Prothonotary Warbler Conservation and Monitoring Report
November 2018

A Report of the:

Barataria-Terrebonne National Estuary Program

By:

Natalie Waters, Bird Conservation Coordinator Barataria-Terrebonne National Estuary Program

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Introduction

Background Information

The destruction of suitable habitat is a fundamental issue responsible for the decline of countless animal and plant species alike. Because of this significant ecosystem issue, populations of breeding birds continue to be threatened by the fragmentation and degradation of natural habitats (Hoover 2009, Wilcove et al. 1998, Askins 2000). This is especially true for birds that depend upon a highly specific habitat to live and successfully reproduce, such as the Prothonotary Warbler (*Protonotaria citrea).*

The Prothonotary Warbler is a Nearctic-Neotropical migrant songbird that inhabits wet forests throughout its range, breeding primarily within swamps, bottomland forests, and other forested wetlands in the southeastern, midwestern, and eastern United States (Petit 1999). It is one of only two species of wood warblers regularly nesting in tree cavities (Bent 1963, Morse 1989). Habitat specificity and a tight link to hydrological processes make Prothonotary Warblers well suited to be indicator species of habitat quality (Hoover 2009).

The species is suffering from overall population declines due to habitat losses in both breeding and wintering grounds. Breeding Bird Survey trend data between 1966 and 2012 indicate long-term average decline of -1.1% annually throughout the United States and -1.8% in Louisiana (Sauer et al 2014). Bottomland hardwood forests, the prime breeding habitat, have been logged or converted to pasture or cropland and only 10% of the original bottomland forest in the lower 48 states remain (Petit 1999). Prothonotary Warblers wintering areas include the Caribbean, Central America, and northern South America (Wolf and Johnson 2015 as cited in Janssen 1987, Ridgely and Gwynne 1989, Stiles and Skutch 1989, Walkinshaw 1991, Robbins and Easterla 1992). Habitat destruction in important wintering areas in the tropics has significantly increased since 1966 (Spalding et al. 2010).

Numerous research and conservation organizations emphasize the importance of developing full life cycle modeling to better understand the limiting factors related to priority bird species such as the Prothonotary Warbler. Full life cycle modeling will allow researchers and conservation organizations to determine the life stages and geographic regions that should be targeted for conservation action.

In an effort to implement conservation actions and to collaborate with other conservation organization's primary goals for the species, the Barataria-Terrebonne National Estuary Program (BTNEP) and the Barataria-Terrebonne Estuary Foundation (BTEF) initiated its Prothonotary Warbler project in the spring of 2016. The primary goals of establishing a Prothonotary Warbler project are to promote the conservation and awareness of the species, increase the nesting success of the species, and to further contribute to the Prothonotary Warbler Working Group's conservation goals to promote full life-cycle modeling. BTNEP conservation actions include the establishment of nest box trails throughout the estuary, data collection to assess breeding demographic rates, community outreach, and to sponsor the use of geolocators to identify connectivity between breeding and wintering grounds.

Methods

Nest Box Installation and Research Area

The project initiated in the spring of 2016 with the establishment of a nest box trail within Brownell Memorial Park and Carillon Tower in Morgan City, Louisiana. Sixteen nest boxes were developed by a local Boy Scout troop. The nest box entrance holes were drilled to 1 ¼ inch in diameter to prevent Brown-headed Cowbirds from entering and parasitizing nests. Nest boxes were mounted on a ten-foot long, metal conduit pole and equipped with an 18-inch conical baffle to deter predators. The nest boxes were placed ~30-40 meters apart along the trail. The 9.5 acre park sits along the edge of Lake Palourde and is bordered by ~200 acres of cypress-tupelo swamp habitat (Figure 1). The main overstory tree species found along the ¼ mile trail include bald cypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*). Other common trees include the swamp red maple (*Acer rubrum var. drummundii L.*), and black willow (*Salix nigra*).

The following spring in 2017, BTNEP staff built seventy new nest boxes. The nest box design utilized was from *Audubon Birdhouse Book: Building, Placing, and Maintaining Great Homes for Great Birds*, written by Margaret A. Barker and Elissa Wolfson. One 1”x4”x8’ cedar board produced two nest boxes. The entrance holes were drilled to 1 ¼ inch in diameter to prevent Brown-headed Cowbirds from entering and parasitizing nests. Nest boxes were mounted on a ten-foot long metal conduit pole and equipped with an 18-inch conical predator guard (Figure 1).

Figure 1. 70 new Prothonotary Warbler nest boxes were constructed and installed in three new locations within the estuary in 2017.

The seventy nest boxes were divided among three new nest trail sites to expand the research effort and to increase public awareness about the species. The nest box trail sites developed in 2017 were installed within the following locations: 1. Northwest Lake Palourde/Avoca Island Cutoff Canal, Morgan City, Louisiana, 2. Mandalay National Wildlife Refuge, Houma, Louisiana, 3. Lockport Elevated Wetlands Boardwalk, Lockport, Louisiana (Figure 2).

Figure 2. Three new Prothonotary Warbler nest trails were developed in southeast Louisiana, 2017

Lake Palourde is a part of the many interconnected swamps, streams, lakes and waterways that form the Atchafalaya Basin. This natural lake covers a surface area of 17 mi^2 and has an average depth of 5 meters. BTNEP developed a new Prothonotary Warbler nest box trail located on the edge of Lake Palourde and within the Avoca Island Cutoff Canal north of Lake

Palourde in St. Martin Parish. Thirty Prothonotary Warbler nest boxes were installed ~100 meters or more apart near the banks of the waterways. The nest boxes are only accessible by boat. Due to logistical complications, nest boxes that were only accessible by boat were installed later in than originally planned. The Lake Palourde/Avoca Island Cutoff Canal nest boxes were installed May 19th, 2017 and the first nest check took place on May 25th, 2017, therefore we missed a large portion of the nesting season (April-early July) at this site during the 2017 season.

The Mandalay National Wildlife Refuge conserves 4,416 acres of freshwater marsh and pond habitat. The refuge is located in Terrebonne Parish, five miles southwest of the city of Houma, Louisiana. The refuge also contains small ridges and spoil banks, which provide suitable habitat for trees such as bald cypress cypress (*Taxodium distichum*), water tupelo (*Nyssa aquatica*), red maple (*Acer rubrum var. drummundii L.*), and black willow (*Salix nigra*). Thirty boxes were installed within or adjacent to Mandalay National Wildlife Refuge. Ten Prothonotary Warbler nest boxes were placed ~50-100 meters apart along the refuge's ¾ mile nature trail. The trail is located at the end of a gravel road, 0.7 miles west of the refuge field office on the south side of Bayou Black Drive (Hwy 182). The remaining twenty boxes were installed along waterways within Hanson Canal and a dead-end canal just south of the Hanson Canal and the Intracoastal Canal. Due to logistical complications associated with the boat transportation, the twenty nest boxes that were only accessible by boat were installed later in the season than originally planned. The nest boxes were installed the May 5th, 2017 and the first nest box check took place on May 11th, 2017. The nest boxes along the trail were installed in early March and the first nest check took place on March 31, 2017.

The Lockport Elevated Wetlands Boardwalk is located in Lafourche Parish, just off of Louisiana Highway 308 near the Lafourche Parish School Board's Career Magnet Center. The 440 feet boardwalk lies within an isolated tract of ~50 acres of mixed forested wetland habitat. Ten Prothonotary Warbler nest boxes were installed throughout the area of the boardwalk in early March. The first nest check took place on March 29, 2017.

Nest Box Monitoring Protocol

The nest data collection and datasheets followed the Cornell Lab of Ornithology's Nest Watch Program protocols, which are based on the nationally recognized Breeding Biology Research and Monitoring Database (BBIRD) Field Protocol. The nest box metadata included site name, box or natural cavity, nest ID, GPS coordinates, cavity orientation, and habitat type. During each nest check, nest status (none, incomplete, complete), number of eggs, number of chicks, approximate development stage of chicks, adult status, young status and management activity were recorded.

Additional data collection included, female and male band number if applicable, female and male age if applicable, nest initiation date (based on the life history of species using nest boxes, eggs were assumed to have been laid one day apart), and number of young fledged (or survival to day eight or nine). The species using the nest box was determined by visual observation of parent and egg identification. Success was defined as at least one chick fledging from the nest. If the nest was empty with no signs of predation (disturbed or partial removal of nest material, feathers or dead chicks on the ground, etc), and the previous check revealed chicks were near the fledge date (day 8-9 or older), the nest was assumed successful. If the nest was not checked near the fledge date and no signs of predation occurred, then the final nest fate was recorded as unknown. Nests were visited 1-2 times a week, depending on accessibility. Nest boxes that were accessible only by boat were visited once a week as weather permitted.

Nest failure was determined by 1) abandonment 2) predation 3) infertile eggs 4) nest box takeover 5) Other. Dead nestlings removed from the nest, missing eggs, disturbed or destroyed nests were indicative of predation. If predation was considered to have occurred, an attempt to identify the specific predator associated with the event (i.e. nest material pulled out of nest box is usually indicative of a mammalian predator). Nest parental abandonment was listed to have occurred when no adults were recorded tending to the nest and the eggs failed to hatch within the species' approximate incubation time. Nest boxes were assumed to be taken-over if a new nest was found built on top of the previous tenant's nest. If this occurred, the previous nest was recorded as failed and a new nesting attempt began with the arrival of the first egg.

Prothonotary Warbler Banding Protocol

Adult male Prothonotary Warblers were captured near the nest boxes using target mist netting techniques where male song is played and a decoy is placed near the mist nests. Adult females were captured when incubating within the nest box by placing a hand held-net in front of the entrance hole. The hand-held net was made of a plastic mesh lemon bag affixed to the end of a plastic rod (~4 ft. long) using pliable metal wire.

Banding measurements and data collection included non-flattened wing chord, mass (nearest 0.1g using a digital scale), molt cycle code, sex, and age based on plumage characteristics described in the *Identification Guide to North American Birds Part 1* by Peter Pyle. The adult birds were banded with USFWS size 0 metal bands and XFD darvic leg bands I/D 2.3mm with a site-specific unique color combination so birds could be identified as an individual. Adult Prothonotary Warblers that were captured in boxes that were only accessible by boat received only size 0 metal bands on the right leg of the bird for recapture purposes, but did not receive darvic color bands due to limited re-sight capabilities within these locations. Nestlings were banded between the ages of 5 – 8 days old with USFW size 0 metal bands. Nestling banding measurements included the mass and age estimate to the nearest day (using pictures in Podlesak and Blem, 2002). Banding data was compiled and submitted to the Bird Banding Laboratory after the conclusion of the breeding season.

