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SATELLITE TELEMETRY REVEALS HABITAT SELECTION AND MOVEMENT PATTERNS OF AN AMERICAN FLAMINGO IN FLORIDA BAY

Steven M. Whitfield[1,2], Judd M. Patterson[3], Antonio Pernas[4], Michelle Davis[5], Jerome J. Lorenz[6], and Frank N. Ridgley[1, 2]

[1]*Zoo Miami, Conservation and Research Department, Miami, FL, USA*

[2]*Florida International University, School of Earth, Environment, and Society, Miami, FL, USA*

[3]*National Park Service South Florida/Caribbean Network, Palmetto Bay, FL, USA*

[4]*Big Cypress National Preserve, Ochopee, FL, USA*

[5]*Cape Florida Banding Station, 2037 SE 14th St, Homestead, FL, USA*

[6]*Everglades Science Center, Audubon Florida, Tavernier, FL, USA*

Abstract.—American Flamingos are among the most iconic—and rarest—of Florida's native birds. Though historical large flocks were decimated by hunting, small groups of flamingos of unknown origin persist in Florida today. Here, we report a satellite telemetry study of an American Flamingo in Florida Bay, Florida, USA, over a 22-month period. The flamingo used an extensive tidal flat at Snake Bight (Everglades National Park) and numerous mangrove-fringed mudflats inside keys within Florida Bay. Movement patterns varied by time of day and time of year and indicated that movements were tracking hydroperiod and prey availability across a landscape mosaic of spatially and temporally variable resources. We used a community science platform (eBird) to assess reporting probability for this flamingo; reporting probability was very low despite the conspicuous nature of the species. Though our telemetry data are from a single individual, this study represents the first empirical field study of any wild flamingo in Florida. Our findings on habitat selection and movement will be foundational to developing evidence-based conservation strategies for flamingos.

Key words: American Flamingo, Florida Bay, habitat selection, satellite tracking, residency

American Flamingos (*Phoenicopterus ruber*) are among the most iconic of Florida's birds. In the nineteenth century, naturalists described flocks of hundreds or thousands of flamingos in Florida Bay and the Florida Keys (Audubon 1839, Wurdemann 1860, McCall 1868, Scott 1890, Ingraham 1893, Howe 1902) and flamingos appear to have nested within Florida (Sprunt 1937, Whitfield et al. 2018). However, by the end of the nineteenth century, flamingo populations throughout the Caribbean and the Bahamas were decimated by hunting (Allen 1956, Rooth 1965, Sprunt 1975, Baldassarre and Arengo 2000) and the Florida population was believed to be extirpated (Scott 1890, Allen 1956, Whitfield et al. 2018). Through the twentieth century, captive flamingos in public animal attractions and private collections likely outnumbered their wild counterparts in Florida and most ornithologists considered flamingo observations in natural areas to be escapees from captive colonies (Bailey 1932; Allen 1954, 1956; Stevenson and Anderson 1994).

Several lines of evidence, however, suggest that Florida's contemporary flamingos are not escapees of captive origin and may instead represent early signs of a recolonizing population. Flamingo populations in the Bahamas and much of the Caribbean rose sharply through the late twentieth century (Allen 1956, Sprunt 1975, Baldassarre and Arengo 2000) and flamingos have started to recolonize nesting areas from which they were historically extirpated (Wiley 1979, Paulino et al. 2011, Sanz D'Angelo 2020). Expanding flamingo populations across the Caribbean are consistent with an increasing number of flamingo sightings in Florida (Whitfield et al. 2018), though to our knowledge recent nesting has not resumed in Florida. On three occasions, flamingos that were banded as chicks in the Yucatan region of Mexico have had confirmed sightings within Florida, illustrating natural connectivity between Florida and other nesting areas (Galvez et al. 2016, Whitfield et al. 2018, Welsh and White 2019). Occurrence records in the Florida panhandle and northeastern Florida also suggest that flamingo sightings there are the result of natural displacement by tropical storms rather than escapees (McNair and Gore 1998, Pranty and Basili 2007).

Most flamingos within Florida are sighted in Florida Bay (Whitfield et al. 2018), a shallow estuary between the southern tip of the Florida peninsula and the Florida Keys (Fourqurean and Robblee 1999, Wingard et al. 2019). Florida Bay represents a mosaic of geomorphological landscape features that vary in water depth, salinity, and hydroperiod—all of which are likely to influence suitability to flamingos for foraging or nesting sites. Much of Florida Bay is remote, inaccessible, or has restricted access; therefore, flamingos that do appear in the area may go unreported.

In the absence of monitoring programs for flamingos, the only data for evaluating population size and population trends are sourced from community science programs (historically called citizen science programs). One well-known example of a community science platform, eBird, has leveraged observational information from recreational birdwatching to create global-scale georeferenced and timestamped observation data for bird species (Sullivan et al. 2009, 2017). Whitfield et al. (2018) recently used data from eBird and other community science platforms to identify trends in flamingo abundance in Florida over several decades. However, community science programs vary in spatial, temporal, and taxonomic coverage resulting in biases in reporting probability (Bird et al. 2014), although large and conspicuously colored species are more likely to be reported than nondescript species (Caley et al. 2020). Because flamingos are both large and brightly colored, reports from eBird may accurately track abundance and distribution. Ultimately, it is difficult to interpret the efficacy of community science programs to reflect actual trends in flamingo abundance without empirical validation.

Satellite telemetry may provide useful insights into the behavior and ecology of American Flamingos in Florida and help to clarify reporting probabilities from community science programs. For other flamingo species, satellite telemetry has revealed long-distance movements that elucidate population connectivity (Amat et al. 2005) and illustrate linkages between foraging and nesting areas (McCulloch et al. 2003). Unlike banding and resighting programs that provide occasional evidence for movements (Sprunt 1975, Galvez et al. 2016) or traditional radio-telemetry, which is labor intensive and not feasible at international spatial scales, satellite telemetry has the advantage of providing multiple locality observations at regular time intervals from almost any location on the planet. Satellite telemetry has been used successfully in other species of flamingos (McCulloch et al. 2003, Amat et al. 2005, Balkiz et al. 2010) but, to our knowledge, has not been reported from American Flamingos.

Here, we report the results of satellite telemetry data for an American Flamingo in Florida Bay. We used these data to seek preliminary answers to several fundamental questions regarding the biology of flamingos in Florida. How are flamingos in Florida connected to nesting or foraging areas outside the state? What landscape features are important habitat for flamingos in Florida Bay? What are the daily and seasonal movement patterns of flamingos? How probable is the reporting of flamingos via the eBird community science project? The answers to these questions should be foundational to developing evidence-based wildlife policies and management practices for one of Florida's most iconic species.

