Long-term monitoring of Yellow-naped Amazons (*Amazona auropalliata*) in Costa Rica: breeding biology, duetting, and the negative impact of poaching

Christine R. Dahlin,[1,3] Chelsea Blake,[1] Jake Rising,[1] and Timothy F. Wright[2]

[1]*Department of Biology, University of Pittsburgh at Johnstown, Johnstown, Pennsylvania 15904, USA*
[2]*Department of Biology, New Mexico State University, Las Cruces, New Mexico 88003, USA*

ABSTRACT. The population of Yellow-naped Amazons (*Amazona auropalliata*) declined by an estimated 50% between 1980 and 2000, and the current population is estimated to be between 10,000 and 50,000. Poaching of young has been a persistent problem, but the species is also threatened by habitat loss and degradation. Because most aspects of their life history, behavior, and ecology have not been examined in wild populations, we studied Yellow-naped Amazons with the following objectives: (1) identify the species of trees used for nesting, (2) determine the size and potential function of breeding territories, (3) determine nesting success, and (4) examine their duetting behavior. We located nests at 16 sites on the Pacific Slope of Costa Rica from 1999 to 2008. We searched for nests from January to May. Every nest was visited at least once and some nests were visited every 2–3 weeks throughout the breeding season. We also collected territory and duetting data at one site (Ahogados). The breeding season of Yellow-naped Amazons was during the dry season (January–May). Yellow-naped Amazons nested in 21 species of trees, but 68% of nests were located in only five species, and cavities in dead coyols (*Acrocomia aculeata*) were used most often. We found no association between breeding success and the species of tree in which birds nested. Mean territory size was 25,578 m^2, and these small areas generally consisted of several trees surrounding a nest tree. Pairs continued to duet throughout the breeding season, suggesting that duetting is important for territory defense. The nest failure rate in our study was 89%, and most nest failures (64%) were due to poaching for the pet trade. We recommend immediate population management and conservation actions, including increased law enforcement to reduce nest poaching, protection of key nesting areas, educational programs, and habitat conservation.

RESUMEN. **Monitoreo a largo plazo del lora de nuca amarilla en Costa Rica: biología de la reproducción, duetos vocales y el impacto negativo de la caza furtiva**
Entre los loros (orden Psittaciformes), hay más especies amenazadas que cualquier otro orden de aves. Una de estas especies es el lora de nuca amarilla (*Amazona auropalliata*); que tiene una población actual de entre 10,000 y 50,000 individuos y una disminución poblacional estimada del 50% entre 1980 y 2000. El saqueo de crías ha sido un problema persistente, y es una de las principales amenazas para la especie, junto a la pérdida del hábitat por destrucción y degradación. La mayoría de las etapas de la historia de vida, el comportamiento y la ecología en poblaciones silvestres de esta especie no se han evaluado sistemáticamente, y por ende se necesitan estudios adicionales. Estudiamos esta especie en la vertiente del Pacífico de Costa Rica de 1999 a 2008 con los siguientes objetivos: (1) identificar las especies de árboles utilizados para la anidación, (2) determinar el tamaño y la función potencial de los territorios de reproducción, (3) determinar el éxito de anidación y (4) examinar su comportamiento de duetos territoriales. La temporada de reproducción de la especie occurrió durante la estación seca entre diciembre a mayo. Los loros nuquiamarillos anidaron en 21 especies de árboles, pero el 68% de los nidos se localizaron en solo cinco especies, de las cuales la palma de coyol muertos (*Acrocomia aculeata*) se usaron con mayor frecuencia. El tamaño medio del territorio fue de 25,578 m^2 y estas áreas pequeñas generalmente consistían en varios árboles que rodeaban un nido. Las parejas usaron los duetos vocales a lo largo de la temporada de cría, lo que sugiere que los duetos se utilizan en la defensa del territorio. La tasa de fracaso de nidos en nuestro estudio fue del 89%. La mayoría de los fracasos de nidos (64%) se debieron al saqueo para el comercio de mascotas, por lo que se necesitan medidas de conservación para disminuir la presión del saqueo o la caza furtiva. Nuestros resultados presentan oportunidades para mejorar el manejo de la población, sobre todo con respecto a la conservación o protección de árboles preferidos y/o vulnerables al saqueo, como la palma de coyol. No encontramos ninguna asociación entre el éxito reproductivo y las especies de árboles en los que anidan los loros, aunque esta falta de asociación puede haber surgido de las tasas bajas de éxito de los nidos en general.

