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3 **Multiple lines of evidence indicate survival of the Ivory-billed Woodpecker in**  
4 **Louisiana**

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23

24 **Abstract**

25 The history of decline of the Ivory-billed Woodpecker is long, complex, and controversial. The  
26 last widely accepted sighting of this species in continental North America was 1944. Reports of  
27 Ivory-billed Woodpeckers have continued, yet in 2021 the U.S. Fish and Wildlife Service  
28 proposed declaring the species extinct. We draw on 10 years of search effort, and provide trail  
29 camera photos and drone videos suggesting the consistent presence of Ivory-billed Woodpeckers  
30 at our study site. Data indicate repeated re-use of foraging sites and core habitat. We offer  
31 insights into behaviors of the Ivory-billed Woodpecker that contribute to difficulty in finding this  
32 species. We discuss results with regard to the value of accumulated evidence, and what repeated  
33 observations may indicate for continued survival of this iconic species.

34

35 **Key words:** bottomland forests, *Campephilus principalis*, drones, endangered species,  
36 extinction, trail cameras

37

38 **Introduction**

39 The history of the decline of the North American population of the Ivory-billed Woodpecker  
40 (*Campephilus principalis*; Ivorybill) is long, complex, and controversial (1-3). Currently  
41 proposed as extinct (4), the species historically inhabited mature bottomland forests associated  
42 with river basins throughout the southeastern United States, with a small, separate population in  
43 Cuba (1). Widespread and perhaps very locally common at times, the Ivorybill was severely  
44 impacted by collectors, subsistence and other hunters, and cutting of bottomland forests in the  
45 U.S. (3, 5). By the late 1930's, a range-wide search in continental North America resulted in an  
46 estimated population of 22 individuals in Florida, South Carolina, and Louisiana (6).

47           The last widely accepted sighting of an Ivory-billed Woodpecker in North America was  
48 in 1944 at the Singer Tract (7), near Tallulah, Louisiana, where Tanner had studied the species  
49 (6). Reports of Ivory-billed Woodpeckers continued, however, with authorities estimating as  
50 many as 200 sightings since 1944 (8, 9). Many of these reports are from less well-known  
51 sources, but some are from game wardens, field biologists, and ornithologists. Observations have  
52 also included physical evidence, such as photographs, audio recordings, videos, and a feather (9-  
53 13). In 2005, a highly publicized video of a possible Ivory-billed Woodpecker in Arkansas was  
54 published (14), but the identification and the survival of the species was strongly debated (15-  
55 23). A follow-up, two-year search did not produce additional imagery or documentation widely  
56 considered conclusive despite at least 15 reported visual sightings (18). Most recently, evidence  
57 suggested that Ivory-billed Woodpeckers were present in the forests along Florida's  
58 Choctawhatchee River (24), and a morphometric analysis of a 2010 photo pointed towards an  
59 Ivorybill in Louisiana (25).

60           These efforts have not resulted in general acceptance of the survival of the species (26).  
61 Objections to conclusions of the continued existence of the Ivory-billed Woodpecker among  
62 scientists, elements of the birdwatching community, and public media have often focused on two  
63 key issues. First, the quality of all reports is said to be so low that they do not offer decisive  
64 proof of a living Ivory-billed Woodpecker (16, 27-29). It is argued that a rare bird needs to be  
65 documented with a higher standard of evidence and a greater threshold of physical support than  
66 routinely adopted for other species; the USFWS defines the objective evidence needed to verify  
67 the continued existence of the species as "clear photographs, feathers of demonstrated recent  
68 origin, specimens, etc." (4). The second issue in consideration of the persistence of Ivorybills is  
69 the lack of repeatability of observations (28). The assumption is that if a rare resident species is

70 found, then it should be repeatedly re-found, and that if it is not re-found then the original  
71 observation or record is inadequate to prove persistence.

72 Here we draw on 10 years of search effort and provide multiple lines of evidence for the  
73 repeated though intermittent presence of Ivory-billed Woodpeckers at our study site in  
74 Louisiana.

75

## 76 **Materials and Methods**

77 Our field research took place in bottomland hardwood forests in Louisiana from 2012-2021.

78 Because of the endangered status of the species and ongoing research concerns, we omit specific  
79 location details. The search area was defined by perceived habitat quality, previous visual  
80 sightings or aural data, and accessibility. The area is a ~93 km<sup>2</sup> mosaic of bottomlands and  
81 uplands. The bottomlands, grown to a variety of hardwoods, occupy a system of drainages and  
82 backwaters ~10 km in length, and in breadth from 50 m along some of the smaller feeder streams  
83 to ~1.5 km in places along the main stream. This system occurs in a landscape with more  
84 remnants of seemingly suitable habitat nearby. The canopy height is ~30 m. Standing and  
85 downed dead trees are patchily important components of the landscape. Like almost all  
86 bottomland habitat in the southeast, the area has a long history of human use, with most, highly  
87 selective lumber extraction having occurred 1890-1940.

88 Field observations were collected through systematic searching at irregular intervals, with  
89 most fieldwork concentrated in the October-May period thought to encompass the breeding  
90 season of this species (1). Observational techniques included slowly moving reconnaissance,  
91 sitting in place, and stakeouts of key areas, points, or cavities. Boats were not used due to the  
92 number and variety of obstructions in the water, reduced mobility, and inability to also handle

93 recording and other equipment. Although skilled, reliable observers reported more than a dozen  
94 high quality observations of Ivory-billed Woodpeckers, these are not described here because of  
95 the lack of photographic verification. Audio data were also collected through the deployment of  
96 ~90 automated recording units. But because of the nature of the known sounds of Ivory-billed  
97 Woodpeckers, auditory evidence of the presence of this species is unlikely to be generally  
98 persuasive. Likewise, therefore, our audio data are not further described.

