

Statistics, Probability, and a Failed Conservation Policy

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ABSTRACT

Many sightings of the Ivory-billed Woodpecker (*Campephilus principalis*) have been reported during the past several decades, but nobody has managed to obtain the clear photo that is regarded as the standard form of evidence for documenting birds. Despite reports of sightings by teams of ornithologists working independently in Arkansas and Florida, doubts cast on the persistence of this iconic species have impeded the establishment of a meaningful conservation program. An analysis of the expected waiting time for obtaining a photo provides insights into why the policy of insisting upon ideal evidence has failed for this species. Concepts in statistics and probability are used to analyze video footage that was obtained during encounters with birds that were identified in the field as Ivory-billed Woodpeckers. One of the videos shows a series of events that are consistent with that species and are believed to be inconsistent with every other species of the region. Another video shows a large bird in flight with the distinctive wing motion of a large woodpecker. Only two large woodpeckers occur in the region, and the flap rate is about ten standard deviations greater than the mean flap rate of the Pileated Woodpecker (*Dryocopus pileatus*). Supplemental materials for this article are available online.

ARTICLE HISTORY

Received July 2018

Accepted June 2019

KEYWORDS

Avian flap rate; Conservation policy; Ivory-billed Woodpecker; Ornithology; Probability; Standard deviation


1. Introduction

Before John Fitzpatrick and his colleagues reported a series of sightings of the Ivory-billed Woodpecker (*Campephilus principalis*) in the Big Woods of Arkansas in an article that was featured on the cover of *Science* in 2005 (Fitzpatrick et al. 2005), several decades had passed since ornithologists had reported this iconic species. Another ornithologist, Geoffrey Hill, was convinced by the reports from Arkansas and assembled his own search team, which had several sightings in the Choctawhatchee River swamp in Florida (Hill et al. 2006). The Ivory-billed Woodpecker has distinctive and prominent field marks, which are visible in the photos in Figure 1, and other characteristics that would make misidentifications unlikely, including a flight that is “graceful in the extreme,” according to the great naturalist, John James Audubon (Bent 1939). Considering it inconceivable that several experienced and well-prepared observers could have misidentified such a bird, I was also convinced by the reports from Arkansas and decided to conduct a search in the Pearl River swamp in Louisiana, where there had been recent reports. A combination of factors favored the success of my search, including the proximity of my employer’s office at the Stennis Space Center, which made it feasible to conduct the type of long-term effort that is required to have a reasonable chance of finding these elusive birds. During eight years of fieldwork, I had 10 sightings, twice heard the ‘kent’ calls of the Ivory-billed Woodpecker (which were recorded in 1935), and obtained video evidence during three of the encounters (Collins 2011, 2017a,b). I had encounters with pairs of

Ivory-billed Woodpeckers in Louisiana and Florida, and one of the videos was obtained during a visit to the area where Hill had recently had a sighting. Each of the videos contains stronger evidence for the persistence of the Ivory-billed Woodpecker than anything else that has been obtained during the past several decades.

The persistence of the Ivory-billed Woodpecker became controversial when nobody managed to obtain the clear photo that is regarded as the standard form of evidence for documenting birds. Updates on the status of this issue that appeared in *Science* (Stockstad 2007) and *Nature* (Dalton 2010) provided platforms for critics to air unsupported opinions, and discussed the questionable activities of non-scientists (one who admitted to faking a photo and another who was seeking a \$50,000 reward for a photo that apparently never materialized), but made no mention of the strongest supporting evidence. Statistics and probability are used here to argue that (1) the evidence that was excluded from the debate cannot be explained in terms of any of the ‘ordinary’ species (all species other than the Ivory-billed Woodpecker) of the region and (2) the expected waiting time for obtaining a clear photo must be several orders of magnitude greater than it would be for a more typical species of comparable rarity. For other endangered North American birds, such as the California Condor (*Gymnogyps californianus*), Whooping Crane (*Grus americana*), and Kirtland’s Warbler (*Setophaga kirtlandii*), there exist longstanding conservation programs that are based on the behaviors, habitats, and needs of the species. The

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 Supplementary materials for this article are available. Please go to www.tandfonline.com/uspp.

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Figure 1. Photos of Ivory-billed Woodpeckers that were obtained by James Tanner at one of the last known nest cavities in 1935. The field marks include two white stripes on the back, a massive white bill, and a white triangular patch that is formed by the white trailing edges of the dorsal surfaces of the wings (which are folded closed on the back). The head of the female is all black. The male has a bright red crest. These photos are in the possession of the U.S. Fish & Wildlife Service and are in the public domain (<https://www.fws.gov/ivorybill/photoalbum/>).

requirement of a particular type of evidence as a prerequisite for establishing (for the first time) a substantive conservation program for the Ivory-billed Woodpecker has proved to be a failed policy.

Nobody has managed to obtain high-quality images of the Ivory-billed Woodpecker in recent decades, but high-quality video footage is not required to resolve flight path, wing motion, flap rate, behaviors, and body proportions. All of the details discussed here are unquestionably resolved in the videos, which may be viewed in the supplementary movies of Collins (2011, 2017b). The analysis of the videos involves comparisons with the Pileated Woodpecker (*Dryocopus pileatus*), which is the only other large woodpecker that occurs north of the Rio Grande, and the Imperial Woodpecker (*Campephilus imperialis*) and Magellanic Woodpecker (*Campephilus magellanicus*), which do not occur in the same region but are closely related to the Ivory-billed Woodpecker and might, therefore, have similar behaviors.

2. A Series of Rare Events and the 2007 Video

A simple, but powerful, concept in probability is that a series of rare and independent events becomes extremely unlikely as the number of events increases. In five-card poker, for example, the probability of being dealt a full house N times in a row is approximately $\exp(-6.543N)$. For some applications, it may not be practical to determine specific values for the probabilities of the individual events, but it may be possible to conclude that a series of events is extremely unlikely if it is known that each of the events is rare in a qualitative sense. This concept may be used to understand the strength of the evidence in a video that was obtained on January 19, 2007, during a visit to Hill's study area in Florida. To formulate a testable hypothesis for the 2007 video, I define the rarity of an event in terms of the expected amount of time in the field that would be required to observe a similar event. Common events would be easy to observe during a few visits to appropriate habitat. An uncommon event might be observed only once every 20 visits on average. A large number of visits would be required to have a reasonable chance of

observing a rare event (which may never occur in the extreme case).

I propose the hypothesis that numerous events appearing in the 2007 video are rare for the ordinary species. Testing the hypothesis does not require accurate estimates of rarity, which may be nearly impossible to obtain for events that are extremely rare. It would be sufficient (and not overly difficult) to obtain qualitative estimates of rarity based on observations of the ordinary species. There are similarities between some of the events, but the argument is applicable even for a series of identical events (such as in the poker example). There is also substantial variety in the events, including different types of swooping flights, deep and rapid flaps, other behaviors, body proportions, and field marks. The argument would break down if the events are sufficiently dependent, but there does not appear to be any logical reason why any of the events would affect the probability of any of the other events. Sickness or an injury could cause a bird to engage in a series of unusual flights and other unusual behaviors, but the high-speed swooping flights and deep and rapid flaps that appear in the video indicate robust health. If the hypothesis is true, the probability would be extremely small that all of the events involve ordinary species. The objective here is to define a testable hypothesis and discuss the events in the video and why they are believed to be rare.

After the birds were detected, there was a delay in starting the camera (the tape needed to be rewound), which was turned off briefly during the encounter (to report the sighting by radio to members of Hill's search team). The times stated here are in minutes and seconds from the beginning of the recording. During an event that begins at 17:44 and appears in Movie S8 of Collins (2017b), a large woodpecker climbs upward, moves to the right and then back to the left, perches upright, delivers a blow that produces an audible double knock, and then takes off into an upward swooping flight. During this event, there are traces of red consistent with the crest of a male Ivory-billed Woodpecker (the female does not have a red crest). The sound of the double knock, which is delayed slightly due to the distance to the bird, is suggestive of a blow by a large woodpecker. Ivory-billed Woodpeckers are known to signal with double knocks (Tanner 1942, p. 62), but this behavior is not consistent with any other woodpecker of the region. Woodpeckers usually remain perched and listen for responses after drumming, but the bird in the video takes off immediately after delivering the blow. The high-speed upward swooping flight that follows the takeoff does not seem to be consistent with any other woodpecker of the region, but the Ivory-billed Woodpecker is known to have remarkable flights. While studying the double knock, I noticed that there appears to be only one thrust of the body; this observation led to an understanding of the double knocks of *Campephilus* woodpeckers and how they relate to the drumming of other woodpeckers; these behaviors may be modeled in terms of a harmonic oscillator, with a periodic forcing for drumming and an impulsive forcing for double knocks (Collins 2017a).