Methods

Capture, rehabilitation, and release.—Our study flamingo (hereafter, Conchy) first appeared at the Naval Air Station (NAS) Key West at Boca Chica Key, Florida, USA (Fig. 1) on 1 September 2015 with two other flamingos foraging in shallow lagoons adjacent to the runways (Gonzalez 2015). The two other flamingos departed, leaving Conchy

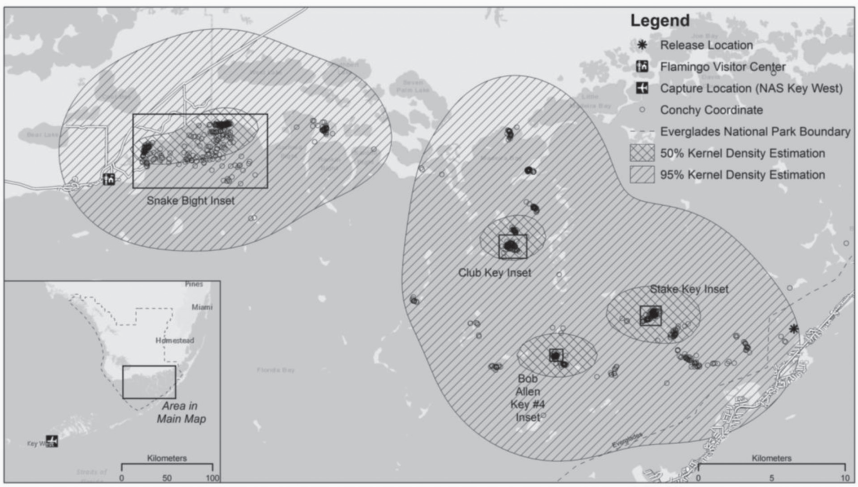

Figure 1. Study area and areas of key importance for Conchy (an American Flamingo) during the 22 months after the second release between Tavernier and Butternut Key, Florida, on 3 December 2015. Most of his satellite fixes were from four main areas: Snake Bight, Club Key, Bob Allen Key #4, and Stake Key. The four boxes in the figure are presented as inset maps in Figure 3.

isolated. After over two weeks of unsuccessful permitted harassment of Conchy to vacate the area by United States Department of Agriculture (USDA) Wildlife Services, we coordinated a capture effort with NAS Key West, Key West Wildlife Center, and USDA Animal Services to prevent potential injury to Conchy, to naval aircraft, and to naval pilots (Gonzalez 2015).

We captured Conchy on 3 October 2015 with a small animal net gun (MagNet Wildlife Capture Services, Flagstaff, AZ, USA). Conchy's generally pink body plumage, pale iris, and gray plumage on the neck and under the wings indicated that he was a sub-adult at the time of capture. Sex determination performed by Avian Biotech International (Tallahassee, FL, USA) identified Conchy as male. We held Conchy in the care of the Key West Wildlife Center (Key West, FL, USA) until initial release. On the day of release, we equipped Conchy with an alphanumeric leg band (blue band with white letters reading US01) and a United States Geological Survey (USGS) metal band (1148-90551) over his left tibiotarsus and a GeoTrack 30-g solar global positioning system platform transmitting terminal (GPS PTT) transmitter (North Star Science and Technology, Oakton, VA, USA; hereafter transmitter) over his right tibiotarsus. We attached transmitter with a modified two-part leg band that we riveted together and padded with a neoprene liner. We released Conchy at Snake Bight, an extensive tidal mudflat in northwestern Florida Bay on the southern coast of the Florida peninsula in Everglades National Park (25.16192°, –80.88204°) at 1724 EST on 20 October 2015.

At ~0800 EST on 27 October 2015, maintenance staff at Everglades National Park found Conchy sitting on a road at the Flamingo Visitor Center (Fig. 1), weak and unable to stand (R. Showler, Everglades National Park, pers. comm.). At that time, we transported Conchy to Zoo Miami's animal hospital for evaluation. Conchy was in poor body condition, was dehydrated, and had a parasitic liver fluke infection. He responded to treatment and regained his strength and body condition over the following five weeks. We housed Conchy at Zoo Miami in isolation and quarantine until his second release. On 3 December 2015, we released Conchy in Florida Bay near Butternut Key (25.07592°, –80.50526°; Fig. 1), 39.7 km to the southeast of the first release location. Capture, handling, and housing protocols followed applicable regulations and guidelines regarding animal welfare, were approved by Zoo Miami's Institutional Animal Care and Use Committee, and were permitted by Florida Fish and Wildlife Conservation Commission (FWC; LSSC-16-00009A to MD), a federal bird banding permit (23166 to MD), and a United States Fish and Wildlife Service (USFWS) Migratory Bird Treaty Act permit (MB056516) to Zoo Miami.

Telemetry data and analysis.—We programmed the GPS device in Conchy's transmitter to collect four daily GPS locations (at 0000, 0600, 1200, and 1800 EST). Every five days the transmitter turned on for a six-hour cycle to upload GPS data and Doppler determined locations to available satellites within the Argos system. Because of the short duration of the initial release (seven days) and because of concerns about Conchy's health and potential impacts of his health on movement patterns, in this study we excluded data from the first release period and only included data following the second release. We filtered GPS and Doppler data to remove low-quality points. Specifically, we removed one GPS point with an accuracy reading of invalid value, and 302 class 2, 1, A, and B Doppler points with estimated accuracies of >250 m.

To evaluate core areas for Conchy, we used the rhr package in R (Signer and Balkenhol 2015) to produce kernel density estimates and constructed 50% and 95% occupancy polygons. To evaluate habitat characteristics, we categorized areas throughout Florida Bay using a spatial dataset of Florida Bay substrate types produced by the USGS (Prager and Halley 1997). We chose this dataset because nearly all of Conchy's GPS locations were within the domain of this dataset, and because we were interested in quantifying selection for specific substrate types within this area. We used each GPS and Doppler point returned from Conchy's time in Florida Bay as an indication of habitat selection, and compared proportion of time spent by substrate type to the overall representation of that substrate type in Florida Bay. To test habitat selection, we conducted a G-test in the package RVAideMemoire (Herve 2020) in R comparing the hectares of each substrate type in the USGS South Florida Information Access (SOFIA) dataset (availability) to the number of GPS fixes from each substrate type (usage).

To evaluate movement patterns across times of day (diel patterns) and across monthly intervals, we calculated 6-hour step lengths between consecutive fixes. We compiled GPS fixes collected at ~6-hour intervals and excluded sequential GPS points that were more than ~6 hours because intermediate GPS fixes were not obtained. We calculated the distance moved between these sequential GPS locations in ArcGIS Advanced 10.6.1 (Esri, Redlands, CA, USA). To examine differences in step lengths between times of year and times of day, we used a general linear model with time of day and month-year as categorical predictor variables with an interaction term, and with log-transformed 6-hour step length as a response variable.

To evaluate reporting probability via eBird, we queried the eBird community science portal for reports of American Flamingos within Florida Bay and surrounding ecosystems for the period during which Conchy's transmitter returned GPS points within Florida Bay. This reporting probability is conceptually similar to detection probability, with the distinction that detection probability classically assumes that sampling intensity is known. We examined each eBird checklist for any indication that a sighted flamingo was banded or was equipped with a transmitter. For each report that contained photographic records, we examined photographs for evidence of a band or transmitter. We sorted eBird records into three confidence categories (definitive, probable, or possible) that an observed flamingo was Conchy. Definitive reports included photographs where Conchy's band or transmitter were visible and there was no doubt that the flamingo reported was Conchy. Definitive reports represent our most conservative estimate for reporting probability, and can be interpreted as the probability that a single individual flamingo will be reported and identified over a given time period. Probable reports included both definitive reports and reports that did not include a photograph with a visible band or transmitter but stated that a flamingo was banded or tagged. These reports are very likely to be of Conchy because Conchy was the only known flamingo in Florida Bay with a transmitter or radio during this study period, though this is a less conservative estimation of reporting probability than our definitive category. Possible reports included all sightings of flamingos over the time period, regardless of evidence of band or transmitter (including all definitive and probable reports), and is best interpreted as the probability that any individual of the species will be documented, given that at least one individual is known to be present.

