tree



100



116.7



133.3



150



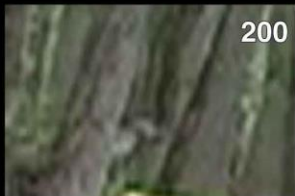
166.7

right wing comes into view

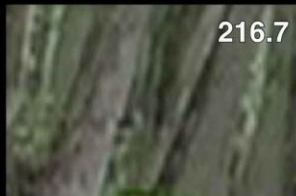


183.3

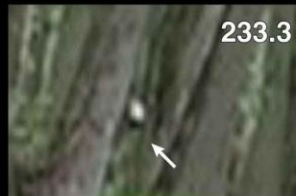
middle of second wingbeat



200



216.7



233.3

black body visible



250

extensive white underwing



266.7



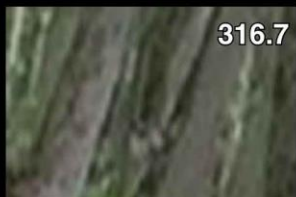
283.3

both wings visible, middle of third wingbeat

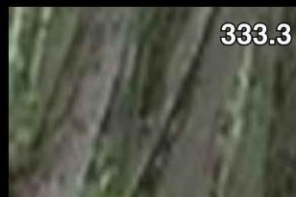


300

black primaries contrasting white secondaries



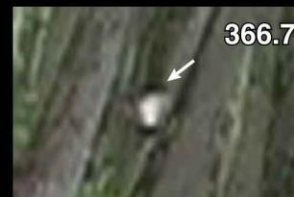
316.7



333.3

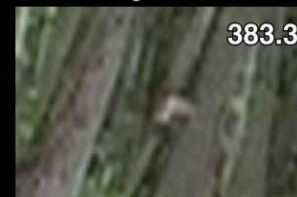


350



366.7

right wing broadly white with black tip



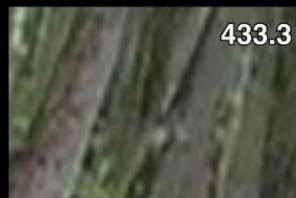
383.3



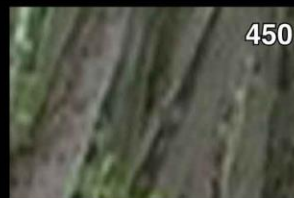
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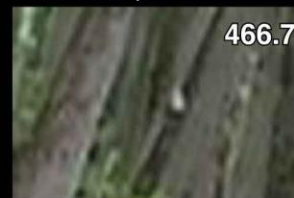
416.7



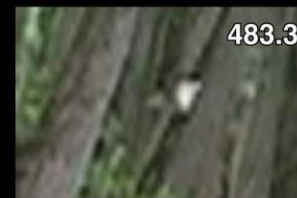
433.3



450



466.7



483.3

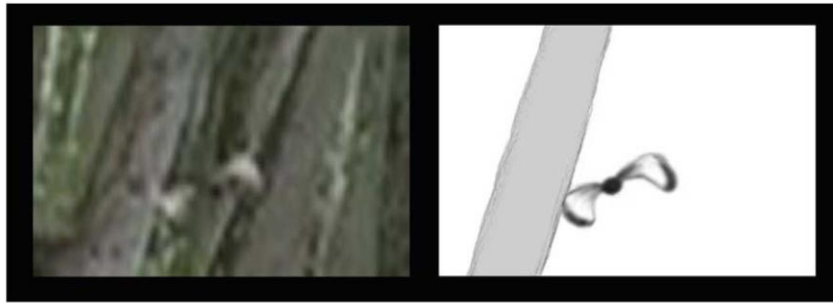
middle of fourth wingbeat



Burlington, VT  
24 December 2008

*Dryocopus pileatus* (Pileated woodpecker)





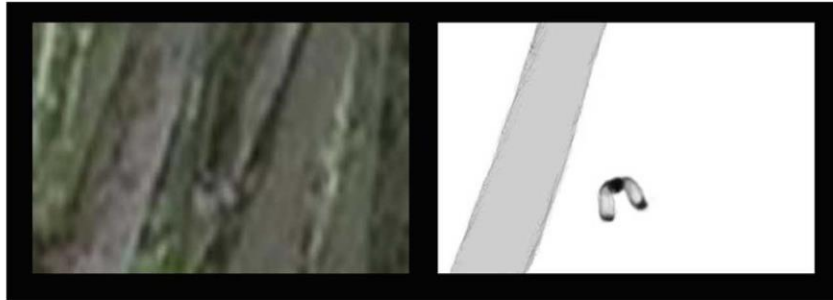
Science frame 283.3; Cornell frame 0932a

Wings tilted forward and viewed from behind show white underside typical of a pileated woodpecker; little white is visible on the wings close to the body contrary to the expectation if one were viewing the tops of an ivory-billed woodpecker's wings.



Science frame 300; Cornell frame 0932b

Wings moving quickly and blurred near bottom of downstroke; twisting to reveal underside and pulled in slightly as they move down. Note the bright white blur just inside the black wingtips. This is consistent with the wing pattern of a pileated woodpecker and not with that of an ivory-billed woodpecker.



Science frame 316.7; Cornell frame 0933a

Near bottom of downstroke, the wings are already being pulled in and up towards the body.

# The Zabruder Film



November 22<sup>nd</sup>, 1963  
Dealey Plaza  
Dallas, Texas

# The Zabrunder Film Of Conservation Biology?



0  
woodpecker behind tree trunk



16.7  
right wing begins to open



33.3  
white secondaries, anterior black patch on wing



50  
wing & tail visible as bird starts to fly



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tail visible, body and wings obscured by tree



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entire bird obscured by tree



100



116.7



133.3



150



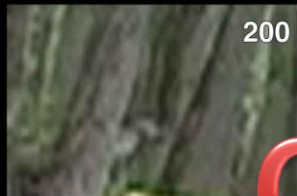
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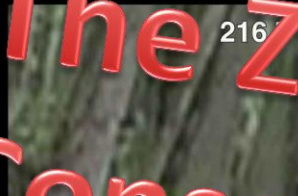