Two unusual behaviors preceded the double knock. When a massive woodpecker moves around in a tree, it would make sense that it would occasionally need to 'flirt' (rapidly open and close) its wings to maintain its balance. According to Tanner (1942, p. 58), flirting the wings is a common behavior of the Ivory-billed Woodpecker (one of the most massive woodpeckers

in the world). As discussed in Movie S9 of Collins (2017b), an Imperial Woodpecker (the most massive woodpecker in the world) flirts its wings in the only film that exists of that species (Lammertink et al. 2011). The bird in the video flirts its wings several times while moving horizontally. This series of behaviors does not seem to be consistent with any of the other woodpeckers of the region. As discussed in Movie S10 of Collins (2017b), Ivory-billed Woodpeckers frequently rotate their bodies from side to side while perched on their tails in the historical film that was obtained in 1935. Other woodpeckers of the region occasionally make these motions at a cavity or drumming site but do not seem to engage in this behavior while moving around. The bird in the video made these motions at two locations, neither of which was at a cavity or drumming site.

Two Ivory-billed Woodpeckers were observed during the encounter, and two birds appear simultaneously in the video in separate events that begin at 5:10. During one of the events, a bird is perched on a horizontal branch, hops behind the trunk of a tree (or perhaps into a cavity), and reappears after taking off from behind the tree 22 s later. In Movie S11 of Collins (2017b), the takeoff of the bird in the video is compared with takeoffs by the Imperial Woodpecker (Lammertink et al. 2011) and the Pileated Woodpecker. The deep and rapid flaps of the bird in the video are not consistent with the Pileated Woodpecker, but they are similar to the deep and rapid flaps of the Imperial Woodpecker and consistent with the Ivory-billed Woodpecker in terms of an account by Christy of “deep and rapid strokes” at takeoff (Christy 1943). During the other event that begins at 5:10, which is shown in Movie S13 of Collins (2017b), there is an upward swooping landing with a highly unusual long vertical ascent. As discussed in Movie S14 of Collins (2017b), the bird in the video has a black body (including the belly) and a right underwing that is mostly white. The Pileated Woodpecker and the Ivory-billed Woodpecker are the only candidate species with those field marks. The bird ascended nearly vertically without flapping for about 1 s, which would correspond to about 5 m for a ballistic flight and an even greater vertical distance for a swooping flight that ends with braking. The long vertical ascent is not consistent with the Pileated Woodpecker, but it is consistent with an account by Eckleberry of an Ivory-billed Woodpecker that “alighted with one magnificent upward swoop” (Eckleberry 1961).

As shown in Movie S15 of Collins (2017b), there is an interesting behavior during a long vertical ascent that occurs at 15:21. The view is from the side at the beginning of the ascent, but the white undersides of the wings are visible when the bird approaches the top edge of the field of view. The bird apparently rotates about its axis during the ascent. This behavior does not seem to be consistent with other woodpeckers of the region, which typically swoop upward a short distance before landing on a surface that faces the direction of approach. As illustrated in Figure 2, a long vertical ascent allows a woodpecker time to rotate about its axis and land on a surface that does not face the direction of approach. During a long vertical ascent, there is time to perform other types of maneuvers before landing. In a film of a pair of Magellanic Woodpeckers (Attenborough 1998), a flight by the female ends with a long vertical ascent that allows time for lateral movement.

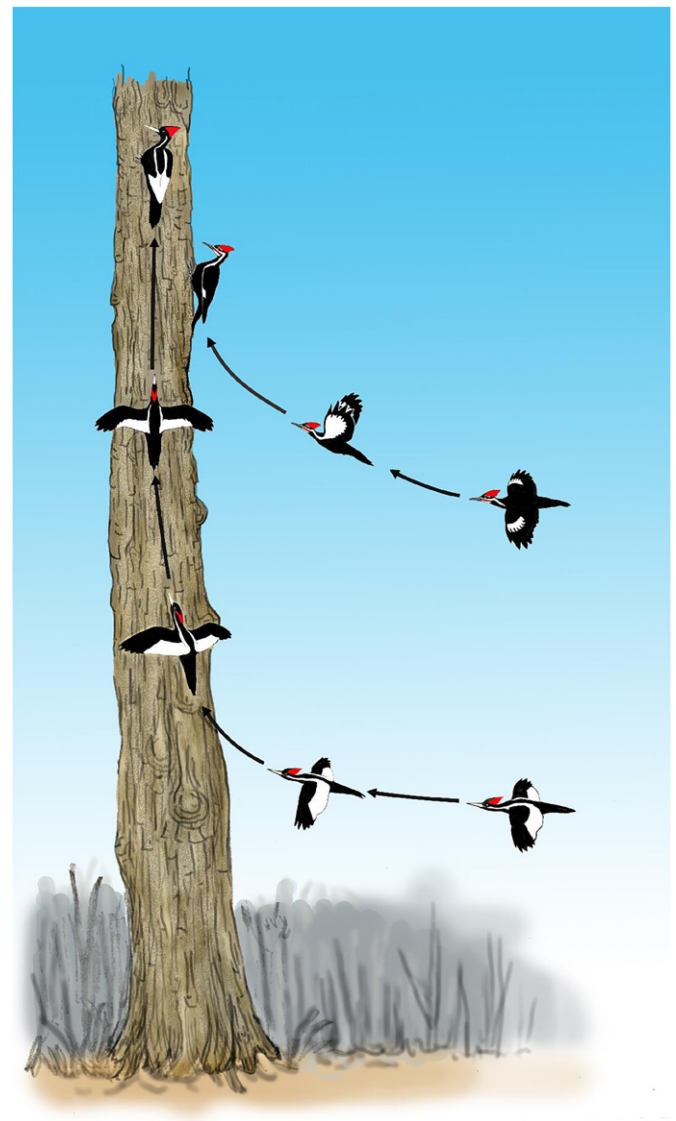


Figure 2. Illustrations of swooping landings by large woodpeckers. The Pileated Woodpecker typically swoops upward a short distance before landing on a surface that faces the direction of approach. The Ivory-billed Woodpecker has long vertical ascents that allow time for maneuvering and landing on surfaces that do not face the direction of approach.

During an event that began at 24:37, there is a downward swooping takeoff that is followed by another upward swooping landing with a long vertical ascent. As shown in Movie S17 of Collins (2017b), the downward swooping takeoff is viewed from the side. As discussed in Movie S18 of Collins (2017b), the bird briefly goes below the field of view before reappearing in a ventral view, ascends nearly vertically for a long distance, and apparently rotates about its axis. As discussed in Movie S18 of Collins (2017b), there is a frame during the ascent that reveals a dark-colored belly, light-colored underwings, a tail that projects behind the wings about the same distance as the width of the wings, and a body width that is a substantial fraction of the width of the wings. This combination of characteristics is consistent with the Ivory-billed Woodpecker but no other woodpecker of the region. When an Ivory-billed Woodpecker is perched with the wings folded closed, the white trailing edges on the dorsal surfaces of the wings form the white triangular patch that appears in the photos in Figure 1. As discussed in Movie

S19 of Collins (2017b), there are flashes of white consistent with this field mark when the bird climbs after landing.

There was a swooping takeoff at 2:02 that is similar to the swooping takeoff at 24:37, but in this case the bird leveled off into a long horizontal glide that is consistent with the following account by Audubon (Bent 1939):

The transit from one tree to another, even should the distance be as much as a hundred yards, is performed by a single sweep, and the bird appears as if merely swinging from the top of the one tree to that of the other, forming an elegantly curved line.

The bird was hidden behind vegetation along much of the flight path, but it appears at various points in Movie S20 of Collins (2017b), and there is a flash of white from the underwings in the reflection from the water in Movie S21 of Collins (2017b).

