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Breeding biology of the endangered Santa Marta Parakeet *Pyrrhura viridicata*

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The breeding biology of the Santa Marta Parakeet *Pyrrhura viridicata* is described based on the study of the population inhabiting the San Lorenzo Ridge, an Important Bird Area within the Sierra Nevada de Santa Marta, Colombia. We performed surveys during 2005–2008 and installed 48 nest boxes at four sites in May 2006. Nineteen nesting attempts were recorded: nine were made in nest boxes and ten occurred in natural cavities. Clutches of the Santa Marta Parakeet averaged 4.5 eggs per nest and up to seven eggs were observed in a single cavity. Previously undescribed breeding behaviours are reported for the species: cooperative breeding and replacement clutching. The only natural cavities used for nesting were in dead Wax Palms *Ceroxylon ceriferum*. This palm is one of the most common and numerous tree species in the San Lorenzo Ridge between 2300–2700 m elevation and key for the species' breeding cycle.

Key words: Neotropics, nest boxes, *Pyrrhura viridicata*, San Lorenzo Ridge, Sierra Nevada de Santa Marta

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The Santa Marta Parakeet *Pyrrhura viridicata* is endemic to the Sierra Nevada de Santa Marta in north-eastern Colombia, inhabiting the montane wet forest between 1900–3200 m (Botero-Delgadillo *et al.* 2012) and is assessed as Endangered (Oliveros-Salas *et al.* 2016, Birdlife International 2017). Although recent studies have documented relevant aspects of the species' ecology and distribution (e.g. Botero-Delgadillo *et al.* 2010, 2011, 2012), there is still a lack of crucial information regarding its breeding biology.

Breeding biology is well known for only 30% of all living bird species, and for Neotropical species this is even less (Xiao *et al.* 2016). Reproduction is, however, a key aspect in developing effective conservation programs for threatened taxa (Sodhi & Ehrlich 2010). Here we present aspects of the breeding biology of the Santa Marta Parakeet based on nests found in natural cavities and nest boxes, describing the eggs and nest development, documenting clutch size and evaluating nesting success for the species.

METHODS

Study area

Surveys were conducted at four sites in premontane and montane forest between 2000 and 2700 m in San Lorenzo Ridge (11°08'N, 74°01'W), which reaches 2800 m and is located on the northern slope of the Sierra Nevada de Santa Marta, north-eastern Colombia. The lowest elevation site, Betoma, is located at 2000 m within the El Dorado Reserve, managed by the local conservation NGO Fundación ProAves. Common trees are *Alchornea* sp., *Sapium* sp. and *Miconia* spp. The site of El Palmar is also found within the El Dorado Reserve, between 2300–2400 m elevation and constitutes a conserved forest dominated by Wax Palms *Ceroxylon ceriferum*, and the trees *Paragynoxys martingrantii*, *Viburnum tinoides* and *Croton* sp. The other two sites, La Laguna and Finca Vistahermosa, are located near the Cerro Kennedy peak in the highest part of this ridge (2500–2700 m), within the surroundings of the

Sierra Nevada de Santa Marta National Park. The area is a mixture of pastures and forest dominated by *C. ceriferum*, *Podocarpus oleifolius*, *Myrcia* sp, *Schefflera* sp. and *Chusquea* sp.

Nest searching and monitoring

The breeding biology of the Santa Marta Parakeet was studied during four periods in consecutive years: March–June 2005, April–November 2006, February–October 2007 and March–September 2008. Searches for nests in cavities within trees were performed in the forest of Finca Vistahermosa.

In May 2006, 48 nest boxes were put up at three of the sites between 2000–2600 m elevation: four at Betoma, 24 at El Palmar and 20 at La Laguna. At Betoma nest boxes were placed in the forest edge, at El Palmar within the forest and at La Laguna mainly in an area of pasture with scattered trees. Nest boxes had a base of 20×20 cm and a height of 1 m. They had one entrance at approximately 80 cm from the base and an inspection door at 10 cm from the base. Nest boxes were installed singly, at a height between 5 and 13 m, mainly on palms, which are more practical to climb. A few boxes were installed on trees of *Alchornea* sp. (one nest box), *Myrcia* sp. (two) and *Sapium* sp. (one). Trees for box placement were selected based on their condition (alive), proximity to a tree with a box already installed and accessibility (avoiding plants located in insecure spots). The boxes were observed weekly and inspected every three days when active and at least once per month when inactive. Eggs that were abandoned were measured with a calliper.