183.3

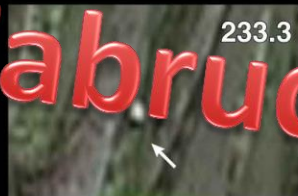
middle of second wingbeat



200



216



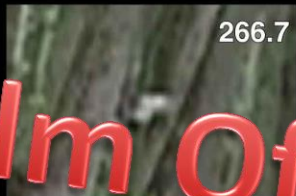
233.3

top of body visible



250

extensive white underwing

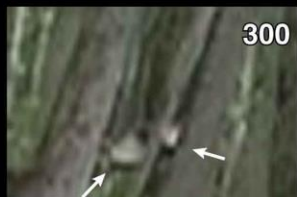


266.7



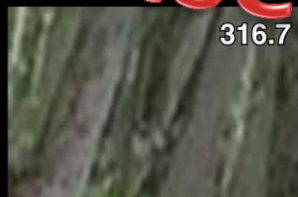
283.3

both wings visible, middle of third wingbeat



300

black primaries contrasting white secondaries



316.7



333.3

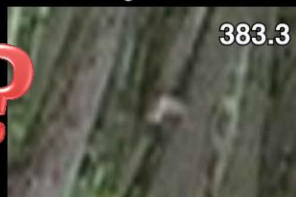


350



366.7

right wing broadly white with black tip



383.3

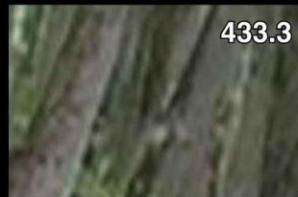


400



416.7

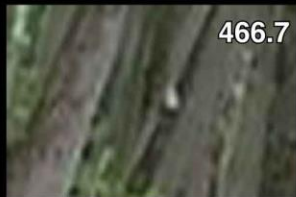
middle of fourth wingbeat



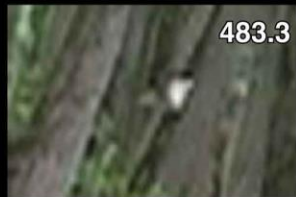
433.3



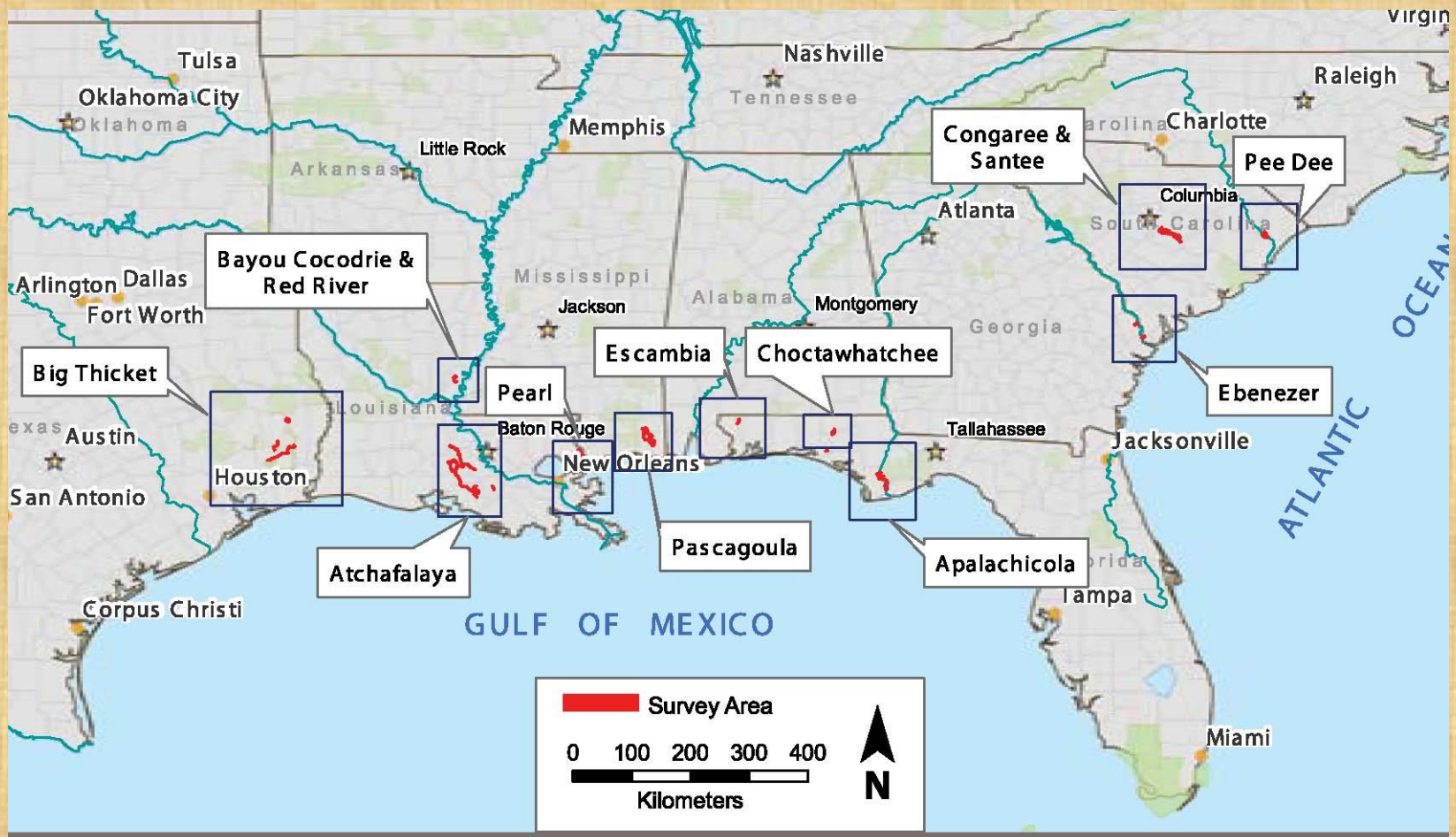
450



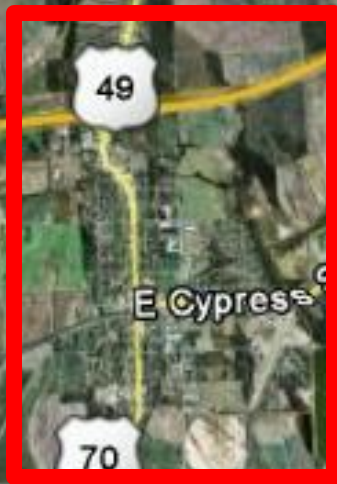
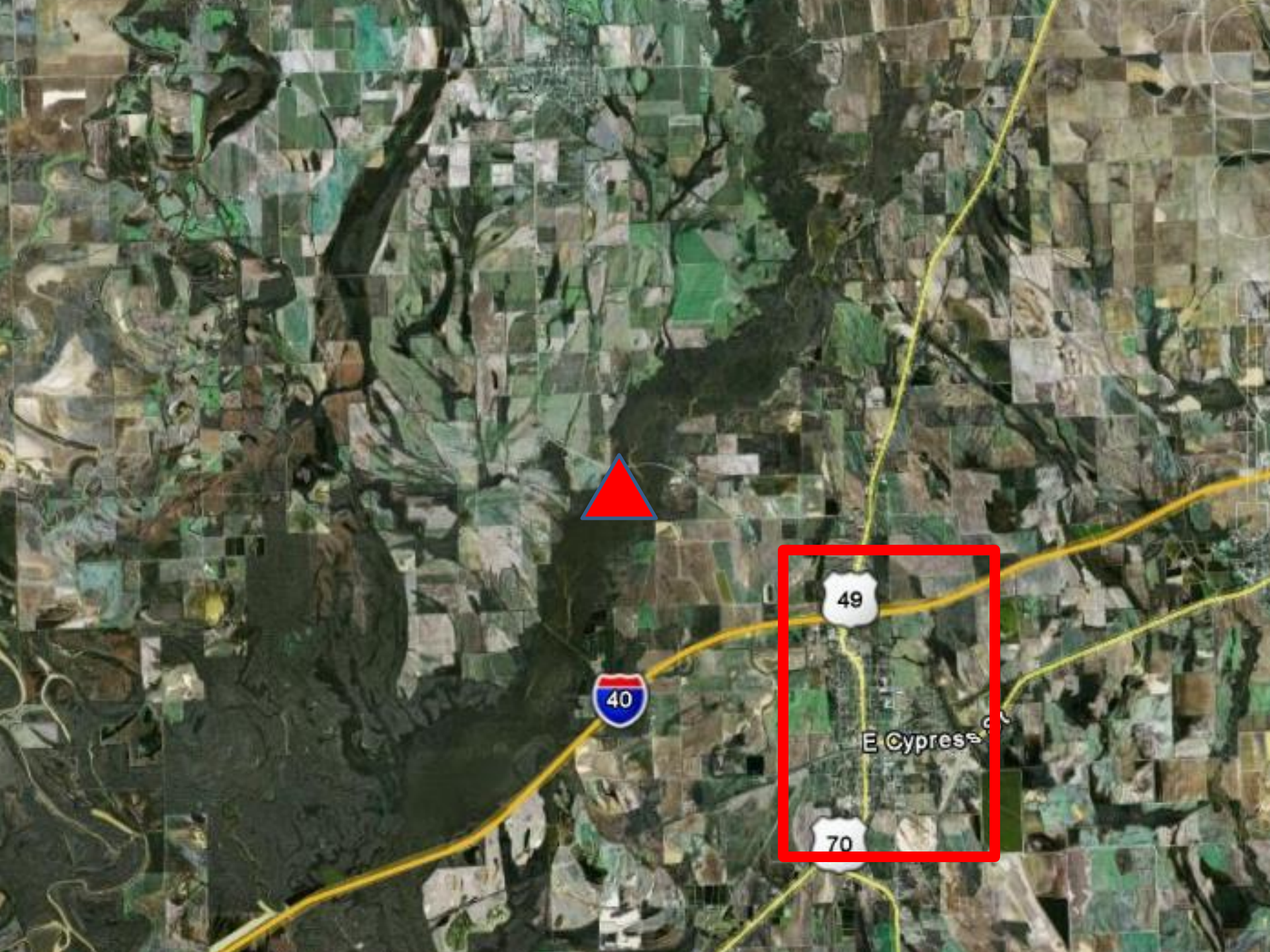
466.7



483.3







49

70

E Cypress



# REWARD



## IVORY-BILLED WOODPECKER

**ALIASES:** THE LORD GOD BIRD, THE GRAIL BIRD, GHOST BIRD

**APPROACH WITH CAUTION:** THIS RARE WOODPECKER IS EXTREMELY ELUSIVE AND IS CONSIDERED AN ENDANGERED SPECIES

 **LAST SEEN IN THE BIG WOODS OF ARKANSAS**

A \$50,000 reward will go to the individual responsible for leading a project scientist to a living Ivory-billed Woodpecker at a nesting, roosting or foraging site.