For each checklist, we extracted the date, time, and location. We assigned a value of one to each time point with a report and a value of zero for each time period with no report. We calculated reporting probability for each of our three confidence categories (definitive, probable, and possible) over three temporal scales (daily, monthly, and annually). For our possible reporting probability, for each point estimate of reporting probability, we estimated 95% binomial confidence intervals as a statistical indication of the range of possible values surrounding our point estimates. Finally, from each eBird report we also extracted the number of flamingos because this provides evidence for group size and social structure.

RESULTS

Conchy's transmitter returned GPS and Doppler coordinates between 3 December 2015 and 24 September 2017. Our resulting database included 1,265 GPS locations and 168 Doppler locations over the 661-day period. Of these points, we were able to construct 914 6-hour step lengths. The number of telemetry points returned per month was variable, ranging from 108 points in May 2016 and a low of 4 points in February 2017 (Fig. 2). There was a general low point in number of telemetry points between September 2016 and May 2017.

Habitat selection and movement patterns.—Within 24 hours after release, Conchy flew from the release site near Butternut Key to a mudflat inside Stake Key, which was fringed by mangroves (Figs. 1, 3A, 4A), and most transmitter points returned through December 2015 and January 2016 were from this interior mudflat (Figs. 2, 3A, 4A). In February 2016, Conchy began to visit nearby keys with similar interior mudflats (including Club Key and Bob Allen Key #4; Figs. 1, 2, 3B, 3C, 4A), where he spent considerable time through much of April to September 2016 (Figs. 2, 4B, 4C, 4D). In March 2016, we received the first transmitter coordinate from Snake Bight (Figs. 2, 3D, 4B), although ≤15% of points in any month were returned from Snake Bight until November 2016 (Fig. 2). From November 2016 through May 2017, nearly all of the returned coordinates were from Snake Bight (Figs. 2, 4D, 4E, 4F). We received only a single point from Club Key in June 2017 and continued to receive points from a mudflat within Bob Allen Key #4 in June through September 2017 (Figs. 2, 4G, 4H). The last coordinates returned from Conchy's transmitter were on 24 September 2017 from Snake Bight (Fig. 4H).

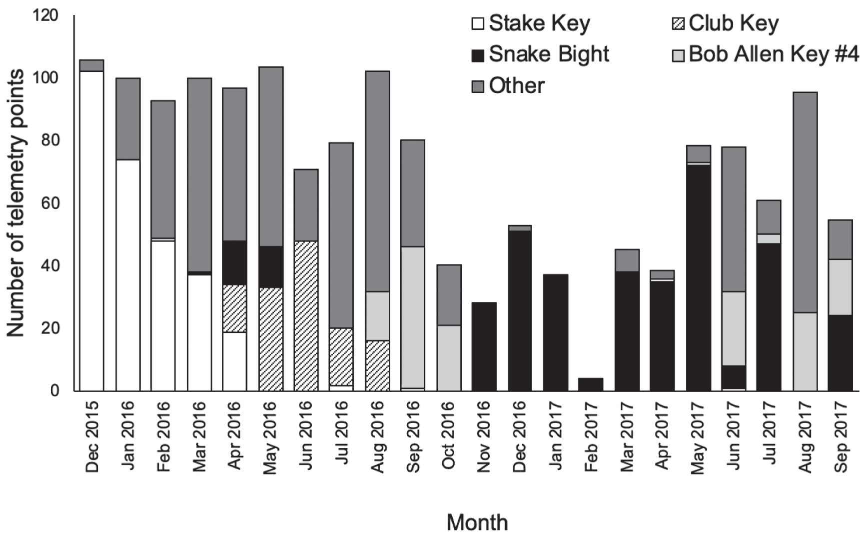

Figure 2. Usage of several key areas used by Conchy (an American Flamingo) in Florida Bay, Florida, illustrated by month. His movement patterns indicate clear temporal shifts in areas used.

Over the entire 22-month period, all but three of the GPS and Doppler fixes were within Florida Bay. One point on 24 May 2016 was in Biscayne Bay near Turkey Point, and two points were just east of Key Largo in January and June 2016. Our 50% core area contour identified four polygons encompassing a total area of 5,704 ha (Fig. 1). One polygon ranged from Snake Bight to Santini Bight, with most points spread between Snake Bight and Garfield Bight (Figs. 1, 3D). The three other polygons each included Stake Key, Club Key, and Bob Allen Key #4 (Figs. 1, 3A, 3B, 3C). The 95% core area contours included two larger but separate polygons, encompassing 66,796 ha (Fig. 1).

There were clear differences in types of substrate used compared to their availability (Figs. 5, 6; G-test, df = 9, G = 1,731, $P < 0.001$). Conchy's transmitter returned far more points on land (including interior mudflats on Florida Bay keys) or on mud bank suite substrates, although these areas only included 29.0% and 11.8% of the area within Florida Bay, respectively. Conchy avoided open water, mixed bottom suite, and hardbottom suite substrates, and avoided all densities of seagrass.

Conchy's 6-hour step lengths varied by month (Figs. 4, 7; $F_{21,871} = 9.52$, $P < 0.001$) and time of day (Fig. 7; $F_{1,871} = 5.94$, $P = 0.015$), but there was no interaction effect between month and time of day ($F_{20,871} = 14.63$, $P = 0.086$). Conchy's travel distances were lowest in December 2015, January 2016, November 2016, December 2016, and