99         Field observations included here were collected through the deployment of trail cameras  
100 and the use of drones to record videos. Trail cameras are rugged, weatherproof, programmable,  
101 and capable of taking photos automatically at timed intervals or when motion is detected.  
102 However, trail cameras are also primarily designed for large animals at ground level and have  
103 limited value when shooting upwards to distant treetops where light levels are extreme and  
104 motion may not be detected. Nevertheless, trail cameras are one of the few tools available to the  
105 Ivorybill searcher. Early images in our search were obtained using Reconyx trail cameras  
106 programmed to capture images at 10-sec intervals. Other early images were obtained using  
107 Plotwatcher Pro cameras with a dedicated time-lapse device. Plotwatcher software rendered the  
108 time lapse in video form; these videos could then be exported in various movie formats, and  
109 individual frames exported as jpegs. Image quality was relatively poor, but the review process  
110 was simplified. The nature of the time-lapse feature, however, tends to exaggerate the jerkiness  
111 of woodpecker movements. More recently, we have used a variety of trail cameras including  
112 Moultrie, Bushnell, and Stealth Cam. These were either set on a motion sensitive setting or  
113 programmed to take photos at intervals of 5-60 sec.

114         We placed trail cameras strategically at sites where, a) tight-barked trees appeared to  
115 have been scaled, b) trees were damaged or in poor health and expected to die, or c) upright or

116 fallen trees of species favored for feeding by Ivorybills. However, our best results followed  
117 placements made when informed by personal visual or aural encounters with Ivorybills. In some  
118 instances we focused cameras on the high branches in the mid- to upper-canopy as the strata  
119 favored by foraging Ivorybills; however, results showed poor resolution due to distance and light  
120 conditions compared to cameras that were focused on lower portions of trunks and fallen  
121 branches. Cameras trained to capture images of birds foraging in the mid- to upper-canopy relied  
122 on time-lapse programming, while those targeting lower portions of trunks were most often set to  
123 a motion sensitive setting.

124         We sometimes made adjustments to original imagery using standard consumer programs,  
125 including Photoshop and Apple Photos. All processing, except cropping, was applied to the  
126 entire image; there was no attempt to alter the appearance of individual subject birds. All original  
127 still photos presented here were adjusted for contrast and brightness unless otherwise stated.

128         We have been flying drones equipped with video cameras since July 2019 after published  
129 demonstrations of their utility to assess habitat and search for Ivorybills (30), primarily by flying  
130 very low over the forest canopy. However, our search method recognizes that Ivorybills  
131 regularly fly through the treetops and over the canopy (6), so we hover a drone in place well  
132 above the forest, passively filming the treetops to record any birds flying within view of the  
133 onboard camera. Hovering the drone at a high altitude, usually just below the Federal Aviation  
134 Administration's maximum height of 400 feet, minimizes disturbance to birds and other wildlife,  
135 and creates a relatively stable platform for the camera which results in less blurring of video  
136 images than if the drone were moving.

137         The question of where to aim the camera is an ongoing point of discussion, but our  
138 consensus has been that while a directly downward (nadir) view offers the possibility of a very

139 clear view of a passing Ivorybill, it also significantly reduces the field of view and limits the  
140 chance of getting a video image of the target bird species. Instead, we film with a shallower  
141 (oblique) angle that includes treetops up to 800 m away, increasing the opportunities for an  
142 encounter. Finally, where we fly the drones and shoot video is itself informed by many factors,  
143 including available habitat, the configuration of habitat on a landscape scale, accessibility of  
144 launch sites, permit requirements, and most critically, our history of aural detections and  
145 sightings of birds, and locations of foraging signs and cavities.

146 Flights during 2019 were made with a DJI Mavic 2 Zoom filming with a 4K camera,  
147 often using the 2X optical zoom lens. In spring of 2020, we began using Autel Evo II drones  
148 with swappable 6K and 8K cameras. Due to a smaller sensor, the 8K camera did not perform  
149 well in low light level conditions such as during early morning and on cloudy days, so most  
150 videos are now recorded with the 6K camera.

151 Although the perspective is very different when viewing birds from high above, the  
152 process of identifying a species appearing in drone videos is similar to that for birders on the  
153 ground, including the basics of assessing the bird's size and shape, coloration, behavior and  
154 habitat. We have been able to distinguish in our footage a wide variety of birds in flight,  
155 including Pileated Woodpeckers, and a variety of species of hawks, vultures, ducks, wading  
156 birds, and others. We use computer applications such as VLC Media Player, iMovie, Apple  
157 Photos, and Topaz Video Enhance AI (for resizing) to analyze our video. We found that analysis  
158 was improved significantly with the use of a high quality, high resolution computer screen to  
159 view drone videos. As with photo processing, all methods other than cropping were uniformly  
160 applied. We also used Photoshop to create a chronophotograph to visualize flights recorded by  
161 drones. Chronophotography makes it possible to observe the movement of an object through

162 space in a single still image, thus splitting the perceptual difference between a still image and a  
163 moving image, by creating a kind of spatio-temporal snapshot.

164

## 165 **Results and Discussion**

166 We simultaneously deployed 6-19 trail cameras/yr resulting in ~438,000 camera-hrs of  
167 activity. Our most important series of trail camera photos followed our sighting of an Ivory-  
168 billed Woodpecker landing at ~40 m distance in a live but declining sweetgum (*Liquidambar*  
169 *styraciflua*) tree on 27 October 2019. Trail cameras, nearly continuously deployed on this tree  
170 since then, subsequently captured photos of Ivorybills visiting the tree intermittently from at least  
171 29 November 2019 to 10 February 2020, and then again from 12 September 2021 to December  
172 2021.

173 Trail camera photographs taken on 30 November 2019 and 1 October 2021 at this and a  
174 nearby tree, each show a bird with a clear, white saddle on the lower part of the folded wings  
175 (Figure 1). Comparative photos of other birds in the same tree (Figure 2), including an  
176 unidentified small woodpecker, a Pileated Woodpecker (*Dryocopus pileatus*), and a Red-headed  
177 Woodpecker (*Melanerpes erythrocephalus*), confirm the large size of the target bird. While the  
178 image quality is too poor for precise measurement, the relatively long neck aspect ratio, proposed  
179 as characteristic of the Ivorybill (25), is also highly suggestive. We compare these photographs  
180 to one of a known Ivorybill from a separate Cuban population (31) that was also photographed at  
181 a considerable distance (Figure 3). The remarkable similarities in the images can be attributed in  
182 part to having been shot from ground level, as opposed to almost all existing photos of North  
183 American Ivorybills that were obtained from cavity-level blinds (6, 32).