No national wildlife refuges or wildlife management areas will be closed because of the presence of an Ivory-billed Woodpecker. No private land has been condemned to protect this species and there is no intention of doing so.

The land use of the area where the woodpecker is found is likely compatible with the bird's needs. If interested, private landowners with birds using their property may receive additional funding and technical assistance to benefit the woodpecker's habitat.

To collect the reward, you must provide video, photographic or other compelling information and lead a project scientist to a living wild Ivory-billed Woodpecker for verification.

Anyone with information leading to the safe location of a living Ivory-billed Woodpecker should call Allan Mueller at (501) 614-5092 or (800) 440-1477.

# \$50,000

What is the probability that the ivory-billed woodpecker persists today?





BA0985 [RM] © www.visualphotos.com



Provenance of Art Works...

...and Museum Specimens

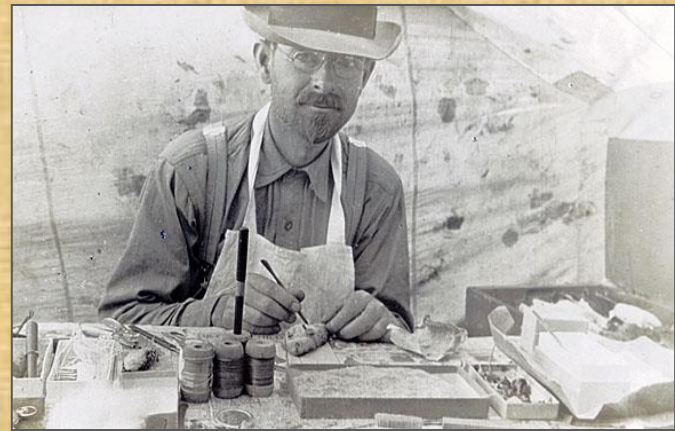
# The Value of Natural History Museum Collections



Grinnell, J. 1910. The methods and uses of a research museum. The Popular Science Monthly 77:163-169

“...I wish to emphasize what I believe will be the greatest value of our museum. This will not however be realized until the lapse of many years, possibly a century...the student of the future will have access to the original record of the faunal conditions...

...He will know the proportional constituency of our fauna by species, the relative numbers of each species, and the extent of the ranges of species as they exist today”