Key words: conservation, duet, life history, parrot, poaching, reproduction, territory

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[3]Corresponding author. Email: cdahlin@pitt.edu

The family Psittacidae (hereafter, parrots) is among the most threatened bird families in the world, with 37% of 176 extant species listed as vulnerable, endangered, or critically endangered in the New World alone (IUCN 2016). Thus, information about population trends and basic life-history data are clearly important for parrot conservation, especially considering the reliance of many species on diminishing habitats. However, such information is only available for a few species in the genus *Amazona* (Snyder et al. 1987, Gnam 1991, Gnam and Rockwell 1991, Wilson et al. 1995, Renton and Salinas-Melgoza 1999, Seixas and Mourão 2002, Renton and Salinas-Melgoza 2004, Berkunsky et al. 2016).

Yellow-naped Amazons (*Amazona auropalliata*) are among the most popular parrots in the pet trade and, as a result, poaching of young has been a persistent problem, with levels suspected to be as high as 100% in some areas of Costa Rica and Guatemala (Wright et al. 2001, BirdLife International 2016). This species is also threatened by habitat loss and degradation (Juniper and Parr 1998, BirdLife International 2016). The wild population of Yellow-naped Amazons has been estimated to be between 10,000 and 50,000 birds (BirdLife International 2016), with the population declining by an estimated 50% between 1980 and 2000 (Anon 2008).

Given the worrisome population trends, additional studies of Yellow-naped Amazons are needed. Most aspects of their life history, behavior, and ecology have not been systematically assessed in wild populations. Matuzak and Brightsmith (2007) estimated that the breeding season of Yellow-naped Amazons in Costa Rica was from December through March, and Joyner et al. (2016) found that nestlings fledged in December and January on the Nicaraguan island of Ometepe. In Costa Rica, a study of radio-tagged Yellow-naped Amazons revealed preferences for savannah and riparian habitats (Salinas-Melgoza et al. 2013). These studies have provided important information, but gaps in our knowledge of Yellow-naped Amazons remain.

We studied Yellow-naped Amazons on the Pacific Slope of Costa Rica over a 10-year period. Our objectives were to: (1) determine their breeding phenology, (2) identify the species of trees used for nesting, (3) determine the size and potential function of breeding territories, (4) determine breeding success, and (5) examine the duetting behavior of Yellow-naped Amazons. We included analyses of duetting behavior during the breeding season because the results of previous studies suggest that duetting may be important in territory defense (Dahlin and Wright 2012b).

METHODS

Our study was conducted at 16 different sites in northwestern Costa Rica (Fig. 1), including human-modified habitats (cattle ranches and early successional forest) as well as secondary tropical dry forest and mangroves intermixed with patches of agriculture. Many sites where Yellow-naped Amazons roost and nest in Costa Rica, including some of our sites, were close to human dwellings and roads.