184 A series of photographs taken on 12 October 2021 at the same tree occurred in early  
185 morning fog (Figure 4). These images of a bird with the typical posture of a large woodpecker  
186 are notable for the white saddle. However, the size and prominence of the white saddle changes  
187 with the angle of the bird to the camera (Figure 4), as has been previously noted and illustrated  
188 (Figure 5) by Jackson (5). We also note that the intersection between the white saddle and the  
189 overlying black coverts is uneven in a way that might be expected of feathering. We interpret the  
190 image additionally as showing the white dorsal stripe.

191 Camera images obtained on 14 October 2021 show multiple frames with birds exhibiting  
192 distinctive traits of *Campephilus* woodpeckers (Figure 6). A distinctly crested woodpecker with a  
193 white saddle, or at least a suggestion of a lighter lower body, is present in many frames. Most  
194 intriguing is that these images depict the distinctive morphological adaptations of the feet and  
195 legs of *Campephilus* woodpeckers as compared with *Dryocopus* woodpeckers like the Pileated  
196 Woodpecker (33). The phenotypically similar Pileated is one of the most unspecialized of the  
197 truly arboreal woodpeckers, while the *Campephilus* woodpeckers are characterized by  
198 pamprodactyly, a pedal morphology that enables the forward rotation of all four toes (33). The  
199 specialized modifications in the highly arboreal Ivory-billed Woodpecker are not so much in the  
200 structure of the toes as in the position of the legs. The feet are held outward from the body and  
201 are directed diagonally upward and sidewise (Figure 7), with both feet wide apart and more  
202 anterior relative to the body (33, 34). Usually the angle between the tarsi and the horizontal plane  
203 is  $\leq 45^\circ$ , and often seem to be pressed against the tree trunk. This is very different from the  
204 condition seen in most woodpeckers, as, for example, the Pileated Woodpecker, where the legs  
205 are held more or less beneath the pelvic girdle, the joints are fully flexed, and the tarsi are held  
206 well away from the tree trunk. This generally results also in a more obtuse angle of the intertarsal

207 joint (where the leg bends between the tibiotarsus and the tarsometatarsus), and is evidence of  
208 the better scansorial adaptations of the Ivory-billed Woodpecker compared to the Pileated  
209 Woodpecker (33). This obtuse angle is visible from a distance, is readily seen in our images  
210 (Figures 6, 7), and can be a useful identification clue in situations where lighting or distance  
211 makes it hard to observe plumage details with clarity (35). Combined with feet extended  
212 diagonally upward and to the side of the body, the stance of the birds appearing here are  
213 consistent with that of a *Campephilus* sp.

214 A final set of trail camera images offers further behavioral clues to the identification of  
215 these birds. On 9 January 2020, an apparent male-female pair of Ivory-billed Woodpeckers was  
216 photographed (Figure 8). This image shows one bird with an apparent red crest, another with an  
217 apparent black crest, and a prominent white saddle on the male. One of the photo sequences we  
218 find most compelling, however, was obtained on 30 November 2019. These trail camera photos  
219 involve what appears to be a foraging family group. When viewed in succession (Supplemental  
220 Movie S1), the resulting “video” clip appears to show three large woodpeckers moving and  
221 foraging together. The “video” is composed of individual trail camera photographs taken  
222 automatically every 5 sec. Although distance and lighting are difficult, a white saddle can be  
223 clearly seen in multiple frames, including a frame extracted and reproduced in Figure 1 showing  
224 a woodpecker with a prominent white saddle on the lower part of the folded wings. We note also  
225 the proximity of the three birds to one another in the “video”, and their foraging behavior,  
226 including movements throughout the tree: on the bole and major branches, and even on smaller  
227 branches. Foraging appears to be very active and even acrobatic at times, with birds clinging to  
228 the tops, sides, and undersides of the branches. We recorded very similar foraging behavior on  
229 the same tree on 12 October 2021, with very active and acrobatic movements across the tree,

230 including smaller branches (Supplemental Movie S2). The apparent ~2-yr gap in foraging by  
231 Ivorybills on this nearly continuously monitored tree is interesting, suggesting that there is an  
232 intermittency in woodpecker movements, or more likely, in the phenology of beetle prey and  
233 their larvae. Continued, long-term monitoring of trees utilized by Ivorybills is warranted to better  
234 understand foraging patterns.

235         Intraspecific behavior may also support the identification of these birds as Ivory-billed  
236 Woodpeckers. Ivory-bills reportedly show no indication of being strongly territorial (6). In the  
237 Singer Tract, home ranges did not appear to be defended during the breeding season, and  
238 wandering birds that were encountered seemed to be tolerated by resident birds. In addition,  
239 Sonny Boy, the male offspring that Tanner banded in 1937, remained with his family group for a  
240 full two years after fledging (32). By contrast, the Pileated Woodpecker generally appears to be  
241 territorial year-round, only tolerating birds from other territories at distances of >100 m (36).  
242 Adult Pileateds typically drive young away from the territory in the fall, often as early as  
243 September, but anecdotal reports do exist of three Pileateds together during winter months (36).  
244 Our observations of three birds appearing just a few meters apart, well after a presumed fledging  
245 period, and for an extended time, is more consistent with an Ivorybill family group than an  
246 unusual Pileated or mixed-species group, but should not be considered definitive. However,  
247 considering that we see white on the wings of birds in successive frames (Figures 1), even at  
248 considerable distance and under poor lighting conditions, we are confident that these sequences  
249 include Ivory-billed Woodpeckers.

250         In addition to the evidence of a family group, the observed foraging behavior is distinctly  
251 unlike that of a Pileated Woodpecker. Pileateds select large diameter trees (36, 37), and dead  
252 trees are used out of proportion to availability (37). Large rectangular excavations are

253 characteristic; these can be >30 cm in length (36). Although Pileateds may also glean and peck,  
254 their bark scaling behavior is a distinctly uncommon activity in Louisiana bottomlands (37).  
255 Pileated Woodpecker foraging tactics are rather slow and methodical, and concentrated on the  
256 bole and major branches of large trees, as the species avoids trees in smaller size classes (37).  
257 The foraging style of the Ivory-billed Woodpecker seems to be largely undescribed, other than  
258 the importance of scaling of bark of hardwoods (6). It is unclear from the literature whether  
259 foraging as active as we document is typical of the species, but our subsequent careful inspection  
260 of the smaller branches of the tree where the Ivorybills were photographed did reveal extensive  
261 scaling of even the smaller branches in the canopy. Furthermore, photographs taken by Tanner in  
262 1939 similarly reveal a group of three Ivorybills foraging together on a tree at the same time,  
263 while also documenting that the three birds were also less than a meter apart from one another  
264 (32).