Additional Nest Site Habitat Data

Figure 3. Tree canopy coverage above nest box

Tree basal area and canopy coverage data was collected at each nest box during the 2018-breeding season. Basal area data was gathered by using the wedge prism (BAF 20) method. We completed a 360-degree sweep of the area next to each nest box and tallied the number of trees that are 'in' the prism and every other tree that was 'borderline'. We estimated canopy coverage by taking a photograph of the tree canopy directly above the nest box using a Nikon D3100 digital camera with an 18-55mm lens. Canopy closure estimates were calculated using the program ImageJ. Each image was converted to a binary black and white image allowing the software to distinguish pixels representing the canopy from those representing the open sky. The number of 'closed' pixels divided by the total number of pixels and then multiplied by 100 provided the percent canopy closure estimate for each photo. This data will be further analyzed within the next report.

BTNEP Project History

2016 Season Summary

In order to promote environmental stewardship and to educate the local youth about the species, BTNEP hosted a Prothonotary Warbler nest box-building workshop with Boy Scout Troop 453. The workshop began by educating the troops about the species, its life cycle, and habitat specifications along with identifying contributing factors that has led to the species overall population decline and what actions we can do to help the species. The Boy Scout troops then proceeded to build the boxes by following the printed schematics given to them and using the pre-cut cypress wood kits developed specifically for the workshop. The nest box entrance hole was 1 ¼" to deter Brown-headed Cowbird parasitism. The boxes were later mounted on ¾" electrical metallic tubing (conduit). Sixteen nest boxes were placed along the trail throughout Brownell Memorial Park and Carillon Tower and the GPS coordinates of each nest box was recorded. Each nest box was given a unique alphanumeric ID and labeled with permanent marker. The nest boxes were then equipped with an 18-inch metal conical baffle onto the pole to deter predators.

Nest box monitoring began at Brownell Memorial Park and Carillon Tower in mid March 2016 and continued throughout July. The use of artificial boxes by these warblers has been well documented (Fleming and Petit 1986, Petit et al. 1987, Blem and Blem 1991, 1994). The size of the breeding population depends on availability of suitable nest sites and flooded forest habitat. Breeding density can be increased 5-6 times with the addition of nest boxes (Petit

1999). Many similar long-term studies have been conducted while monitoring Prothonotary Warblers. The Virginia Commonwealth University began Prothonotary nest box studies in 1987 and it continues to this day. More than 26,000 Prothonotary Warblers have been raised from their boxes, likely being the reason that Virginia is one of the few states where the population is increasing (Vcu.edu 2014).

During the 2016 nesting season at Brownell Memorial Park and Carillon Tower, a total of 9 Prothonotary Warbler nesting attempts were recorded utilizing the newly installed nest boxes. Overall, a total of 34 Prothonotary Warbler chicks hatched within the nest boxes. Seven out of the nine Prothonotary Warbler nest attempts within the nest boxes produced fledglings (assumed fledged when chicks reached day 8-9), a nest success rate of 78%. An estimated total of 30 fledglings were raised within the nest boxes.

A total of 17 adult Prothonotary Warblers were banded at Brownell Memorial Park during the 2016 breeding season. Mist nests were set up near nest boxes to target and capture territorial males. A total of nine adult males were banded, five out of the nine received only USGS metal bands and four adult males received both USGS metal bands and a unique (for the site) color combination darvic leg bands I/D 2.3mm. Five adult females were captured while incubating within the nest box by placing a hand held-net in front of the entrance hole of the box and three were captured passively using a mist net when targeting territorial male warblers. Six out of the eight females that were banded were documented nesting within a nest box. Three banded males were observed feeding young at a nest box. The age composition of females that were banded revealed that the majority of females observed nesting in the nest boxes were aged as second years birds, signifying this breeding season was their first year to breed. The majority of the adult male Prothonotary Warblers that were netted were aged as ASY (after second year) birds, indicating that this was not their first breeding season.

In early June 2016, the Director of Bird Conservation for Audubon Louisiana, Dr. Erik Johnson, outfitted two adult females nesting within a nest box at Brownell Memorial Park with light level geolocators. Geolocators use a light sensor to generate and store light level data at regular intervals. Day length varies with latitude while time of solar noon varies with longitude, therefore by measuring these variables, scientists can determine the general location of the tagged individual. In order for the data to be extracted and processed from the geolocator, the bird must be recaptured the following breeding season to remove the geolocator and analyze the data. Audubon Louisiana, along with several other entities that belong to the Prothonotary Warbler Working Group, have been deploying geolocators on Prothonotary Warblers to better understand connectivity between breeding and wintering grounds, identify patterns of migration and important stopover and wintering regions.

Figure 4. June 9, 2016. ASY female Prothonotary Warbler nesting in nest box B12 was one of two adult females to receive a geolocator at Brownell Memorial Park and Carillon Tower, Morgan City, Louisiana.

One of the females that was equipped with a geolocator within Brownell Memorial Park was recorded nesting in box B05 and was aged as a SY female. The female was observed incubating her nest with four eggs on the following nest check visit after the geolocator was attached. The following nest checks revealed that she was no longer incubating the nest nor was she observed again throughout the season, resulting in a failed nest attempt due to nest abandonment. The second adult female equipped with a geolocator at Brownell Memorial Park was an ASY female nesting in box B12 with a four-egg clutch (Figure 4). After banding and attaching the geolocator she continued incubating her nest and produced three fledglings. During the 2016 breeding season no chicks were banded while in the nest box, but future monitoring will attempt to band nestlings. Eleven Prothonotary Warbler hatch year birds were caught while mist netting for adults and were banded with USGS metal bands.

2017 Season Summary

A total of 52 Prothonotary Warbler nest attempts were observed during the 2017-nesting season across the four sites monitored listed in Table 1. Two hundred five Prothonotary Warbler eggs were recorded with an overall hatch success rate of 80%. The average clutch size across all sites was 3.94 eggs per nest. One hundred fifty-three live young were documented, averaging 3.12 nestlings per nest (Table 2). The earliest nest initiation date was recorded on April 4th at Brownell Memorial Park and Carillon Tower, Morgan City, Louisiana.

The 30 newly installed nest boxes at Lake Palourde and Avoca Island cutoff canal had the highest number of Prothonotary Warbler nest attempts despite the nest boxes being installed during the second half of the breeding season due to logistical complications. The first nest check date at the Lake Palourde/Avoca Island Cutoff Canal took place on May 25th, 2017. The Brownell Memorial Park and Carillon Tower nest trail experienced an increase in nest attempts from the previous year from 9 attempts in 2016 to 15 attempts in 2017.

Table 1. The proportion of nest boxes used by Prothonotary Warblers during the 2017 season.

Site	No. Nest Boxes Present	Nest Box Occupancy by PROW	No. Nest Attempts
Brownell Memorial Park	16	11/16 (0.69)	15
Lake Palourde/Avoca Island Cutoff Canal	30	23/30 (0.77)	27
Mandalay NWR	30	8/30 (0.27)	9
Lockport Boardwalk	10	1/10 (0.10)	1
Total	**86**	**43/86 (0.50)**	**52**

Table 2. Prothonotary Warbler nest results from four study sites across southeastern Louisiana during the 2017 season.

Site	No. Boxes Monitored	No. Active Nests Monitored	First Egg Date	Mean Clutch Size	Mean No. Nestlings/Nest (all attempts)	Mean No. Fledged/Nest (Known Fate)	Total No. Known Fledglings	Total No. Unknown Fledglings	Raw Nest Success (%)	Unknown Final Fate (%)	Failed (%)
Brownell Memorial Park	16	15	4-Apr-17	4.30	3.27	3.23	42	4	73.4	13.3	13.3
Lake Palourde/Avoca Island Cutoff Canal	30	27	n/a	3.7	2.81	2.53	43	27	48.2	37.0	14.8
Mandalay National Wildlife Refuge	30	9	10-Apr-17	3.9	3.44	3.5	6	10	66.7	33.3	0.0
Lockport Boardwalk	10	1	13-Apr-17	6.0	6.00	6	21	0	100.0	0.0	0.0
TOTAL	**86**	**52**		**3.94**	**3.12**	**3.03**	**112**	**41**	**59.6**	**28.8**	**11.5**

The proportion of nests known to be successful across all sites was 59%, however, a high proportion of final nest fates were recorded as unknown, mainly caused by limited access to nest boxes that could only be accessible by boat. Nest checks were once a week by boat and inclement weather occasionally delayed nest checks. For example, if the nest check revealed chicks present at the approximate age of 5-6 days old, the chicks weren't close enough to their fledge date to assume the nest is successful and the proceeding nest check a week later will be passed their estimated fledge date.

No signs of predation occurred within the nest boxes during the 2017 season. All nests recorded with a final fate of unknown possessed fecal sacs and a flattened nest cup, indicative of the presence of older nestlings. If the proportion of nest attempts recorded as unknown were assumed to be successful, nest success would increase to 88%.

Six out of the 52 nest attempts resulted in definite failure. A total of three nests across all sites were abandoned, two at Brownell Memorial Park and 1 nest at Lake Palourde/Avoca Island Cutoff Canal. Three nest attempts failed due to nest box takeover at Lake Palourde/Avoca Island Cutoff Canal. The eggs were buried with nest material by another female Prothonotary Warbler and a new nest attempt began with the arrival of the first egg.

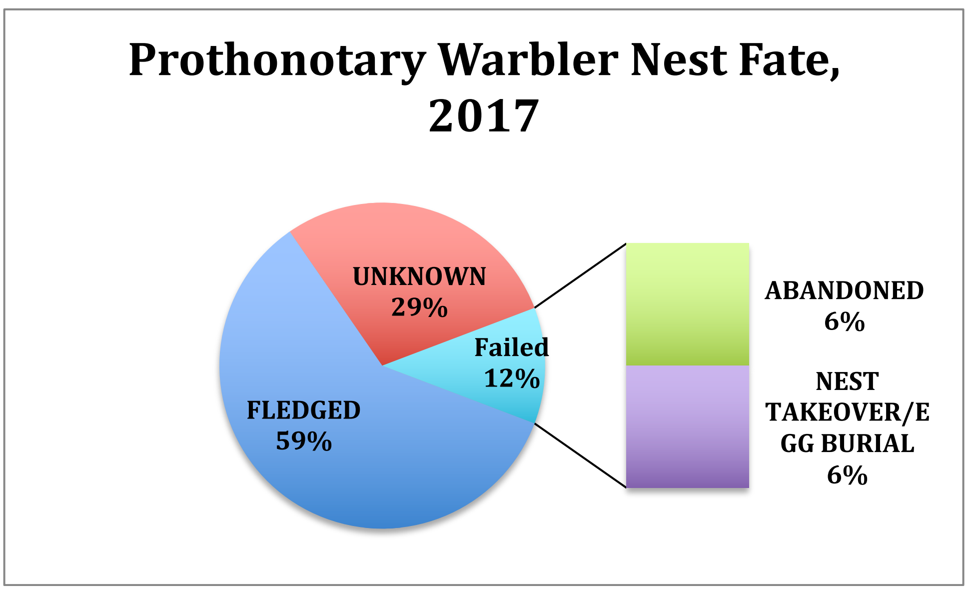

Figure 5. Nest fate across all BTNEP nest box sites monitored during the 2017 season (N=52 nest attempts)

Monitoring for the 2017 breeding season at Brownell Memorial Park and Carillon Tower began on March 28, 2017. Three color-banded individuals that were banded during the 2016 season were observed that day, two males and one female. The banded female initiated nest building in nest box B09, the same nest box she nested in the previous season. Eight out of the twelve color banded individuals were recaptured/re-sighted during the 2017 breeding season at Brownell Memorial park, a return rate of 66.7%.