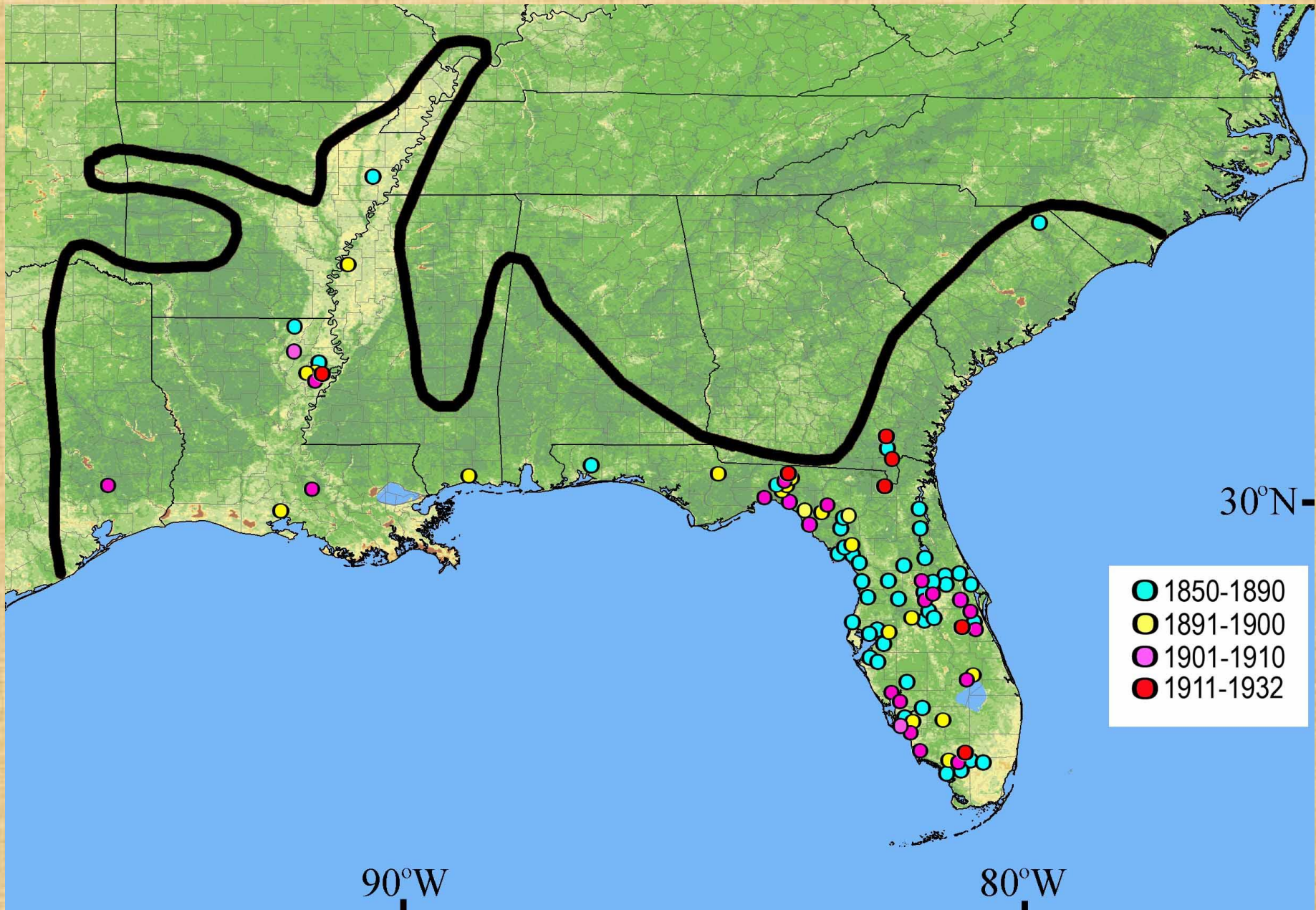


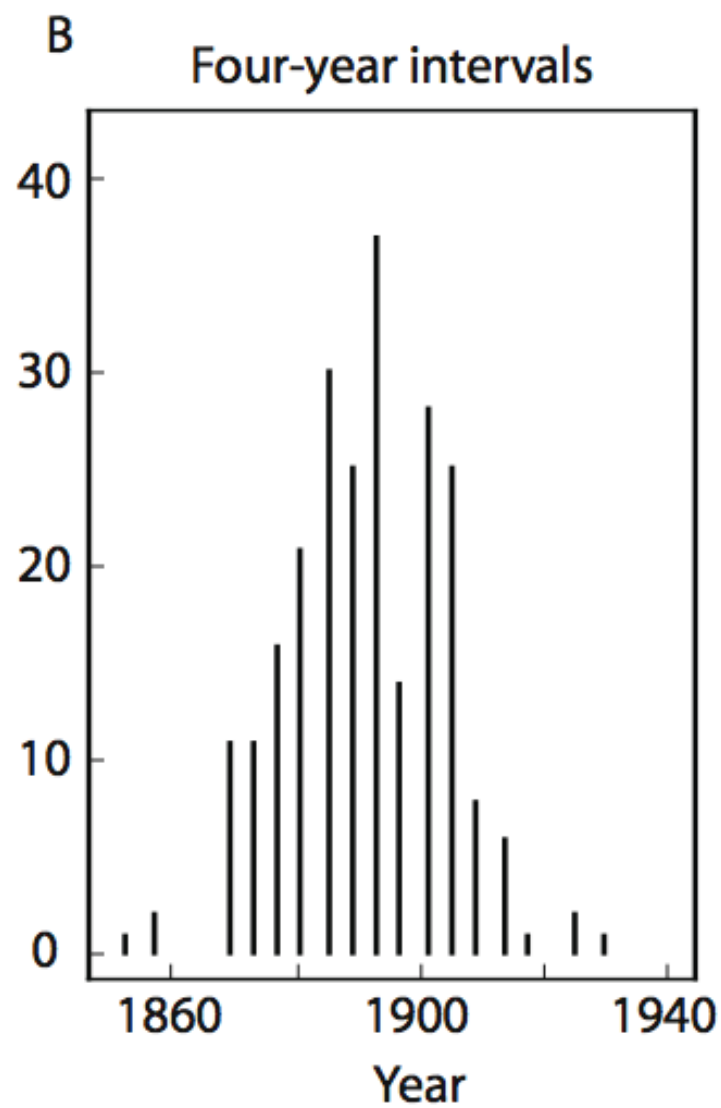
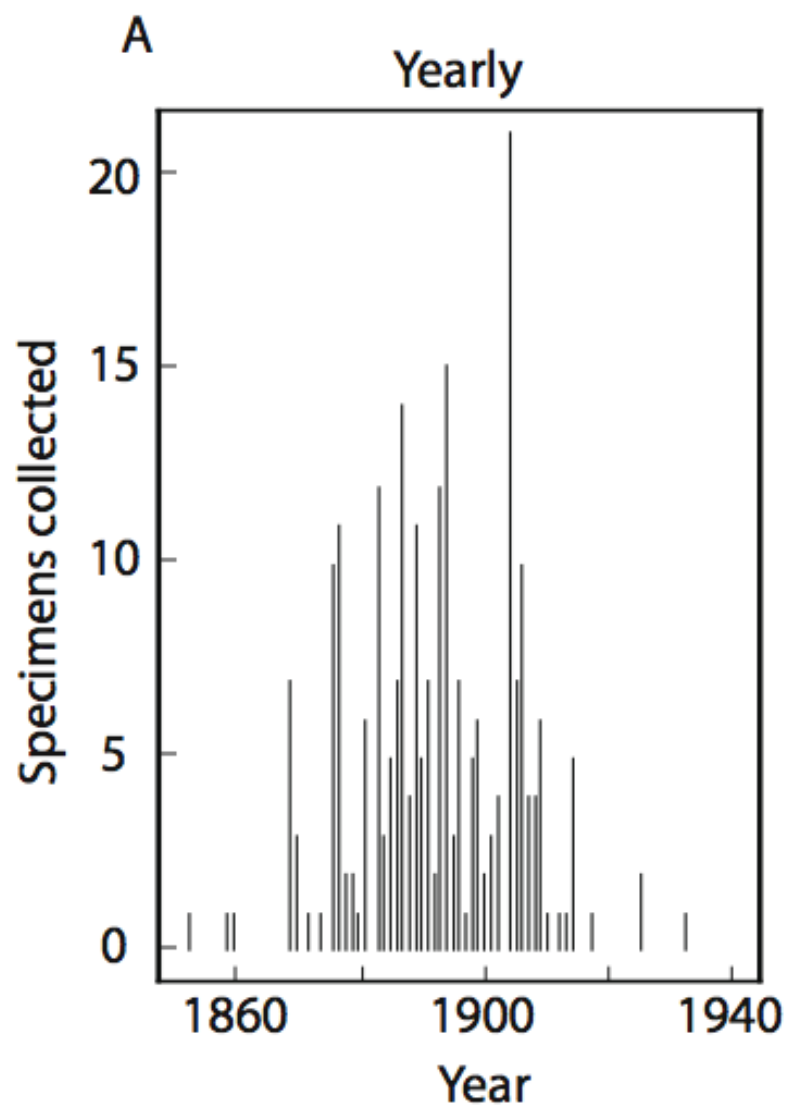
Joseph Grinnell  
Museum of Vertebrate Zoology  
University of California, Berkeley



Dated,  
georeferenced  
museum specimens  
(1850-1932)  
(N = 239 specimens)

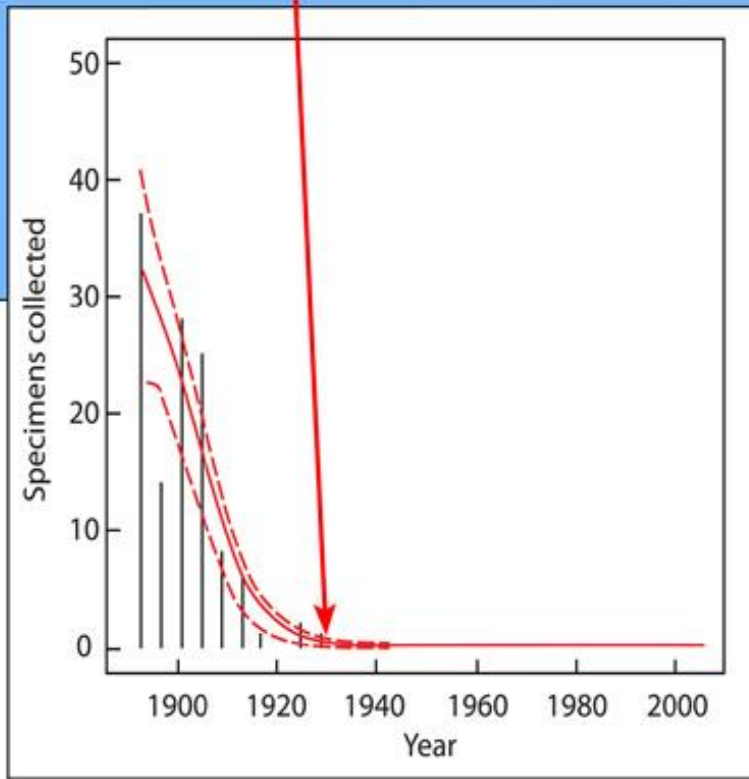
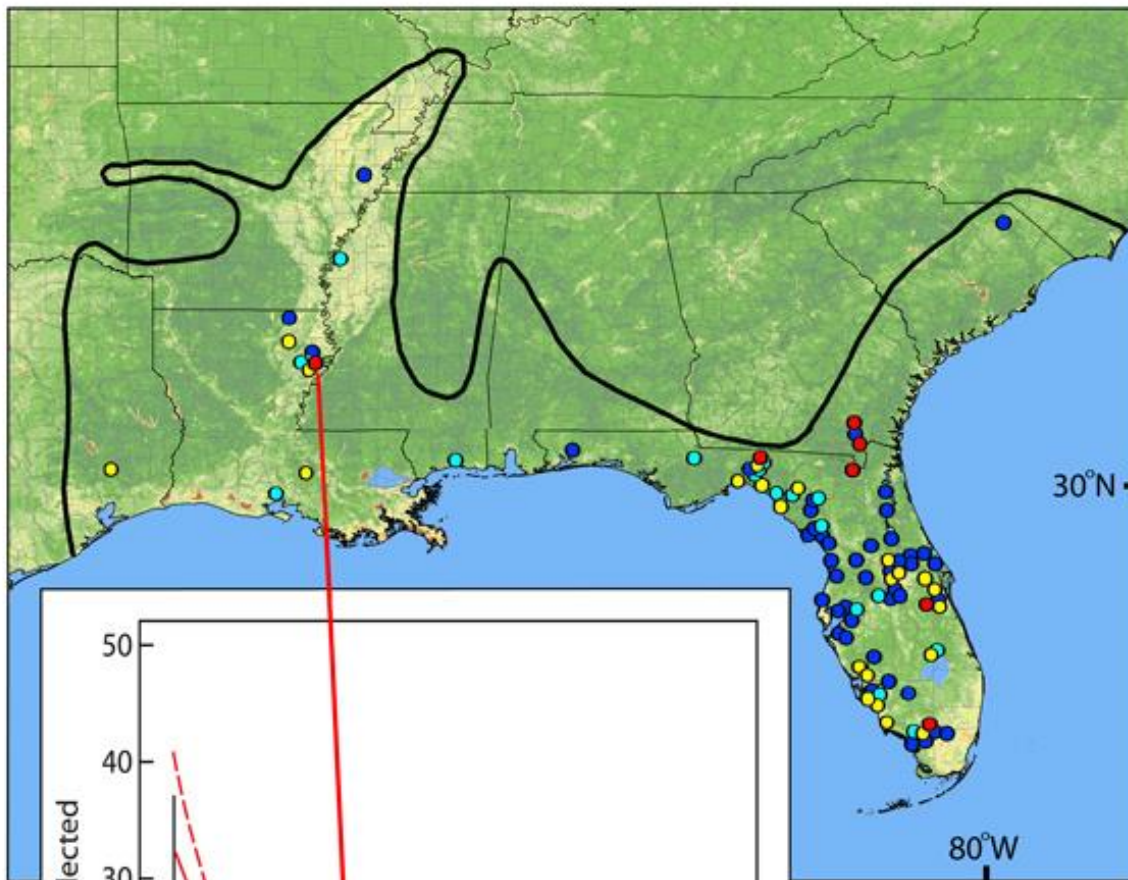