3. A Series of Sightings and the 2006 Video

During a five-day period in February 2006, I had five sightings with clear views of definitive field marks, twice heard kent calls (once coming simultaneously from two directions), and

obtained the first video (Collins 2011, 2017b). All of this activity occurred in a concentrated area along English Bayou in the Pearl River swamp. On February 16, I was drifting down the bayou when an Ivory-billed Woodpecker flushed from close range on the left bank. I saw the prominent white patches on the dorsal surfaces of the wings as clearly as indicated in the recreation of this sighting that appears in Figure 3. The rapid wingbeats seemed highly unusual for such a large bird, but they are consistent with an account of “deep and rapid strokes” at takeoff by Christy (1943). The Ivory-billed Woodpecker is one of the most massive woodpeckers in the world, and it has narrow wings that are suited for long flights at high speed. It makes sense that such a bird would require rapid wingbeats at takeoff. Late that afternoon, I returned to the area and heard three kent calls. During one of my three sightings on February 17, the bird glided low across the bayou and provided a view across the dorsal surfaces of the wings as clear as in the recreation of this sighting that appears in Figure 3. As illustrated in Figure 4, I had an encounter with two Ivory-billed Woodpeckers on February 18. While drifting down the bayou that morning, I heard a long series of kents coming from behind a fallen tree on the bank. From a branch a few meters up, an American Robin (*Turdus migratorius*) was scolding an Ivory-billed Woodpecker that was



Figure 3. Illustrations of sightings in the Pearl River swamp on February 16 (top) and 17 (bottom), 2006, in which Ivory-billed Woodpeckers are painted onto photos of the sites.



Figure 4. Illustration of an encounter with a pair of Ivory-billed Woodpeckers in the Pearl River swamp on February 18, 2006. I sat in the kayak ready to take a photo as a steady stream of kents came from behind the fallen tree. A few minutes later, kents started coming from behind me and on the opposite side of the bayou.

hidden from my view. As kents continued to come from behind the fallen tree, I quietly maneuvered the kayak up to the bank (within perhaps 5 m of the bird) without being detected. As I sat in the kayak and waited for an opportunity to obtain a photo, kents started coming from behind me on the opposite side of the bayou. After the second bird apparently saw me, there were a few harsh scolding calls from that direction, the kents from the first bird stopped, and then a series of high-pitched calls began coming from the direction of the second bird.

On February 20, my second day in the field with a video camera, I came upon an Ivory-billed Woodpecker that was briefly perched in the area where the calls came from the second bird two days earlier. Seeing the light-colored eye, which was conspicuous against the surrounding dark plumage, gave me the impression that it was staring at me. The dark eyes of the Pileated Woodpecker are located in dark bands of plumage and do not usually stand out in the field. The Ivory-billed Woodpecker has yellow eyes, but I did not detect color on that overcast morning. I was paddling the kayak up the bayou, and my initial decision was to continue upstream and then wait for a while before drifting back through the area with the video camera recording. I changed my mind when the high-pitched calls that I heard two days earlier started coming from the direction of the bird as it flew into the woods. I pulled out the video camera, turned the kayak around, started drifting back downstream, and managed to record several of the high-pitched calls. After the high-pitched calls seemed to stop, I backed the kayak into an observation position on the opposite bank. There were additional high-pitched calls that allowed me to track the movements of the bird, and the camera was aimed in the right direction when I detected motion deep in the woods about ten minutes into the video.

The 2006 video shows a large woodpecker (one of only two that occur north of the Rio Grande) with several characteristics and behaviors that are consistent with the Ivory-billed Woodpecker but do not seem to be consistent with the Pileated Woodpecker. The large woodpecker in the video was perched on a tree that was collected after it was blown down. Two forks in the tree made it possible to scale images from the video relative to a photo of the tree specimen on which a Pileated Woodpecker specimen was mounted. From the comparison that appears in Figure 5, the bird in the video appears to be larger than a Pileated Woodpecker. The bird in the video is partially hidden by vegetation in the image on the lower left of Figure 5, but it is in full view in the images at the top, when it took a short flight between limbs. Julie Zickefoose, an avian artist whose paintings of Ivory-billed Woodpeckers have appeared on the covers of an ornithology journal (*The Auk*, January 2006) and a book on this species (Jackson 2004), provided the following assessment of the 2006 video (Collins 2011):

I like the head/neck/crest and especially bill to head proportions. They do not suggest Pileated Woodpecker to me—too massive, especially the large, long bill. The rared-back pose, long but fluffy and squared-off crest, and extremely long, erect head and neck suggest Ivory-billed Woodpecker. The flapping leap the bird takes to the right, across the two trunks, is very unusual, and unlike anything I've seen a Pileated Woodpecker do. The flight appears ponderous and heavy,



Figure 5. A Pileated Woodpecker specimen is mounted on part of the perch tree. Frames from the 2006 video were scaled using forks in the tree (dashed lines). A meter stick is placed at the point where the flight between limbs occurred. The inset shows Pileated Woodpecker and Ivory-billed Woodpecker specimens that were photographed side by side at the National Museum of Natural History. The bird in the video is partially hidden by vegetation in the image on the lower left, but it is fully in view in the images at the top when it took the flight between limbs.

and the wings altogether too long and thin for a Pileated Woodpecker. The bird overall just looks very large and heavy.

Many photos of Pileated Woodpeckers are readily available online, but there do not appear to be any with characteristics that match those of the large woodpecker appearing in the image from the video that appears on the lower left in Figure 5, which shows some of the characteristics that Zickefoose mentioned. When the brightness of that image is adjusted, a feature consistent with the left dorsal stripe of an Ivory-billed Woodpecker is revealed as shown in Figure 6. When the crest was not raised in the image in Figure 7, the shape of the head and crest resemble the same features of an Ivory-billed Woodpecker specimen.

The Ivory-billed Woodpecker is one of the most massive woodpeckers in the world, and it has relatively narrow wings that are adapted for high-speed flights to distant foraging sites. This combination of characteristics is consistent with Tanner's account that the Ivory-billed Woodpecker usually flaps its wings during short flights between limbs (Tanner 1942, p. 58). The Pileated Woodpecker has a much lower mass and broader wings that are adapted for the short flights of a territorial species, and it frequently makes such flights nearly effortlessly. The large woodpecker in the video required a deep and rapid flap to cover a distance of less than 1 m during a short flight between limbs. This flight is not consistent with the Pileated Woodpecker but



Figure 6. The brightness of an image from the video (upper left) has been adjusted to reveal a feature that is consistent with the left dorsal stripe, which is lined up with the dashed line. Based on an image from the video when the bird was out of view (lower left), it is clear that there is no vegetation at the location of the dorsal stripe feature. An artistic impression appears on the right.



Figure 7. Comparison of a female Ivory-billed Woodpecker specimen (bottom), an image from the video (top left), and an artistic impression (top right). The rounded shape of the top of the head and the shape of the crest of the large woodpecker in the video appear to be consistent with the specimen.

is consistent with Tanner's account. Movie S3 of Collins (2017b) is a comparison between short flights by Pileated Woodpeckers and the short flight in the video, which Zickefoose described as "unlike anything I've seen a Pileated Woodpecker do." Movie S3 of Collins (2011) shows a takeoff into a flight that Zickefoose described as "ponderous and heavy." Movie S1 of Collins (2011)



Figure 8. Photos that show the difference in the color of the feet of the large woodpeckers. The Ivory-billed Woodpecker photo (top) is in the possession of the U.S. Fish & Wildlife Service and is in the public domain (<https://www.fws.gov/ivorybill/photoalbum/>).

shows unusual motions and a "rared-back pose" that is consistent with the Ivory-billed Woodpecker. Near the end of that movie, there are flashes of white that appear to be the left foot; as shown in Figure 8, the Ivory-billed Woodpecker has light-colored feet, but the Pileated Woodpecker has dark-colored feet.