The highlight of the season was re-sighting and recapturing one of the two females equipped with a geolocator on June 9, 2016. The ASY female, band number 2750-86678, was re-sighted on April 6, 2017 while she was carrying nest material into nest box B11, approximately 40 meters from her previous nest site in box B12. On April 11, 2017 she was recaptured, band data was recorded, and the geolocator was safely removed and returned to Audubon Louisiana for data analysis and compilation. The female continued nest building in nest box B11 and successfully raised six young.

The data obtained from the geolocator revealed the bird's extraordinary migratory journey (Figure 6). She began her fall migration to her wintering grounds in early August 2016. She arrived on the Yucatan Peninsula by August 10, 2016 and continued southward thru Central America until reaching her wintering grounds in Northern Columbia by the end of September 2016. By March 1, 2017 she had left her wintering home to return to her breeding grounds in Louisiana. She returned to Brownell Memorial Park by the end of March, completing her spring migration in just a few weeks time. The data have been combined with 33 geolocator recoveries from 6 states into an analysis and scientific manuscript that Audubon Louisiana has submitted with PROW Working Group partners for peer-review and publication.

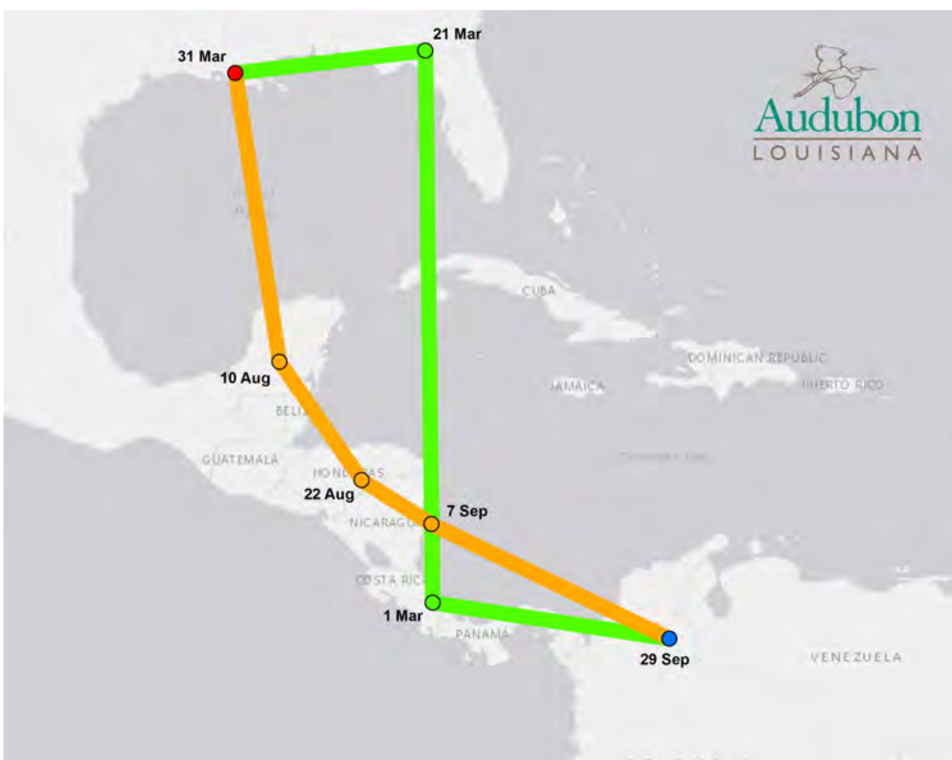

Figure 6. Estimated migratory routes of a Prothonotary Warbler, band number 2750-86678, fitted with a geolocator at Brownell Memorial Park and Carillon Tower, Morgan City, Louisiana. Map and data source: unpublished data, Audubon Louisiana.

A total of 141 Prothonotary Warblers were banded during the 2017 season. The majority of the banded Prothonotary Warblers were nestlings (L) present within the nest boxes. Both adult males and females utilizing nest boxes were targeted for capture if the nest boxes were accessible by foot. Adult females were captured while incubating inside nest boxes with boat only access, but no attempts were made to catch the male Prothonotary Warblers as admittance to the adjacent land to set up mist nests was limited. Band data was compiled and reported to the Bird Banding Laboratory.

Table 3. Prothonotary Warbler banding summary for the 2017 season.

Location	ASY Banded Females	SY Banded Females	ASY Banded Males	SY Banded Males	AHY Banded Females	AHY Banded Males	Banded Nestlings (L)	HY Sex Unknown	Total Banded
Brownell Memorial Park & Carillon Tower	2	4	4	2	1	0	43	0	56
Lake Palourde/Avoca Island Cutoff Canal	3	8	0	0	2	0	39	0	52
Mandalay National Wildlife Refuge	3	3	3	1	1	0	20	1	32
Lockport Elevated Wetlands Boardwalk	0	0	1	0	0	0	0	0	1
Total	8	15	8	3	4	0	102	1	**141**

2018 Season Preliminary Results and Discussion

Nest Box Usage

A total of 75 Prothonotary Warbler nest boxes were monitored across three sites during the 2018 breeding season. The sites monitored were Brownell Memorial Park, Lake Palourde/Avoca Island Cutoff Canal, and Mandalay National Wildlife Refuge. The number of nest boxes that were utilized by Prothonotary Warblers increased from 55% during the 2017 season to 73% within the three sites monitored (Table 4).

At Brownell Memorial Park, the number of nest boxes that were used by Prothonotary Warblers at least once increased slightly from 11 to 12 boxes out of the 16 boxes that are present, however, the number of nest attempts increased from 15 to 25. The Lake Palourde/ Avoca Cutoff Canal site had the highest number of nest box usage with 28 out the 29 available nest boxes being utilized by the species. Mandalay National Wildlife Refuge had the lowest nest box occupancy of the season, however, the number of boxes used by Prothonotary Warblers increased from 27% during the 2017 season to 50% in 2018.

Table 4. The proportion of nest boxes used by Prothonotary Warblers, 2018

Site	No. Nest Boxes Present	Nest Box Occupancy by PROW	No. Nest Attempts
Brownell Memorial Park	16	12/16 (0.75)	25
Lake Palourde/Avoca Island Cutoff Canal	29	28/29 (0.97)	56
Mandalay NWR	30	15/30 (0.50)	19
Total	75	55/75 (0.73)	100

Prothonotary Warbler Nest Summary

100 Prothonotary Warbler nest attempts were monitored across the three sites in 2018. The earliest nest initiation date or first egg date of the 2018 season occurred at the Lake Palourde/Avoca Island Cutoff Canal site on March 30, 2018 (Figure 7). The earliest nest initiation date at Brownell Memorial Park was March 31, 2018. Mandalay NWR had the latest first egg date of the season, which occurred on April 10, 2018.

The mean clutch size for Prothonotary Warblers across all three sites was 4.56 eggs/nest (Table 5). 456 Prothonotary Warblers eggs were recorded, 393 (86%) hatched. The mean number of nestlings observed per nest was 3.83 young per nest. The raw nest success of the 100 Prothonotary Warbler nest attempts was 62%, however, 25% were recorded as final fate unknown because the last active nest check did not fall close enough to the fledge date and the following nest check was past the estimated fledge date window. 13% of the nest attempts failed to produce one or more fledglings.

The Lake Palourde/Avoca Island Cutoff Canal site produced the highest number of nest attempts with 56 Prothonotary Warbler nests and 223 young documented during the 2018 season. Brownell continued its upward trend in nest attempts and number of fledglings produced this year, with 25 nest attempts and 84 nestlings documented, 68 of those young were known to have fledged (Figure 8). Mandalay National Wildlife Refuge had 19

Prothonotary Warbler nest attempts with a total of 76 nestlings recorded, 55 of the nestlings were recorded as successfully fledging from the nest.

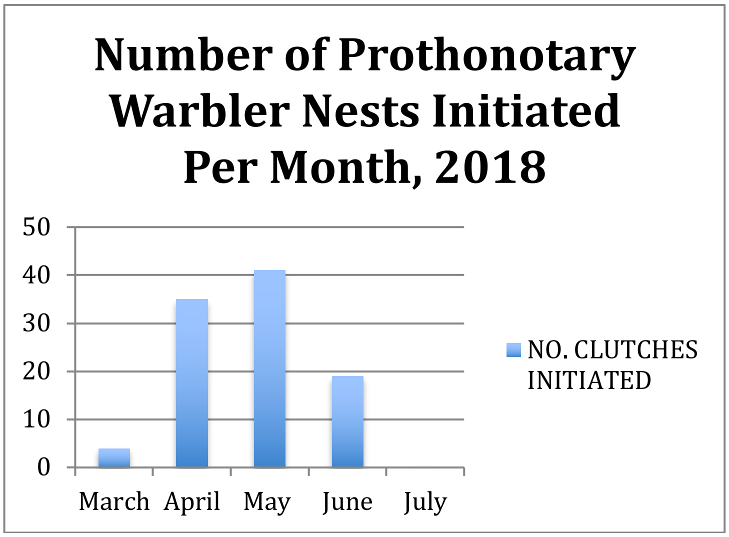

Figure 7. Number of Prothonotary Warbler nest attempts each month across the three sites monitored, 2018