Active nests were observed *ad libitum*, between 7:00 and 18:00, and between one and two days per week, from a distance of 20–30 m in open areas and 10 m within forests in order to maximise visibility of nests in response to vegetation cover. The reproductive stages (egg laying, incubation and chick rearing) were identified based on the content (eggs, nestlings, fledglings) encountered during nest box inspections. The laying interval was not observed and assumed to be two days as this is the time noted for the closely related White-eared Parakeet *Pyrrhura leucotis* (Forshaw 1973). Details of the pectoral orange band allowed determination of age class (absent in juveniles, incomplete in immatures and heavily marked in adults). The use of cavities in Wax Palms and nest boxes by other species is reported.

Nest characterization

Nests were classified as natural cavities or as nest boxes. Nests were characterized based on height above the ground, plant species, diameter and estimated height of the plant, height of the entrance and type of entrance (top or lateral). Nest placement was classified according to three habitats: forest, forest edge, and pasture.

Nest productivity and success

Productivity was calculated for nesting attempts between 2006–2008 following the breeding parameters described by Masello & Quillfeldt (2002): (1) clutch size, (2) hatching success, i.e. the percentage of eggs laid that hatched, (3) fledging success, i.e. the percentage of hatchlings that fledged, (4) successful attempts, i.e. the percentage of nests with at least one fledged chick. Nest fate was classified as successful or failed, and failure was classified as known (if there was evidence to support cause of failure) or unknown (in absence of evidence to support the cause of failure).

RESULTS

Nests

A total of 19 nesting attempts were recorded in 17 cavities. Ten attempts occurred in cavities within dead palms and nine in nest boxes. One natural cavity was used in two consecutive years. Two consecutive clutches were laid in one nest box, the second one after we removed eggs that did not hatch in the first clutch. Of the total attempts, seven occurred in 2005 (all in natural cavities), two in 2006 (both in nest boxes), eight in 2007 (six in nest boxes), and two in 2008 (both in nest boxes).

Nest boxes were used by five other bird species and one mammal: Scarlet-fronted Parakeet *Psittacara wagleri*, Red-billed Parrot *Pionus sordidus*, American Kestrel *Falco sparverius*, Strong-billed Woodcreeper

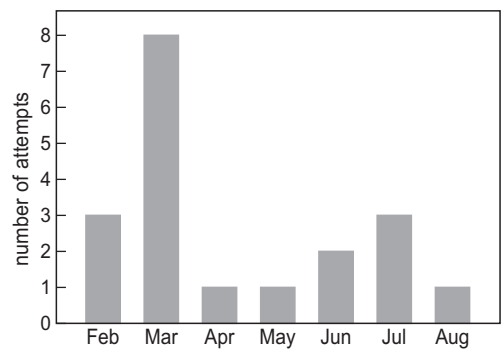

Figure 1. Number of Santa Marta Parakeet nesting attempts initiated per month between 2005 and 2008 in the San Lorenzo Ridge (Sierra Nevada de Santa Marta).

Figure 2. Wax Palm *Ceroxylon ceriferum* occupied by Santa Marta Parakeet and breeding habitat dominated by Wax Palms and bamboo *Chusquea* sp.

Xiphocolaptes promeropirhynchus, Black-banded Woodcreeper *Dendrocolaptes picumnus* and Red-tailed Squirrel *Sciurus granatensis*. Some nest boxes were also occupied by bees. Cavities in dead palms were also used by Scarlet-fronted Parakeet and Strong-billed Woodcreeper.

Nesting period

Santa Marta Parakeets nested between February and October. Nest initiation occurred in every month from February to August, but was concentrated between February and May with 68% of the attempts occurring during these months (Figure 1).

The nesting period lasted 69–79 days (n = 2), depending on the number of eggs laid and hatched. Incubation lasted 22 days (n = 1). Fledging occurred when chicks were between 45 and 48 days old (n = 2). The nest that was occupied for 69 days produced one fledging and four eggs that did not hatch.

Cooperative breeding

In twelve of the nesting attempts (63%) more than two individuals cooperated in the rearing of chicks. We will refer to these birds as helpers. Between one and five helpers (average: 2.5 ± 1.68 SD, n = 12) were present at these nests during the whole nesting period. In nest boxes the number of helpers per nesting attempt was higher (3.57 ± 1.51, n = 7) compared to natural nests (1.2 ± 0.45, n = 5).

Helpers were either immature or adult birds and assisted in searching for food and feeding of the incubating individual and chicks. During some visits, chick feeding was mainly performed by immature helpers. Cooperation was also observed in guarding and defence of the nest. On one occasion a group of four parakeets was observed protecting the nest by surrounding an Emerald Toucanet *Aulacorhynchus prasinus*, a potential nest predator that was within 3–4 m of the cavity.