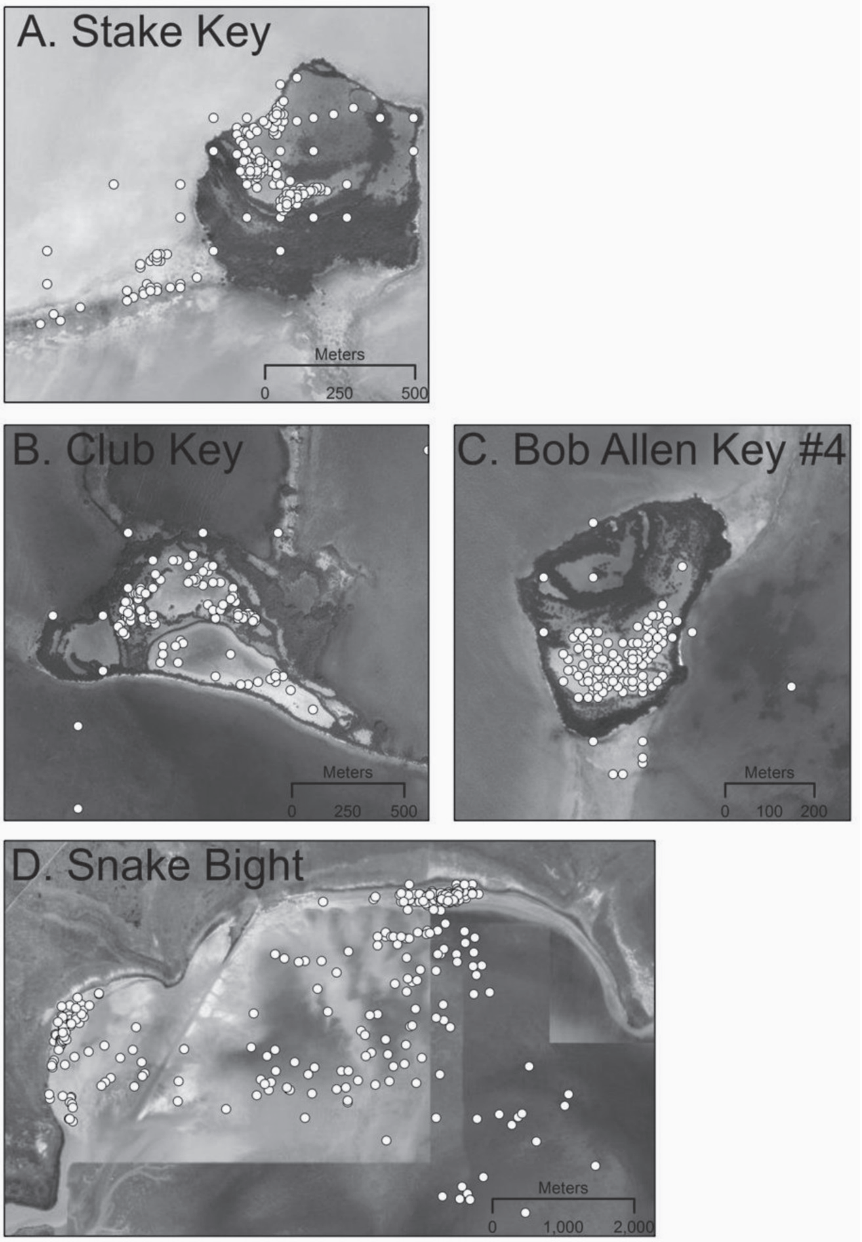

Figure 3. Satellite imagery of four key areas used by Conchy (an American Flamingo) in Florida Bay, Florida, 2015–2017. The three keys shown here (Club Key, Bob Allen Key #4, and Stake Key) each has an interior mudflat and is ringed by a mangrove berm, and Snake Bight is an extensive tidal mudflat in northwestern Florida Bay.

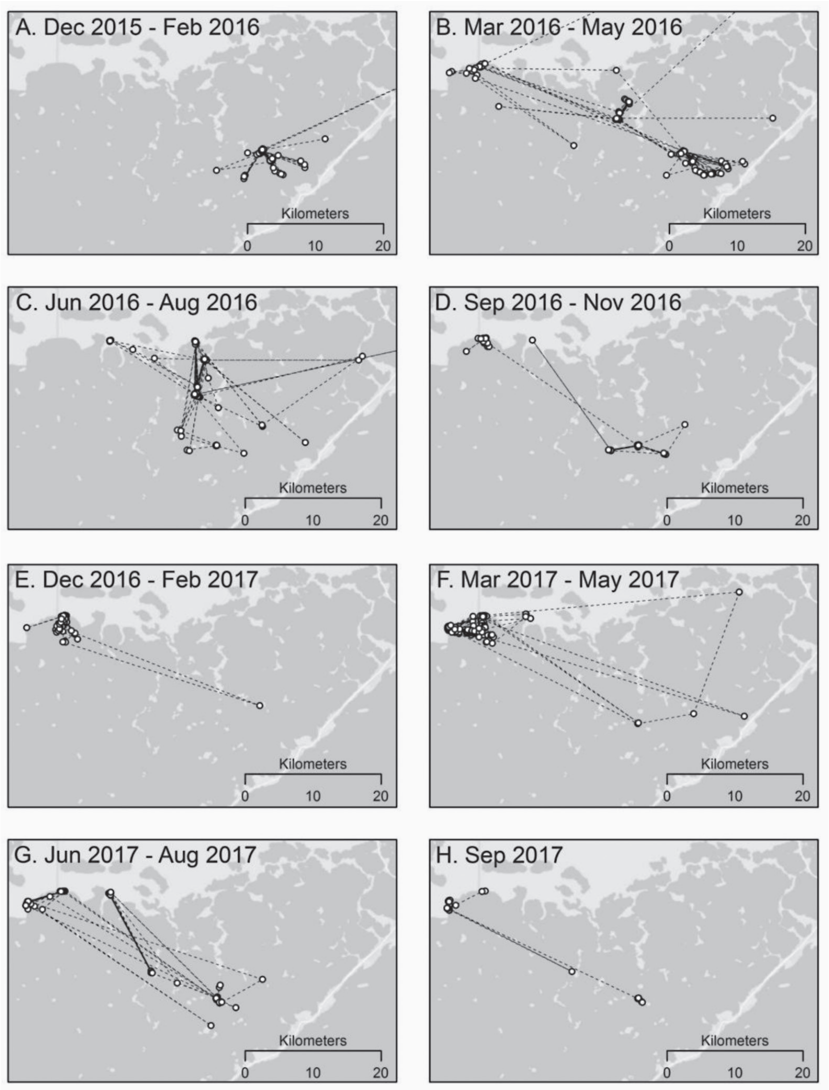

Figure 4. Habitat selection and movement patterns by Conchy (an American Flamingo) in Florida Bay, Florida, as listed by 3-month intervals: A) December 2015–February 2016, B) March 2016–May 2016, C) June 2016–August 2016, D) September 2016–November 2016, E) December 2016–February 2017, F) March 2017–May 2017, G) June 2017–August 2017, and H) September 2017.

September 2017. His greatest average distances were in July and August 2016, July and August 2017, and April 2016. Conchy's greatest travel distances were between 1200 and 1800 hours, and his distances were considerably lower between 0000 and 1200 hours (Fig. 7).