Table 5. Prothonotary Warbler nest results across three sites in Louisiana, 2018

Site	No. Boxes Monitored	No. Active Nests Monitored	First Egg Date	Mean Clutch Size	Mean No. Nestlings/Nest (All Attempts)	Mean No. Fledged/Nest (Known Fate)	Total No. Known Fledglings	Total No. Unknown Fledglings	Raw Nest Success (%)	Unknown Final Fate (%)	Failed (%)
Brownell Memorial Park	16	25	31-Mar-18	4.60	3.36	2.96	68	6	72.0	8.0	20.0
Lake Palourde/Avoca Island Cutoff Canal	29	56	30-Mar-18	4.66	3.98	3.51	130	81	54.0	34.0	12.0
Mandalay National Wildlife Refuge	30	19	10-Apr-18	4.2	4.00	3.67	55	13	74.0	21.0	5.0
TOTAL	**75**	**100**		**4.56**	**3.83**	**3.37**	**253**	**100**	**62.0**	**25.0**	**13.0**

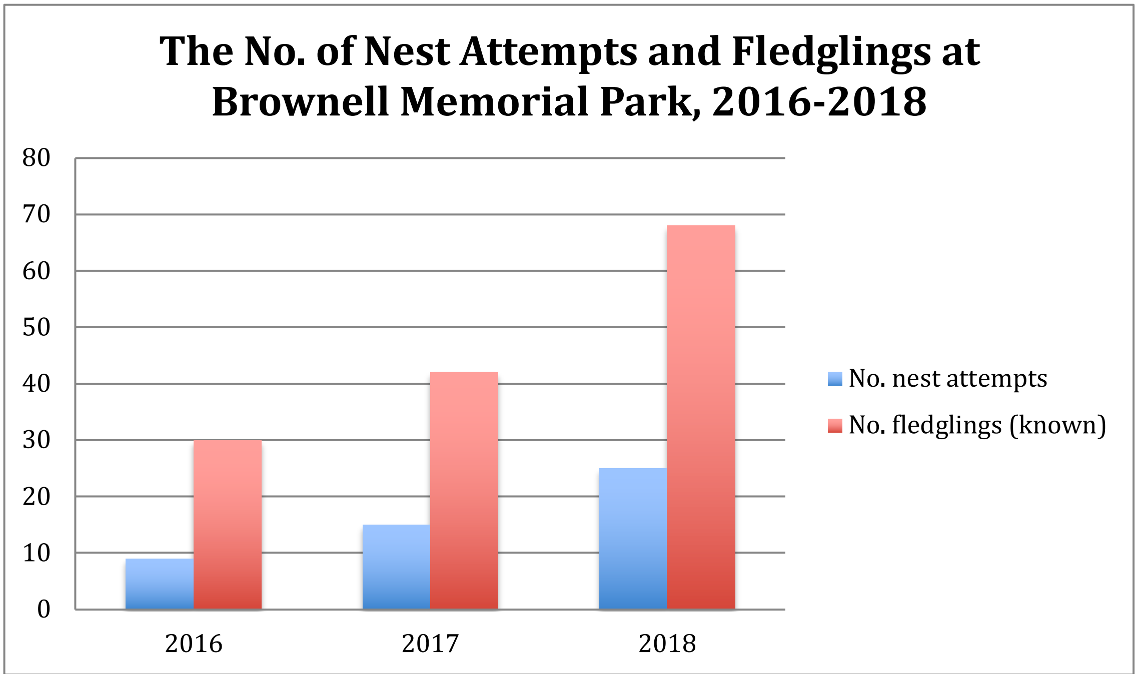

Figure 8. The Number of nest attempts and fledglings at Brownell Memorial Park from 2016-2018

Causes of Nest Failure

There were 13 nest attempts that failed to produce at least one fledgling. The causes of failure included abandonment, egg burial/nest box takeover, cause unknown, weather, predation, and infertile eggs (Figure 9). Nest abandonment after one or more eggs were laid accounted for the highest portion of nest failure. Egg burial/nest box takeover by another female Prothonotary Warbler was documented only at the Lake Palourde/Avoca Island Cutoff site, similar to the 2017 season. Two nests that failed were recorded as cause of failure unknown, all of the young in each nest were found dead in the nest cup. One nest attempt failed at the Lake Palourde/Avoca Island Cutoff site after a heavy wind and rainstorm event; the nest box was leaning over and the eggs rolled against the side of the box and were damaged. One nest was assumed depredated although the event was not witnessed and type of predator could not be determined. The nest box was under a low-lying branch and it was moved a few ft. farther from the branch in order to deter future predation events. One nest failed due to infertile eggs at Brownell Memorial Park. The nest had the latest initiation date, which occurred on June 30, 2018, but the female was observed incubating the nest thru July 17th, 2018 indicating that the female did not abandon the nest during the incubation period. The last nest check took place on July 25th, 2018 and the nest had failed to hatch, the female was no longer present on or near the nest.

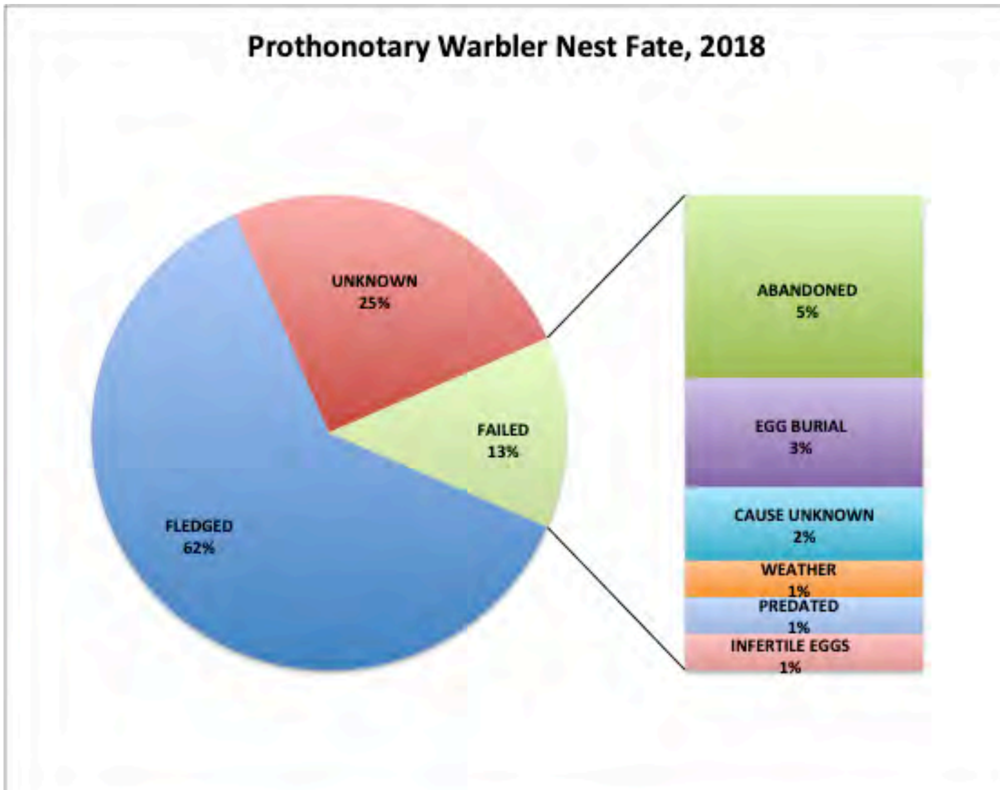

Figure 9. Prothonotary Warbler nest fate during the 2018-breeding season (N=100)

Return Rates

The return rate for Prothonotary Warblers banded as adults in previous years across the three sites monitored in 2018 was 51% (Table 6). Brownell Memorial Park had the highest overall return rate with 16/25 (64%) color-banded adults returning that were previously banded during the 2016 and 2017 season. The Lake Palourde/Avoca Island Cutoff Canal and Mandalay National Wildlife Refuge nest box sites were established in 2017, therefore they have a lower overall number of adults banded compared to Brownell Memorial Park. Mandalay National Wildlife Refuge had a surprisingly low female return rate with 2/7 (29%) encountered and although the sample size for the males at the site was smaller, 3/4 (75%) of the adult males banded in 2017 returned in 2018. Lake Palourde/Avoca Island Cutoff Canal had the lowest return rate with 4/13 (31%) of the banded adult females recaptured.

A Prothonotary Warbler that was banded as a chick at Mandalay National Wildlife Refuge in nest box M01 on June 30, 2017 was re-sighted singing above nest box M22 at Mandalay National Wildlife Refuge on April 25, 2018. The now second year (SY) male, band number 2820-58838, was recaptured on May 2, 2018 near nest box M22, approximately 1.9 miles southwest from its natal site. The male paired with an ASY female and successfully raised two young in nest box M22.

Table 6. Adult Prothonotary Warbler return rates, 2018

2018 Return Rates			
Site	**Male**	**Female**	**Total**
Brownell	7/10 (70%)	9/15 (60%)	16/25 (64%)
Mandalay NWR	3/4 (75%)	2/7 (29%)	5/11 (45%)
Lake Palourde/Avoca Island Canal	0/0 (0%)	4/13 (31%)	4/13 (31%)
Total	**10/14 (71%)**	**15/35 (43%)**	**25/49 (51%)**

2018 Banding Data

219 Prothonotary Warblers were banded during the 2018 breeding season (Table 7). 167 Prothonotary Warbler nestlings were banded with a single metal USFWS band on the left leg. A total of 51 adult Prothonotary Warblers were banded and one hatch year that was captured while attempting to target capture an adult male Prothonotary Warbler. Banding data was compiled and sent to Mr. Marty Floyd for review and submittal to the Bird Banding Laboratory after the conclusion of the breeding season.

Table 7. Prothonotary Warbler banding summary, 2018

Location	ASY Banded Females	SY Banded Females	ASY Banded Males	SY Banded Males	AHY Banded Females	AHY Banded Males	Banded Nestlings (L)	HY Sex Unknown	Total Banded
Brownell Memorial Park & Carillon Tower	3	2	2	2	0	0	65	1	75
Lake Palourde/Avoca Island Cutoff Canal	14	14	0	0	2	0	61	0	91
Mandalay National Wildlife Refuge	5	4	1	2	0	0	41	0	53
Total	**22**	**20**	**3**	**4**	**2**	**0**	**167**	**1**	**219**

Additional Statistical Analysis

In addition to the general seasonal nesting summaries provided in this report, the 2017-2018 Prothonotary Warbler nest data will be further analyzed to determine daily survival rates (DSR), final nest fate, nest success based upon chronological initiation, and habitat variables in relation to productivity and nest fate, within the following final report. The report will include a description that defines the analysis and models used and it will state any final conclusions that the analysis may support.