As illustrated by the examples in Movie S4 of Collins (2017b), I frequently observed Pileated Woodpeckers that showed no concern for my presence at ranges of a few tens of meters. In 1892, Arthur T. Wayne observed Ivory-billed Woodpeckers that were too wild to be "approached nearer than 300 or 400 yards" (Tanner 1942, p. 63). While obtaining the 2006 video, I was sitting in a kayak at a distance of 128 m from the perch tree (the distance was determined later using a laser rangefinder), which is well beyond the range at which a Pileated Woodpecker would become alarmed but well within the range at which an Ivory-billed Woodpecker would become alarmed according to Wayne's account. The large woodpecker in the video showed signs of being alarmed, including raising its crest and hiding behind a branch. The encounter began about an hour after sunrise, when a non-alarmed Pileated Woodpecker would be actively foraging, calling, and drumming, but none of those behaviors appear in the video. There is no calling or drumming

by a Pileated Woodpecker in the audio track of the video, which runs for 37 min.

4. Flap Rate Statistics and the 2008 Video

As illustrated in Figure 9, I observed an Ivory-billed Woodpecker in flight in the Pearl River swamp on March 29, 2008, from about 23 m up in a cypress tree that was used as an observation platform. The idea was to keep watch over a much larger area than is visible from the ground, but it flew nearly directly below the observation tree, which is located a short distance up the bayou from the location where the 2006 video was obtained. The 2008 video, which appears in Movie S5 of Collins (2017b), documents that I had an ideal vantage point from close range and nearly directly above for observing the definitive dorsal field marks. I saw the two white stripes on the back that appear in the photos in Figure 1, the black leading edges of the dorsal surfaces of the wings, and the white trailing edges of the dorsal surfaces of the wings. Based on the observed field marks, there was no question that it was an Ivory-billed Woodpecker. After returning from the swamp and inspecting the video, however, I was faced with an apparent paradox.



Figure 9. Illustration of the flyunder in the Pearl River swamp on March 29, 2008, as viewed from my observation position 23 m up in a cypress tree. When the wings are folded closed in flight, the dorsal stripes and the white triangular patch have the same appearance as they do for the perched birds in Figure 1. As discussed in Movie S6 of Collins (2017b), the wings of an Ivory-billed Woodpecker in a historical photo and of the bird in the 2008 video have the swept-back appearance of the wings in the middle image.

It was widely believed that the Ivory-billed Woodpecker has ‘duck-like’ flaps in which the wings remain extended throughout the entire flap cycle, but there is no question that the bird in the video folds its wings closed in the middle of each upstroke as discussed in Movie S6 of Collins (2017b). It turns out that there had been a misconception about the wing motion of the Ivory-billed Woodpecker. Historical accounts of a duck-like flight had been misinterpreted to pertain not only to the flight itself but also to the wing motion. Before the 2008 video was obtained, Zickefoose produced a painting of the large woodpeckers in flight that shows a series of images of each species as the wings move through the flap cycle. The images of the Pileated Woodpecker correctly show the wings folding closed in the middle of each upstroke, which matches the wing motion of the Pileated Woodpecker in Movie S7 of Collins (2017b) and the bird in the 2008 video. The images of the Ivory-billed Woodpecker show the wings remaining extended (never folding closed) throughout the flap cycle, which was representative of conventional wisdom at the time. The apparent paradox was resolved when Dalcio Dacol noticed that a historical photo of an Ivory-billed Woodpecker in flight was taken at an instant when the wings were nearly folded closed (Collins 2011). In hindsight, it should have been obvious that it would be highly unusual for the Ivory-billed Woodpecker to have a radically different wing motion than other members of the woodpecker family. The Ivory-billed Woodpecker and the Pileated Woodpecker are the only large birds north of the Rio Grande that fold the wings closed in the middle of the upstroke.

Bret Tobalske, an expert on the flight mechanics of woodpeckers, digitally analyzed the wing motion using an approach that he had previously developed and applied to other woodpeckers (Tobalske 1996) and provided the following assessment of the 2008 video (Collins 2011):

I am confident it is a large woodpecker. I base this conclusion on the small upstroke/downstroke span ratio and the pauses in mid-upstroke during which the bird holds its wings flexed in a ‘bound’ posture. This style of flight is consistent with Pileated Woodpecker, but I do not think that it rules out the bird being an Ivory-billed Woodpecker. Casual observers of a live bird in the field (e.g., Tanner) would likely miss the brief pauses even if they were present. There are two fields in which there is considerable white (or light gray) visible on the upper surface of the wings. Those patches of light-colored feathers would seem to be consistent with an Ivory-billed Woodpecker.

The bird in the video is a large woodpecker according to Tobalske; it would be easy for anyone to study this footage and confirm that the wings are folded closed during the middle of each upstroke. The Pileated Woodpecker and the Ivory-billed Woodpecker are the only large woodpeckers in the region. The bird in the video was in level cruising flight; for this type of avian flight, the flap rate is amenable to statistical analysis (Pennycuik 1990, 1996). Tobalske obtained the flap rate statistics of the Pileated Woodpecker (5.2 Hz mean and 0.4 Hz standard deviation) from well-sampled data that were obtained in Montana (Tobalske 1996); his results are consistent with data that were obtained during my fieldwork in Louisiana, and it would be easy for anyone who wishes to confirm them to obtain their own data

for this common and widespread species. It is straightforward to determine the flap rate of a bird in a video by counting the number of frames per flap cycle, which extends from the point when the wings begin to open until the point when the wings close; brief intervals when the wings are paused in the closed position are excluded (Tobalske 1996). The flap rate of the bird in the video is approximately 10 Hz (Collins 2011), which is about ten standard deviations greater than the mean flap rate of the Pileated Woodpecker (Tobalske 1996).

As discussed in Movie S6 of Collins (2017b), the swept-back appearance of the wings, narrow shape of the wings, prominent white patches on the dorsal surfaces of the wings, and high flight speed of the bird in the video are consistent with the Ivory-billed Woodpecker but not the Pileated Woodpecker. As shown in Figure 9, the white trailing edges on the wings form the white triangular patch that appears in the photos in Figure 1 when the wings are folded closed; a white patch consistent with this feature appears in frames 395 and 396 of Movie S5 of Collins (2017b); the reflection of the bird from the water can be used to confirm that the wings are folded closed in that part of the video. The flight speed was determined using images from the video to position marker stakes at reference points (Collins 2011). The bird flew approximately 66.5 m in 4.38 s, which corresponds to 15.2 m/s. The flight speed of the bird in the video is substantially greater than the flight speed range of 7.5 to 11.6 m/s of the Pileated Woodpecker (Tobalske 1996). Since the bird and its reflection appear in the video, it was possible to determine positions along the flight path and estimate the wingspan by placing a reference object of known size at the site and taking reference photos (Collins 2011). As shown in Figure S2 of Collins (2011), the wingspan appears to be greater than 61 cm, and there is no question that the wings are folded closed during the middle of each upstroke. Among the birds of the region that have a wingspan greater than 61 cm, only the Pileated Woodpecker and the Ivory-billed Woodpecker have that distinctive wing motion. All of the other large birds of the region keep their wings extended throughout the entire flap cycle during cruising flight. Among the birds of the region that have a wingspan less than 61 cm, the Belted Kingfisher (*Megasceryle alcyon*) is the largest that folds its wings closed (or nearly closed) during the flap cycle, but it has the bold pattern of black and white field marks on the dorsal surfaces of the wings that is shown in Figure 3 of Collins (2017a). There is no trace of those field marks in the video, which does show prominent white patches that are consistent with the Ivory-billed Woodpecker.

5. Expected Waiting Time for Obtaining a Clear Photo

The Ivory-billed Woodpecker is an extremely rare and wary bird that resides deep within vast swamp forests and has repeatedly been feared extinct only to be rediscovered. The first rediscovery was in 1924, when Arthur Allen found a pair in Florida (Allen and Kellogg 1937), but a taxidermist shot those birds the next day. The next rediscovery, in the Singer Tract in Louisiana in the 1930s (Allen and Kellogg 1937), was dismissed until a freshly killed specimen was produced, but those birds disappeared as

the area was being logged. There were several waves of interest in the Ivory-billed Woodpecker during the next several decades, when there were sporadic reports of sightings throughout its range (Eastman 1958; Dennis 1967; Stoddard 1969; Agey and Heinzmann 1971; Jackson 2004). The wave of interest that followed a report of a pair of Ivory-billed Woodpeckers in the Pearl River swamp (Martel 2000) ultimately led to the most recent rediscovery (Fitzpatrick et al. 2005). The Ivory-billed Woodpecker would be a good candidate for the most elusive bird in the world on the basis of the following set of facts (which is unique to this species): (1) it has a long history of rediscoveries; (2) nobody has ever managed to obtain a clear photo without knowing the location of an active nest; (3) many sightings have been reported but nobody has managed to obtain a clear photo during the past several decades; (4) ornithologists were unable to obtain a clear photo during intensive multi-year searches at sites where they were convinced these birds were present; and (5) it is a species of great interest that resides in a region that is easily accessible to a large number of bird watchers. Clear photos were obtained at the nest in the Singer Tract, but photos obtained away from the nest during that study are of poor quality.

