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ECOLOGY AND MANAGEMENT OF NATURAL AND ARTIFICIAL SCARLET MACAW (*ARA MACAO*) NEST CAVITIES IN COSTA RICA

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Resumen. – Ecología y manejo de cavidades de anidación naturales y artificiales de la Lapa Roja (*Ara macao*) en Costa Rica. – Estudiamos cavidades de anidación de la Lapa Roja (*Ara macao*) en el Área de Conservación del Pacífico Central, Costa Rica entre 1992 y 2000. Encontramos un total de 56 nidos. De 46 nidos identificados en 11 especies de árboles, el gallinazo (*Schizolobium parahybum*) (37%) y la ceiba (*Ceiba pentandra*) (22%) fueron los más usados por las lapas. Observamos 61 instancias de lapas utilizando 42 nidos diferentes en diez especies de árboles (nueve identificadas) durante los períodos de anidación entre los años 1993 y 1997. Varios nidos fueron ocupados mas de una vez durante el estudio, incluyendo cinco nidos ocupados durante tres años y nueve nidos ocupados durante dos años. Durante un año, fueron ocupados 28 nidos. Confirmamos la salida de tres pichones de un nido después de colocar un radio collar a cada uno de ellos. Las cavidades naturales fueron encontradas en varios habitat, incluyendo bosque primario (30%), bosque secundario (34%), potrero (29%), y manglar (7%). Los nidos variaron en altura desde los 8 m en *Rhizophora mangle* hasta los 40 m en *C. pentandra*. Cavidades de nidos fueron más comunes en troncos de árboles (35 de 56; 63%) que en ramas de árboles (21 de 56; 37%). La orientación de los nidos en las cavidades de árboles no fue al azar. Un 64% de las 56 cavidades de anidación fueron consideradas con un alto riesgo de robo y 23% con un riesgo mediano de robo; un 66% de los nidos se encontraron en tierras privadas, mientras que el 34% se encontraron en áreas silvestres estatales. De los 56 nidos, 42 (75%) estaban en árboles vivos al momento de encontrarlos. Entre los años 1993–97, fueron destruídos 7 de 8 (88%) nidos en árboles muertos y 6 de 19 (32%) en árboles vivos cuando el árbol hospedero se cayó. Las cavidades-nido en árboles muertos se perdieron a una tasa anual de 22%, comparadas con una tasa anual de pérdida de 8% en árboles vivos. Fueron construídos y montados 38 nidos artificiales entre los años 1995–2000 y la mayoría fue visitada por lapas. Sabemos de 11 camadas de Lapas Rojas que nacieron en seis nidos artificiales hechos de madera (un nido y dos grupos de pichones), tubos de poli-vinilo de chlorido de 14 pulgadas (dos nidos y tres grupos de pichones) y barriles de poli-acrilo de amido de 55 galones (tres nidos y seis grupos de pichones). Rastreamos la salida de ocho pichones de cuatro camadas basados en estudios de radio-telemetría. Calculamos que otros 13 pichones salieron, fueron robados por laperos o desaparecieron por causas naturales. Recomendamos los siguientes prácticas de manejo para mejorar el éxito reproductivo de la Lapa Roja: a) cuantificar los parámetros de nidos y de habitats que resultan en anidaciones exitosas; b) eliminar los árboles muertos que utiliza la lapa para anidar; c) comparar detalladamente el éxito de anidación en nidos artificiales y naturales; d) monitorear y experimentar con nidos activos (e inactivos) para promover éxito; e) concentrar los nidos artificiales en un sitio para promover la protección y reducir los gastos de protección; f) cerrar nidos con un alto riesgo de robo; g) adaptar estrategias del manejo para

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asegurar el uso y el éxito de nidos artificiales y naturales; y h) coordinar visitas a los nidos por biólogos con niños y turistas para promover la educación ambiental y el ecoturismo local.