Acknowledgements

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Statistical Analysis of 2017 and 2018 Prothonotary Warbler Data

By: Paul Leberg, University of Louisiana at Lafaytte

Report on analyses of 2017 and 2018 Prothonotary Warbler nesting data

Methods

Analysis of Daily Survival Rates

Following the corrections made to the data set of problems identified in preliminary analyses and in consultation with BTNEP personnel, the samples used in this portion of the study are described in Table 1. To be used to estimate daily survival rates (DSR), nests had to be observed more than once, creating observation intervals. A nest is considered to have survived an observation interval if it was still active at the end of the interval or if there was evidence that at least one young had fledged. Based on instructions from BTNEP personnel, once a nest was designated as fledged, additional observations of the clutch were not included in DSR estimates. An active nest is considered to have failed if there was evidence that it had been depredated or abandoned at the end of the interval. A number of nests were identified as having unknown status. These were nests nearing their expected fledging date when the chicks disappeared, and there was no evidence of the presence of predators or chicks. Observation intervals of these nests with unknown fates were excluded from estimates of DSR.

Table 1. Characteristics of data sets used to estimate daily survival rates.

Year	Location	Nest boxes with at least one observation interval[1]	Number of observation intervals across nests boxes	Observation intervals survived	Observation intervals-failed	Fate unknown in final observation interval
2017	Brownell	16	87	82	3	2
	Lake Palourde	26	81	68	3	10
	Mandalay	9	31	28	0	3
2018	Brownell Park	25	131	124	5	2
	Lake Palourde	54	194	170	5	19
	Mandalay	19	71	66	1	4

[1]Excludes one nest found in a fence post, rather than a nest box, a single clutch what was monitored at another site (Lockport), and two nest boxes from Lake Palourde from 2017 that did not have measurements of all of the covariates.

Logistic Exposure Analysis (Shaffer 2004a) was used to estimate daily survival rates and to test the hypotheses that initiation date, exposure date, year, study site, box location (edge vs. core), canopy closure, and basal area had no effect on nest survival. For this analysis initiation date, exposure date, canopy closure, and basal area were treated as linear covariates; year, study site, and box location were treated as categorical variables. Initiation Date was the estimated Julian date the first egg in a clutch was laid. Exposure date was determined as the Julian date that was the midpoint of each observation interval. Canopy closure and basal area were measured only once, in 2018, but because these variables were unlikely to change much over between two breeding seasons, these estimates were applied to both the 2017 and 2018 data.

The effect of year, and its interaction with other covariates on daily nest survival was evaluated by combining the 2017 and 2018 data sets. Fitting polynomials of initiation date and exposure date did not improve model fit; therefore those results are not presented here. Because basal area, canopy closure and box location (interior vs edge) were both logically and statistically correlated ($|r| = 0.39 – 0.65$), these variables were never included in the same model. Likewise, because initiation date and exposure date were highly correlated, they were also not included in the same models ($r \geq 0.93$). The decision was made to present only the results of models using initiation date as a covariate, as the results were virtually identical to models using exposure date. Finally, there was a strong association between nest location and study site (all Lake Palourde nest boxes were on forest edges). Therefore, study site and nest box location were never included in the same model. All of the other covariates had correlations between than -0.1 and 0.1) which were small enough that they were unlikely to bias parameter estimation.

For this analysis, models were fit for each individual covariate, as well as for all possible pairs of covariates, with and without their interaction terms. If a covariate, pair of covariates, or a pair of covariates with their interaction, appeared to provide information on nest status (survived or failed), the remaining covariates were added to this model, to see if they improved model fit. The relative information contained in each regression model was evaluated with the Akaike information criterion (AIC). When comparing models, those with lower values of AIC contain more information about the dependent variable (nest survival in this case). More complex models, in terms of additional covariates, or interaction terms, were considered to be more informative than simpler models, if they decreased the AIC value by 2 or more.

Once the models with the lowest AIC values relative to simpler models was determined, daily survival rates were determined following Shaffer and Thompson (2007). When initiation date proved to be an important influence on daily survival rates, we estimated daily survival for the Julian dates of 89, 129, 218. These were the averages, for the two years, of the first, mean, and last estimated nest initiation dates, respectively.

The data had a large number of clutches with unknown fates as a result of the difficulty in making frequent visits to the nest boxes. To better understand the potential effects of this uncertainty on parameter estimates and model results, the analyses above were repeated, treating all the unknown nests and either having survived or as having failed during their last exposure period.

Nest period survival, or the probability of a nest surviving 26 days, was determined from the DSR. All analyses were conducted using SAS 9.3 (SAS 2011), using code and macros found at www.npwrc.usgs.gov/resource/birds/nestsurv/index.htm (Shaffer 2004b). See Appendix A for the data, SAS code and results of the DSR analyses.

Nest Box Productivity
Because the study monitored nest boxes, the productivity of those boxes was assessed. Covariates for this analysis included year, study site, location (edge vs forest interior), basal area, and canopy. Initiation Date was not included in this analysis as a box might produce several clutches during the course of a season.

In addition to the covariates included from the DSR analysis, I also included whether another species nested in a box as a covariate. Because the number of such nesting attempts were small (6 and 7 boxes in 2017 and 2018, respectively), and not independent of study site (11 of the 13 such attempts were in Brownell), the presence of another species was not included as an interaction term in any model (Table 2).

Table 2. Characteristics of data used to assess factors affecting nest box use and productivity.

		Number of boxes		
Year	Study Site	Total	on forest edge	with a clutch of another species
2017	Brownell	16	3	6
	Palourde	28	28	0
	Mandalay	30	25	0
2018	Brownell	16	3	5
	Palourde	29	29	2
	Mandalay	30	25	0

The influence of covariates on whether or not box was used by PROW was assessed with logistic regression (SAS Institute Inc. 2011). The influence of covariates on several measures of productivity was assessed using Poisson regression (SAS Institute Inc. 2011). The number of clutches that occurred in a box, and the number of clutches where one or more eggs hatched, were estimated for all the boxes that were surveyed. The total number of PROW eggs laid, and the number of eggs that hatched, were estimated for each of the boxes used by PROW during a breeding season. And finally, the total number of PROW young that fledged was determined for each of the boxes where at least one egg hatched during a season.

In this analysis, nest box, and not clutch, is the unit of replication. The model selection procedure was identical to that described in the DSR analysis.

Results

Factors affecting DSR
The model with the lowest AIC values included Initiation Date, Study Site and their interaction (Table 3). However, this model provided more than a trivial improvement over the model that contained only initiation date. Furthermore, using the traditional 0.05 significance criteria, only initiation date was statistically significant. Other informative models all included Initiation Date; other variables did not provide more information about DSR.

Table 3. Akaike information criteria (AIC) for the 10 models that contained the most information on daily survival rate (DSR) for nests surveyed in 2017 and 2018; the constant survival model was included for comparison. K is the number of parameters in the model. Models with the smallest AIC values are considered to have the most information about DSR. Delta AIC is the difference between the most informative model and the model under consideration; values <2 are considered to be similar to the top model in terms of information content. The model weight (AIC Weights) is the relative likelihood of each model with values closer to 1 having the highest likelihood. Analysis was based on 551 exposure periods.

Model	K	AIC	Delta_AIC	AIC Weights
Initiation Date + Study Site + Initiation Date*Site	6	135.7	0.0	0.166
Initiation Date	2	136.2	0.5	0.132
Initiation Date + Study Site	4	136.3	0.6	0.124
Initiation Date + Year	3	136.9	1.2	0.092
Initiation Date + Location	3	137.0	1.3	0.088
Initiation Date + Basal Area	3	137.1	1.3	0.085
Initiation Date + Year + Year* Initiation Date	4	137.5	1.8	0.068
Initiation Date + Canopy Cover	3	138.1	2.3	0.052
Initiation Date + Location + Initiation Date*Location	4	138.9	3.1	0.035
Initiation Date + Basal Area + Initiation Date*Basal Area	4	139.1	3.3	0.031
constant survival	1	139.4	3.7	0.026

There is no evidence that any of the covariates, other than Initiation Date, affected DSR. DSR was estimated for clutches with Initiation Dates associated with the initiation, mean, and end of nesting activity (Table 4). Comparing predictions of this model to the constant survival model, it is clear that DSR and Period survival period decreased substantially over the duration of the nesting season.

Table 4. Comparison of DSR and period survival estimates for nests with early, average, or late Initiation Date (Julian Dates (JD) 89, 129, and 181. respectively). The predictions from the constant survival model (CS) are provided for comparison.

Julian Date of Initiation	DSR	Lower 95% CI Limit	Upper 95% CI Limit	Probability of surviving 26 days	Lower 95% CI Limit	Upper 95% CI Limit
CS	0.995	0.992	0.997	0.886	0.819	0.930
89	0.999	0.995	1.000	0.967	0.869	0.992
129	0.996	0.993	0.998	0.907	0.834	0.949
181	0.985	0.956	0.995	0.670	0.314	0.872

It is recommended that when nest fates are unknown for their final exposure period, data from those exposure periods should be removed from the analysis, as has been done here. However, there are a large number of nests with unknown fates during their final exposure period in this study (Table 1). Therefore, I conducted a sensitivity analysis to try to understand how estimates and statistical comparisons would have been affected if the unknown nests had all either succeeded or failed. The results of the model selection process did not change; the model with initiation date was the most informative (results not shown). Treating the nests with unknown fates as having survived, did not have any large effects on survival estimates, perhaps because these estimates were already quite high. Estimates of DSR and period survival did decrease considerably when clutches of unknown fates were treated as having failed. It is impossible to know how many of the clutches with unknown fates actually failed, but more precise estimates of nest fates would increase the confidence that the estimates presented in Table 4.

Because the number of unsuccessful clutches was small (17), it was not possible to conduct a statistical analysis of the influence of the different covariates on the cause of nest failure (Table 5). Of the nests where the cause of failure was identified, the most cause was abandonment.

Table 5. Causes of failure of PROW based on nest surveys

Cause	Number
Abandoned	8
Buried	2
Depredated	1
Infertile	1
Takeover	1
Unknown	2
Weather	2

Conclusion— DSR estimates were high. Initiation Date appears to have a negative effect on DSR and period survival. DSR and period survival were not measurably affected by year, study site, box location, basal area or forest canopy. Estimates of nest survival would benefit from more extensive monitoring of clutches as they approached fledging.

Factors affecting Nest Box Use and Productivity

Box Use- The most informative models of nest box use by PROW nest success contained year, study site and basal area (Table 6). However, this model did not contain much more information than the model with only year and study site. Furthermore, the effect of basal area on model fit was not statistically significant using the traditional statistical criterion of 0.05. There was no evidence that any covariates, besides the effects of year and study site, influenced whether nest boxes were used by PROW.