# Modeling Specimen Numbers

- Data binned into 5-year intervals
- Specimen number =  $f(\text{time})$
- Fit Poisson generalized additive model
- Curve fit with penalized regression spline model (Wahba 1990, Ruppert et al. 2006)
- Generates expected number of museum specimens in any 5-year time interval



- 1850-1890
- 1891-1900
- 1901-1910
- 1911-1932

Period	$\hat{\mu}_t$	se( $\hat{\mu}_t$ )	Period	$\hat{\mu}_t$	se( $\hat{\mu}_t$ )
1929-32	0.4225	0.2468	1969-72	0.000375	0.001495
1933-36	0.2157	0.1634	1973-76	0.000184	0.000829
1937-40	0.1078	0.1048	1977-80	$9.08 \times 10^{-5}$	0.000457
1941-44	0.0532	0.0657	1981-84	$4.47 \times 10^{-5}$	0.00025
1945-48	0.0262	0.0401	1985-88	$2.20 \times 10^{-5}$	0.000136
1949-52	0.0129	0.024	1989-92	$1.08 \times 10^{-5}$	$7.32 \times 10^{-5}$
1953-56	0.0064	0.0142	1993-96	$5.33 \times 10^{-6}$	$3.93 \times 10^{-5}$
1957-60	0.0031	0.0082	1997-00	$2.62 \times 10^{-6}$	$2.10 \times 10^{-5}$
1961-64	0.0015	0.0047	2000-04	$1.29 \times 10^{-6}$	$1.12 \times 10^{-5}$
1965-68	$8.00 \times 10^{-4}$	0.0027	2005-08	$6.36 \times 10^{-7}$	$5.94 \times 10^{-6}$

# Model Formulation

Last single individual collected in 1932

Assume that  $1/N$  = proportion of population represented by that individual

$p = 1/N$  = probability of a single individual being collected as a specimen

Population size at any future time  $n(t)$  can be estimated as:

$$u(t) = n(t)p$$

$$n(t) = u(t)/p = u(t)N$$

Probability of persistence =  $1 - \exp(-n(t))$

[= non-negative portion of Poisson distribution]

# Model Assumptions

- Declining collection curve of museum specimens mirrors overall population decline of IBW
- Per individual probability of capture as a museum specimen ( $= p$ ) is constant
- Population size  $n(t)$  at time  $t$  is a stochastic realization of a Poisson process
- Population size in 1932 ( $=N$ ) is known or inferred

# Benchmark Test of Model



Undisputed  
photographic  
records  
1933-1944

Ivory-billed Woodpecker, (c) Arthur A. Allen, 1935

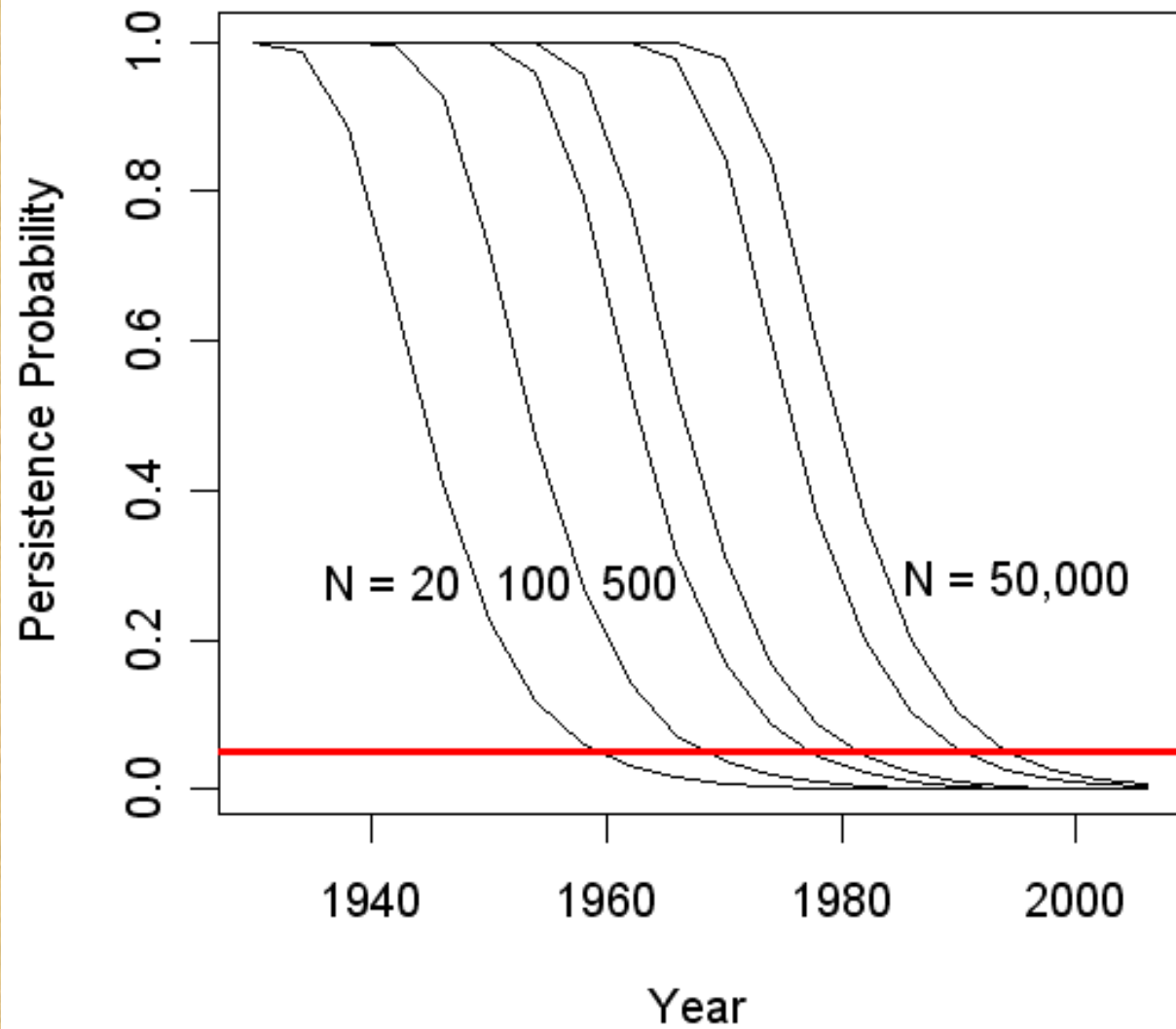
# Benchmark Test with Photo Records

Assumed N in 1932	$u(t)$ in 1944 (extrapolated)	$p = 1/N$	$n(t) = u(t)/p$	P(persistence in 1944)
100	0.0532	0.01	5.32	0.995
20	0.0532	0.05	1.064	0.665

# Benchmark Test with Photo Records

Assumed N in 1932	u(t) in 1944 (extrapolated)	p = 1/N	n(t) = u(t)/p	P(persistence in 1944)
100	0.0532	0.01	5.32	0.995
20	0.0532	0.05	1.064	0.665

Result: Model based on last museum specimen collected in 1932 correctly predicts persistence of ivory-billed woodpecker in 1944, when it was known from photographic records.