The elusiveness of the Ivory-billed Woodpecker stems from a combination of factors related to habitat and behavior. An analysis based on these factors suggests that the expected waiting time for obtaining ideal evidence must be several orders of magnitude greater than it would be for a ‘baseline’ species of comparable rarity that has more typical behaviors and resides in a more typical baseline habitat (Collins 2017b). The analysis is based on the model,

$$E = \frac{A}{B} \sigma, \quad (1)$$

where E is the expected waiting time for obtaining a clear photo, A is the area of the habitat that must be searched, B is the net area that is searched per unit time along all search paths, and the dimensionless coefficient σ depends on habitat and behavior. Since the model would be expected to break down when the activities of the searchers are sufficient to influence the behavior of the bird, it may not be an effective strategy to excessively increase B in an attempt to reduce E . It would be difficult to explicitly determine σ , but this may be avoided by considering the dependence of this quantity on habitat and behavior relative to the baseline species. A single individual of the baseline species is present in the baseline habitat, and the expected waiting time for obtaining a photo is

$$E_0 = \frac{A_0}{B_0} \sigma_0, \quad (2)$$

$$\frac{E}{E_0} = \frac{A}{A_0} \frac{B_0}{B} \frac{\sigma}{\sigma_0}, \quad (3)$$

where A_0 , B_0 , and σ_0 are the corresponding quantities for the baseline case.

The Ivory-billed Woodpecker resides in swamp forests that cover areas on the order of 100 km². The drone image in Figure 10 gives an impression of the vastness of the Pearl River swamp, even though it shows only a small fraction of the area. Visibility is limited to small areas in the interior of a southern



Figure 10. An image of the Pearl River swamp that was obtained from a drone at an altitude of 120 m near the sites where video evidence was obtained in 2006 and 2008. This image shows only a small fraction of the Pearl River swamp, but it gives an impression of the vastness of the area and shows thick vegetation that limits visibility from the ground.

swamp forest, even when the leaves are down during the winter. This factor affects B by reducing the average amount of habitat that is visible at any given time while moving along a search path. Thick vegetation in the interior of a forest also has an effect on σ by providing many hiding spots for a wary bird and making photography more difficult. The lack of visibility on the ground was the motivation for the approach of observing from tall trees that was used to obtain the 2008 video. The vastness and lack of visibility in a southern swamp forest make A relatively large and B relatively small, but these factors alone are not sufficient to explain the elusiveness of the Ivory-billed Woodpecker. During my fieldwork in the Pearl River swamp, for example, I observed a White-tailed Kite (*Elanus leucurus*), which is a rare bird at that site (possibly even more so at that time than the Ivory-billed Woodpecker). About a year later, there was another sighting of that species (possibly the same bird), which has behaviors that make it relatively easy to observe.

In declining to consider an analysis of my video footage for publication, the editor of a leading ornithology journal wrote, “People get great photos of extremely rare birds all the time.” It is true that clear photos of rare birds are frequently obtained, but this is due to the heavy coverage of many (but not all) habitat types by a large community of bird watchers. Most bird watchers never visit the interiors of southern swamp forests, which have relatively low species diversity to attract them (Hill 2007) and numerous deterrents to keep them away. Alligators, wild boars, and venomous snakes are abundant, and there is a danger of heat stroke during the summer and hypothermia during the winter. Strong currents, rapidly rising water, and heavy hunting activity (an especially strong deterrent to many

bird watchers) also make southern swamp forests dangerous. During eight years of fieldwork, I had many experiences with those deterrents, occasionally saw bird watchers along a paved road that provides access to a small percentage of the habitat, but never saw bird watchers in remote areas in the interior of the Pearl River swamp. Hill did not notice any sign of bird watchers during his first year of fieldwork in the Choctawhatchee River swamp, but he did notice discrepancies in the *Florida Breeding Bird Atlas* that suggest that the area was not regularly visited by bird watchers (Hill 2007). Bird watchers who are not deterred from visiting southern swamp forests are faced with the difficulty of moving along a search path and covering all parts of the habitat; there are flooded areas and networks of bayous that impede access on the ground and areas with thick vegetation and the aftermath of hurricanes through which it is difficult to approach a wary bird without being detected. The difficulty of searching in southern swamp forests and the relatively low coverage of such habitats by bird watchers both contribute to making B relatively small.

A lack of conspicuous behaviors can have a profound effect on the elusiveness of a bird. The Blue Jay (*Cyanocitta cristata*) is usually one of the more conspicuous birds of North America. Bachman’s Sparrow (*Peucaea aestivalis*) is known for its lack of conspicuous behaviors during the winter. If these species were present in an acre of flatwoods pine habitat in Florida, an experienced bird watcher would probably detect the jay almost immediately but might fail to notice the sparrow during several visits to the habitat. On the basis of their observations in the Singer Tract, Allen and Kellogg (1937) provided the following accounts

indicating that the Ivory-billed Woodpecker lacks conspicuous behaviors:

We had hunted for three days for this particular pair of birds without ever hearing them, even though we were frequently within three hundred yards of the nest, which we finally found because we happened to be within hearing distance when the birds changed places on the nest.

They are not noisy except when disturbed.

Their voice does not carry nearly as far as that of the Pileated Woodpecker.

In the big trees which they normally frequent they are easily overlooked.

We camped for five days within three hundred feet of one nest and, except when the birds were about to change places on the nest or were disturbed, seldom heard them.

Ivory-billed Woodpeckers that were studied near the last known nest sites became acclimated to the presence of humans (Allen and Kellogg 1937; Tanner 1942), but the behavior of those birds is not relevant to the expected waiting time for obtaining a photo when there does not exist a known nest site. The Ivory-billed Woodpecker is an exceptionally wary species according to John James Audubon and Arthur T. Wayne (Tanner 1942, p. 63), and their accounts from the 19th Century are consistent with numerous reports during the past several decades. A bird that lacks conspicuous behaviors (such as soaring above, using a prominent perch, or making frequent vocalizations that can be heard from a distance) may not be detected until there is a close encounter, and there may be many near misses along the search path (e.g., see the first comment above by Allen and Kellogg). If the bird is also wary, it may move away from the search path before it can be detected, and it will rapidly seek cover when flushed.

It is known from historical accounts that Ivory-billed Woodpeckers fly long distances to forage (Allen and Kellogg 1937; Tanner 1942), which means that most sightings are likely to be far from a nest. By the 1930s, ornithologists had recognized that this non-territorial behavior accounts for sporadic sightings of Ivory-billed Woodpeckers that could not be relocated (Bent 1939). When a non-territorial and wary bird is flushed at a location far from a nest, an opportunity to obtain a photo might last for only a few seconds. If the camera is not ready or the view is not favorable at that moment, it might take years of fieldwork before another opportunity arises. In addition to regular foraging flights, Ivory-billed Woodpeckers are believed to make long-term moves as the abundance of food varies with ecological cycles. For example, Richard Pough noted that a drought created ideal foraging conditions for Ivory-billed Woodpeckers in the Singer Tract in the early 1930s and that those birds began to disappear from the area as the food sources waned before logging commenced (Pough 1944). Due to this nomadic behavior and the ephemeral nature of foraging habitats, Ivory-billed Woodpeckers could be absent from sites that seem favorable but present at sites that have been overlooked.