Table 7. Akaike information criteria (AIC) for the 10 models that contained the most information on nest box use in 2017 and 2018; the null model was included for comparison. K is the number of parameters in the model. Models with the smallest AIC values are considered to have the most information about DSR. Delta AIC is the difference between the most informative model and the model under consideration; values <2 are considered to be similar to the top model in terms of information content. The model weight (AIC Weights) is the relative likelihood of each model with values closer to 1 having the highest likelihood.

Model	K	AIC	Delta AIC	AIC weight
Study Site + Year + Basal Area	5	161.6	0.0	0.276
Year + Study Site	4	161.8	0.3	0.242
Study Site + Year + Other Species	5	162.1	0.5	0.211
Study Site + Year+ Canopy Closure	5	163.8	2.2	0.091
Year + Study Site + Year*site	6	164.0	2.5	0.080
Study Site + Basal Area	4	166.2	4.6	0.027
Study Site	3	166.4	4.8	0.025
Study Site + Other Species	4	166.8	5.2	0.020
Study Site + Canopy Closure + Site*Canopy Closure	6	167.8	6.3	0.012
Study Site + Canopy Closure	4	168.3	6.7	0.009
Null	1	196.0	34.4	0.000

Nest box use was higher in 2018 than in 2017 at all three sites (Fig. 1). In each year, nest box use was highest in Lake Palourade and lowest in Mandalay.

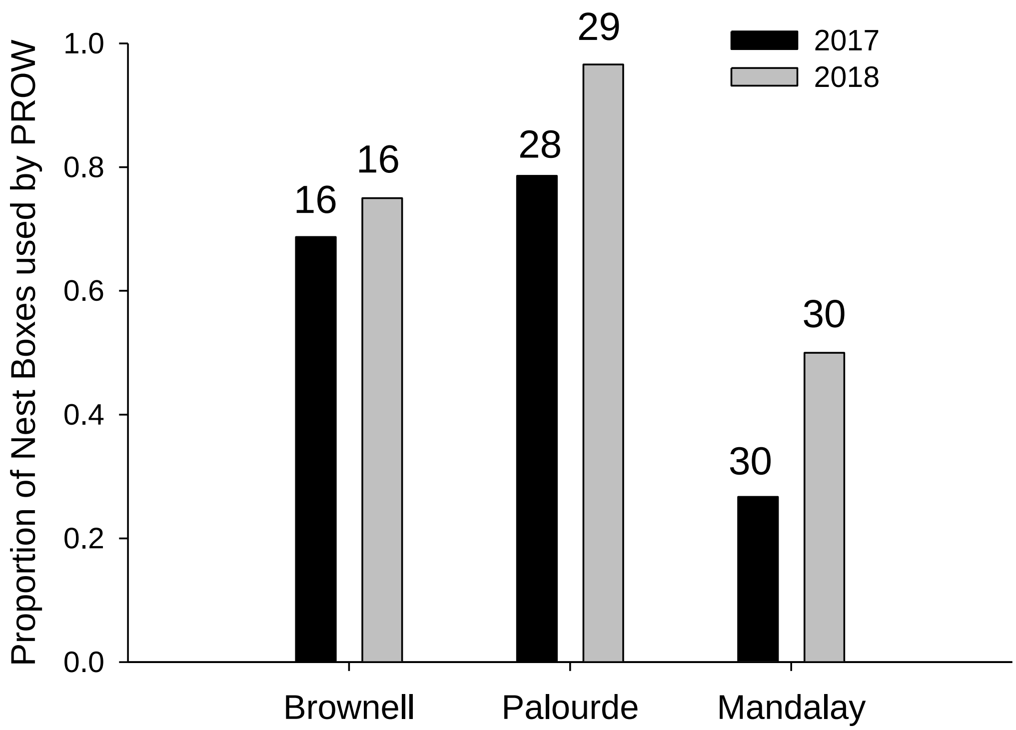

Fig 1. Proportions of nest boxes used by PROW across study sites and years. The number of nest boxes used to estimate each proportion is found above each bar.

Conclusion—Measurements of forest cover or the use of boxes by other species did not have a strong effect on their use by PROW.

Number of Clutches and Successful Clutches— These analyses were based on all the nest boxes in the survey for which there were covariates of forest cover (Table 2). The most informative model explaining the number of clutches in all the surveyed nest boxes contained Year, Site, and Other species (Table 8). These three terms were found in many of the most informative models and none of the other covariates contributed much to our understanding of the variation in clutch number among nest boxes.

Table 8. Akaike information criteria (AIC) for the 10 models that contained the most information on the number of clutches per nest box; the null model was included for comparison. K is the number of parameters in the model. Models with the smallest AIC values are considered to have the most information about DSR. Delta AIC is the difference between the most informative model and the model under consideration; values <2 are considered to be similar to the top model in terms of information content. The model weight (AIC Weights) is the relative likelihood of each model with values closer to 1 having the highest likelihood.

Model	K	AIC	Delta AIC	AIC weight
Year + Study Site + Other Species	5	334.2	0.0	0.385
Year + Study Site + Other Species + Basal Area	6	334.8	0.6	0.282
Year + Study Site + Other Species + Canopy Closure	6	336.0	1.8	0.154
Study Site + Year	4	338.1	3.9	0.054
Study Site + Year + Basal Area	5	338.2	4.0	0.051
Study Site + Year + Basal Area +Year*Basal Area	6	339.8	5.6	0.023
Study Site + Year + Canopy Closure	5	340.1	5.9	0.020
Study Site + Year + Study Site*year	6	341.6	7.4	0.009
Study Site + Year + Basal Area + Study Site*Basal Area	7	341.7	7.5	0.009
Study Site + Year + Canopy Closure + Year*Canopy Closure	6	342.1	7.9	0.007
Null	1	379.9	45.8	0.000

The number of clutches per nest box was highest for Brownell and lowest for Mandalay (Fig. 3). Like nest box use, the number of clutches per nest box was highest in 2018. Not surprisingly, if another species used a nest box for a clutch, the number of PROW clutches was reduced (Fig. 3).

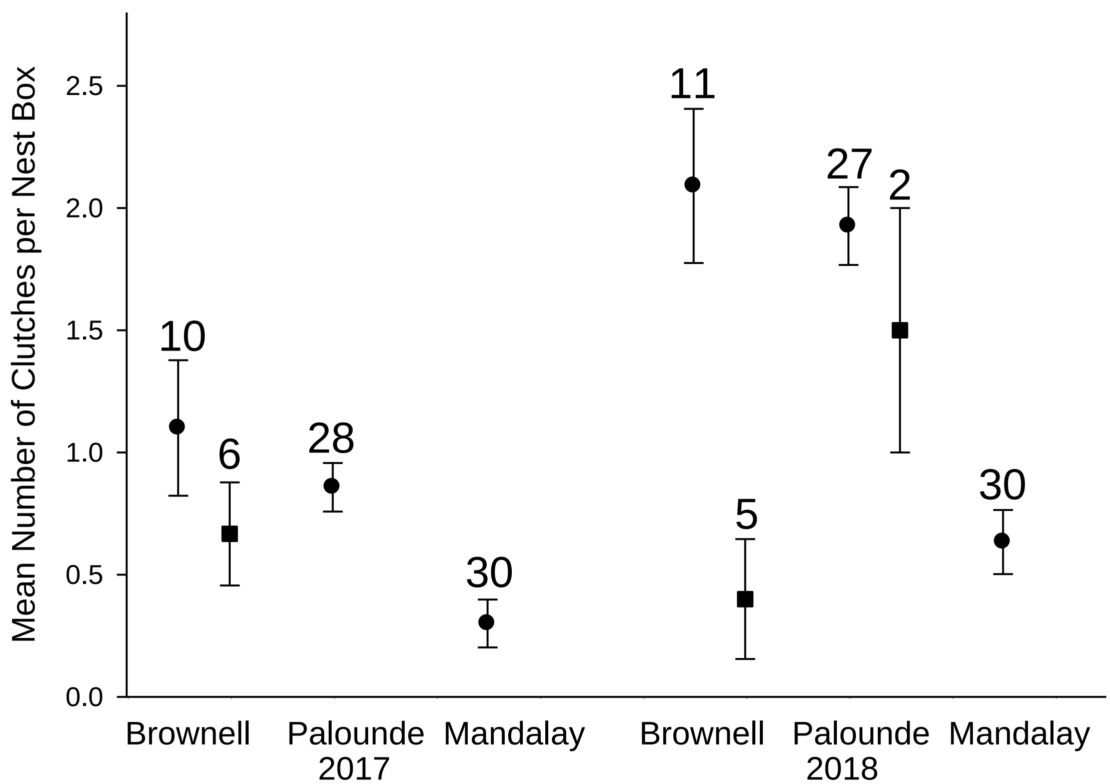

Fig 2. Mean (and SE) of the number of PROW clutches per nest boxes across years and study sites. Means for boxes with and without a clutch of a species other than PROW, are represented by solid squares and circles, respectively. In several combinations of study sites and years, there were no nest boxes that were used by other species, and thus no means. Sample sizes are located above the standard error bars.

The most informative model explaining the number of successful clutches (where at least one egg hatched), contained Year, Site, and Other species (Table 9). These three terms were found in many of the most informative models and none of the other covariates contributed much to our understanding of the variation in the number of successful clutches per nest box.

Table 9. Akaike information criteria (AIC) for the 10 models that contained the most information on the number of successful clutches; the null model was included for comparison. K is the number of parameters in the model. Models with the smallest AIC values are considered to have the most information about DSR. Delta AIC is the difference between the most informative model and the model under consideration; values <2 are considered to be similar to the top model in terms of information content. The model weight (AIC Weights) is the relative likelihood of each model with values closer to 1 having the highest likelihood.

Model	K	AIC	Delta AIC	AIC weight
Year + Study Site + Other Species	5	322.2	0.0	0.3183
Year + Study Site + Other Species + Basal Area	6	322.9	0.7	0.2228
Year + Study Site + Other Species + Canopy Closure	6	324.2	1.9	0.1201
Study Site + Year	4	324.5	2.3	0.1032
Study Site + Year + Basal Area	5	324.8	2.6	0.0876
Study Site + Year + Basal Area +Year*Basal Area	6	326.4	4.2	0.0388
Study Site + Year + Canopy Closure	5	326.5	4.3	0.0380
Study Site + Year + Study Site*year	7	327.6	5.3	0.0220
Study Site + Year + Basal Area + Study Site*Basal Area	7	327.9	5.7	0.0183
Study Site + Year + Canopy Closure + Year*Canopy Closure	6	328.3	6.1	0.0154
Null	1	355.3	33.0	0.0000

The number of successful clutches was highest in nest boxes at Brownell and Lake Paloude and lowest in boxes at Mandalay (Fig. 4). The number of successful clutches per nest box was higher in 2018 than in 2017. If another species used a nest box for a clutch, the number of PROW clutches that hatched one young was lower than if only PROW used the box in that year (Fig. 4).

