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Remote Ornithology: Studying Nesting Behavior of Bermuda Petrels via Live Webcam

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Running Title: Webcam Study of Nesting Bermuda Petrels

The Bermuda Petrel *Pterodroma cahow* (hereafter, Cahow) is one of the rarest seabirds in the world (Fitzpatrick 2019; Brinkley and Sutherland 2020). After being presumed extinct for 300 years, the species was rediscovered in 1951 (Murphy and Mowbray 1951). Since then, an aggressive restoration program has increased the population (Madeiros *et al*. 2012; Brinkley and Sutherland 2020). A relocation scheme using artificial concrete nest burrows has succeeded in re-establishing a breeding population in Nonsuch Island, off the main island of Bermuda (Carlile *et al*. 2012).

Incubation behavior of *Pterodroma* petrels is difficult to study because of their burrowing and nocturnal behavior (Warham 1990). Although a lot of information is available about petrel breeding biology in general, little is known about the behavior of incubating parents. The advent of webcams has afforded an opportunity to fill this gap in knowledge.

In 2011, Nonsuch Expeditions, a Bermuda-based tour company, installed a live web camera inside an artificial nest burrow in Nonsuch Island, Bermuda, to livestream infrared video and audio. In 2016, they collaborated with the Bird Cams project at the Cornell Lab of Ornithology, resulting in 20 million minutes of footage from three seasons (Cornell Lab Bird Cams 2019). Jeremy Madeiros, Senior Conservation Officer (Terrestrial), in Bermuda's Department of Environment and Natural Resources, made periodic health checks of the nest and posted public updates on Twitter or YouTube (on egg and parental mass, etc.).In this note, we supplemented our own observations with those updates. We also included some observations from a second nest nearby with a webcam.

We observed the Cahow nest (Colony A, nest #831) via webcam for 167.3 hours in 2019, noting behaviors and involuntary movements of parents incubating a single egg. This is the first time an entire study has been done from remote via Webcam. Both parents were moved to the larger and more elevated Nonsuch Island by biologists in 2006 as nearly fledged nestlings from two separate nesting islands nearby. This parental pair has been together since at least 2009. They had produced a nestling successfully for 5 years in a row since 2014 (J. Madeiros via video posted 21 March 2019). The website provided 4 hours of recording at any given time, enabling us to backtrack and make up to 4 hours of observation per access of camera feed. We monitored the nest for all but 9 days of the 55-day observation period. We missed those 9 days due to time conflicts. To ensure a balanced round-the-clock coverage, we monitored our coverage of each hour of the 24-hr clock throughout the study. We coordinated our observation efforts to cover all hours of the day and night. Although some time periods of the 24-hr clock were opportunistically covered better (e.g., 1000-1100 hrs Bermuda time) than others (0200-0300 hrs Bermuda time), we accomplished our goal to observe the nest at all times of the day and night. The percentage of total time observed ranged from 2% at 0200 h to 7% at 1100 h (Bermuda time) (Fig. 1). Almost equal time was spent observing the nest during day (81.4 hours) and night (85.9 hours).

Sexes look alike in Cahows, making sex identification via the webcam feed impossible. So, we based sex identifications on online postings made by Jeremy Madeiros. He reported using external cloacal examination to sex the birds within three weeks of egg-

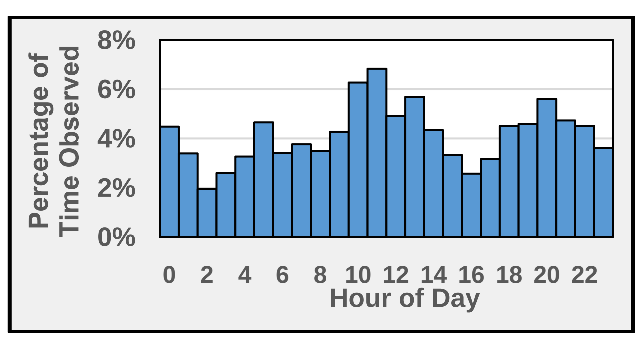

Figure 1. Time of observations.

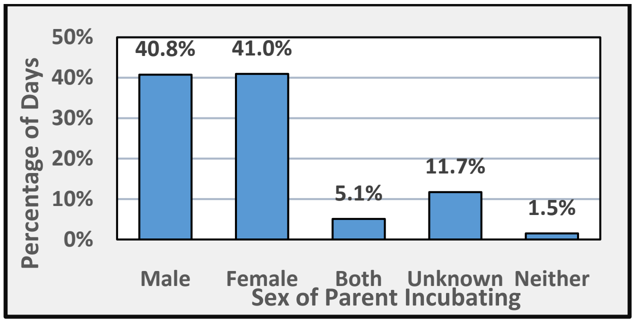

Figure 2. Sex of incubating parent vs. percentage of observation time.

laying. Outside this period, he found that nesting birds consistently showed a significant difference in mass and bill length, which are greater in adult males than adult females (as cited as a personal communication in Brinkley and Sutherland 2020).