To apply the model, it is necessary to specify a baseline case. The baseline habitat would be small enough to be thoroughly

searched in one day; visibility would be good out to long distances in all directions; it would be easy to follow a search path; and there would be regular visits by a substantial number of bird watchers. The baseline species would have conspicuous behaviors that make it easy to find and photograph; be sufficiently non-wary to remain in the area after a sighting and to allow a close enough approach to obtain a clear photo; have a territory that is small enough so that it would be easy to relocate a bird after an initial sighting; and reside in the same areas for many generations. Since Ivory-billed Woodpeckers typically reside in habitats that cover on the order of 100 km², it would be challenging to thoroughly search the baseline habitat in one day even for the case $A/A_0 = 100$, which means that A_0 is on the order of 1 km² and

$$\frac{E}{E_0} = 10^2 \frac{B_0}{B} \frac{\sigma}{\sigma_0}. \quad (4)$$

Visibility typically starts becoming limited beyond ranges of a few tens of meters in a southern swamp forest, even when the leaves are down in the winter. A large bird with prominent field marks, such as an Ivory-billed Woodpecker, could be identified with binoculars out to hundreds of meters in the baseline habitat. Since the ratio of distances is about 10, the ratio of areas is about 100, and B_0/B would be approximately 100 if bird watchers were to cover the same net distance per unit time along all search paths in both habitats. If the coverage by bird watchers is much greater in the baseline habitat, then E/E_0 is much greater than $10^4 \sigma/\sigma_0$. The ratio of the proportionality factors depends on the relative degree to which the species are wary, conspicuous, territorial, and nomadic and the difficulty of moving along search paths in the habitats. The above discussions of these factors suggest that σ/σ_0 is large and that the expected waiting time for obtaining a clear photo of an Ivory-billed Woodpecker is several orders of magnitude greater than it would be for a more typical species of comparable rarity. This estimate is consistent with the history of the Ivory-billed Woodpecker during the past hundred years, and it suggests that it is impractical to expect clear photos for documenting this species.

6. A Persistent Pattern of Folly and Politics

Based on the expected waiting time analysis, it is not surprising that the requirement for ideal evidence has proved to be a failed policy for the Ivory-billed Woodpecker. A persistent pattern of folly and politics has allowed this policy to remain in place for several decades despite indications that this species is an exceptional case that calls for a different approach. This aspect of the history of the Ivory-billed Woodpecker is disturbing, but it needs to be told in the interest of the conservation of an iconic species. The story is joined here after James Tanner concluded that approximately 22 Ivory-billed Woodpeckers remained in 1939 on the basis of eight months of searching and gathering information throughout the range of this bird (Tanner 1942). Hill stated a reluctance to criticize Tanner, which he compared to “criticizing a patron saint,” but he described Tanner’s attempt to estimate the population of the Ivory-billed Woodpecker as “one of the greatest follies in the history of U.S. bird conservation” (Hill 2007).

When John Dennis reported a sighting and obtained a recording of apparent kent calls in Texas in the 1960s (Dennis 1967), he should have been taken seriously on the basis of having previously discovered a remnant population of Ivory-billed Woodpeckers in Cuba (Dennis 1948); but Tanner said, “Dennis badly wants to find ivorybills; when he says he has seen them he believes he has seen them—but he hasn’t” (Moser 1972). At the time, Tanner was “generally recognized as the country’s leading authority on the ivorybill” (Moser 1972). It seems unusual that anyone could be regarded as an expert on any species merely on the basis of having studied a small number of individuals at one location, but Tanner’s views are still widely regarded as authoritative. Dennis reported observing an Ivory-billed Woodpecker flush from the ground, but Tanner claimed that this would be “very unusual for an ivorybill, very unusual” (Nevin 1974). After listening to Dennis’ recording of apparent kent calls, Tanner asked, “What was the bird doing in the same habitat with a Pine Warbler?” (Tanner 1974), which can be heard singing in the recording. It is easy to see that these criticisms are flawed from Plate 11 of Allen and Kellogg (1937); the photo shows a male Ivory-billed Woodpecker perched on a tree in a pine forest, which is ideal habitat for the Pine Warbler (*Setophaga pinus*); the caption states that a female Ivory-billed Woodpecker was on the ground at the time. That photo appears in the most significant article on the Ivory-billed Woodpecker that was published during the 20th Century, and the lead author was Tanner’s thesis advisor. It is surprising that Tanner failed to notice the connection between that photo and criticisms with which he managed to discredit Dennis. Those mistakes were apparently not discovered until decades later, but there was an attempt to put forth a challenge to some of Tanner’s other assertions decades earlier.

During the winter of 1943–44, Richard Pough spent several weeks surveying the Singer Tract and observing the last known Ivory-billed Woodpecker in the area. Pough was “the foremost land preservationist of his time and a versatile innovator in bird conservation” (Graham 2004). This major figure in American conservation prepared a report that is rich with insights into the Ivory-billed Woodpecker and its habitat (Pough 1944). He discussed a drought in the Mississippi Delta in the 1920s that caused a die-off that affected mostly mature trees; mentioned that this event would have made the conditions favorable for Ivory-billed Woodpeckers in the early 1930s; and noted that the timing was consistent with the fact that this species began disappearing from the Singer Tract before logging commenced in the late 1930s. Pough brought into question Tanner’s claim that the Ivory-billed Woodpecker requires virgin forests, which has had a negative impact on conservation in two ways: (1) it has fostered the mindset that there is no hope for saving this species from extinction since very little virgin forest remains within its range; and (2) it has been used to discredit reports of sightings in areas that lack virgin forest. Pough pointed out that Tanner’s report does not begin to “explain the reasons for the drastic decline in this species” and still left “a lot of questions concerning the ivorybill unsolved,” but his report was apparently never published. It seems unusual that such a unique report on such an important topic in conservation by such an eminent conservationist apparently exists only in draft form, but this could have been

due to a conflict of interest; it was submitted to the National Audubon Society two years after that organization published Tanner’s report.

Another unique report on this topic existed only in draft form during a period when its publication might have made a difference in the debate on the persistence of the Ivory-billed Woodpecker. Observations, data, and analysis that are relevant to a topic of interest should be made available to the science community in a timely manner, but the publication of a comprehensive report of my findings was delayed for a decade for reasons that had nothing to do with science. After they were finally published (Collins 2017b), John Fitzpatrick sent me a note of congratulations for “perseverance against long odds and irrational opposition.” After receiving undeserved criticism for leading the search in Arkansas and having the courage to publish the results, Fitzpatrick pointed out that nobody else would have dared to do it (Stockstad 2007). While trying to get my work published, I realized that such courage is rare when it comes to the Ivory-billed Woodpecker. I made more than 40 submissions before finding an editor who was willing to disregard politics and do the right thing as Fitzpatrick had done. As discussed in Appendix S1 (supplementary materials), a by-product of all those submissions is a collection of comments by anonymous reviewers that helps to reveal the depth of the folly and politics that have impeded the establishment of a meaningful conservation program for the Ivory-billed Woodpecker.

7. Discussion

With the fate of an iconic species at stake, it would be worthwhile for scientists with an interest in conservation to revisit this issue and consider evidence that was excluded from the debate that took place in *Science* and *Nature*. If the events in the 2007 video are rare for the ordinary species (a hypothesis that would be easy to test), the probability is extremely small that all of the events involve ordinary species, but all of them are consistent with the Ivory-billed Woodpecker. The woodpecker in the 2006 video appears to be larger than a Pileated Woodpecker, and it has several characteristics that are not consistent with that species but are consistent with the Ivory-billed Woodpecker. An expert on the flight mechanics of woodpeckers concluded that the bird in the 2008 video is a large woodpecker on the basis of a flap style in which the wings are folded closed during the middle of each upstroke. Among the large birds that occur north of the Rio Grande, the two large woodpeckers are the only species with that distinctive wing motion, which is unquestionably resolved in the video. Only two large woodpeckers occur in the region, but the flap rate of the bird in the video is about ten standard deviations greater than the mean flap rate of the Pileated Woodpecker. Ivory-billed Woodpecker is the only remaining possibility, and the bird in the video has several characteristics consistent with that species but not the Pileated Woodpecker.