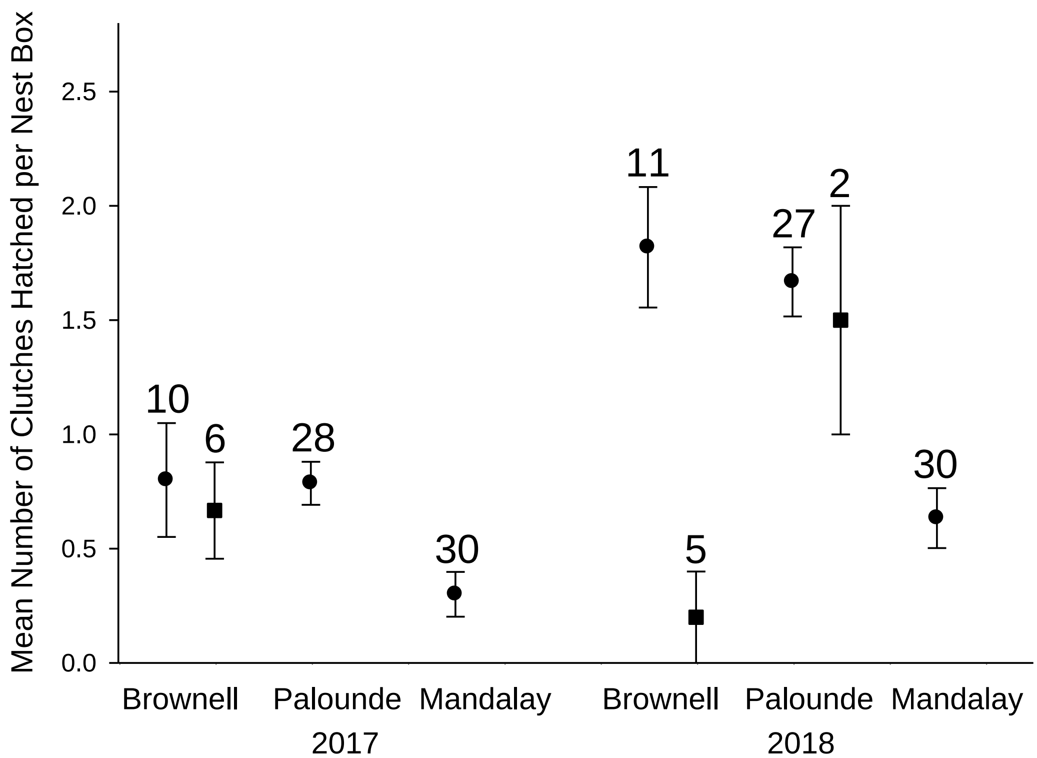

Fig 3. Mean (and SE) of the number of PROW clutches that hatched at least one egg across years and study sites. Means for boxes with and without a clutch of a species other than PROW, are represented by solid squares and circles, respectively. In several combinations of study sites and years, there were no nest boxes that were used by other species, and thus no means. Sample sizes are located above the standard error bars.

Conclusion—Year, site and use by another species all affected the number of PROW clutches, and the number of successful clutches, in a nest box. There was no evidence that the number of clutches or successful clutches, was affected by any of the forest cover covariates.

Number of Eggs laid and number of Eggs Hatched per nest box— These analyses were based on the nest boxes where eggs were laid (Table 2). They differ from the previous analyses of clutch productivity in that boxes that were unused in a given year were excluded from these analyses.

The most informative model explaining the total number of eggs laid in a box contained Year, Study Site, Other species and the interaction between Year*Study site (Table 9). These terms occurred in all of the most informative models and no models with fewer terms approached this model in information content concerning the number of eggs laid per box. None of the other covariates contributed much to our understanding of the variation in egg number among nest boxes.

Table 9. Akaike information criteria (AIC) for the 10 models that contained the most information on number of eggs laid in nest boxes in 2017 and 2018; the null model was included for comparison. K is the number of parameters in the model. Models with the smallest AIC values are considered to have the most information about DSR. Delta AIC is the difference between the most informative model and the model under consideration; values <2 are considered to be similar to the top model in terms of information content. The model weight (AIC Weights) is the relative likelihood of each model with values closer to 1 having the highest likelihood.

Model	K	AIC	Delta AIC	AIC weight
Year + Study Site + Study Site*Year + Other Species	7	446.0	0.0	0.446
Year + Study Site + Study Site*Year + Other Species + Basal Area	8	446.4	0.4	0.372
Year + Study Site + Study Site*Year + Other Species + Canopy Closure	8	447.9	1.8	0.178
Study Site + Year + Other species	5	455.8	9.8	0.003
Year + Study Site + Study Site*Year	6	460.1	14.1	0.000
Year + Study Site + Study Site*Year + Basal Area	7	460.4	14.4	0.000
Year + Study Site + Study Site*Year + Canopy Closure	7	462.1	16.1	0.000
Study Site + Year + Basal Area + Year*Basal Area	7	465.9	19.9	0.000
Study Site + Year	4	466.2	20.2	0.000
Study Site + Year + Basal Area	5	467.1	21.0	0.000
Null	1	527.5	81.5	0.000

The number of eggs laid in a nest box did not follow a consistent pattern among the study sites over the two years. In 2017, the number of eggs in the average nest box at Brownell was higher than at either Lake Palunde or Mandalay (Fig. 4). In 2018, egg production per box was higher in both Brownwell and Lake Palunde than in Mandalay (Fig. 4). As was the case with the analyses based on number of clutches, the number of PROW eggs laid in a box decreased when another species used the box for part of the breeding season.

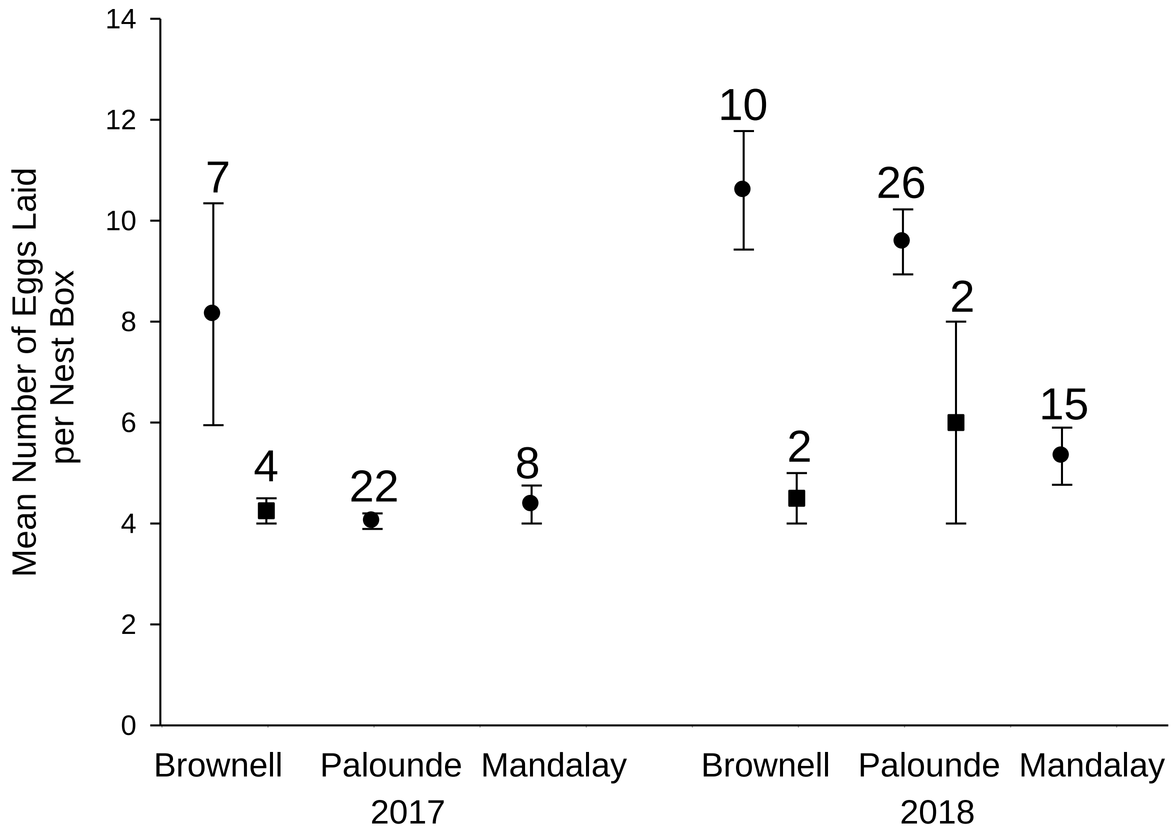

Fig 4. Mean (and SE) of the number of PROW eggs per nest boxes across years and study sites. Means for boxes with and without a clutch of a species other than PROW, are represented by solid squares and circles, respectively. In several combinations of study sites and years, there were no nest boxes that were used by other species, and thus no means. Sample sizes are located above the standard error bars.

The most informative model explaining the total number of eggs that hatched in a box contained Year, Site, Other species and the interaction between year*site (Table 9). These terms occurred in all of the most informative models and no models with fewer terms approached this model in information content concerning the number of eggs that hatched. None of the other covariates contributed much to our understanding of the variation in hatchling number among nest boxes.

Table 9. Akaike information criteria (AIC) for the 10 models that contained the most information on number of eggs hatched per nest box; the null model was included for comparison. K is the number of parameters in the model. Models with the smallest AIC values are considered to have the most information about DSR. Delta AIC is the difference between the most informative model and the model under consideration; values <2 are considered to be similar to the top model in terms of information content. The model weight (AIC Weights) is the relative likelihood of each model with values closer to 1 having the highest likelihood.