We tracked the relative roles played by each parent in incubation (Fig. 2). Both parents contributed equally to incubation. Each was observed an equal proportion of observation time when they were solo in nest. The nest was left unattended only 1.5% of the observed time (Fig. 2).

The female (weighing 359g) laid a single egg (weighing 59g) on 10 January 2019. Our observations started on 11 January. An onsite health check on 17 January recorded the male parent's mass as 397g. Our observations were terminated on 6 March on the 55th day, 5 days after the known incubating time of 50 days from the same parents from the 2018 season. The mean incubation period reported for Cahows is 52.4 days (Warham 1990) and 53 days (Madeiros *et al*. 2012). The first Nonsuch Island chick hatched on 3 March 2019, in another nest. A health check of our nest on 6 March showed that the male had lost 85g since the last check, down to 312g. On 11 March 2019, the 60th day since laying, the egg was examined and found to be not viable. The parent continued incubation. Cahows are known to incubate for "up to a month" after failed incubation (J. Madeiros via video posted 21 March 2019).

We tracked several parental incubation behaviors (with codes used and percentage of observed time in parentheses). Sedentary behaviors of resting (R, 56%) and sleeping with head tucked back (S, 31%) accounted for most of the observed behaviors. We categorized behavior as "resting" when parents' head was upright with eyes open. Wheelwright and Boersma (1979) found that incubating Fork-tailed Storm Petrels spend majority of time sleeping, "often tucking bill under scapulars". Warham (1990) indicated that petrels might sleep with head erect but eyes covered by nictitating membrane. "Comfort movements" (Warham 1990), i.e., preening (P, 5%) and nest maintenance (N, 3%) were also observed. Nest maintenance (rearranging fibers and/or digging ground) was observed 153 times with a mean time of 2.06 minutes per observation. Vigorous nest maintenance of 4–13.5 minutes was observed 22 times. Both parents were observed together in 21 different intervals. During 19 of these, allopreening (PA) was observed constituting 8% of the time while both parents were together. Moving (M) and shuffling around occupied only 1% of observed time. In addition, we noted the following other (O) less commonly observed behaviors: "yawning", wing stretching, head scratching, and adjusting egg with bill, together accounting for 0.5% of observed time. We counted 102 "yawns" (parent momentarily opening mouth wide), 42 wing stretches (parent extending one wing), 45 head scratches (all done over wing), and 41 egg adjustments (parent touching egg with bill to adjust its position) during the observation period. On 5 occasions the pair called to each other while both were in the nest, and on 1 occasion apparent copulation was observed. The attentive period, defined as proportion of time spent incubating was 98.5%; i.e. both parents were away (A) with the egg unattended for only 1.5% of observed time (Fig. 3). This high attentiveness is supported by studies on petrels in general (Warham 1990). We found no evidence of nest-ventilating behavior, wherein parent rises to its feet to expose egg (Grant *et al*. 1982).

Orientation of incubating parent on the nest was noted breaking directions down into 12 equal sectors as in the numbers on a clock, with the camera at 6:00 and 12:00 facing directly away from the camera. The camera was mounted on the side, facing so that the entrance was located at 11:00. The incubating parent

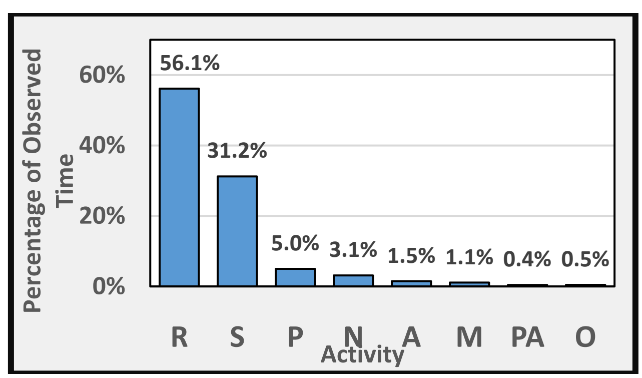

Figure 3. Behaviors of incubating parent as percentage of observation time (R=Resting, S=Sleeping with head tucked back, P=Preening, N=Nest maintenance, A=Away, M=Moving, PA=Allopreening, O=Other)

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faced the entrance of the nesting burrow, orienting within 30° of the opening, 49% of the time. The exact opposite orientation was also common, with the parent facing within 30° of opposite the opening 28% of the time. Orientation perpendicular to the opening was rare (Fig. 4). These observations are supported by Warham (1990), who found that, generally, burrowing petrels face the entrance, apparently to greet a partner or deter intruders.