Abstract. – We studied Scarlet Macaw (*Ara macao*) nest cavities in the Central Pacific Conservation Area, Costa Rica from 1992 to 2000. A total of 56 natural nest cavities were found. Of 46 identifiable nest trees (11 species), *Schizolobium parahybum* (37%) and *Ceiba pentandra* (22%) were the most common species used by macaws for nesting. We observed 61 instances of macaws inhabiting 42 different nests in 10 tree species (9 identified) during breeding seasons from 1993 to 1997. Several nests were occupied repeatedly during the study, including five nests occupied for three years and nine nests occupied for two years. Twenty-eight nests were occupied for a single year. We confirmed the fledging of three chicks from one nest by radio telemetry. Nest trees were found in primary forest (30%), secondary forest (34%), pasture (29%), and mangrove swamp (7%). Nest cavity entrances ranged in height from 8 m (in *Rhizophora mangle*) to 40 m (in *C. pentandra*) from the ground. Nest cavities in tree trunks (35 of 56; 63%) were more common than those in branches (21 of 56; 37%). Orientation of nest cavity entrances was non-random. Of 56 known nest cavities, 64% were considered at high poaching risk and 23% at intermediate poaching risk, with 66% of nests on private lands and 34% on government lands. Of 56 nest trees, 42 (75%) were alive when found. From 1993 to 1997, nests were destroyed when 7 of 8 (88%) dead trees and 6 of 19 (32%) living trees fell during the study. Nest cavities in dead trees were lost at a rate of 22% annually, compared to 8% annual loss rate of living trees. We mounted 38 artificial nests from 1995 to 2000 and macaws visited most at least once. We know of at least 11 broods that hatched in four artificial nests made from various materials, including wood, poly-vinyl chloride 14-inch tubes, and 55-gallon poly-acryl amide barrels. Eight chicks fledged from artificial nests based on radio-telemetry tracking. An additional 13 chicks fledged were poached or disappeared for unknown reasons. We recognize the need for detailed, long-term data on macaw nest site selection and nesting success to aid in management of natural and artificial nests, and to increase recruitment rates. These data include: a) quantifying habitat features and nest characteristics of successful nests cavities; b) eliminating snags with nest cavities so macaws cannot nest in them; c) comparing successful fledging from nests in softwood vs. hardwood trees; d) using artificial nests to increase number of breeding pairs and reproductive success; e) concentrating nests so several nests can be protected together to reduce economic and human resource investment; f) closing high poaching risk nests; g) utilizing adaptive management to ensure that natural and artificial nests are successful and utilized by macaws; and h) coordinating visits to nests when scientists are measuring chicks by children and tourists to promote environmental education and local ecotourism. *Accepted 6 January 2003.*

Key words: Scarlet Macaw, *Ara macao*, Costa Rica, management, nest cavities, artificial nests.

INTRODUCTION

The parrot family, Psittacidae, contains more endangered species than any other bird family (Collar *et al.* 1994). In the Neotropics, 46 of 145 psittacine species are threatened with worldwide extinction (Snyder *et al.* 1999). Since psittacines are secondary cavity nesters, nest cavity scarcity as well as poaching may limit successful breeding pairs and lower recruitment (Snyder 1978, Munn 1992, Iñigo-Elías 1996, Collar 2000, Wright *et al.* 2001). If the breeding density of a population is limited by scarcity of cavity nests, the production of young is limited, along with population growth (Newton 1994). Increasing reproductive output is key to the future existence of many psittacine species (Collar 2000).

The Scarlet Macaw (*Ara macao*) is the most widely distributed of the 17 macaw species (Mexico to Brazil) (Forshaw 1989). It is considered threatened throughout most of its range (Iñigo-Elías 1996, Collar 2000). In Costa Rica, the Scarlet Macaw originally occupied 42,000 km^2 of forested habitat. Cur-

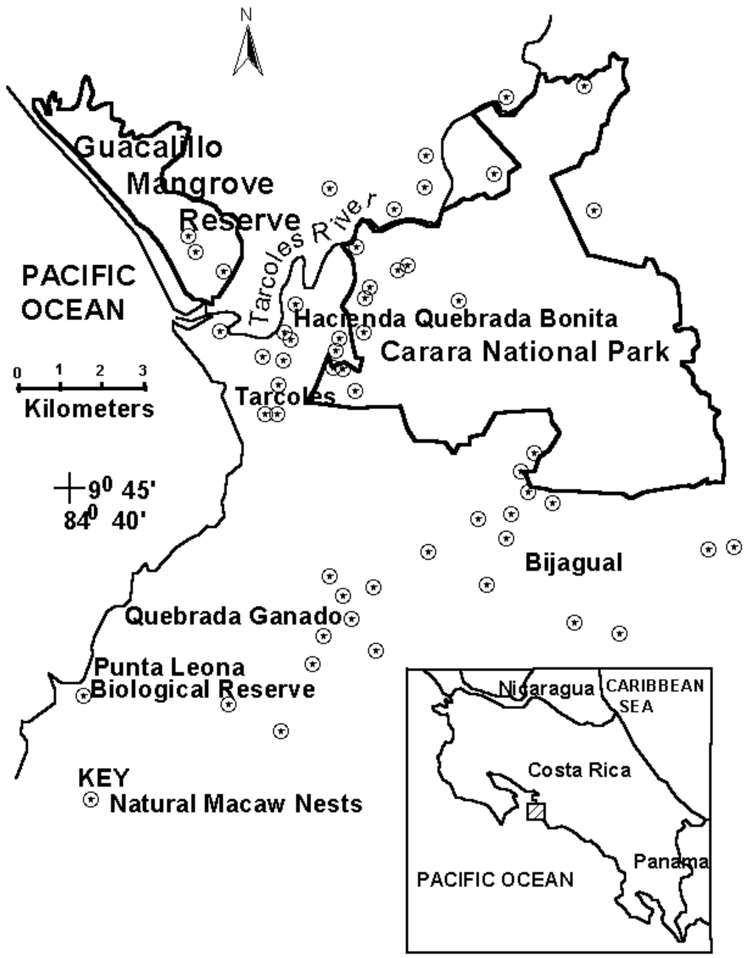

FIG. 1. Map of study area for Scarlet Macaw nesting in Central Pacific Costa Rica.