Nest site characteristics

All natural nests were found in standing dead Wax Palms (Figure 2). Average height of palms used for nesting was 13 m (range: 5–20 m, n = 10) and average trunk diameter at 1.2 m was 16.12 cm (range: 13.0–19.1 cm, n = 9). Only one dead tree was inspected, finding the base of the cavity to be above 6 m. Of the palms selected for nesting, seven (66.7%) had only a top entrance and three (33.3%) had top and side entrances. Nest boxes used for breeding were placed between 5 and 10 m (8.0 ± 1.7 m (±SD), n = 8).

Most of the nesting attempts occurred in cavities located within forest (73.7%); to a lesser extent in forest edge (15.8%) and pastures (10.5%). Nesting in Wax Palms was only detected above 2500 m, despite palms being present from 2000 m and apparently suitable snags commonly available from 2300 m up. Breeding in nest boxes occurred between 2300 and 2600 m.

Nesting success and productivity

Reproductive parameters are presented in Table 1. Eight of the 19 nesting attempts fledged at least one young, representing a 42% success rate. Success in nest boxes (55%) was higher than for natural cavities (30%). Additionally, nine nesting attempts failed (five in palm cavities and four in nest boxes) and in the remaining two, the outcome was unknown.

Eggs measured 27.3 ± 0.93 mm × 21.0 ± 0.46 mm (n = 6) and clutches averaged 4.5 ± 1.4 SD) eggs per

nesting attempt (range: 3–7, $n = 7$). Overall, successful nesting attempts produced 3.3 ± 1.8 chicks (range: 1–5, $n = 8$) and with no difference observed between natural cavities (3.6 ± 0.57, $n = 3$) and nest boxes (3.2 ± 1.48, $n = 5$).

In total, 18 out of 32 eggs hatched, representing a success of 56%. In three attempts eggs were found abandoned and fractured.

Causes for nest failure were known in three attempts: in one case the nest was abandoned after the eggs did not hatch, while in the other two failure was due to nest displacement by Scarlet-fronted Parakeets and Red-tailed Squirrels, respectively. In the nest displaced by Scarlet-fronted Parakeets chicks were found both injured and dead.

DISCUSSION

Nesting period

Considering our findings and those of Tamaris (2004), we conclude the main breeding season for the Santa Marta Parakeet occurs from December to May. This period corresponds with the dry season as well as the nesting season for the majority of parrot species in northern Colombia (Rodriguez-Mahecha & Hernández-Camacho 2002). Nesting in the dry season has been documented for other *Pyrrhura* parakeets (Stiles & Skutch 1989) and has been linked to availability of food resources in other parrot species (Rinke 1989, Renton & Salinas-Melgoza 1999). However, nest initiation was also recorded in June, July and August, and given that the Santa Marta Parakeet was the only parrot species in the region to start nesting in mid-year, this prolonged nesting season could be a response to competition for cavities. Notably, Scarlet-fronted Parakeet was observed displacing Santa Marta Parakeets from snags and occupying natural cavities and nest boxes in higher frequencies (Olaciregui & Botero-Delgadillo unpubl. data). A second nesting peak has been reported for other *Pyrrhura* species (Botero-Delgadillo *et al.* 2013) as well as other neotropical parrots (Waltmann & Beissinger 1992, Carantón 2007) but the reason for their second peak is unknown.

Cooperative breeding

A bird species can be considered a cooperative breeder if conspecific individuals additional to a pair participate in the rearing of the chicks at a single nest (Cockburn 2006, Koenig 2017). This was observed in the Santa Marta Parakeet. Our findings, together with those of Arenas-Mosquera (2011) and Klauke *et al.* (2013), add to the increasing knowledge of cooperative breeding in *Pyrrhura* parakeets. Probably, the estimate that 5% of parrot species are cooperative breeders (Cockburn 2006) is too low and should be updated.

In birds, parental care carried out by helpers can take several forms: nest building, incubation, feeding chicks and nest defence (Stacey & Koenig 1990). In the Santa Marta Parakeet, cooperation was observed during incubation, chick rearing and nest defence, and the number of helpers was similar to those reported for El Oro Parakeet *Pyrrhura orcesi* (Klauke *et al.* 2013).

We report the first evidence of clutch replacement for the Santa Marta Parakeet. Clutch replacement has been used as a management strategy for threatened bird species in order to enhance their productivity (Morrison & Walton 1980, Snyder & Hamber 1985, Snyder *et al.* 1987) and potentially this strategy could be used in the Santa Marta Parakeet.