Breeding behavior and nest-site characteristics.   We consolidated nesting data collected from January to May 1999–2008.
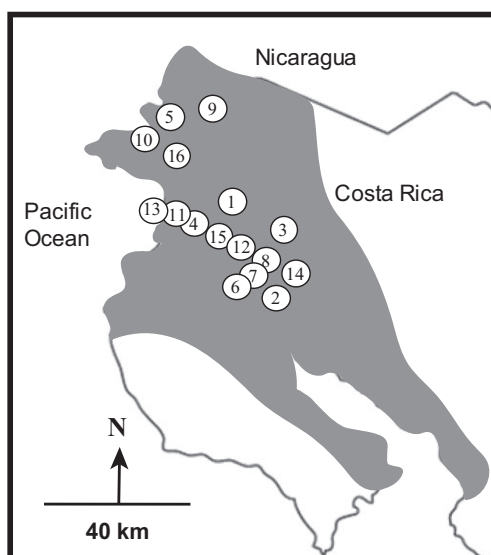

Fig. 1. Map of northwestern Costa Rica depicting the 16 sites where nest data were collected. The gray area indicates the range of Yellow-naped Amazons in Costa Rica. Sites included Ahogados (1), Finca Tamarindo (2), Finca Wilson (3), Horizontes (4), Junquillal (5), Las Playitas (6), Llano Cortez (7), Lomas Barbudol (8), Los Inocentes (9), Murciélego (10), Papagayo (11), Pelon Bajura (12), Playa Cabuyal (13), Rancho Verde (14), San Jerónimo (15), and Santa Rosa (16).

Nesting data were collected opportunistically during studies of vocal behavior so sampling strategies varied among years, with some nests visited repeatedly and others only once or twice. We included data from both confirmed and non-confirmed nests. We confirmed the presence of nests by ascending trees with a modified single-rope technique and observing nest contents (Renton and Salinas-Melgoza 1999). Some cavities were inaccessible, but these nests were included in our analyses if birds were observed going into cavities repeatedly during subsequent observation sessions and displaying behaviors consistent with either incubation or feeding young (Brightsmith 2005a,b). To determine nest contents (e.g., empty, eggs, or nestlings), we either observed nests directly or used a nest camera (< 5% of nests). We examined every accessible nest at least once and, at some sites, continued to observe nests every 2–3 weeks through April or May. Thus, the timing of breeding events, such as egg laying or hatching dates, may represent an estimate that fell between these 2–3 week time intervals. When possible, we recorded the following dates for each nest: (1) nest cavity located (amazons observed entering cavity), (2) birds engaged in incubation behavior, which we defined as one member of a pair spending > 30 min in a cavity, (3) first egg observed, (4) first nestling observed, and (5) nest failure was determined (Renton and Salinas-Melgoza 1999). We did not determine fledging dates for most nests because nests failed, nestlings were still present when our field season ended, or young were assumed to have fledged due to a lack of evidence of poaching or predation. We usually identified nest trees to the species or genus level, using leaves, bark, and fruit.

Based on our observations, we classified nest fate as successful (at least one nestling fledged or was assumed to have fledged), failed (no nestlings fledged), or unknown. To discriminate between nest success and failure, we initially categorized all nests as failures when nests were empty at a stage when nestlings were too young to have fledged. We further categorized empty nests as having failed due to poaching, predation, or abandonment. We categorized nests as poached when we observed cut marks on trees or understory vegetation consistent with a machete or blade (Rodríguez Castillo and Eberhard 2006).

Nesting territory size. We studied the behavior of pairs of Yellow-naped Amazons at one site, Ahogados, over a 3-year period from 2006 to 2008. We identified some individuals by drawing distinctive features of yellow napes on profiles. We also assumed that pairs in the same territory in subsequent years were the same pair. At the time of our study, Ahogados was a cattle ranch with an estimated 30–40 Yellow-naped Amazons (censused in 2005). We observed four pairs in 2006, 10 in 2007, and 13 in 2008. We monitored each pair every 5–14 days throughout the breeding season from January to April. During each field season, we also drew maps of territories and noted the location of trees where duets were performed. The results of previous studies suggest that duets serve a territory defense function (Wright and Dorin 2001, Dahlin and Wright 2012a,b) so it is likely that trees where birds duet represented territory boundaries. At the end of each field season, we created maps of territories by pacing (and thus estimating distance) between trees where pairs were observed duetting during three or more observation periods. Average paces for 10 m were first determined for each researcher (each researcher walked 10 m five times to calculate an average), and those averages were then used to convert numbers of paces into distances. We calculated maximum territory size by forming polygons around the outermost points of the territory and calculating the area of all polygons for each territory (Odum and Kuenzler 1955, Seddon et al. 2004).