265 We also used drones to document the presence of Ivory-billed Woodpeckers at our study  
266 site. We made ~2,590 drone flights and recorded ~864 hr of video from July 2019 - October  
267 2021. We recorded several drone videos in February 2020 that captured images of large birds  
268 with black on the leading edge of the wings and white on the trailing edges. These videos were  
269 taken in an area where we had had recent sightings and had recorded vocalizations suggestive of  
270 Ivorybills. In a video that was recorded on 25 February 2020, an apparent Ivory-billed  
271 Woodpecker crosses the field of view and banks upward and to the right before landing on a  
272 large, emergent tree. To illustrate the approach and landing, we present the landing sequence as a  
273 chronophotograph (Figure 9). The black leading edge with white trailing edge is repeated in  
274 multiple frames. While the white in several images looks more like a tail, similar to that of a  
275 Bald Eagle (*Haliaeetus leucocephalus*), other images make it clear that the white is on the back

276 of the wings. In addition, a Bald Eagle with a white tail would always show a bold white head,  
277 which never appears on this bird. We believe that the false appearance of a white tail in some  
278 frames is a result of the positioning of the wings closer together toward the posterior of the bird  
279 during the return wing stroke. The bird also appears to land in a distinctly woodpecker-like  
280 fashion on a vertical tree trunk or slightly inclined limb with a quick upward swoop and a few  
281 braking wing-beats (6). The bird's white saddle then appears to be visible on the trunk of the tree  
282 after landing. Based on shade patterns on other trees, the bird is not in full sun at the time of  
283 landing so the apparent white saddle is not an aberration caused by reflected direct sunlight.

284 A second informative video from 23 December 2019 shows two large birds in flight  
285 above the treetops. Shortly after entering the view of our camera, the first bird appears to engage  
286 in flight bounding, a behavior in which a bird stops flapping by temporarily folding its wings  
287 onto its back. For a moment, it speeds missile-like before flapping again. As the bird alternates  
288 between flapping and flight bounding, the result is a flight path that appears slightly undulating,  
289 which is common among woodpeckers. Although the historical literature about the Ivory-billed  
290 Woodpecker does not mention flight bounding, a 1939 photograph of an adult Ivorybill flying  
291 overhead (Figure 10) is evidence that there are moments when the wings are folded on top of the  
292 body. An additional clue to what an Ivory-billed Woodpecker's bounding flight should look like  
293 from a drone can be found in a 1956 video (38) of the closely-related Imperial Woodpecker in  
294 Mexico (Figure 11). The video offers a partial side view showing some of the white patch on the  
295 bird's back during flight bounding.

296 Our December 2019 clip similarly shows a large dark-colored bird as it flies away from  
297 the camera and to the right; our video perspective is from above and behind the subject bird. In  
298 the frames reproduced in Figure 12, the white plumage appears along the trailing edge of the

299 wing as the bird begins to fold its wings inward. In subsequent frames, the white condenses into  
300 a bright patch as the wings complete their fold onto the bird's back, then appearing very nearly  
301 as a typical white saddle of an Ivory-billed Woodpecker.

302 Two compelling behavioral features are derived from the drone videos. One is the height  
303 at which the bird appears to travel. Flights above the treetops extending “for a half mile or more”  
304 and “dodging the trees with very little deviation from their course” have been described for the  
305 Ivorybill in North America (6); Ivorybills have also been reported to fly high over canyons and  
306 treetops in Cuba (39). A second compelling feature is the high speed and direct flight of  
307 Ivorybills. Direct flight was previously noted in the Ivorybill (6, 40), while Pileated Woodpecker  
308 flight is characterized as “rather slow, but vigorous and direct” (36).

309 The data presented here offer no doubt that the multiple images and videos are those of a  
310 large woodpecker. Our opinion that these images represent Ivory-billed Woodpeckers is based  
311 on the appearance of broad white saddles, white trailing edges on the wings of birds in flight, a  
312 white stripe along the side of the neck, a heavy, light-colored bill, a unique morphology of the  
313 legs and feet, and a pair of birds with one suggesting a black crest. With the number of images  
314 available, some with multiple individuals present, one can also safely eliminate unusual  
315 aberrations and leucistic oddities that are sometimes posited as explanations for a large,  
316 woodpecker-like bird with extensive white plumage. Related to aberrations are defects or  
317 distortion of the video, frequently recognized as foreign artifacts. However, artifacts are far less  
318 of an issue with recent HD video technology, and should be of much less significance in  
319 evaluating video shot in 4K or 6K HD as we have presented here.

320 We note that through many trail camera encounters at these distances, many photographs  
321 remain ambiguous. Some frames clearly show the white saddle of the Ivorybill, and these field

322 marks can be seen in successive or multiple frames. However, in some cases, successive frames  
323 may show no white visible for the same birds. As mentioned above, we suggest that lighting  
324 conditions and position of the bird accounts for the absence of white in these cases, as  
325 documented by some historic photographs of known Ivorybills in the Singer Tract (Figure 5),  
326 where the white saddle is almost totally obscured. In addition, the angle of the camera to the bird  
327 affects the amount of white appearing in a photograph. In this case, we are shooting an apparent  
328 Ivory-billed Woodpecker from underneath and at considerable distance when the trail camera is  
329 near ground level and the canopy is ~30 m high. These conditions contrast markedly with those  
330 which produced almost all photographs in the historical record; all but a handful of existing  
331 photographs of known Ivory-billed Woodpeckers were taken from a blind placed at nearly eye-  
332 level to a nesting cavity in the Singer Tract. These ideal photographic conditions have, we  
333 believe, impacted expectations of what photographs are likely under field conditions.