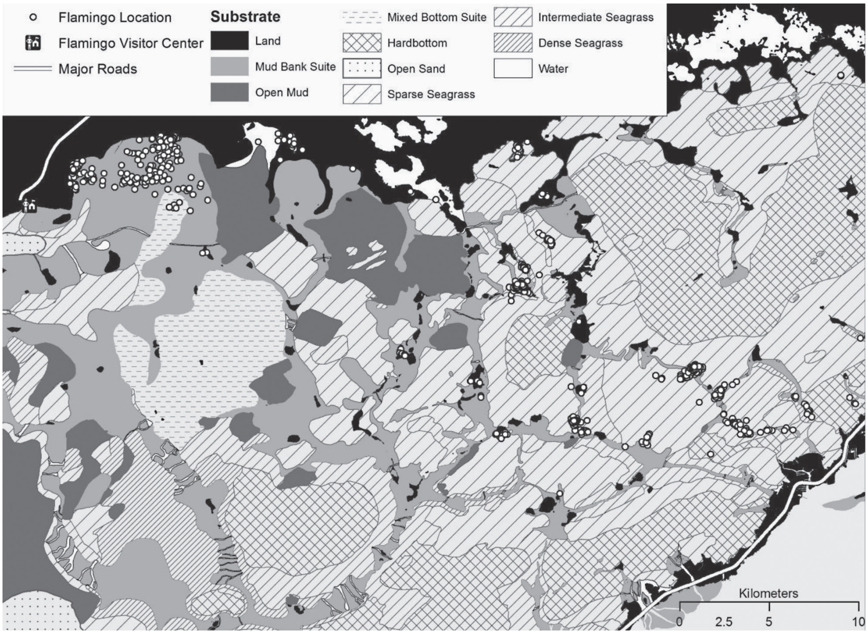

Figure 5. Habitat selection of Conchy (an American Flamingo) in Florida Bay, Florida, 2015–2017, as a function of substrate type. The most important substrate type was mud bank suite followed by land. Conchy selected against remaining substrate types.

Reporting probability through eBird.—Our review of eBird reports yielded 13 definitive Conchy reports, 4 probable Conchy reports, and 9 possible Conchy reports (Table 1). Of the definitive and probable Conchy reports, only two observations were from 2016 and the remainder were from 2017. One definitive report and one probable report were at or near Stake Key (4 January 2016 and 12 April 2016). One possible report was west of Key Largo in December 2016. All 22 remaining reports were from Snake Bight over a relatively short interval between 1 May and 29 July 2017, and 17 reports were from July 2017 alone. During this period of high observations, there were even multiple independent reports from the Snake Bight on the same day (Table 1).

Over the 661 days that Conchy was known to be in Florida Bay, our estimates for daily reporting probabilities were <4% for all confidence categories (Fig. 8), and our 95% confidence intervals indicated that even our highest confidence interval for possible reports was <5%. At the monthly scale, over the 22 months that Conchy was in Florida Bay, monthly reporting probability ranged 13.6% for our most conservative confidence category to 27.3% for our most lax reporting category. For each confidence category, our yearly reporting probability was 100%,

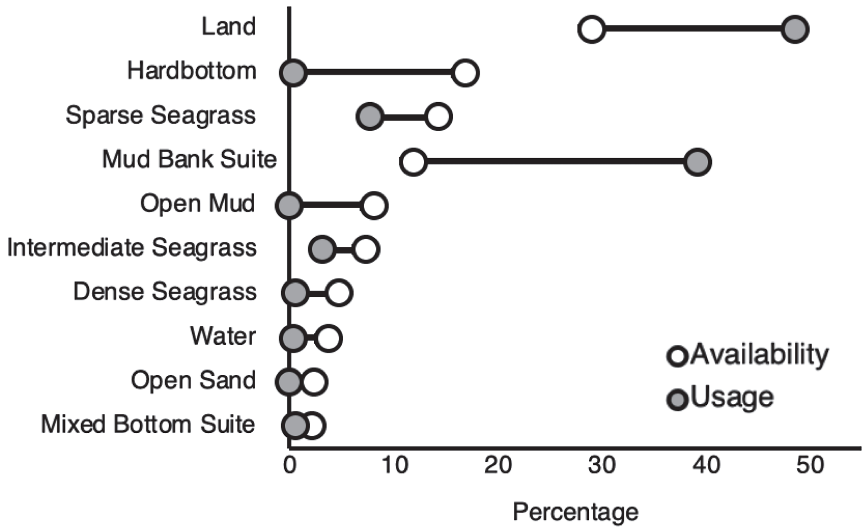

Figure 6. Substrate types selected by Conchy (an American Flamingo) in Florida Bay, Florida, 2015–2017. Conchy strongly preferred land (including impounded ponds on islands) and mud bank suite bottom types.

although our confidence intervals ranged from 15% to 100%, which indicated very low confidence in estimating reporting probability at this temporal scale.

The eBird portal provided additional data on the number of flamingos sighted with Conchy (Table 1). The two observations in 2016 showed him alone, but during May–July 2017 he was typically reported with two additional flamingos.

Discussion

We obtained the first data for habitat selection of an American Flamingo in Florida Bay, and found that flamingos may reside in Florida Bay for nearly two years. We identified four key areas (Snake Bight, Stake Key, Bob Allen Key #4, and Club Key), and two major landscape features (tidal mudflats and interior mudflats) used by this flamingo and others in his small group. We obtained the first satellite telemetry data for this species and identified daily and seasonal differences in movement patterns. Finally, we concluded that eBird has low probability for reporting flamingos, despite their large size and conspicuous nature.

Although our study is restricted to habitat selection and movement patterns of a single individual, Conchy's satellite transmitter returned data that improves our understanding of flamingo habitat selection in Florida Bay. Conchy's transmitter functioned for nearly two

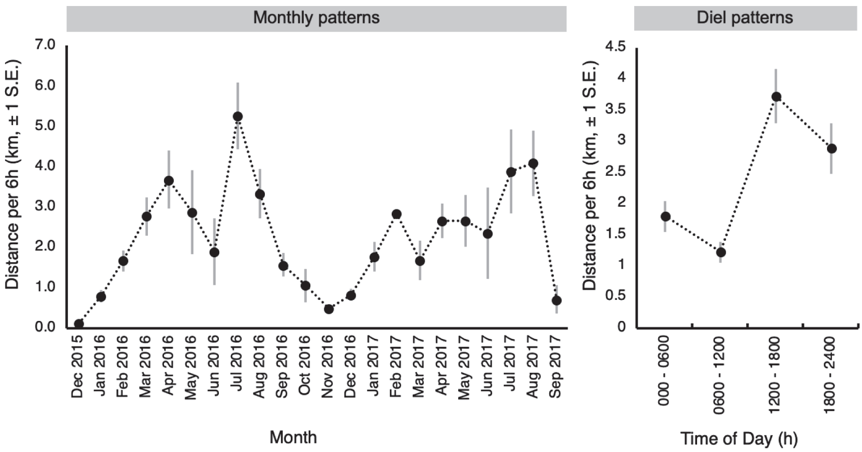

Figure 7. Distances traveled by Conchy (an American Flamingo) in Florida Bay, Florida, 2015–2017, over 6-hour intervals between subsequent location fixes. Conchy moved greater distances in summer months than in winter, and moved greater distances at night than during the day.

years, although the number of GPS points was temporally variable and appeared to decline over the study period (Fig. 2). Likely, the transmitter or antennae suffered some damage from corrosion in the saline environment of Florida Bay and the interior mudflats, or lost the ability to generate solar power through biofouling of the solar panel on the transmitter. However, it is also possible that many GPS fixes could not be obtained if Conchy was foraging in waters that submerged the GPS device or satellite transmitter.