Duetting behavior. We monitored the vocal behavior of breeding pairs of Yellow-naped Amazons in their nesting territories between 16:10 and 18:30 (when pairs returned from foraging and vocalized in their territories before leaving to roost shortly after dark) at one site (Ahogados) in 2007 and 2008. We conducted observations of 12 pairs between 5 February and 18 March 2007 and of 19 pairs between 17 January and 3 April 2008. Yellow-naped Amazons congregate in noisy roosts at dusk. However, when females are incubating or brooding, fewer birds congregate at roosts, with females remaining in cavities and males either remaining near nest trees or returning to roosts.

We video- and audio-recorded pairs using a tripod-mounted directional microphone (model ME67; Sennheiser) and digital video

recorder (model Elura 100; Canon). For each session, we noted the time of arrival of each pair and the departure time or time that a pair member entered the nest cavity and ceased vocal behavior. Departure time was not observed in 64 of 136 taped observations. In those cases, we assumed that the departure time was 18:00, which was the most common departure time based on 72 observation sessions. We also recorded the vocal behavior of all pairs, including the number of primary duets (hereafter, duets) and warble duets. Both types of duets consist mainly of sex-specific calls repeated antiphonally (Dahlin and Wright 2012a,b). Warble duets have a larger and more variable repertoire of note types than do duets (C. Dahlin, unpubl. data). Duets are frequently given in a manner analogous to the territorial singing of songbirds, with neighboring pairs counter-singing or, in this case, counter-duetting (Dahlin and Wright 2012b).

For each session, we calculated the average number of duets and warble duets per minute. We ran repeated-measures ANOVAs on the log-transformed values with Pair as a random effect and Nesting Status as the main effect using JMP Pro 12. Nesting status was categorized as: (1) nest searching when parrots were observed either entering or vocalizing at cavities, but spending < 30 min in them, (2) incubation stage when eggs were either observed in nests or adults began spending > 30 min at a time in nest cavities, (3) nestling stage when nestlings were observed or heard in cavities, and (4) post failure when a nest was no longer occupied due to predation, poaching, or some other cause. No nestlings fledged during our observations. We did not have data concerning nesting status for all pairs, so we ran an additional analysis where

we replaced nesting status with a proxy variable of date as a biweekly block.

Breeding success in relation to tree species. We tested whether nest success was influenced by tree species. We analyzed the data with Binomial Generalized Linear Models with pair as a Random Effect nested within the main effects using JMP Pro 12. To simplify the analysis of tree species, we used the five species of trees selected 10% or more of the time, and lumped the remaining species into an "other" category. We initially judged nests as successful if nestlings were predicted to have successfully fledged from the nest, which was our most conservative analysis. We conducted a second analysis where nests were considered successful if eggs hatched and unsuccessful if the nest failed before eggs hatched. These analyses thus removed the impact of poaching. Values are presented as means ± SE.

RESULTS

Timing of nesting. We collected data for 128 breeding events representing 115 pairs of birds over a 10-year period. No birds were banded, but individuals were identified based on plumage characteristics and other physical attributes. If distinguishing physical characteristics were unavailable, we operated on the assumption that pairs would continue using the same territory and thus we identified pairs based on their location. The earliest date that we located an occupied cavity (birds observed entering cavity) was 10 January; thus, mid-January through early February represented the general beginning of the nesting season, but pairs varied considerably in the onset of nesting (Fig. 2). We determined
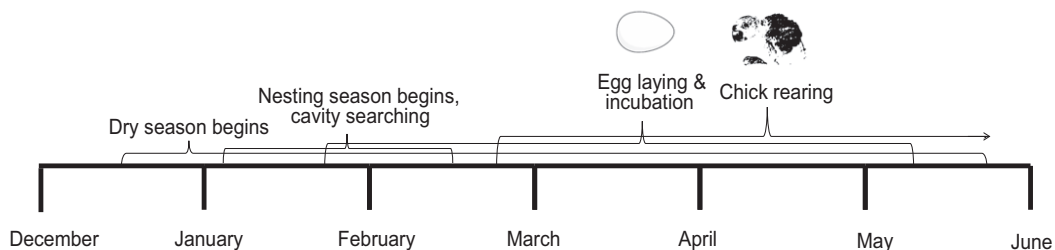