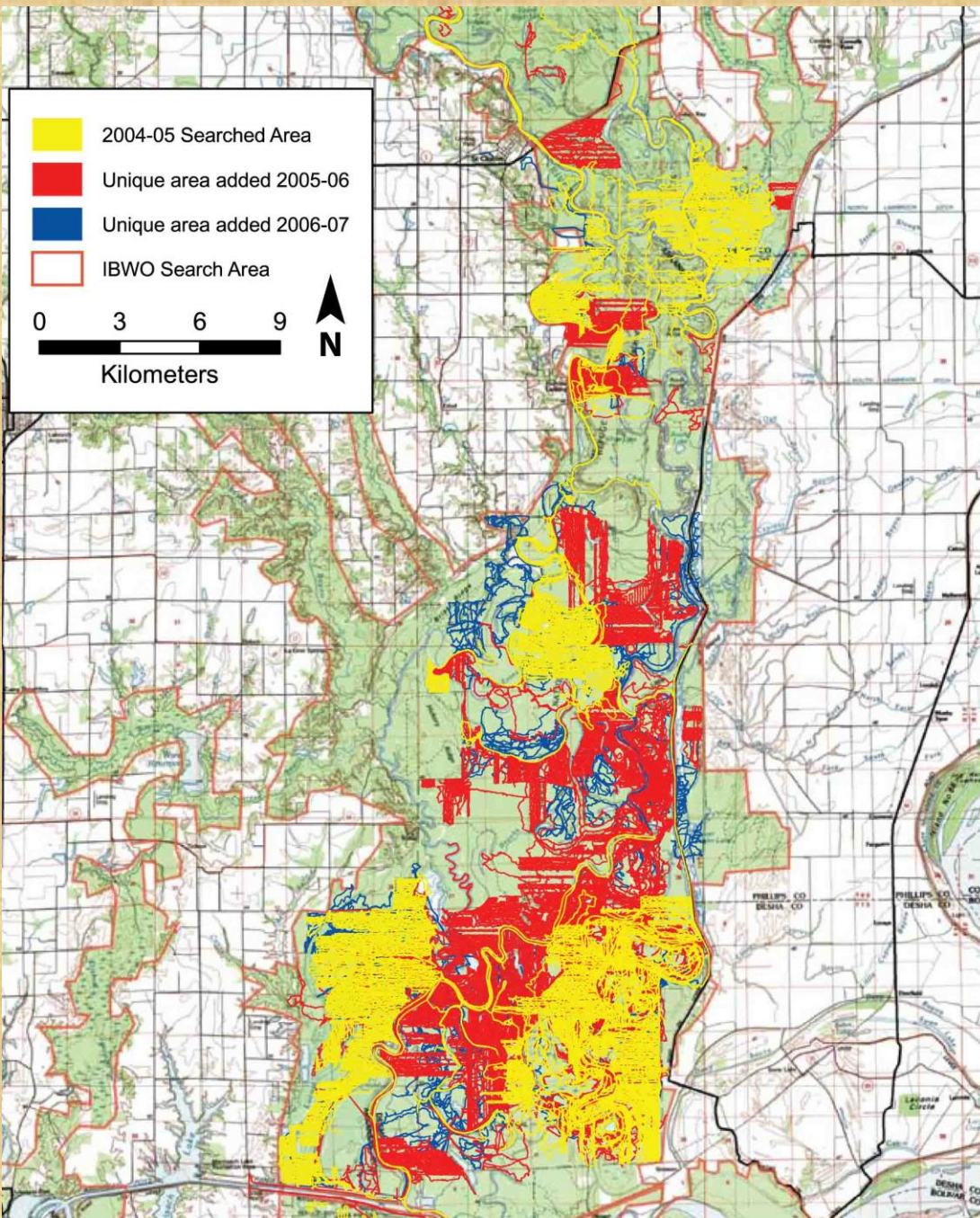


# Estimated Extinction Date

1932 Population Size	Estimated Year of Extinction ( $p < 0.05$ )
20	1961
100	1969
500	1977
1000	1981
5000	1993
10,000	1997
50,000	2005



Contemporary avian census records  
from IBW search efforts



# Statistical Inference

- Data on the frequencies of rare species in a collection can be used to estimate the number of undetected species
- The greater the frequency of “singletons” and “doubletons”, the greater the number of undetected species

# Summary of Census Data (2006-2007)

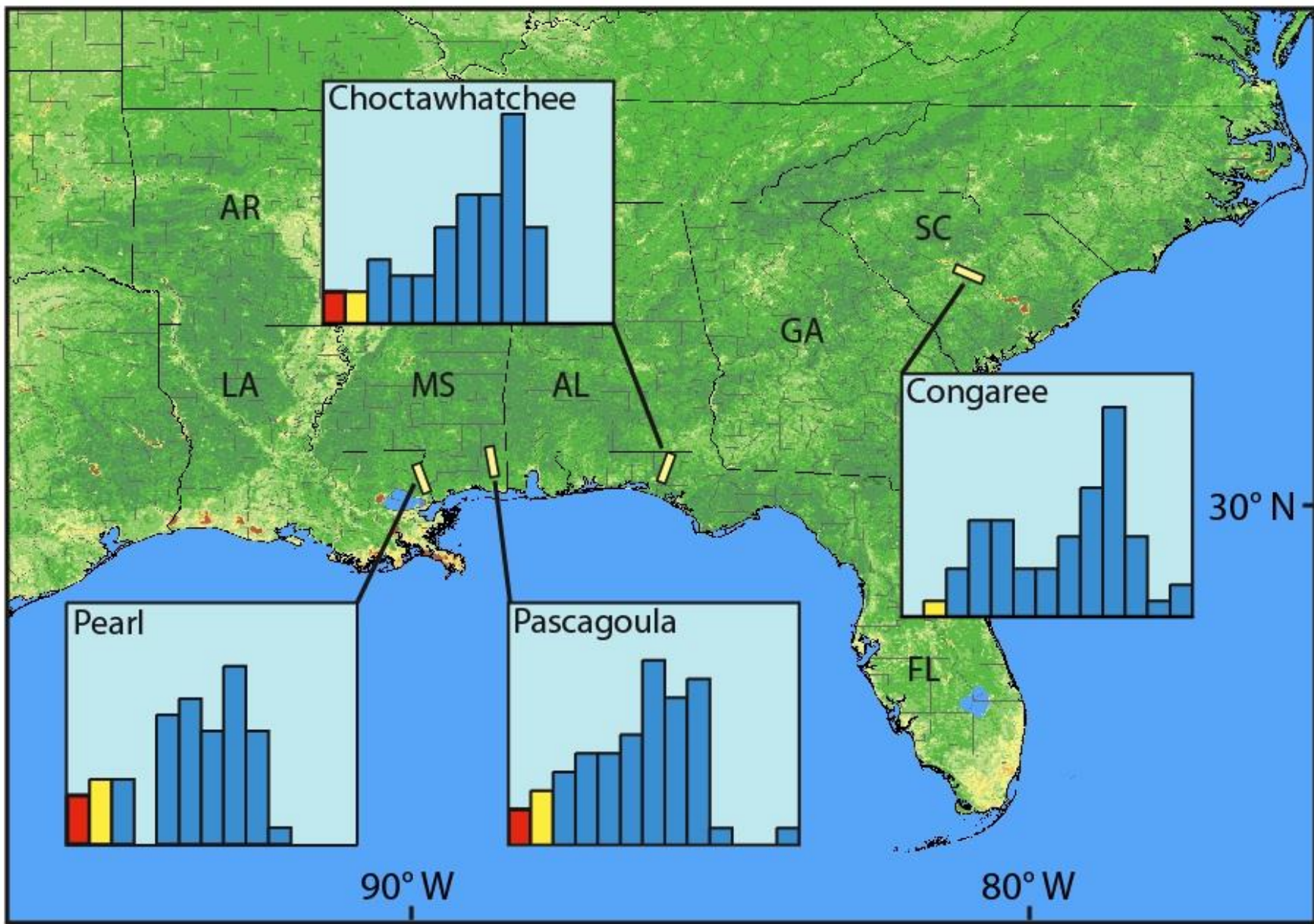
Site	Number of Individuals Censused	Number of Species Recorded	Search Effort (Days)
Congaree River, SC	15500	56	26
Choctawhatchee River, FL	6282	55	14
Pearl River, LA	3343	54	9
Pascagoula River, MS	6701	54	9

Four-person search teams on foot, by canoe

Sunrise to sunset searches

Comparable methods at all sites

Records for resident and migratory species that winter in flood plain forest habitats



# Efficient “Stopping Rule” for terminating searches for undetected species

$f(1)$  = frequency of “singletons” [= number of species represented by exactly one individual]

$R$  = expected reward for finding an undetected species (including IBW)