Connectivity and long-distance dispersal.—Ultimately, this study failed to indicate any linkage between Florida's flamingos and foraging or nesting locations outside of Florida. To date, the only evidence for movement of flamingos from the Caribbean to Florida comes from three individual flamingos banded as chicks in the Yucatan of Mexico (Galvez et al. 2016, Welsh and White 2019). However, recent banding programs have been more intensive in the Yucatan than in Cuba or the Bahamas (Arengo and Childress 2004, Galvez et al. 2016), both of which are closer to Florida and have larger overall population sizes. It is unlikely that all flamingos in Florida Bay are of Mexican origin.

Movement between Florida and major nesting areas in the Yucatan, Cuba, and The Bahamas is certainly within normal range of long-distance flights for flamingos (Allen 1956). For example, young flamingos banded in the Yucatan have been sighted in Cuba, Texas, and the Caiman Islands (Galvez et al. 2016). Flamingos banded in Great Inagua in The Bahamas have been resighted in Hispaniola and throughout Cuba (Sprunt 1975). Amat et al. (2005) conducted satellite

Table 1. Sightings of American Flamingos as reported by eBird during the period that Conchy (an American Flamingo) was within Florida Bay (3 Dec 2015–24 Sep 2017). Conchy was sighted on 13 definitive occasions, 3 probable occasions, and 10 possible occasions. A large proportion of sightings were over a 2-month period in June and July 2017.

Date	Observer(s)	Locality	Confidence category	Supporting evidence for confidence category	Number of Flamingos Observed	Citation
4 Jan 2016	P. Frezza and H. Brewer	Stake Key	Definitive[a]	No, cropped from photo[a]	1	https://ebird.org/checklist/S26690793
12 Apr 2016	E. Cantelmo	West of Stake Key	Probable	Description says band or bandage on leg	1	https://ebird.org/checklist/S28902226
19 Dec 2016	T. Davis	Moonbay, Key Largo	Possible	None	1	https://ebird.org/checklist/S33094146
23 Dec 2016	A. Washuta	Snake Bight	Possible	None	2	https://ebird.org/checklist/S33185298
1 May 2017	M. M.	Snake Bight	Probable	Description states band on leg	2	https://ebird.org/checklist/S36466856
22 Jun 2017	B. Showler	Snake Bight	Possible	None	1	https://ebird.org/checklist/S37740114
30 Jun 2017	B. Chou and T. Ford-Hutchinson	Snake Bight	Definitive	Band readable in photograph	3	https://ebird.org/checklist/S37887845
1 Jul 2017	Sam Saunders	Snake Bight	Possible	None	3	https://ebird.org/checklist/S37913859
1 Jul 2017	A. Trentler and B. Trentler	Snake Bight	Definitive	Band and transmitter visible in photograph	3	https://ebird.org/checklist/S37912307
1 Jul 2017	J. Baureister	Snake Bight	Probable	Checklist indicates one flamingo tagged	3	https://ebird.org/checklist/S37919597

[a]In this instance, the observer worked with one of the authors of the present study (JJL) and intentionally cropped the band out of the photograph to prevent undesired attention paid to Conchy by birders in the period shortly after Conchy's release.

Table 1. (Continued) Sightings of American Flamingos as reported by eBird during the period that Conchy (an American Flamingo) was within Florida Bay (3 Dec 2015–24 Sep 2017). Conchy was sighted on 13 definitive occasions, 3 probable occasions, and 10 possible occasions. A large proportion of sightings were over a 2-month period in June and July 2017.

Date	Observer(s)	Locality	Confidence category	Supporting evidence for confidence category	Number of Flamingos Observed	Citation
1 Jul 2017	S. Cotrell	Snake Bight	Definitive	Band code readable in photograph	3	https://ebird.org/checklist/S37903726
4 Jul 2017	S. Olsen	Snake Bight	Definitive	Band visible from photograph	3	https://ebird.org/checklist/S37963315
8 Jul 2017	E. Ahlbrandt	Snake Bight	Possible	None	3	https://ebird.org/checklist/S38036464
8 Jul 2017	C. Hill and M. Hill	Snake Bight	Definitive	Transmitter visible in photograph	3	https://ebird.org/checklist/S38076014
8 Jul 2017	B. Galvin and P. Galvin	Snake Bight	Possible	None	3	https://ebird.org/checklist/S38150128
8 Jul 2017	S. Zuckerman	Snake Bight	Definitive	Band readable in photograph	3	https://ebird.org/checklist/S38035778
12 Jul 2017	T. Witt	Snake Bight	Possible	None	3	https://ebird.org/checklist/S38110342
16 Jul 2017	N. Frade	Snake Bight	Definitive	Band readable in photograph	3	https://ebird.org/checklist/S38170424
21 Jul 2017	A. Yappert	Snake Bight	Definitive	Band readable from photograph	3	https://ebird.org/checklist/S38250405
22 Jul 2017	Y. Morelle	Snake Bight	Possible	None	3	https://ebird.org/checklist/S38264199

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Date	Observer(s)	Locality	Confidence category	Supporting evidence for confidence category	Number of Flamingos Observed	Citation
22 Jul 2017	D. Pettee and D. Bernstein	Snake Bight	Definitive	Transmitter visible in photographs	3	https://ebird.org/checklist/S38268436
23 Jul 2017	D. Olavarria and R. Hattaway	Snake Bight	Definitive	Transmitter visible in photographs	3	https://ebird.org/checklist/S38292048
23 Jul 2017	N. Stuart	Snake Bight	Possible	None	3	https://ebird.org/checklist/S38288652
24 Jul 2017	K. Peart	Snake Bight	Definitive	Transmitter visible in photographs	3	https://ebird.org/checklist/S38307937
27 Jul 2017	E. Rottino, D. Rottino, D. Rottino, T. Rottino	Snake Bight	Definitive	Band readable from photograph	3	https://ebird.org/checklist/S38353310
29 Jul 2017	M. Zimmerman	Snake Bight	Possible	None	2	https://ebird.org/checklist/S38451588

[a]In this instance, the observer worked with one of the authors of the present study (JJL) and intentionally cropped the band out of the photograph to prevent undesired attention paid to Conchy by birders in the period shortly after Conchy's release.

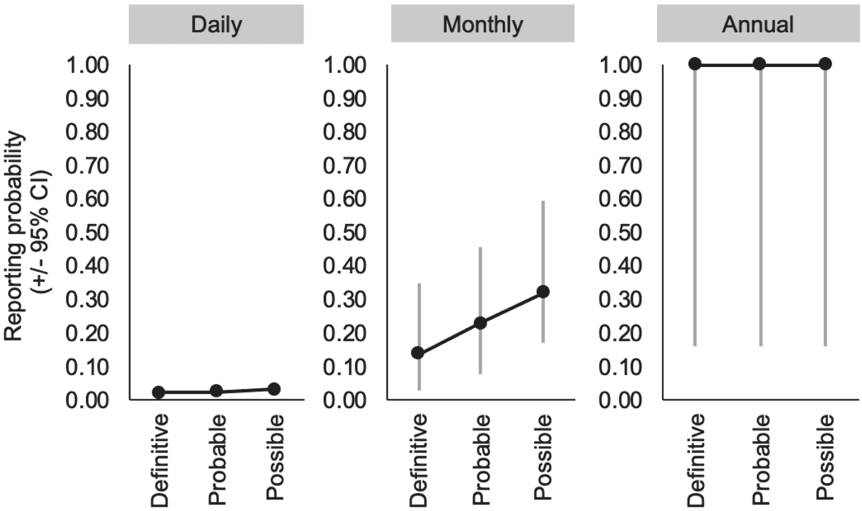

Figure 8. Reporting estimates for Conchy (an American Flamingo) in Florida Bay, Florida, 2015–2017, from the community science portal eBird at three temporal scales (daily, monthly, and annual) and three reporting confidence intervals (definitive, probable, and possible). Each value is the percentage chance of Conchy being reported in the reporting time interval. Error bars for the daily reporting probabilities are obscured by marker points because confidence intervals for these metrics were very small.