Fig. 2. Timeline of breeding behavior of Yellow-naped Amazons in northwestern Costa Rica. Observations of several nests that were still active in April and May after observations had ended indicate that the nesting season continued into early May.

the day when incubation was initiated at 16 nests (birds spending > 30 min in a cavity), with the earliest date being 24 January. Mean clutch size was 2.5 ± 0.2 eggs (range = 1–5 eggs; $N = 38$ nests). Of those nests, 26 were visited only once and any nestlings in the nest were added to the egg total. For a subset of 12 nests visited multiple times during egg laying, mean clutch size was 2.6 ± 0.4 eggs (range = 1–4 eggs). The earliest observation of eggs was on 22 January. The mean number of nestlings per nest was 2.1 ± 0.1 (range = 1–4, $N = 57$ nests). The earliest observation of nestlings was on 27 February, and the latest on 6 May.

Nest outcomes. Of 128 nests, the outcome for 62 (48%) was unknown. Of the remaining 66 nests, seven likely had young fledge (10.6%) and 59 were unsuccessful (89.4%). The mean number of nestlings for those seven nests was 2.3 ± 0.3. Most unsuccessful nests (38 of 59, 64%) failed due to poaching. In seven cases where nests in the stumps of coyol trees were poached, the stumps were damaged so extensively they could no longer be used for nesting. Damage to cavities in other species of trees may have occurred, but, if so, was either not noted or not apparent. Of the remaining 21 failed nests, the reason for failure of 10 nests was unknown, five nests were abandoned (one or more eggs present, but not being incubated), and six nests were classified as predated based on the presence of a foul smell, egg shell fragments, or observation of a predator. In two cases, garrobos (black iguanas, *Ctenosaura similis*) were observed in or near cavities. We never recorded pairs renesting in the same breeding season after either successful or unsuccessful nesting attempts.

Nest-site characteristics. Based on 124 nesting attempts by 112 pairs (pairs of birds in the same territory were conservatively assumed to be the same pair as in the previous year), Yellow-naped Amazons used cavities in 21 species of trees. Most nests (68%) were in five species of trees, including *Acrocomea aculeata* (Coyol, 21%), *Pithecellobium saman* (Cenízaro, 15%), *Schizolobium parahyba* (Gallinazo, 12%), *Enterolobium cyclocarpum* (Guanacaste, 10%), and *Sterculia apetala* (Panamá, 10%). Yellow-naped Amazons nested in 11 species of trees only once or twice (Table 1). All coyol nests were in

dead snags. Most nest cavities in other trees were in live trees, but we did not classify this sufficiently to provide an accurate percentage. Assuming birds observed in the same territory in consecutive years were the same pairs, we observed seven of 112 pairs for two or three consecutive years. Four of those pairs used nests in either the same tree or the same species of tree, and three pairs nested in different species of trees in consecutive years.

Nesting territory size. We acquired data on 29 nesting territories of 17 pairs. Thus, we measured each territory independently each year because pairs often used different nest cavities and/or the size and shape of their territories changed. Mean territory size was $25,578 \pm 4594$ m^2 (range = 1088–88,888 m^2).

Breeding success in relation to tree species. We found no relationship between breeding success (likelihood that nestlings fledged) and tree species ($G = 5.5$, $P = 0.36$, $N = 58$ nests with seven successful). Re-analyzing the data with nests with hatched chicks treated as successful did not change significance ($G = 1.1$, $P = 0.95$, $N = 65$ nests with 22 successful). Nest success rates were low for all tree species, ranging from no success (coyol and gallinazo), to 1.5% (cenízaro and guanacaste), to 3.1% (panamá) and 4.6% (other).