Model	K	AIC	Delta AIC	AIC weight
Year + Study Site + Study Site*Year + Other Species	7	442.2	0.0	0.495
Year + Study Site + Study Site*Year + Other Species + Basal Area	8	443.3	1.1	0.279
Year + Study Site + Study Site*Year + Other Species + Canopy Closure	8	444.1	1.9	0.187
Study Site + Year + Other species	5	447.3	5.2	0.037
Year + Other species	3	456.7	14.5	0.000
Year + Study Site + Study Site*Year	6	457.4	15.3	0.000
Year + Study Site + Basal Area + Study Site*Year + Study Site*Basal Area	9	457.5	15.3	0.000
Study Site + Year + Basal Area + Year*Study Site	7	458.5	16.4	0.000
Study Site + Year + BA+ Study Site*Basal Area	7	458.6	16.4	0.000
Study Site + Year + Canopy Closure + Study Site*Year	7	458.8	16.6	0.000
Null	1	512.3	70.2	0.000

The number of eggs hatched in a nest box did not follow a consistent pattern among the study sites over the two years. In 2017, the number of hatchlings in the average nest box was slightly higher for Brownell than for the other sites. In 2018, hatchlings per box was considerably higher in Brownell and Lake Palounde than in Mandalay when considering boxes only used by PROW (Fig. 5). As was the case with the analyses based on number of clutches and eggs, the number of PROW hatchlings in a box decreased when another species used the box.

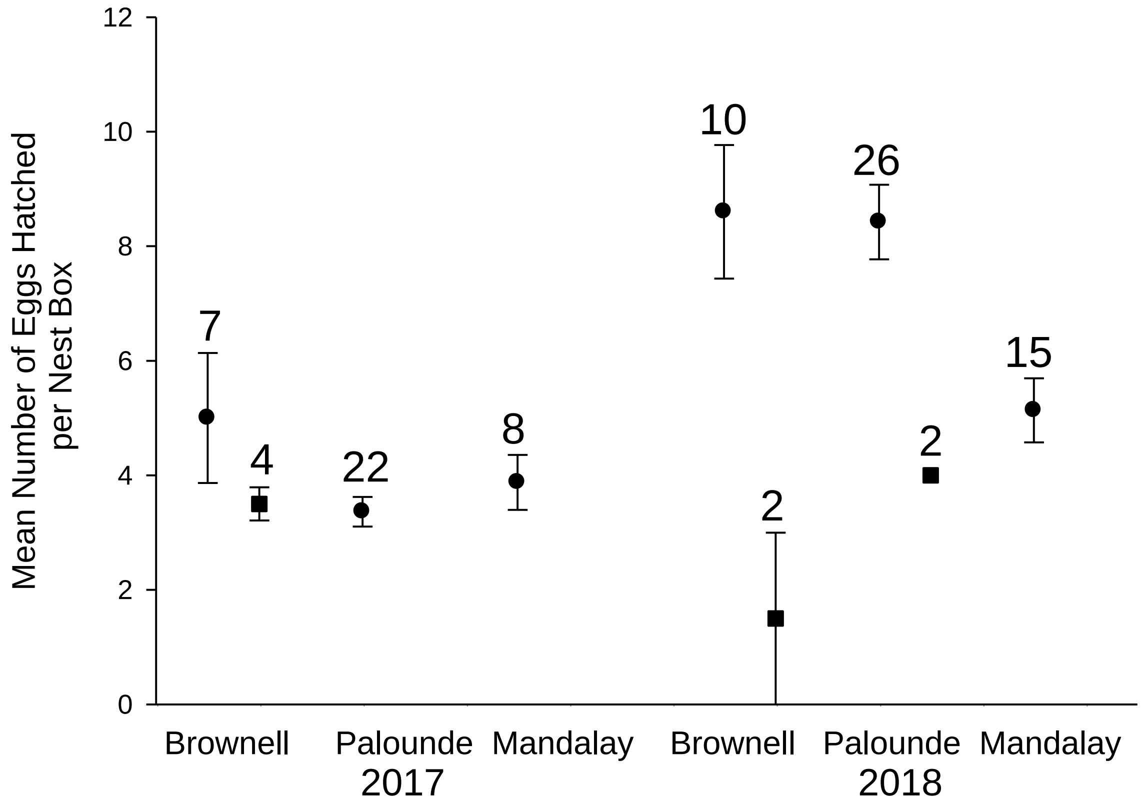

Fig 5. Mean (and SE) of the number of PROW hatchlings per nest boxes across years and study sites. Means for boxes with and without a clutch of a species other than PROW, are represented by solid squares and circles, respectively. In several combinations of study sites and years, there were no nest boxes that were used by other species, and thus no means. Sample sizes are located above the standard error bars

Conclusion—Year, site and use by another species all affected the number of PROW eggs and hatchlings in a nest box. The interaction between years and study sites, was not seen in the measures of clutch number, suggesting that egg productivity at the 3 study sites does not respond the same way to temporal variation. There was no evidence that egg productivity was affected by any of the forest cover covariates.

Number of Young Fledged per nest box— This analysis was based on the nest boxes in which at least one egg hatched (Table 2). It differs from the previous analyses of clutch and egg productivity, which are based on all surveyed boxes or on all boxes used by PROW, respectively.

The most informative model explaining the number of young fledged in a box contained Year, Site, and Other species (Table 10). However, Year was not statistically significant using the traditional 0.05 criteria. Furthermore, this model had only a slight improvement in information content relative to the model that contained only Site and Other Species (Table 10). None of the other covariates contributed much to our understanding of the variation in fledgling number among nest boxes.

Table 10. Akaike information criteria (AIC) for the 10 models that contained the most information on number of PROW young fledged from nest boxes; the null model was included for comparison. K is the number of parameters in the model. Models with the smallest AIC values are considered to have the most information about DSR. Delta AIC is the difference between the most informative model and the model under consideration; values <2 are considered to be similar to the top model in terms of information content. The model weight (AIC Weights) is the relative likelihood of each model with values closer to 1 having the highest likelihood.

Model	K	AIC	Delta AIC	AIC weight
Year + Study Site + Other Species	5	257.9	0.0	0.285
Study Site + Other Species	4	259.1	1.1	0.161
Year + Study Site + Other Species + Basal Area	6	259.7	1.8	0.116
Year + Study Site + Other Species + Study Site*Year	7	259.9	1.9	0.107
Year + Study Site + Other Species + Canopy Closure	6	260.1	2.2	0.097
Year + Study Site	4	261.8	3.9	0.041
Year + Location	3	263.2	5.3	0.021
Year	2	263.3	5.4	0.019
Other Species	2	263.6	5.7	0.016
Study Site + Year + Canopy Closure	5	263.7	5.8	0.016
Null	1	265.0	7.1	0.008

The number of young fledged from a nest box followed roughly the same pattern across years. Boxes from Brownell fledged the most young. In 2017, nest boxes from Lake Palounde and Mandalay fledged similar numbers of young, while in 2018 Lake Palounde boxes fledged more young than those at Mandalay. As was the case with the other productivity variables, the number of PROW fledged from nest boxes decreased when another species used the box.

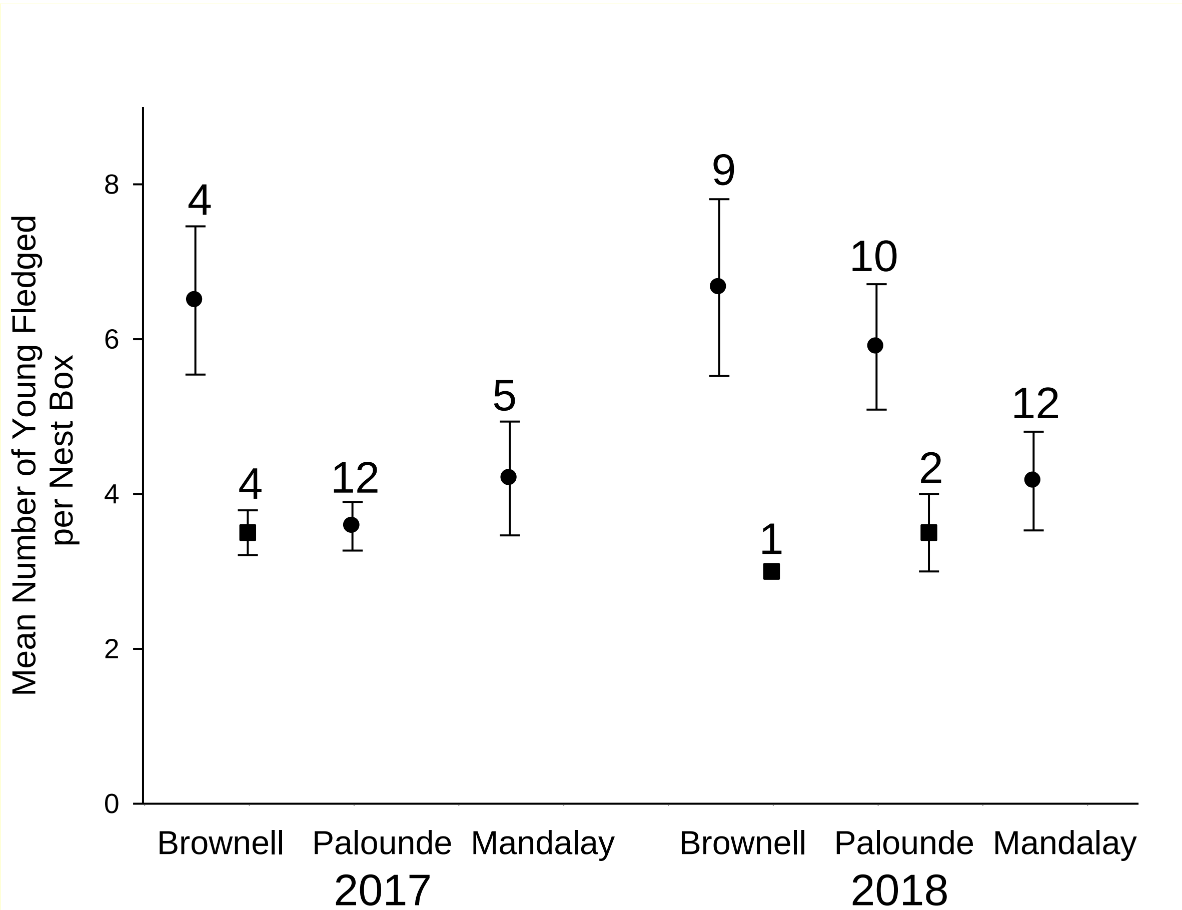

Fig 6. Mean (and SE) of the number of PROW hatchlings per nest boxes across years and study sites. Means for boxes with and without a clutch of a species other than PROW, are represented by solid squares and circles, respectively. In several combinations of study sites and years, there were no nest boxes that were used by other species, and thus no means. Sample sizes are located above the standard error bars.

Conclusion—Site and use by another species affected the number of PROW fledglings from nest boxes. There was no evidence that the number of fledglings was affected by forest cover covariates.

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