Nest site characteristics

We found that the Santa Marta Parakeet seems to nest exclusively in dead trees or snags of Wax Palms, and association with this palm species has been observed at another locality on the eastern slope of the Sierra

Table 1. Reproductive parameters of the Santa Marta Parakeet at the San Lorenzo Ridge between 2006–2008. Although active nests were detected in 2005, parameters could not be calculated as it was not possible to observe the interior of the cavities or monitor productivity. [1]Number of nesting attempts supplied data only for successful attempts. [2]Clutch size was not observed for every nesting attempt; in parenthesis the number of attempts used in the calculation of hatching and fledging success.

Year	Number of nesting attempts[1]	Reproductive parameters			
		Clutch size[2]	Hatching success (%)	Fledging success (%)	Successful attempts (%)
2006	2	5 ($n = 1$)	100.0	100	100
2007	8	4.8 ($n = 5$)	38.5	80	50
2008	2	3 ($n = 1$)	100.0	100	50

Nevada de Santa Marta (L. Caceres pers. comm.). Locals also report that the species nests in cavities in *Brunellia integrifolia*, but we did not observe this, despite searching such trees. Palm trees are perhaps the most common plants used by parrots for nesting in the Neotropics (Forshaw 1989, Collar 1997, Brightsmith 2005) and in Colombia this has been recorded for at least 17 species (Rodriguez-Mahecha & Hernandez-Camacho 2002). Nesting exclusively in a determinate tree species has been documented for many parrots (Rojas-Suarez 1994, Collar 1997, Brightsmith & Bravo 2006, Pacheco-Garzón & Losada-Prado 2008, Botero-Delgadillo & Páez 2011) and can be critical for the persistence of wild populations. Therefore, protecting and restoring Wax Palm forests in the Sierra Nevada de Santa Marta will be key for the conservation of the Santa Marta Parakeet.

Productivity and nesting success

Clutch and brood size of the Santa Marta Parakeet was found to be within the values known for other *Pyrrhura* species in the wild and in captivity (Forshaw 1989, Aguilar 1996, Collar 1997, Rodriguez-Mahecha & Hernández-Camacho 2002).

Although the Santa Marta Parakeet was the second most frequent species to use artificial nests, hatching success in nests of this parrot was low in comparison with other species in the area (Olaciregui & Botero-Delgadillo unpubl. data): overall, half of the eggs hatched. The reason for this low hatching rate in nest boxes is unknown but possible causes could be the inexperience of the breeders, decreased nutrient reserves in females or infertility (Smith & Saunders 1986, Rojas-Suárez 1994).

Despite the low hatching success recorded during our years of study, the overall fledging success for the species was high, with 93% of chicks that hatched leaving the nest. Similarly high rates of fledging success have been found in other species, such as the Burrowing Parrot *Cyanoliseus patagonus* (Masello & Quillfeldt 2002). This was attributed to the absence of predation; however, it does not necessarily imply high breeding success, due to the absence of studies on survival of post-fledging juveniles. The fact that we measured crude breeding success could overestimate our results (Beintema 1996). Given that breeding success in parrots appears to be higher for breeders in intact forests (Saunders *et al.* 1982, Monterrubio *et al.* 2002), efforts must be put in place to protect the sites where the Santa Marta Parakeet naturally nests and to restore those that have been subject to deforestation and fires.

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SAMENVATTING

In dit artikel wordt de broedbiologie van de Santa-Martaparkiet *Pyrrhura viridicata* beschreven op basis van een onderzoek aan de populatie op de San Lorenzo bergrug, een 'Important Bird Area' in de Sierra Nevada de Santa Marta in het noorden van Colombia. We hebben in 2005–2008 broedvogelinventarisaties uitgevoerd en in mei 2006 op vier locaties 48 nestkasten opgehangen. Er zijn in totaal 19 nestpogingen waargenomen: 9 in nestkasten en 10 in natuurlijke holtes. De legselgrootte bedroeg gemiddeld 4,5 eieren per legsel (met een maximum van 7). We vonden dat na verlies van het legsel een vervolglegsel kan worden gemaakt en dat meer individuen dan het paar zelf voor de jongen zorgden ('cooperative breeding'). Beide verschijnselen waren nog niet bekend van deze soort. De enige natuurlijke holtes die werden gebruikt voor broeden bevonden zich in dode Waspalmen *Ceroxylon ceriferum*. Deze palm is een van de meest algemene en talrijkste soorten op de San Lorenzo bergrug op hoogtes van 2300–2700 m. De palm speelt een sleutelrol in de broedcyclus van de parkiet.

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