Duetting behavior. We found no significant variation in duetting behavior during the breeding season based on either date or nesting stage (Table 2). The number of duets recorded during evening observation periods (including both types) ranged from 0 to 70 (mean = 5.9 ± 0.9, median = 1). Pairs gave significantly more duets than warble duets (paired $t = 6.0$, $P < 0.001$, $N = 135$). Counterduetting occurred during 12.5% of all duet sessions.

DISCUSSION

Yellow-naped Amazons are dry-season breeders; pairs initiated cavity exploration in January and completed breeding by May. This is similar to other species of parrots in the dry forests of Mesoamerica, including Scarlet Macaws (Vaughan et al. 2003b), Orange-fronted Conures (*Eupsittula canicularis*; Hardy 1963), Lilac-crowned Amazons (*Amazona finschi*; Renton and Alejandro 1999), and Yellow-crowned Parrots (*Amazona*

Table 1. Species of trees that were selected for nesting by Yellow-naped Amazons ranked by percent use. Scientific name and heights are from Zuchowski (2007) and www.tropicos.org.

Species	Common name	Number and percent of nest cavities	Maximum tree height (m)
Acrocomia aculeata	Coyol	26 (0.21%)	10
Albizia saman	Cenízaro	19 (0.15%)	30
Schizolobium parahyba	Gallinazo	15 (0.12%)	30
Enterolobium cyclocarpum	Guanacaste	13 (0.1%)	35
Sterculia apetala	Panamá	12 (0.1%)	50
Sideroxylon capiri	Tempisque	9 (0.07%)	35
Psidium sp.	Guayabito	5 (0.04%)	10
Pachira quinata	Pochote	5 (0.04%)	30
Ceiba pentandra	Ceiba	3 (0.02%)	50+
Ficus sp.	Ficus	2 (0.02%)	30+
Mangrove species (four possible families)		2 (0.02%)	10–20
Quercus oleoides	Oak	2 (0.02%)	20
Terminalia catappa	Alconorque	3 (0.02%)	25
Anacardium excelsum	Espavel	1 (0.01%)	40+
Cassia grandis	Carao	1 (0.01%)	30
Cedrela odorata	Cedro	1 (0.01%)	30+
Erythrina poeppigiana	Poró	1 (0.01%)	30
Guaiacum sanctum	Guayucán	1 (0.01%)	7
Mangifera sp.	Mango	1 (0.01%)	30
Spondias mombin	Jobo	1 (0.01%)	15
Terminalia oblonga	Guayabón	1 (0.01%)	45

Table 2. Average number of duets per minute by pairs of Yellow-naped Amazons during the breeding season by date (divided into biweekly intervals: 1–15 January = 1, 16–31 January = 2, 1–15 February = 3, 16–29 February = 4, 1–15 March = 5, and 16–31 March = 6) and breeding stage (nest searching = 1, eggs = 2, nestlings = 3, or failed = 4).

	Pair nested within treatment[a]		Fixed effect[a]		Sample size for bi-weekly time interval or breeding stage					
	F statistic and df	*P*	*F* statistic	*P*	1	2	3	4	5	6
Duets by date	$0.6_{77,52}$	0.98	$1.2_{5,122.3}$	0.33	16	41	33	12	23	11
Warble duets by date	$0.8_{77,52}$	0.86	$0.2_{5,116}$	0.86	16	41	33	12	23	11
Duets and breeding stage	$0.7_{28,32}$	0.83	$1.5_{3,45.5}$	0.22	20	23	9	12	–	–
Warble duets and breeding stage	$1.0_{28,32}$	0.54	$0.3_{3,41.0}$	0.80	20	23	9	12	–	–

[a]Analyses were run on log-transformed data. Results are shown for standard duets (duets) and warble duets.

ochrocephala; Rodríguez Castillo and Eberhard 2006). Relative abundance of food at the beginning of the dry season may help optimize breeding success (Renton and Salinas-Melgoza 1999, Renton 2001). The mean clutch size of Yellow-naped Amazons in our study was 2.5 eggs, similar to clutch sizes reported for other species of parrots (Enkerlin-Hoeflich and Hogan 1997, Rodríguez Castillo and Eberhard 2006, Koenig et al. 2007, Berkunsky et al. 2016).