The presence of a rigidly stationary camera gives the opportunity to observe behaviors and involuntary movements that would be impossible to obtain otherwise. For the first time, breathing rates and headshaking rates were quantified in a seabird. We opportunistically quantified breathing rates (in breaths per minute) of the incubating parent for 189 times during the observation period, by counting the rhythmic heaving movements of the body for a minute. The breath rate of the male was significantly higher than that of the female (Table 1 and Fig. 5; 2-sample 2-tailed *t*-test, $p < 0.0001$, $t = 4.12$). A 95% confidence interval for the difference (male – female) in breath rate was [1.3, 3.7] breaths per minute.

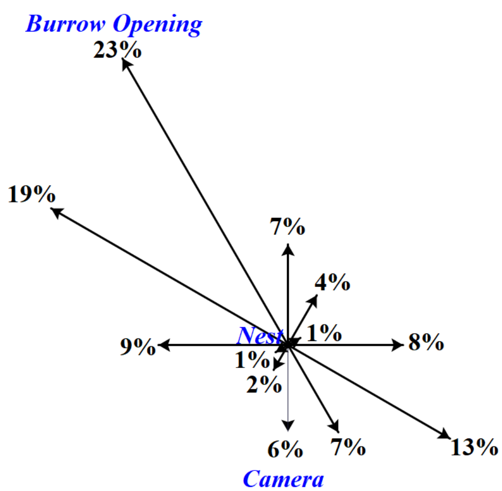

Figure 4. Orientation of incubating parent.

Tube-nosed seabirds are known for their head-shaking behavior while at nest to remove salty secretions from their nostrils. When we observed these head shakes, we recorded the rate of the shakes. Male parent shook head significantly more than the female (Table 1 and Fig. 5; 2-sample 1-tailed *t*-test, $p = 0.016$, $t = 2.44$). A 95% confidence interval for the difference (male – female) in number of shakes was [1.4, 14.0] shakes per minute. It is not clear why this difference was observed, since both parents spent equal proportion of time incubating, and presumably, equal amounts of time foraging and getting exposed to salt. Excel was used to create graphs and calculate basic statistics.

There were 5 incubation shifts (parental "changing of the guard") during our study. This agrees with typical frequency of incubation shifts in other petrels (Brown 1966; Warham *et al*. 1982; Thomas *et al*. 1983; Jouventin *et al*. 1985). Our observations, plus information provided by J. Madeiros on when the parents exchanged places, enabled us to track which days the parents were on the nest. The male was observed at the nest with the female absent for stretches of up to 13 days. Similarly, the female went up to 11 days without relief from her mate (Table 2). The female's return on 22 January, after being away for 8 days, was a surprise. She was expected to be away for 2-3 weeks, leading to a tweet from J. Madeiros

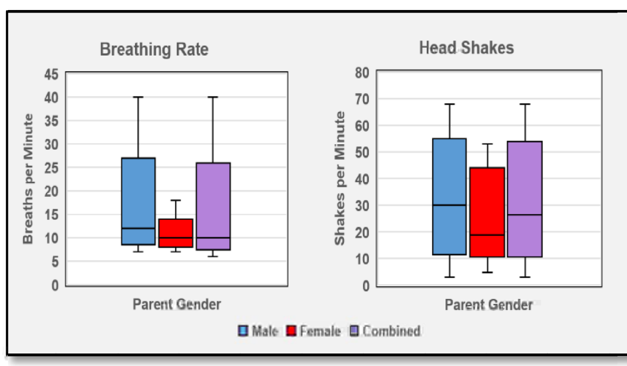

Figure 5. Involuntary movements*

Table 1. Involuntary movements

	Breathing Rates (breaths per minute)			Head Shakes (shakes per minute)		
	Male	Female	Combined*	Male	Female	Combined*
Number of Observations	62	65	189	49	37	96
Median	12	10	10	30	19	26.5
Mean	12.5	10.0	10.7	33.1	25.4	29.6
Standard Deviation	4.4	1.9	1.8	16.0	13.3	14.8

*Combined includes observations when sex of the parent was unknown.

Table 2. Sex of parent in the nest by date. Top line (blue) Male, Bottom line (pink) Female, Black (sex unknown), Shaded dates indicate dates when the authors did not make observations.