334         The variety of evidence we have gathered over many years indicates repeated re-use of  
335 foraging sites and core habitat, and offers unusual repeatability of detections of the species. Lack  
336 of repeatability of observations has been raised in the past to dismiss purported Ivorybill  
337 sightings. For example, countering claims around the Luneau video from Arkansas, critics  
338 suggested that, “experience with other rare birds, especially resident species, suggests that any  
339 valid sighting should very quickly lead to more sightings” (28). This criticism was lodged  
340 despite the fact that the Luneau video followed a series of sightings, and was itself followed by  
341 additional sightings and acoustic recordings (14). Repeatability in our observations is seen at a  
342 variety of scales. All of the observations reported here took place in a single forested block and a  
343 single watershed. Almost all of the encounters reported here occurred within 1.6 km of one

344 another; and the majority of the best trail camera photos were taken over two, 3-month periods  
345 on the same tree.

346         We believe that our observations contribute to a clearer understanding of the twin  
347 problems of why the Ivory-billed Woodpecker has been so difficult to detect and to relocate over  
348 the past 80 years. These issues begin with the misperception that, if present, the Ivorybill is  
349 relatively easy to find – a misperception that extends at least as far back as Tanner (6). Tanner  
350 was a meticulous observer, but he apparently never located an Ivory-billed Woodpecker outside  
351 the Singer Tract, despite his numerous searches throughout the southeast (6, 41). Tanner noted  
352 that, “The difficulty of finding the birds, even when their whereabouts was known ... limited the  
353 number of observations (6).” Nonetheless, the misperception emerged, sometimes fueled by  
354 Tanner himself, that the Ivorybill should be noisy and easy to find. But this was entirely based on  
355 a single family group during the nesting season, and in later years Tanner acknowledged that this  
356 was usually not, in fact, the case (42).

357         Misperceptions on the ease of finding the Ivorybill extend to the frequent argument that  
358 in the modern era it is unlikely that a large, distinctive woodpecker could escape the sights,  
359 cameras, and recorders, of birdwatchers and other people who are recreating or working outdoors  
360 in remote areas (43-45). For example, even with the popularity of birdwatching, birdwatchers are  
361 not everywhere. The eBird citizen science program (<https://ebird.org/home>) has amassed >33  
362 million checklists (46). While the most thorough coverage occurs in North America, modeling of  
363 the range and relative abundance of individual species at a 3 km spatial resolution resulted in  
364 areas of “no predictions” because there was an insufficient number of qualifying checklists to  
365 assess whether a species was present or absent (47). While eBird checklists occur at easily



366 accessible places in the vicinity of our study area, no eBird checklists occur from within our  
367 specific area.

368         The authenticity of reports from non-scientists, hunters, fishermen, and rural residents,  
369 who may be the most likely people to access habitats such as those occupied by the Ivorybill, are  
370 often dismissed. Though often keen and knowledgeable observers of their natural world, their  
371 observations of rare or unusual species are frequently devalued relative to the science-based  
372 perspectives of researchers (48, 49). Increasingly, however, new approaches to science  
373 methodology recognize that local people often have a very intimate relation with the  
374 environment and natural resources. The closeness of these relations and dependencies is such  
375 that these people have a very particular and detailed knowledge of local environmental  
376 conditions and ecological relations that is of value to science (50).

377         Beyond the questions of detection and documentation, our data offer insights into how  
378 the ecology and behavior of the Ivory-billed Woodpecker would contribute to the difficulty in  
379 finding or re-finding this species. We know that the Ivorybill inhabits some of the most difficult  
380 to access habitat in the U.S., and that mature bottomland forests are a core component of that  
381 habitat. Behaviorally, our observations showing long, high-altitude flights by single birds and  
382 pairs are suggestive of a species with a vast home range, and accustomed to utilizing dispersed  
383 and likely fragmented habitats. Home ranges may vary seasonally, but the Ivorybill pair studied  
384 in the Singer Tract may have had a range up to four miles or more in diameter (6). Ivorybills  
385 have also been reported to wander over even greater distances and to cross cutover and otherwise  
386 unsuitable habitat (6, 51). Large home ranges, distant wandering across unsuitable habitat, and  
387 high flights all suggest the need, and the willingness, of the Ivorybill to travel widely for patchily  
388 distributed resources. That may be to search for a suitable roost site, but more frequently, it may

389 be related to exploitation of abundant but ephemeral food sources that occur in dead or dying  
390 trees or branches.

391

## 392 **Conclusion**

393 The habitat as described above applies to many other places in the American Southeast. The  
394 continuing survival of Ivory-billed Woodpeckers in Louisiana has conservation management  
395 implications not only in that state, but also widely within the historic range of the species. We  
396 expect that Ivorybills persist in some of these other places also, if not permanently then  
397 episodically. Their numbers cannot be expected to improve unless many more large and  
398 continuous bottomland hardwood forests are actively or passively managed to exhibit old growth  
399 characteristics. Forested tracts must be large enough so that ecological changes caused by natural  
400 catastrophic events such as fires, floods, or hurricanes, as at Congaree National Park owing to  
401 Hurricane Hugo in 1989, will allow surviving Ivory-billed Woodpeckers opportunity for a  
402 diversity of habitats. Only then, can there be an expectation of a larger number of populations or  
403 subpopulations of this iconic species.

404 The report contained here is not the end of our efforts. We are encouraged and energized  
405 by what we have accomplished. We are optimistic that technologies will continue to improve our  
406 outcomes, including documentation through environmental DNA and other physical evidence.  
407 We believe that our intentional and systematic survey design is paying off through  
408 complementary lines of investigation. Our findings begin to tell a larger story not just of whether  
409 the Ivory-billed woodpecker persists in Louisiana, but how it has survived and why its survival  
410 has been so difficult to document. Finally, we also believe that our methodologies can be  
411 translated to other sites, thus offering opportunities for additional documentation of the species.

412 Our findings, and the inferences drawn from them, suggest an increasingly hopeful future for the  
413 Ivory-billed Woodpecker.