On the basis of factors that affect the expected waiting time for obtaining a photo and the difficulty of detections, it is not surprising that (1) the Ivory-billed Woodpecker has been feared extinct only to be rediscovered several times since the 1920s, (2) there have been many reports of sightings that are not supported by clear photos during the past several decades, and

(3) the recent multi-year searches led by ornithologists failed to produce ideal evidence. There is a need to adopt feasible approaches for documenting the Ivory-billed Woodpecker, which has unusual flight characteristics that can be used along with other behaviors, partial field marks, and body proportions for documentation in low-quality video footage. Hill and his colleagues explored the possibility of determining if these birds are present using foraging sign, cavity size, and audio recordings (Hill et al. 2006). Drones can be used to survey vast and remote habitats and may also be useful for directly searching for Ivory-billed Woodpeckers (Collins 2018). The habitats of the Ivory-billed Woodpecker have been recovering during the past several decades. Continuing to protect such areas could improve the chances of saving the Ivory-billed Woodpecker from extinction while also benefitting other species. Due to the ephemeral nature of favorable feeding areas, it would be a mistake to afford temporary protection to an isolated area, as was done in the Chipola River swamp in Florida after a series of sightings in the 1950s (Eastman 1958). There is a need for long-term protection of habitat throughout the range of the Ivory-billed Woodpecker.

Estimating the population of an endangered species is an important aspect of conservation, but this may not be practical for the Ivory-billed Woodpecker. Various approaches for estimating avian populations have been used (Verner 1985; Thomas 1996; Bibby et al. 2000; Taylor and Pollard 2008), but none of them is reliable for a species that typically requires several months (and perhaps years) of fieldwork per sighting. The Ivory-billed Woodpecker was thought to be extinct for the first time around 1920. At the time, the population had been reduced to a level such that, when combined with factors related to behavior and habitat, this bird had become barely detectable. There is no reason to conclude that the population was greater in 1920 than it was when there were reports of these birds in Arkansas, Florida, and Louisiana between 2004 and 2008. Considering that the Ivory-billed Woodpecker managed to survive in barely detectable numbers for nearly a century, there is reason for hope that it might continue to persist for decades, especially if southern swamp forests are allowed to continue recovering from logging.

Although it would be nearly impossible to obtain a reliable estimate of the present population of the Ivory-billed Woodpecker, it is possible to reason out an order-of-magnitude estimate for the maximum population that has occurred since 1920. If the population had ever approached 1000, it would seem that active nests would have been discovered at multiple sites during the past several decades. If the population had never exceeded 10 since 1920, the Ivory-billed Woodpecker would almost certainly have gone extinct decades ago. When a population remains that low for a long period of time, extinction becomes inevitable. There is no margin for surviving bad luck, such as an imbalance in the ratio of males to females or losses due to predators, accidents, disease, and nest failures. It would appear that 100 is the only plausible order-of-magnitude estimate for the maximum population since 1920. During intensive multi-year searches at sites where ornithologists were convinced that Ivory-billed Woodpeckers were present, there were only a handful of sightings of this elusive bird, which has a large range that contains many areas with suitable habitats. If the current

population is on the order of 100, that number would not be inconsistent with the rate of sightings of such an elusive bird that has such a large range. Since southern swamp forests have been recovering from logging for several decades, there is reason to hope that the maximum population occurred recently.

Supplementary Materials

Appendix S1 discusses some of the 40+ submissions of the data and analysis between 2006 and 2016. The comments of anonymous reviewers help to reveal the depth of the folly and politics that have impeded the establishment of a substantive conservation program for the Ivory-billed Woodpecker.

Acknowledgments

The author is a scientist at the Naval Research Laboratory, but the work was privately funded. Michael DiGiorgio prepared the illustrations that appear in the figures.

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Appendix S1: Comments by Anonymous Reviewers

A recurring theme in the reviews was Carl Sagan's quote, "extraordinary claims require extraordinary evidence," but the Ivory-billed Woodpecker is not a mythical creature, such as the Unicorn or Bigfoot. This species is known to science, and it is easy to understand why it has a long history of rediscoveries and elusiveness on the basis of its habitat and behaviors. There is no reason to require extraordinary evidence to demonstrate the persistence of the Ivory-billed Woodpecker. All that should be required is evidence that shows characteristics that are consistent with that species but no other species and for those characteristics to be sufficient in number to rule out the plausibility of any alternative explanation. The videos provide such evidence, and it is extraordinary evidence in the sense that it is the strongest to be obtained in several decades and it reveals fascinating flights and other behaviors of the Ivory-billed Woodpecker that do not appear in the 1935 film.

Some reviewers claimed that attempts to glean information from the historical record of sightings (Roberts et al. 2009; Elphick et al. 2009; Gotelli et al. 2011; Solow et al. 2011) have produced a convincing case that the Ivory-billed Woodpecker is extinct. It might be possible to obtain a reasonable estimate of the extinction date of a species from a data base of sightings that is adequately sampled throughout the range of the species, but the record of sightings of the Ivory-billed Woodpecker is extremely sparse both spatially and temporally, and the intensity of efforts to find these birds has varied substantially with the comings and goings of searchers such as Arthur Allen, John Dennis, Whitney Eastman, John Fitzpatrick, and Geoffrey Hill. It seems unlikely that reliable information can be obtained from such a data set, but Gotelli et al. (2011) claimed that these studies "point to the inescapable conclusion that the Ivory-billed Woodpecker is now extinct."

The analysis of the 2008 video is based on using flap rate to rule out the Pileated Woodpecker. It is not based on any assumptions about the flap rate of the Ivory-billed Woodpecker, but some reviewers suggested that the high flap rate of the bird in the video is not consistent with the Ivory-billed Woodpecker. They claimed that flap rate decreases as size increases and that the Ivory-billed Woodpecker should therefore have a lower flap rate than the Pileated Woodpecker, but it was established decades ago that flap rate depends on multiple parameters. Pennycuik (1990, 1996) applied a large data set involving a wide range of species to develop an empirical flap rate model that is based on three parameters. His model predicts that flap rate tends to increase as body mass increases, which is the opposite of the dependence claimed by reviewers. The other parameters in the model are the wingspan and the surface area of the wings. There is a relatively small difference between the wingspans of the two large woodpeckers, but the Ivory-billed Woodpecker has narrower wings, which favors a high flap rate in the model. The prediction of the model is consistent with Tanner's account that the Ivory-billed Woodpecker has a high flap rate.

For a submission to *BMC Ecology* in 2011, one of the reviewers claimed, "Tanner's statements are qualitative, and we have no way of knowing what he meant." Tanner would have had no reason to state that the Ivory-billed Woodpecker flies with "rapid wing-beats" unless it meant something; and the comment would make sense only if it were a tacit comparison with the flap rate of the Pileated Woodpecker, the only species of the region that is even remotely similar to the Ivory-billed Woodpecker. Since all of Tanner's accounts of flights are based

on observations in the field (no flights appear in the 1935 film), the Ivory-billed Woodpecker would need to have a substantially higher flap rate than the Pileated Woodpecker in order for Tanner to have been in a position to make a definitive statement about this issue. The flap rate of the bird in the 2008 video is about double the flap rate of the Pileated Woodpecker, and everything is consistent between the video, Tanner's account, and the model. A film that was published less than a year after the submission to *BMC Ecology* reveals that the even larger Imperial Woodpecker also has rapid wingbeats (Lammertink et al. 2011).

The flap rate of the bird in the 2008 video is about ten standard deviations greater than the mean flap rate of the Pileated Woodpecker. Despite having some training and experience in statistics, I sought the opinion of an expert with extensive experience in applications of statistics regarding what may be concluded from ten standard deviations for the types of distributions that occur in nature. According to David Banks of Duke University, ten standard deviations is sufficient to conclude with "statistical certainty" that the bird in the 2008 video is not a Pileated Woodpecker. One of the reviewers of the submission to *BMC Ecology* made the comments: "I reject the validity of the quote from David Banks. He is not an ornithologist. Banks clearly thinks that the Pileated Woodpecker only has a single wingbeat frequency." Banks was aware that the flap rate of the Pileated Woodpecker is a statistical quantity that varies within a distribution that has a mean and standard deviation.

Reviewers also questioned the 15.2 m/s flight speed of the bird in the video, which is substantially above the range of 7.5 to 11.6 m/s that Tobalske (1996) obtained for the Pileated Woodpecker. There were claims that the high flight speed could have been affected by a tail wind, but the video shows delicate strands of Spanish moss hanging motionless on a morning that was still (as can be verified from weather archives). One of the reviewers of the submission to *BMC Ecology* made the following comments:

Estimates of flight speeds from wild birds are highly uncertain. It is not valid to use 11.6 m/s measured by Tobalske as the maximum flight speed. In fact there are a lot of absurd or bogus estimates of flight speeds of all kinds of birds in the literature. Likely this number was limited in some way by Tobalske's measurement technique, and that he was being conservative—this was the maximum speed he measured, rather than the actual maximum speed. I would guess Pileated reaches at least 18 or 20 m/s, as this is a speed reached by birds smaller than Pileated, such as large passerines or doves or parrots, when they are tested in a wind tunnel. The only safe numbers to use for flight speed are those obtained from a wind tunnel study, or perhaps with radar. To suggest that the pileated has an actual maximum speed of 11 m/s is ludicrous, it is to suggest that it cannot fly as fast as many medium-sized passerines, or even a hummingbird!