January	11		pink	
January	12		pink	
January	13		pink	
January	14	blue		
January	15	blue		
January	16	blue		
January	17	blue		
January	18	blue		
January	19	blue		
January	20	blue		
January	21	blue		
January	22	blue	pink	
January	23	blue	pink	shaded
January	24	blue	pink	
January	25	black	black	
January	26	blue	pink	
January	27	blue	pink	
January	28	blue	pink	
January	29	blue	pink	shaded
January	30	blue	pink	
January	31	blue	pink	shaded
February	1	blue	pink	
February	2		pink	
February	3		pink	
February	4		pink	
February	5	blue		
February	6	blue		
February	7	blue		
February	8	blue		shaded
February	9	blue		
February	10	blue		
February	11	blue		shaded
February	12	blue		shaded
February	13	blue		shaded
February	14	blue		
February	15	blue		
February	16	blue		
February	17	blue		
February	18		pink	
February	19		pink	
February	20		pink	
February	21		pink	
February	22		pink	
February	23		pink	
February	24		pink	
February	25		pink	
February	26		pink	
February	27		pink	shaded
February	28		pink	
March	1	black	black	
March	2	black	black	
March	3	black	black	
March	4	blue		shaded
March	5	blue		
March	6	blue		

Figure 6. Parent burying inviable egg. From CahowCam, Cornell Lab Bird Cams project.

speculating that she probably found food closer to Bermuda than expected. However, the male stayed in the nest with the female for 11 more days (Table 2). Both parents were in the nest for only portions of 11 out of the 55 days (19%) of our observations, supporting Warham's (1990) observations from other petrels that parents seldom return to an incubation partner without relieving it. Both parents often called and preened each other while together, as in the Fork-tailed Storm Petrel (Boersma and Silva 2001). Warham (1990) wrote that incubation shifts are frequent but "rarely seen" in gadfly petrels and other burrowers, but we observed them. On 20 March 2019, one of the parents buried the egg before departing the nest and concluding the effort. It used its breast and wings to push soil and debris from the tunnel to help cover the egg (Fig. 6). It also used its feet to fling debris from the back and over its body on to the egg in front. This is the first time egg-burying behavior has been recorded in petrels.

We do not know if the behaviors we observed are characteristic of the species, considering that we only observed a single nesting pair for one season, and the nesting attempt was unsuccessful. We encourage future research using our methods to ascertain if behaviors remain consistent across successful nesting attempts. It is typical of this species to lay one egg per year. By producing a nestling successfully for 5 previous years, this pair had outperformed the norm of reproducing once every other year or 2 out of every 3 years for this species. Egg failures can be up to 40% in the entire colony (J. Madeiros, video posting dated 21 March 2019).

The incubating parents shared the nest burrow with a pholcid spider and several ants. Sometimes the ants swarmed on the apparently unperturbed parent. On 16 May 2019, the webcam filmed a land crab (*Cardisoma guanhumi*) eat the inviable egg. In the other nest with a webcam, a land crab was filmed on 29 May 2019, entering the burrow with a nestling inside. The crab scurried away after the nestling woke up and moved. This suggests that land crabs eat eggs but not nestlings. It is not clear if land crabs can be classified as egg predators, because they may only scavenge unattended or inviable eggs. The endangered Bermuda skink (*Plestiodon longirostris*) was seen inside the nest

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burrow post-season (17 May), when it was empty. For five years in a row since 2017, another webcam in the island recorded a Leach's Storm-Petrel (*Oceanodroma leucorhoa*) visiting and staying in an active Cahow nest burrow (Cornell Lab Bird Cams 2021). The list of intruders also includes an aggressive young Cahow prospecting for a nest site (Cornell Lab Bird Cams 2017).

This study would not have been possible without the collaboration between The Cornell Lab of Ornithology, Nonsuch Expeditions, and Jeremy Madeiros of Bermuda's Department of Environment and Natural Resources. Technology such as this opens many new avenues of data collection resulting in observations previously deemed impossible or impractical. Furthermore, making this video stream public allows for remote observations from around the world. The authors were able to perform these observations from Arkansas and New York without having to visit Bermuda. This study is especially unique since the authors have never seen a Cahow in person, yet they were able to make observations from the comforts of their offices or homes thousands of kilometers away. We encourage similar efforts to further the ability to do research of this kind and make the information widely available. It will also help surpass logistic and financial hurdles in conducting field studies and encourage the future use of webcams by teachers for collaborative citizen science investigations in their classrooms. The study was initiated as a special high school science project by one of the authors (TC).

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