414

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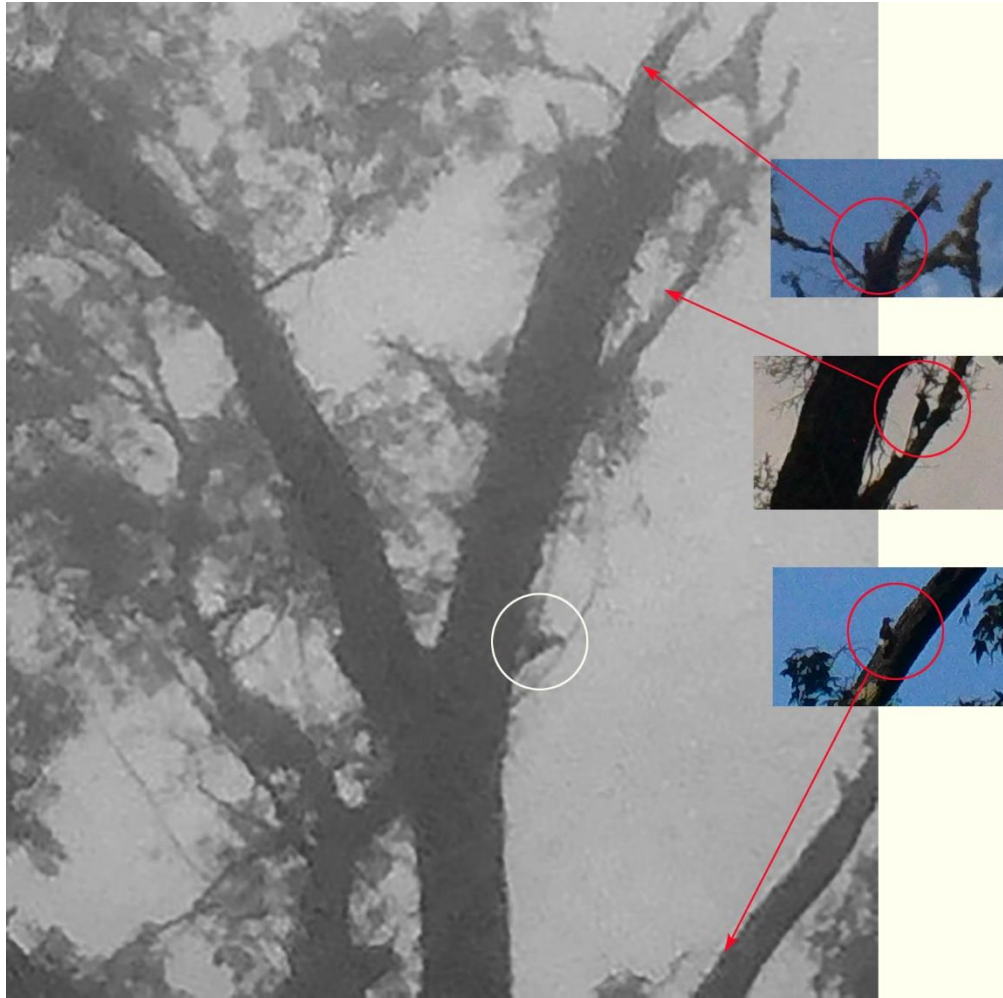
546 **Figure 1**



547

548 **Fig. 1:** Trail camera photos taken within 50 m of one another on 30 November 2019 (top), and 1  
549 October 2021 (bottom) of apparent Ivory-billed Woodpeckers showing a prominent white saddle  
550 present on the lower part of the folded wings. The image from 30 November is extracted from  
551 the “video” clip composed of trail cam photographs taken at 5-sec intervals and presented as  
552 Supplemental Movie S1.

553 **Figure 2**



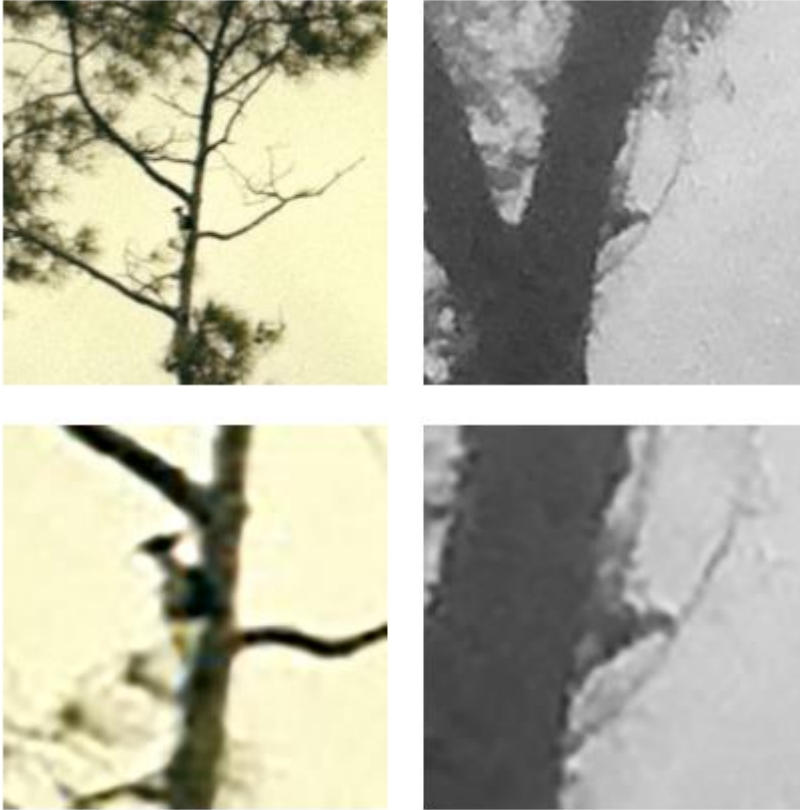
554

555 **Fig. 2:** Composite figure comparing the size of three woodpeckers to the apparent Ivory-billed  
556 Woodpecker. Inset species were photographed on the same tree, with the same camera in the  
557 same place, but at different times. These three images were extracted from their original frames  
558 and placed as insets on a fourth frame that shows the Ivorybill on 1 October 2021. All  
559 woodpeckers here are depicted at the same scale in their original, unedited size. Arrows point to  
560 the location of where each bird was located on the tree. Inset include an unidentified small  
561 woodpecker (top), a Pileated Woodpecker (middle), and a Red-headed Woodpecker (bottom).  
562 The Ivory-billed Woodpecker is circled in white without an arrow.

563 **Figure 3**

564 A.

B.