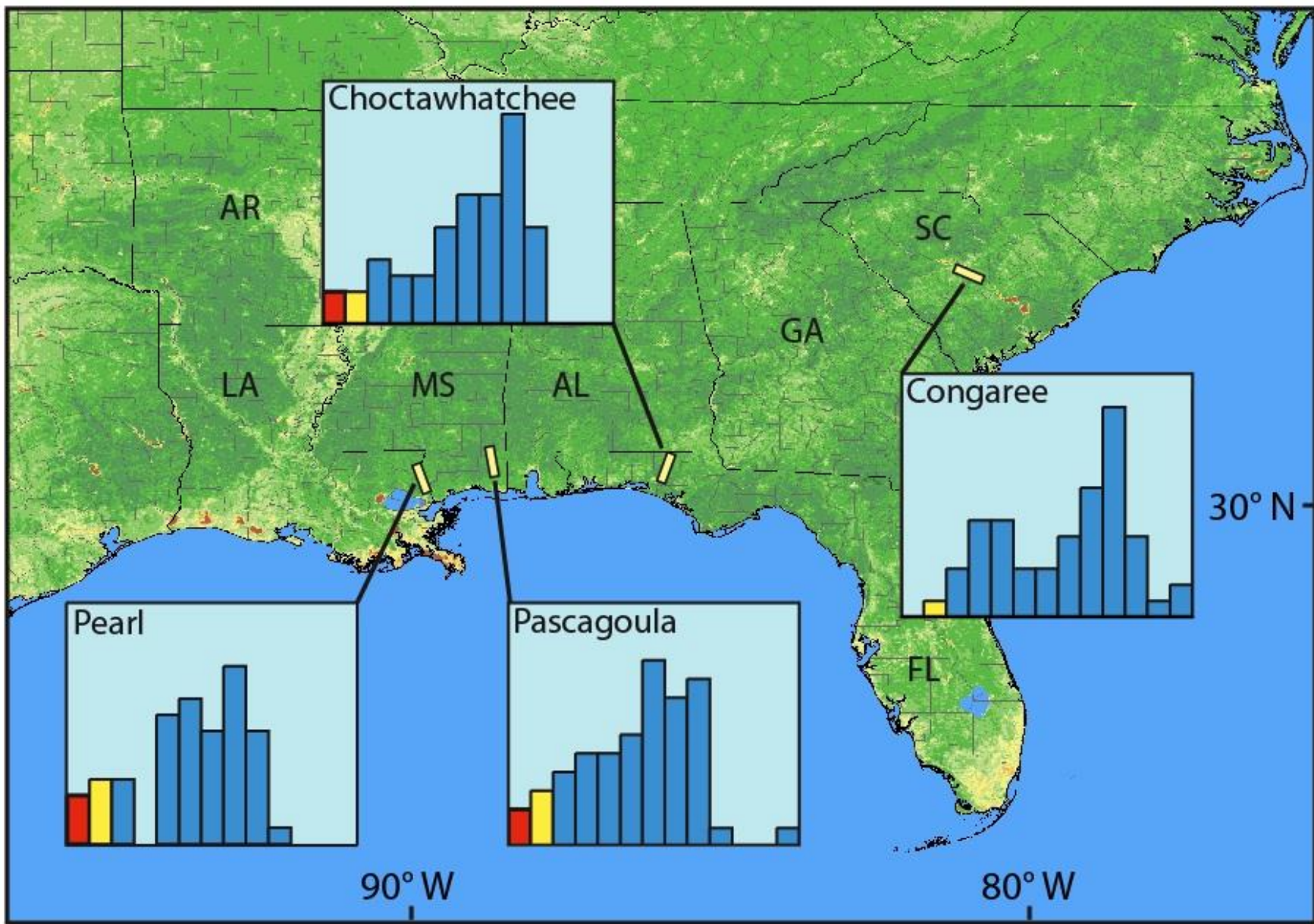
$c$  = cost of censusing one more bird

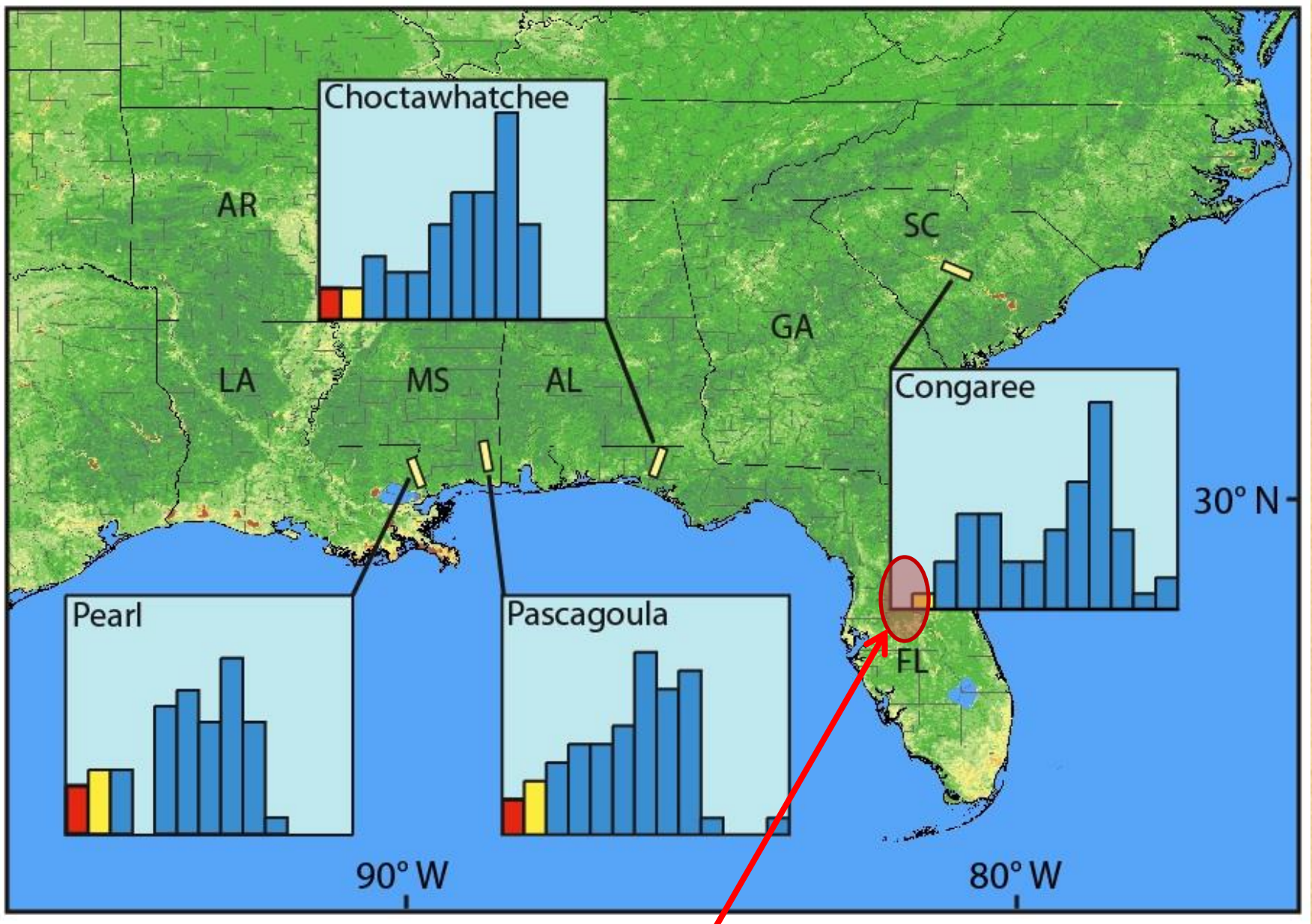
$n$  = number of individuals censused so far

Abandon search when  $f(1)/n < c/R$

Because  $c/R \approx 0$  for IBW, abandon search when all individuals are represented by at least 2 individuals (i.e. no singletons)

Rasmussen, S. & Starr, N. Optimal and adaptive search for a new species. *Journal of American Statistical Association* **74**, 661–667 (1979).