telemetry with Greater Flamingos (*Phoenicopterus roseus*) and found that nesting adults foraged up to 200 km from the nesting colony, that flamingos may travel up to 400 km in a single night, and that adults wintered up to ~2,000 km away from nesting sites. Such long travel distances would place Florida within foraging range of nesting colonies in northern Cuba, and within wintering range of all nesting populations of American Flamingos except for the Galapagos Islands.

Habitat associations.—Our analysis using bottom types should provide a preliminary indication of habitat associations. Conchy largely used substrates identified as mud bank suite, which includes areas dominated by carbonate mud or sand where water depth is generally less than 0.6 m in depth. The largest contiguous spatial unit of this substrate in Florida Bay is at Snake Bight, with smaller patches of mostly submerged mud banks spanning between keys and forming divisions between basins in the bay (Fig. 5). The land category in our analysis included mangrove berms ringing Florida Bay Keys and the interior mudflats themselves. These substrate classifications are certainly simplifications that obscure important habitat features for flamingos, yet we are unaware of other existing classification layers for Florida Bay, and reclassification *de novo* is beyond the scope of this study.

Still, Snake Bight and the interior mudflats and salt ponds inside Florida Bay keys differ in a number of important ways. Snake Bight is an expansive (39 km^2) carbonate mud flat that experiences tidal exchange with Gulf of Mexico and has an average daily tide of 1 m that alternately exposes the entirety of the Bight's mud bottom, followed by flooding of up to 0.6 m. Snake Bight is typical in this respect to other estuaries (e.g., Celustun Lagoon in the western Yucatan Peninsula of Mexico) where large concentration of flamingos can be found roosting on large mud banks at low tide (J. J. Lorenz, Audubon Florida, pers. obs.). Conchy's frequent use of tidal mudflats at Snake Bight confirms historical observations of this area as important habitat for flamingos, going back to the mid-nineteenth century (Wurdemann 1860, Scott 1890, Ingraham 1893, Allen 1956).

The interior mudflats are ecologically rather distinct from Snake Bight. Their hydrology is functionally independent from Snake Bight, and from each other. Eastward across Florida Bay, a series of interlocking mud banks and island chains dampens tidal effects, resulting in a diurnal tidal signature <1 cm in northeastern Florida Bay, which is easily masked by even mild winds (Holmquist et al. 1989, Wang et al. 1994). The three islands that Conchy used frequently were further protected from tidal influence by a mangrove fringe that is found on a berm along the perimeter of the islands (Wingard et al. 2019; Fig. 3). The interior mudflats of these islands lay slightly below sea level (Wingard et al. 2019) and are generally isolated from direct surface hydrologic communication with the surrounding Bay. The mudflats dry through evapotranspiration and periodically reflood with Bay water because of strong wind tides (J. J. Lorenz, pers. obs.) or rainfall (G. L. Wingard, USGS, pers. comm.). Although these interior mudflats are poorly studied, salinity normally ranges from 0 to 75 psu (G. L. Wingard, unpublished data), and the mudflats can fluctuate from being essentially dry with isolated and extremely hypersaline puddles (165 psu) to fully flooded with fresh water or ambient salinity bay water in a 24-hour cycle (G. L. Wingard, unpublished data; J. J. Lorenz, pers. obs.). In the event that reflooding events become infrequent, the mudflats gradually dry out over days or weeks depending on the volume of water. Although these biologically harsh conditions keep the interior ponds free of vascular plants, algal communities often form mats that cover the bottom (Wingard et al. 2019). Many of the small fishes and crustaceans typically found throughout Florida Bay's mangrove forests are well adapted to these rapidly fluctuating conditions (Lorenz and Serafy 2006) and are frequently observed within the ponds (J. J. Lorenz, pers. obs). This prey availability probably makes them suitable for foraging by flamingos, but the foraging conditions would be very different than those found at Snake Bight. Use of these interior mudflats as foraging habitat by flamingos has not been previously described.

Diel and seasonal movement patterns.—Conchy's movements varied seasonally and by time of day. The shortest step lengths were in winter months (Figs. 4, 7), and we found considerably longer average distances traveled during summers. We also found that Conchy's movement distances varied by the time of day with much longer distances in the afternoon and evening than before noon. Presumably, these movements indicate tracking of prey availability over time, and are likely influenced by variable hydroperiods of the key areas identified above.

Reporting probability.—Our review of eBird records indicated that reporting probability was low, and was highly inconsistent over space and time. Thirteen of seventeen definitive or probable sightings over a ~2-year period were within a single month at Snake Bight. This was likely the consequence of an initial eBird report in June 2017 that motivated numerous observers to seek flamingos from a known and relatively accessible location. Although a large amount of Conchy's time was spent in interior mudflats, there was only one definitive observation over the 22-month period in these areas. All but three keys in Florida Bay are closed to visitation by people according to Everglades National Park regulations. Clearly, community science observations alone are likely to dramatically underestimate the number of flamingos within Florida Bay and may not produce accurate information on habitat associations. The very low reporting probability we estimated is somewhat surprising given flamingos' large body size, conspicuous coloration, and gregarious nature.

The biases we identified in community science reporting probabilities have implications for our understanding of the number and distribution of flamingos in Florida. Although most flamingos are likely to go unreported, flamingos that are observed may be substantially overcounted if they reside in a small area for an extended period. Unfortunately, there are no ongoing monitoring efforts for flamingos in Florida, despite considerable attention that is devoted to monitoring other species of wading birds in South Florida by state and federal agencies (Frohring et al. 1988, Hunter et al. 2006, Cook and Baranski 2019). We suggest that the low reporting probability we describe underscores a need for systematic monitoring, and we suggest that the habitat associations we identified herein could help optimize a monitoring program in Florida Bay.

Flamingos as year-round residents in Florida.—We did not expect at the onset of our study that Conchy would reside within Florida for nearly two years. Rather, we assumed that flamingos are short-term stopovers in Florida Bay, or intermittent foragers that would return within weeks to foraging areas outside of Florida. Still, Conchy remained in Florida Bay despite two periodic cold snaps (late January 2016 and late January 2017) when air temperatures fell below 8°C. These cold snaps are likely beyond the temperature extremes experienced by flamingos in The Bahamas or the Caribbean, yet they still did not drive Conchy to leave to warmer areas.