565

566 **Fig. 3:** A side-by-side comparison of cropped photos from: A) the unenhanced image of an  
567 Ivory-billed Woodpecker from Cuba (31), and B) the original, unretouched Project Principalis  
568 photo from Louisiana from 1 October 2021. Each photograph is also shown enlarged and further  
569 cropped below each original. These comparisons emphasize the similarities of appearance among  
570 Ivorybill images obtained from ground level under challenging field conditions, as opposed to  
571 almost all existing photos of North American Ivorybills that were obtained from cavity-level  
572 blinds (6, 32).

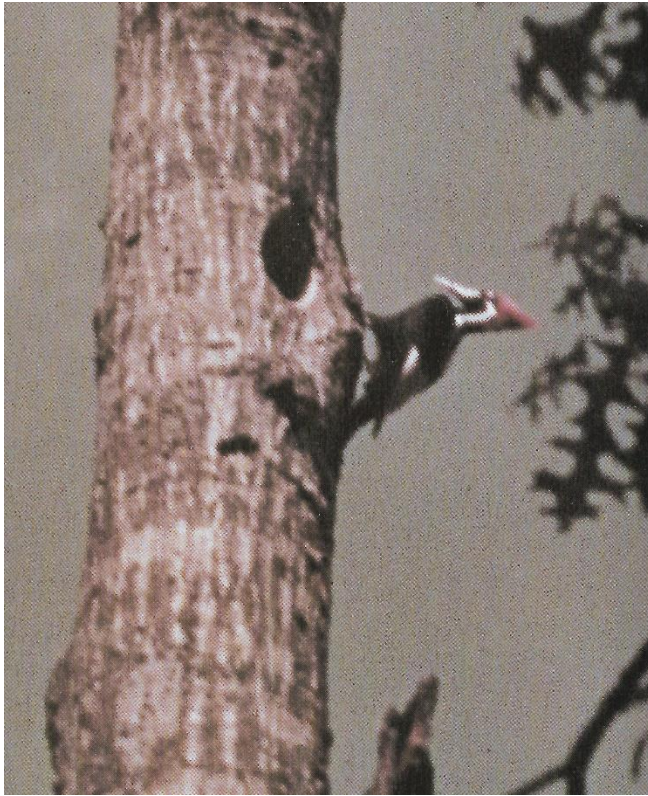
573 **Figure 4**



574

575 **Fig. 4:** Images of a bird with the typical posture of a large woodpecker, notable for the white  
576 saddle despite the heavy, early-morning fog. The size and prominence of the white saddle  
577 changes with the angle of the bird to the camera. We also note that an apparent partial white  
578 dorsal stripe is present.

579 **Figure 5**



580

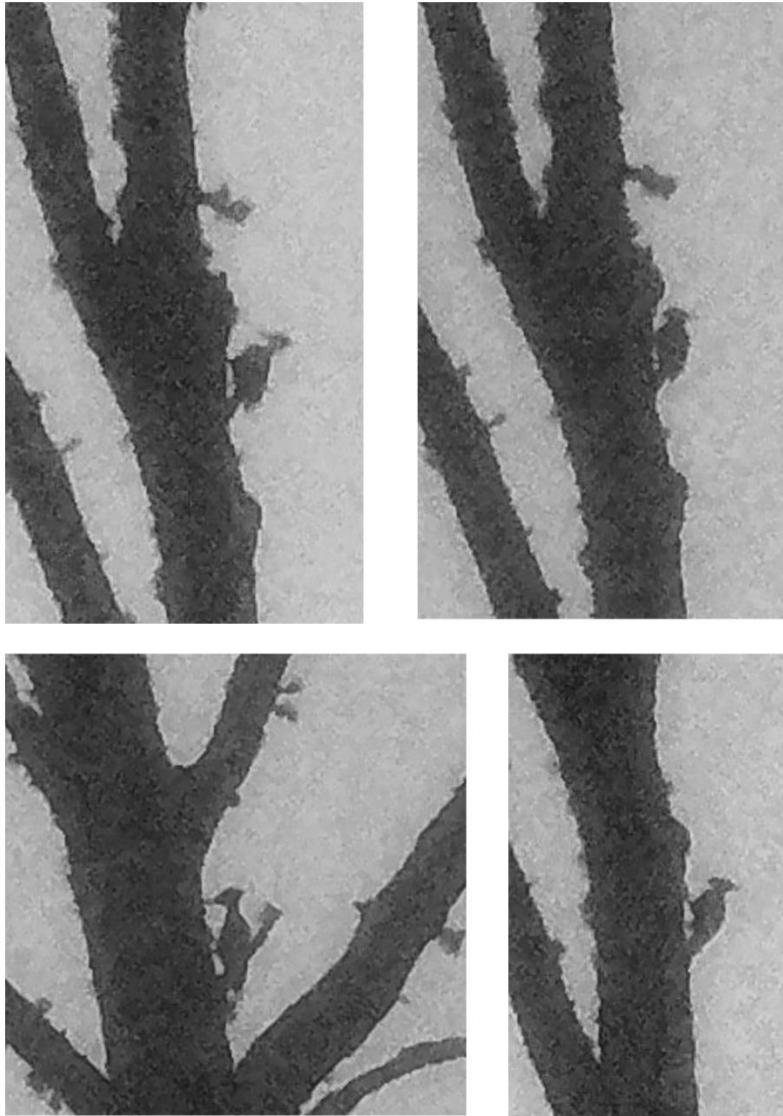
581 **Fig. 5:** A known Ivory-billed Woodpecker photographed in color in the Singer Tract by James T.

582 Tanner (c. 1939), illustrating how the visibility, size, and prominence of the diagnostic white

583 saddle may be obscured under certain light levels, and depending on the angle of the bird to the

584 camera. Photo by James T. Tanner (5).