$f(1) = 0$  (no singletons)

# Estimates of Undetected Species and Necessary Census Efforts

Site	Number of Individuals Censused	Number of Species Recorded	Undetected Species	Additional censuses required to find undetected species	Probability that next individual censused is a new species
Congaree River, SC	15500	56	~0	-	$8.32 \times 10^{-9}$
Choctawhatchee River, FL	6282	55	1-2	6613	$3.18 \times 10^{-4}$
Pearl River, LA	3343	54	1-3	3061	$8.97 \times 10^{-4}$
Pascagoula River, MS	6701	54	1-2	4179	$2.98 \times 10^{-4}$

# Other Published Analyses

- Elphick et al. (2010)
- Binary sequence data (...000101000....)  
analyzed with extreme value theory
- Solow et al. (2012)
- Bayesian analysis of mixture model (“certain”  
observations), (“uncertain” observations)

# Comparison of Models

## Extreme Value Theory

- Assumes sudden population collapse
- Uses a mixture of specimens, photographs, sightings (binary)
- Traces disappearance of last remaining population
- May be vulnerable to repeated observations of same animals

## Specimen-based Modeling

- Assumes gradual decline of IBW population
- Uses only data from dated, geo-referenced museum specimens (integer)
- Models decline of specimens throughout geographic range
- Specimen data only counted once

# Comparison of Model Results

Study	Estimated Extinction Date of IBW
Specimen-based modeling	1981 (assuming N in 1932 > 1000)
Elphick et al. (2010)	1941-1945
Solow et al. (2012)	Extinction >4x more likely than persistence

# Responses From Ornithological Community



Bobby Harrison,  
President & Treasurer  
Ivory-billed Woodpecker Foundation  
(2004 rediscovery team)

"They can do all the math they want, but that doesn't negate what I've seen..."

"I have seen Ivory-bills six times and have seen at least two different birds."

# Responses From Ornithological Community



"I think their conclusions are fairly sound and their approaches interesting and complementary"

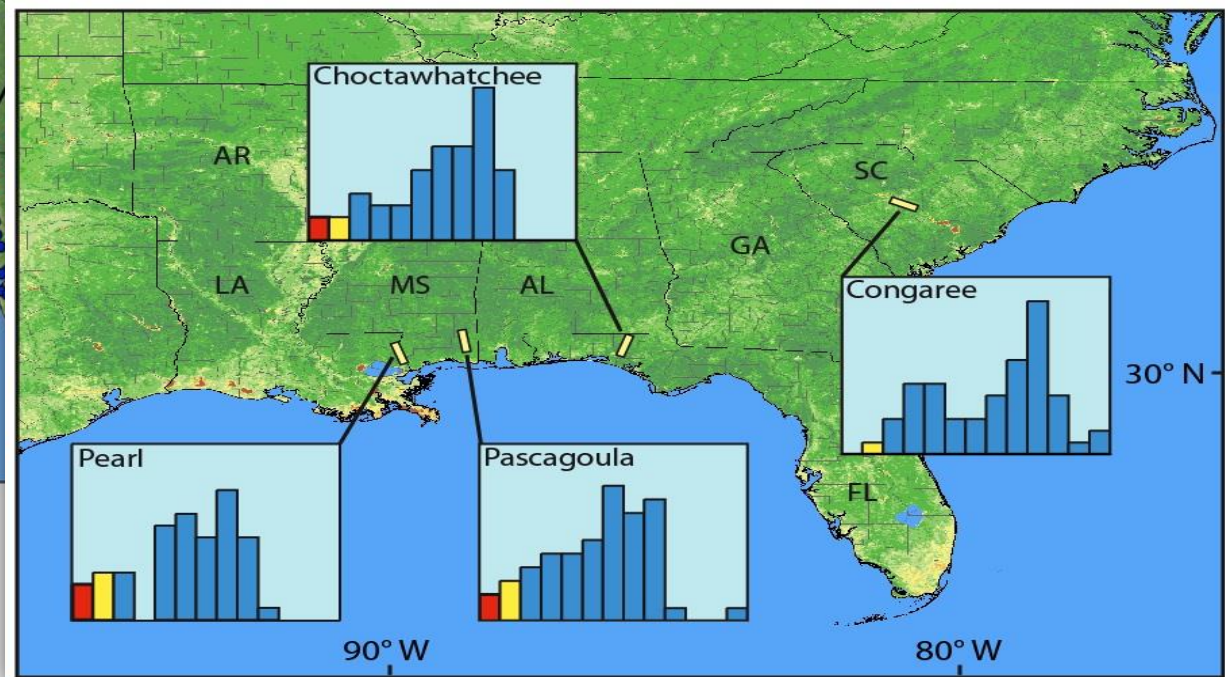
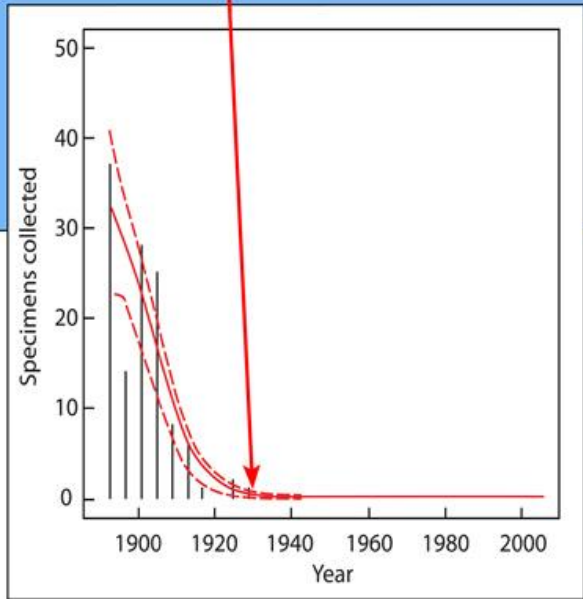
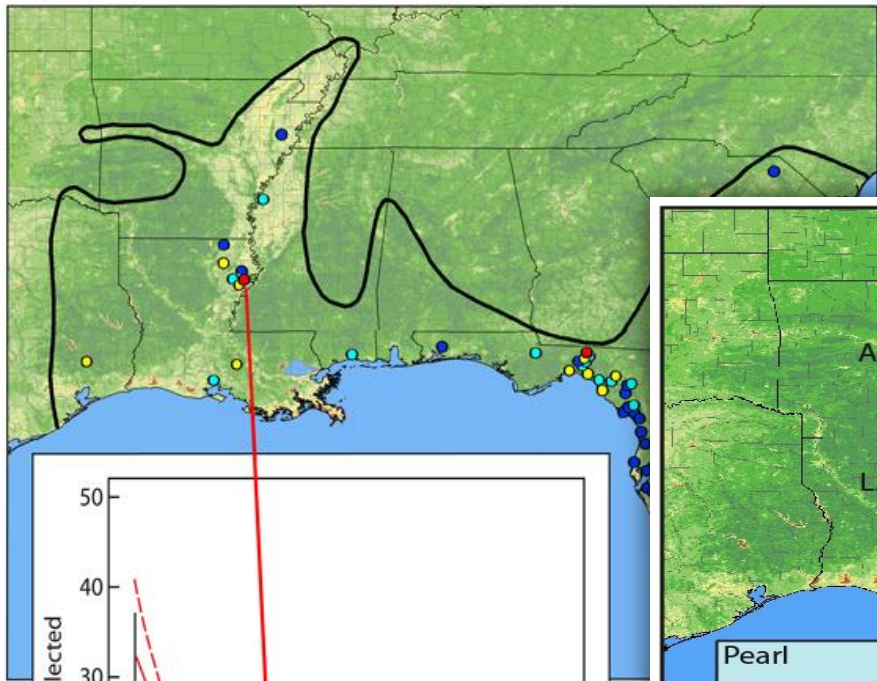
"Other factors, if added in to these studies, might suggest an even higher probability of extinction," he adds.

Jerome Jackson,  
Author, *In Search Of The  
Ivory-billed Woodpecker*

"People see what they want to see or what they believe to be out there."

"For both studies, I think there is a social/psychological factor involved — all of those sightings in the 1960s and again in 2004-2005 were not independent, and following an initial report each time, later sightings were certainly influenced by earlier ones."

# What is the probability that the ivory-billed woodpecker persists today?



# Summary

- Specimen-based modeling estimates population decline from museum records
- Contemporary surveys estimate the number of undetected species and necessary sampling effort
- For IBW, surveys nearly complete
- For IBW, 2011 persistence  $P = 10^{-3}$  to  $10^{-5}$
- **IBW is now extinct**