We found that territories were often located in close proximity to one another. The relatively small size of territories in our study suggest that they serve primarily to defend nest sites rather than as multipurpose foraging and nesting territories; indeed, when individuals were not incubating, they left

territories during the day to forage (C. Dahlin, pers. obs.) Salinas-Melgoza et al. (2013) determined the approximate size of the home ranges of Yellow-naped Amazons by tracking radio-tagged birds in one of the same regions we worked (Ahogados), and the mean size of 1041 ha was much larger than the mean territory size of 2.55 ha in our study. We also found much variation in the size of territories of different pairs, likely due to the patchiness of the cattle-ranching habitat where the birds were breeding. The smallest territories were in small, isolated patches of trees.

We found no significant correlation between duetting behavior and breeding stage, providing support for the hypothesis that territory defense is a primary function of these duets (Dahlin and Wright 2012b). Most other species of birds that duet (81%) have also been found to use duets to defend resources (Dahlin and Benedict 2014). Overall, pairs of Yellow-naped Amazons in our study engaged in more duets than warble duets throughout the breeding season, and our observations of pair behavior during warble duets suggests that they play a role in mediating or escalating conflict situations. Warble duet counterexchanges generally occurred during interactions between pairs at territory borders or when pairs were interacting with trespassing individuals. In addition, physical altercations we observed were preceded by warble duets and growls, and Yellow-naped Amazons tended to use more warble duets in response to duet playbacks (Dahlin and Wright 2012b).

Yellow-naped Amazons appear to be less specialized in their selection of nest trees than several other species of parrots where 50% or more of breeding populations nest in two or three different species, including Blue-throated Macaws (*Ara glaucogularis*; Berkunsky et al. 2014), Scarlet Macaws (Vaughan et al. 2003b), Tucuman Parrots (*Amazona tucumana*; Berkunsky and Reboreda 2009a), and Lilac-crowned Amazons (Salinas-Melgoza et al. 2009). In a recent review, Renton et al. (2015) reported similar trends, with most parrots commonly nesting in just two or three species of trees. Yellow-crowned Amazons and Blue-fronted Parrots, however, appear more similar to Yellow-naped Amazons because they have been observed nesting in several tree species (Seixas and Mourão 2002, Rodríguez Castillo and Eberhard 2006, Berkunsky and Reboreda 2009b). More specialized species may base their selection on structural characteristics such as size, with larger macaws relying on trees with larger cavities; other species may simply base their selection on availability (Stojanovic et al. 2012, de la Parra-Martínez et al. 2015, Renton et al. 2015).

Yellow-naped Amazons in our study nested in 21 different species of tree, but most nests were in five species of trees. Coyol was the most frequently used species (21% of nests), and all nests were in stumps where trees had begun to rot from the inside to form dry cavities. Coyol stumps may be safer from terrestrial predators because they lack low-hanging branches and have large spines on the trunk. The next four most frequently used species of trees used for nesting by Yellow-naped Amazons mature at 30 m or more in height (Zuchowski 2007, Tropicos 2016). Thus, as reported for several other species of parrots, Yellow-naped Amazons use two extremes in terms of nesting trees; relatively short, decaying tubes and tall mature trees (Brightsmith 2005a,b, Berkunsky et al. 2014).