The reviewer implied that larger birds have greater flight speeds than smaller birds, but there are several examples of the opposite dependence (by a large margin in some cases) in the data set obtained by Pennycuik (1990). The reviewer claims that estimates of flight speeds obtained in the field are "absurd or bogus," but it is straightforward to obtain reliable estimates of flight speed using landmarks (Tobalske 1996). The most reliable

predictor of flap rate that has been developed to date is based on the physics of vortex shedding (Taylor et al. 2003; Nudds et al. 2004); according to the model, there is a linear relationship between flap rate and flight speed for a bird in cruising flight. An implication of the model is that, if either the flap rate or the flight speed has a relatively narrow distribution, then the other quantity should also have a relatively narrow distribution; both of these quantities have a relatively narrow distribution for the data obtained by Pennycuik (1990, 1996) and Tobalske (1996). If it were true that the Pileated Woodpecker can achieve a cruising flight speed of 20 m/s, which is approximately double Tobalske's mean flight speed of 9.6 m/s, the model would suggest a flap rate of approximately double Tobalske's mean flap rate of 5.2 Hz, which would be more than ten standard deviations above the mean flap rate of that species.

One of the reviewers of a submission to the *Proceedings of the National Academy of Sciences* in 2009 made the following claims: (1) "A sample size of one flight from one bird is not conclusive," but it is indeed possible to rule out the Pileated Woodpecker in a single flight on the basis of the known flap rate statistics of that species; (2) the prominent white patches on the dorsal surfaces of the wings "could potentially derive from solar specular reflection," but the video reveals that the sky was overcast that morning (as can be verified from weather archives); and (3) "The low temporal resolution of the camera precludes detailed assessment of wingbeat motions," but Tobalske had no problem digitizing the wingtip motion from the NTSC video, which is sampled at 60 frames per second and clearly reveals the motions of the wings. The same reviewer made the following comments:

The estimates of wingbeat frequency suggest values much higher than those known to characterize flight of Pileated Woodpeckers, but the inference that the sequence is therefore necessarily that of an Ivory-billed Woodpecker (for which no frequency data are available in any event) is flawed. The larger size of the latter species should correspond to lower and not higher wingbeat frequencies given the well-characterized negative allometry of this quantity in birds and other flying animals. In fact, an alternative explanation is simply that the time base is incorrect, i.e., that the sequence corresponds to 30 frames/second rather than 60 frames/second, thus yielding a wingbeat frequency for the sequence that is closer to 3.5 Hz and well within the range for a Pileated Woodpecker. If this is the case, then the flight speed estimate is also too high by a factor of two, which would bring the value to 7.5 m/s which is more realistically consistent with reported flight speeds for a Pileated Woodpecker.

Some of these comments are similar to comments that have already been discussed; they reflect a lack of awareness of Pennycuik's findings, Tanner's account of a high flap rate, and the fact that the analysis of the video does not require any information about the flap rate of the Ivory-billed Woodpecker. By speculating that the temporal sampling had been altered, the reviewer essentially conceded that the large woodpecker in the video cannot be a Pileated Woodpecker. That line of discussion could be interpreted as an implication of fraud, but I was not given an opportunity to provide the original digital videotape for inspection. From that tape, it would have been easy to confirm that the temporal sampling is correct.

A submission to *PLOS ONE* in 2013 was recommended for publication by two of the three reviewers. One of the positive reviews contains the following comments:

This is a fascinating paper, laying a claim of a highly controversial topic, namely, the flight characteristics of the Ivory-billed Woodpecker, actually, the very continuing existence of it. The work is indirect but the effort is highly methodical and justifiable. It will surely create disagreement but I strongly recommend the paper for publication so that there is a framework to foster open discussion and debate.

The reviewer understood that it is essential to publish relevant findings in a timely manner in order to "foster open discussion and debate." The other positive review contains the following comments:

The manuscript contains an insightful analysis of flight characteristics of the Ivory-billed and Imperial woodpeckers, using analysis of historical and video data to make a case for considering the footage in the putative videos to be that of the Ivory-billed woodpecker. Flight characteristics are the key to the analysis, although other aspects of wing shape and markings are also pointed out. Looking at the putative video before seeing the analysis, one may wonder how any progress on deciding if the video is of the Ivory-billed woodpecker can be made, since it is fleeting footage from far away. I am impressed by the author's being able to provide an analysis of flap rate and takeoff and landing characteristics that is very compelling.

When asked to evaluate video evidence for the persistence of the Ivory-billed Woodpecker, it is only natural to hope to see images that are as clear as in the film that was obtained in 1935, but nobody has managed to obtain high-quality footage in recent decades. As the reviewer discovered, however, the videos contain evidence that is "very compelling" when carefully examined. The negative review contains the following claims: (1) "The poor quality of the data does not allow proper kinematic analysis," but an expert on woodpecker flight mechanics had no problem analyzing the video, which unquestionably shows the wings folding closed in the middle of each upstroke; and (2) "The strange attempt to use a kinematic model shows the ignorance of the author," but it would be a trivial matter for any scientist to apply that model, which is based on a simple equation involving the flap rate, flight speed, and wingspan (Taylor et al. 2003; Nudds et al. 2004). The reviewer did not provide any details to support the claim that the model was used improperly, but I consulted with one of the developers of the model, Adrian Thomas of Oxford University, who confirmed that I applied it properly for a previous submission. When asked why the positive reviews were dismissed and the submission was rejected on the basis of a negative review that contains no valid criticisms, the editor responded with the following:

For your information, there is a long list of potential reviewers for this ms who have all declined, including all the ones you have suggested. The reasons they gave for declining have also contributed to my decision, which was reached in consultation with the editors.

The editor did not provide any supporting information, such as discussions of the data and analysis.

In discussing criticism of the work of Fitzpatrick and his colleagues, Haney mentioned that “one cannot entirely discount envy, turf-guarding, or other human motivations as contributing to some of the criticism” (Haney 2007). Some of the reviews contain comments that are suggestive of motivations other than a desire to establish the truth. A reviewer of a submission to *MDPI Biology* in 2016 made the following comments:

We have what is called the ‘scientific method’ for a reason. Nearly 500 years ago science existed in an age when men of wealth and power made declarations of what is true and what isn’t true in science—and progress and understanding in science was abysmal. The development of the scientific method gave science a yardstick by which to measure whether something was true or not—whether something existed or not. Scientific credibility—not wealth or power—is the foundation on which decisions to expend vast sums of public resources. Of course wealth and power still give sway to some major expenditures—such as in the case of the Ivory-billed Woodpecker, but science gives us the tool to call them on it.

The reviewer pontificated about the scientific method but did not discuss the analysis of the videos, which happens to be based on the scientific method (e.g., the analysis of the 2008 video is based on woodpecker flight mechanics and the statistics of flap rate). A reviewer of a submission to *Frontiers in Zoology* in 2010 made the following comments:

I know as a result of discussions with others, including members of the Ivory-billed Woodpecker Recovery Team and others associated with the searches of recent years, that the videos mentioned at the beginning of the results section and presented with this manuscript have been thoroughly analyzed by members of the Ivory-billed Woodpecker Recovery Team and convincingly dismissed as being videos of a pileated woodpecker, red-headed woodpecker, and possibly a third species – but almost certainly not one of the images is of an ivory-billed woodpecker.

Without providing any supporting information, the reviewer claimed that unspecified individuals had “thoroughly analyzed” and “convincingly dismissed” the videos. Another reviewer of the same submission (who disclosed his identity in the review) happened to be a member of the group that had supposedly “convincingly dismissed” the videos; but he recommended publication and provided the comment, “After a rather intensive and careful review of the evidence provided by the author, I am inclined to agree that this manuscript offers relatively strong evidence of at least one observation of ivorybill in 2008.”

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