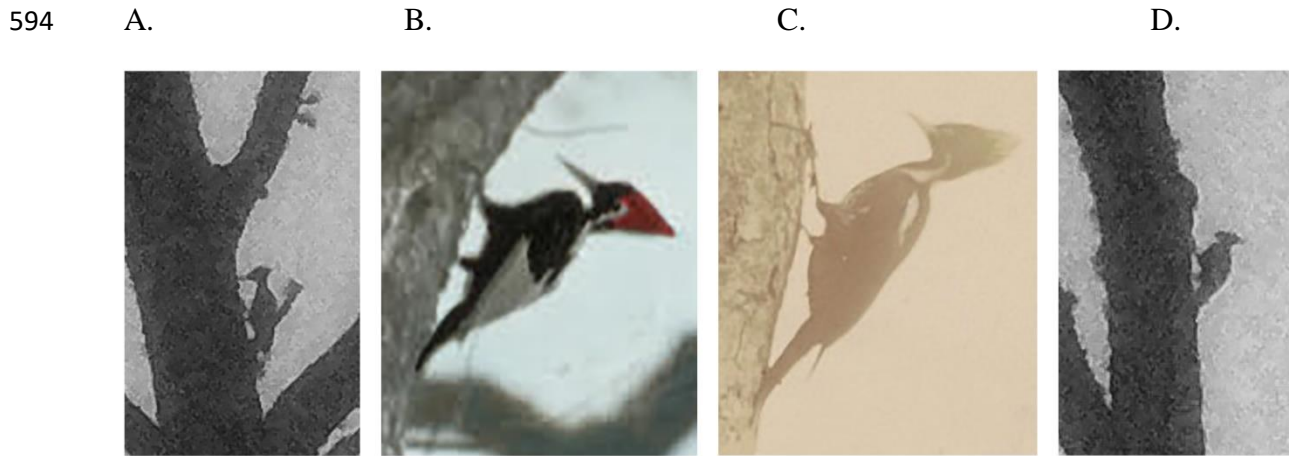
585 **Figure 6**



586

587 **Fig. 6:** Project Principalis images from 14 October 2021 illustrating the specialized  
588 modifications in the position of the legs in the highly arboreal Ivory-billed Woodpecker. The feet  
589 are held to the side of the body and are directed diagonally upward and sidewise, with both feet  
590 wide apart and forward. Usually the angle between the tarsi and the horizontal plane is  $\leq 45^\circ$  and  
591 there is an obtuse angle of the intertarsal joint. While a white saddle is not obvious in these early  
592 morning, very misty silhouettes, several images suggest its presence.

593 **Figure 7**



595  
596 **Fig. 7:** Comparison of photographs taken of apparent Ivory-billed Woodpeckers in Louisiana  
597 from this study (A, D), with a colorized Ivory-billed Woodpecker, also from Louisiana, but taken  
598 by Arthur A. Allen in 1935 (B), and a Pale-billed Woodpecker (*Campephilus guatemalensis*)  
599 taken in Central America (C), also from the Allen Collection. Birds in all photos share the  
600 characteristic posture imposed by the unique structure of the *Campephilus* leg and feet. Feet are  
601 held to the side of the body and are directed diagonally upward and sidewise, with both feet wide  
602 apart and forward. The angle between the tarsi and the horizontal plane is  $\leq 45^\circ$  and there is an  
603 obtuse angle of the intertarsal joint. Photos (B) and (C) are from the James T. Tanner, and the  
604 Arthur A. Allen papers, respectively, courtesy Division of Rare and Manuscript Collections,  
605 Cornell University Library.



606 **Figure 8**

607 **A.**

**B.**



608

609 **Fig. 8:** An apparent male-female pair of Ivory-billed Woodpeckers photographed on 9 January

610 2020 with the bird on the left showing an apparent red crest, and the bird on the right showing an

611 apparent black crest. Among North American woodpeckers, only the female Ivorybill has a black

612 crest. A prominent saddle is present in Figure 8A on the bird on the left, and a partial white

613 dorsal stripe is present in Figure 8A on the bird on the right.

614 **Figure 9**



615

616 **Fig. 9:** A chronophotograph of a landing sequence showing an apparent Ivory-billed

617 Woodpecker in February 2020. The arrows point to individual images of the bird. The direction

618 of flight is generally from lower left to upper right across the field of view.

619

620 **Figure 10**



621

622 **Fig. 10:** A photograph by James T. Tanner from April 1939 of an Ivory-billed Woodpecker  
623 demonstrating flight bounding by this species. Photograph courtesy LSU Digital Libraries,  
624 Louisiana, and the Lower Mississippi Valley Collections, Louisiana State University, Baton  
625 Rouge, Louisiana.

626 **Figure 11**



627

628 **Fig. 11:** Stills (left to right, top to bottom) from a video shot from a Mexican hillside by William  
629 L. Rhein of the closely related Imperial Woodpecker (*Campephilus imperialis*), demonstrating  
630 flight bounding by this species (38). Video available from Macaulay Library at the Cornell Lab,  
631 *Campephilus imperialis* (ML#61027).

632 **Figure 12**



633

634 **Fig. 12.** Stills (left to right, top to bottom) from a drone video shot in Louisiana of an apparent  
635 Ivory-billed Woodpecker demonstrating flight bounding by this species. White plumage appears  
636 along the trailing edge of the wing. In subsequent frames, as the bird begins to fold its wings  
637 inward, the white condenses into a bright patch. The white then appears very nearly as a typical  
638 white saddle as the wings complete their fold onto the bird's back.

639 **Supporting Movies**

640 **Movie S1:** “Video” clip composed of trail cam photographs taken at 5-sec intervals showing  
641 three large woodpeckers foraging together on 30 November 2019. Unlike adult Pileated  
642 Woodpeckers that are territorial year-round and typically drive young away from the territory as  
643 early as September, Ivory-billed Woodpeckers reportedly show no indication of being strongly  
644 territorial, and offspring have remained with family groups for a full two years after fledging.  
645 Figure 1, showing birds with apronounced white saddles, is extracted from this “video” clip.

646

647 **Movie S2:** Time lapse “video” clip composed of trail cam photographs taken at 30-sec intervals  
648 showing two large woodpeckers foraging together on 12 October 2021. The images are in  
649 silhouette, and field marks are not visible until one of the birds is higher on the tree, at which  
650 point the white saddle on the back can be seen. As in Movie S1, these large, crested woodpeckers  
651 demonstrate very active foraging movements on a branch at lower left before moving up the tree.  
652 Foraging is acrobatic; the birds hang from vines and cling to the tops, sides, and undersides of  
653 the branches.