Our results have important management implications for Yellow-naped Amazons. Although nests in coyol snags may provide certain advantages, they may also represent ecological traps because poachers can chop through the soft wood of the trees to reach cavities. Thus, nests in coyols in our study area will only be successful if they are guarded, located in protected areas (Lindsey 1992, Wright et al. 2001, Vaughan et al. 2003b), or antipoaching laws are sufficiently enforced to serve as a deterrent. Preserving large mature trees and promoting regeneration of those trees is also necessary, especially in deforested areas, so that sustainable populations can be maintained. In areas where ranch land is being replaced with monocultures such as sugar cane or rice, governments could provide incentives or otherwise encourage landowners to preserve stands of trees for breeding and foraging habitat (Pidgeon et al. 2015). The Guanacaste tree, for example, provides cavities and grows large legumes that serve as an important source of high-protein food during the breeding season (Zuchowski 2007, C. Dahlin, pers. observ.).

In contrast to the Yellow-naped Amazons in our study, high rates of poaching are not

common for all Amazon parrots, and predation by snakes and other predators is the primary cause of nest failure in some populations of Amazon parrots such as Blue-fronted Parrots, Black-billed Parrots (*Amazona agilis*), and Lilac-crowned Amazons (Renton and Salinas-Melgoza 2004, Koenig et al. 2007, Berkunsky et al. 2016). Species of Amazon parrots where nest failure is due primarily to natural mortality events (e.g., non-human) have nest success rates that average 42.7% (Berkunsky et al. 2016). This contrasts starkly with the success rate of 10.6% for our population of Yellow-naped Amazons, and 12% for a population of Yellow-crowned Parrots in Panamá (Rodríguez Castillo and Eberhard 2006).

Parrots are popular pets in Costa Rica, and more than half the population has owned a parrot (Drews 2001, 2002). During our population surveys in 2016, we observed 15 captive Yellow-naped Amazons (C. Dahlin and T. Lewis, pers. obs.). Poaching clearly remains an ongoing threat to the parrots. Surveys reveal that Costa Ricans feel great compassion for their parrots (Drews 2003), and this natural empathy could serve as an asset. Education of the public needs to be a priority, so that Costa Ricans become aware of the negative impacts of poaching on wild populations. Educational programs in Costa Rica have demonstrated that they can be effective in raising awareness. A 1-month program about Scarlet Macaws demonstrated that children learned about conservation, and transmitted some of that information to their parents (Vaughan et al. 2003a). Beginning in 2007, we collaborated on an education program with the Área de Conservación Guanacaste with the aim of increasing conservation knowledge and pride in the three local species of parrots, including Yellow-naped Amazons (Dahlin 2007). Our program included visits to local parrot habitat and community murals. Education programs may take time to show true benefits, however, because children, who are generally the targets of such programs, do not have an immediate impact on wildlife.

Education needs to be combined with greater enforcement of the current law that makes it illegal to keep native species as pets. Surveys by Ara Project personnel indicate that Costa Ricans do not fear current penalties due to lack of enforcement (T. Lewis, pers. obs.). Proper law enforcement has increased breeding success for several species of parrots. For example, Vaughan et al. (2003b) found that the years with the greatest breeding success by Scarlet Macaws coincided with those with maximum law enforcement effort. Studies of many parrots have shown that breeding success is significantly higher among species that enjoyed greater local and/or national protection from poaching (Wright et al. 2001, Pain et al. 2006, Rodríguez Castillo and Eberhard 2006).

Reducing the threat of poaching for Yellow-naped Amazons will require a multi-pronged approach and collaboration between stakeholders. In a study of Yellow-shouldered Parrots (*Amazona barbadensis*) in Venezuela, education programs alone were not immediately successful (Briceño-Linares et al. 2011). Additional surveillance of nests, police patrols, and artificial nests placed in easily patrolled areas have subsequently been used to reduce poaching levels from 100% to 25% (Briceño-Linares et al. 2011). Thus, education, in combination with other efforts such as surveillance, nest protection, law enforcement, and captive breeding programs, will likely be necessary to save declining populations of parrots from poaching.

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