There are two likely explanations for Conchy's long residence in Florida Bay. First, it is possible that his residence is atypical and uninformative because as a subadult bird upon capture he may have relied on older and more experienced birds to lead him in long-distance movements. Still, after only his second month post-release, he was consistently seen with adult flamingos that may have provided guidance on flyways or regional movement patterns. Alternatively, it is possible that Florida Bay is still habitat for flamingos—at least of sufficient quality for foraging by small groups. Clearly, historical evidence suggests that Florida Bay did once serve as foraging (and likely nesting) habitat for large flocks of flamingos (Wurdemann 1860, Scott 1890, Holt 1924, Allen 1956, Whitfield et al. 2018), yet human alteration of South Florida's hydrology has had major impacts on the function of Florida Bay (McIvor et al. 1994, Fourqurean and Robblee 1999, Lorenz 2014, Wingard et al. 2019), which may influence contemporary foraging and nesting opportunities. It is currently not possible to empirically evaluate quality of habitat in Florida Bay to foraging or nesting for groups of flamingos, although this seems to be a necessary step to facilitate population recovery.

Other rare flamingo information may help put Conchy's long residency in context. One flamingo (band DFJV) sighted in Everglades National Park in October 2002 was banded in the Yucatan and was sighted again in the Yucatan between 2003 and 2006, which suggests a short-term foraging visit to Florida from Mexico. A slowly growing group of flamingos (up to 147 individuals in 2014) has been observed in Stormwater Treatment Area 2 (Palm Beach County, Florida) during the spring for several decades but has no observations reported for other seasons. Likely, these are periodic foragers visiting from outside of Florida, despite the low and spatially variable reporting probabilities we estimate in this study. Finally, an isolated flamingo in the Florida panhandle has been sighted consistently between 1 November 2018 and the date of this writing (December 2020). It seems reasonable to assume that this is the same flamingo, and its residency is at 25 months as of December 2020—exceeding the duration of Conchy in Florida Bay. Collectively, these data suggest that coastal environments throughout Florida appear climatically suitable for flamingos and that foraging habitat is available. Other species of flamingos do not appear exclusively restricted to tropical climates. Greater Flamingos will winter in southern Europe and multiple Andean species of flamingos live in high elevations where nightly temperatures drop below freezing (Caziani et al. 2007). It is unclear if Florida's coastal environments are outside of the thermal tolerances for American Flamingos—and Conchy's persistence through two cold snaps seems to confirm this point.

Regardless of why Conchy would remain in Florida Bay for nearly two years, increasing reports of flamingos in Florida and documentation of year-round residency are concordant with areas outside of Florida where flamingos appear to be recolonizing their historical foraging and nesting habitat decades after populations were decimated by hunting. For example, flamingos were extirpated from their historical nesting areas in Hispaniola but have been present for decades as year-round residents despite repeated failed attempts at nesting (Wiley 1979, Paulino et al. 2011). Flamingos were also extirpated from Isla Margarita in Venezuela, yet have recolonized and resumed nesting after decades of absence (Sanz D'Angelo 2020). To our knowledge, there is no evidence for nesting of flamingos in Florida since at least the early 1900s (Sprunt 1937, Whitfield et al. 2018), yet the absence of formal monitoring programs and low reporting probability we estimate would make detection of nesting areas unlikely. As urged by Hunter et al. (2006), we argue that systematic monitoring for nesting activity should be a conservation priority for flamingos in Florida.

Transmitter failure and Conchy's fate and future.—Conchy's last transmitter communication was on 24 September 2017. On 10 September 2017, just two weeks before, Hurricane Irma made landfall in the Florida Keys as a powerful Category 4 storm, and its path traversed Florida Bay. High winds and storm surge from Hurricane Irma likely had dramatic impacts on areas Conchy used before the storm. Wingard et al. (2019) showed that Hurricane Irma deposited mud and plant detritus within the interior mudflats, and that storm surge caused a loss of elevation on the surrounding mangrove berms. Snake Bight endured major storm surge as well, which dramatically affected the ecology of that area. Conchy's transmitter showed movement between 11 September and 24 September from Bob Allen Key #4 to Snake Bight and large movements within Snake Bight indicating that he very likely survived Hurricane Irma (Fig. 4H). The disturbances to the Florida Bay ecosystem driven by Hurricane Irma could have motivated a long-distance movement for Conchy (and any other flamingos in his group). It is also possible, though less likely, that Hurricane Irma shifted foraging locations for Conchy and that he has moved into an area of South Florida where reporting probability is even lower than Florida Bay.

After our last transmitter reading, the only circumstantial evidence of Conchy's location at the time of writing this manuscript was an eBird checklist on 5 November 2017: a group of five flamingos reported and photographed at Snake Bight (Forsyth 2017). The photographs are from a considerable distance, and the flamingos in the images are obscured by heat shimmer. Yet inspection of the photographs indicates blue and apparently reflective spots on the leg of one of the flamingos, and we have no explanation for these color patterns other than the blue band and reflective transmitter on Conchy's legs. If our interpretation of this photograph is correct, then Conchy survived after transmitter failure. Further, if Conchy was last sighted with a group of four other flamingos, it increases the probability that he dispersed from Florida with these flamingos directing the path to other foraging or nesting areas.

Though satellite telemetry did not produce information on Conchy's origins, it is possible future observations or analysis may yet provide answers. Flamingos are long-lived and may reach 50 years of age in captivity (Lyngle-Cowland and Lynch 2017) and 49 in the wild (USGS Bird Banding Lab 2020) and have high adult survival. It is plausible that Conchy may be resighted at another location or may reappear in Florida Bay at some point in the future. In Greater Flamingos, juveniles that leave their natal colony for distant foraging grounds in their first or second winter typically return to these same foraging grounds outside of the nesting season later in life (Green et al. 1989). Still, more than three years after his last transmitter coordinates, we have no definitive sightings of Conchy from Florida Bay or elsewhere.

The information we provide herein should help inform evidence-based conservation planning for American Flamingos in Florida, which have surprisingly received virtually no research, conservation, or management attention in the era of modern wildlife conservation. American Flamingos were considered native to Florida in the nineteenth and early twentieth centuries, and remain protected as native species under the United States Migratory Bird Treaty Act of 1918. Their rapid decline in the late nineteenth century generated calls for their protection (Scott 1890, Brodhead 1910). But because the provenance of flamingos in Florida has been uncertain for nearly a century (Allen 1954, 1956; Whitfield et al. 2018), there has been considerable confusion on appropriate management or conservation action for flamingos, and there has been no conservation or management attention by state or federal wildlife agencies. Though a report by USFWS argued that flamingos are a species of regional concern in need of critical recovery attention (Hunter et al. 2006), flamingos have never been considered for protection under the United States Endangered Species Act. At the state level, flamingos are not included in Florida's imperiled species management plan (FWC 2016), and are entirely absent from Florida's state wildlife management plan, which includes all species native to Florida (FWC 2012). However, as of December 2020, FWC is conducting a biological status review to determine the flamingos eligibility for inclusion under Florida's threatened species laws. We expect that findings from this study—multi-year residency of flamingos in Florida Bay, identification of Snake Bight and interior mudflats as potential key habitat associations, and low reporting probability via community science programs—should be directly relevant to the formation of appropriate conservation and management actions for the species.

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