rently, two local populations exist; approx. 700 individuals live in the Osa Conservation Area (Stiles & Skutch 1989), and 330 macaws live within a 560-km^2 area of the Central Pacific Conservation Area (Vaughan 1983, Vaughan *et al.* 1991).

Studies on Scarlet Macaws are scarce, especially pertaining to its behavior as an obligate cavity-nester (Munn 1992, Marineros & Vaughan 1995, Nycander *et al.* 1995, Iñigo-Elías 1996). The objectives of this study were to describe nest cavities and their use by the Scarlet Macaw population in the Central Pacific Conservation Area, and to implement nesting management strategies, including the use of artificial nests. The addition of artificial nest boxes has been shown to increase the number of breeding adults of other psittacine species, such as the Green-rumped Parrotlet (*Forpus passerinus*) in Venezuela (Beissinger & Bucher 1992, Newton 1994), and artificial nest boxes may even be more productive than natural nest cavities (Sanz *et al.* 2003).

METHODS

Study site. This study was concentrated in the western portion of the Central Pacific Scarlet Macaw home range in Costa Rica. The study area included the Carara National Park (CNP) (84°35'W, 9°47'N), 5500 ha of primary and secondary forested areas, the Guacalillo Mangrove Reserve (1100 ha), and the Punta Leona Private Biological Reserve (300 ha). It also included cattle pastures, annual or perennial crop fields, forests, and several hundred human dwellings surrounding these areas (Fig. 1) (Fallas 1995, Marineros & Vaughan 1995). Life zones in the study area were tropical dry forest to humid transition, premontane forest, and tropical wet forest (Tosi 1969, Marineros & Vaughan 1995). The climate was humid and hot with a mean annual temperature of 25–30°C (Coen 1983). Approx. 90% of the annual 2.5–3.3 m precipitation fell during the wet season from May to December (Herrera 1986).

Finding nest cavities and monitoring use. Scarlet Macaw nests were found by observing macaw activity in the forest canopy from a distance with binoculars (8x40 mm) or spotting scope (20x50 mm), or by tracking macaw vocalization patterns in early-mid breeding season (December to March). In both instances, the general area was plotted and later found by hiking to the area, at which time trees were carefully examined for cavities. Additionally, nests were found by paying local inhabitants and poachers to reveal nest sites occupied by macaws. Once a tree with a nest cavity was found, the presence of nesting macaws was confirmed by finding eggshells under the nest cavity, observing one or two macaws entering the cavity, or clapping hands to elicit a response from nesting birds. Some nest trees were climbed to confirm presence of nesting birds, chicks, feathers, and eggshells. We defined a successful nesting attempt as one in which one or more chicks were observed flying from the nest cavity. We also placed radio transmitters on three macaw chicks from one natural nest to follow fledgling survival. Finally, in 1997, we closed the entrance of one natural nest cavity that had been used by nesting macaws in the past, and was considered at high risk for poaching.

Nest and nest tree characteristics. Tree species with nest cavities were identified by personal observation, local residents, or submitting samples to the Institute of Biodiversity, Costa Rica. The vegetation surrounding nest trees was classified as primary forest (undisturbed, mostly protected reserves or parks), secondary forest (pioneering species recovering from disturbance, usually >30 ha in height), pasture (grass fields with isolated large trees), and mangrove (brackish wetlands dominated by *Rhizophora mangle*) (Hartshorn & Poveda 1983).

One person estimated heights of nest cavities, while a second person stood next to the tree for reference. Nest cavity height was estimated from the lower lip of the nest cavity to the ground. Nest cavity entrance orientation was estimated using a compass at the tree base. A chi-squared statistical test was performed on entrance orientation (Sokal & Rohlf 1981). During the 1995–96 nesting season, we climbed 10 trees to measure nest cavity dimensions in active nests. We used vertical climbing techniques to minimize damage to trees (Munn 1991). Climbing all nests or observing them until chicks fledged or were poached was not logistically feasible, thus we selected a few nests to monitor regularly (at least once a month), based on the level of activity at the nest (and therefore likelihood that a pair would nest there), and ability to arrive to the nest tree in reasonable time and effort.

A tree was considered dead if it had a rotting trunk and no signs of recent leaves, flow-

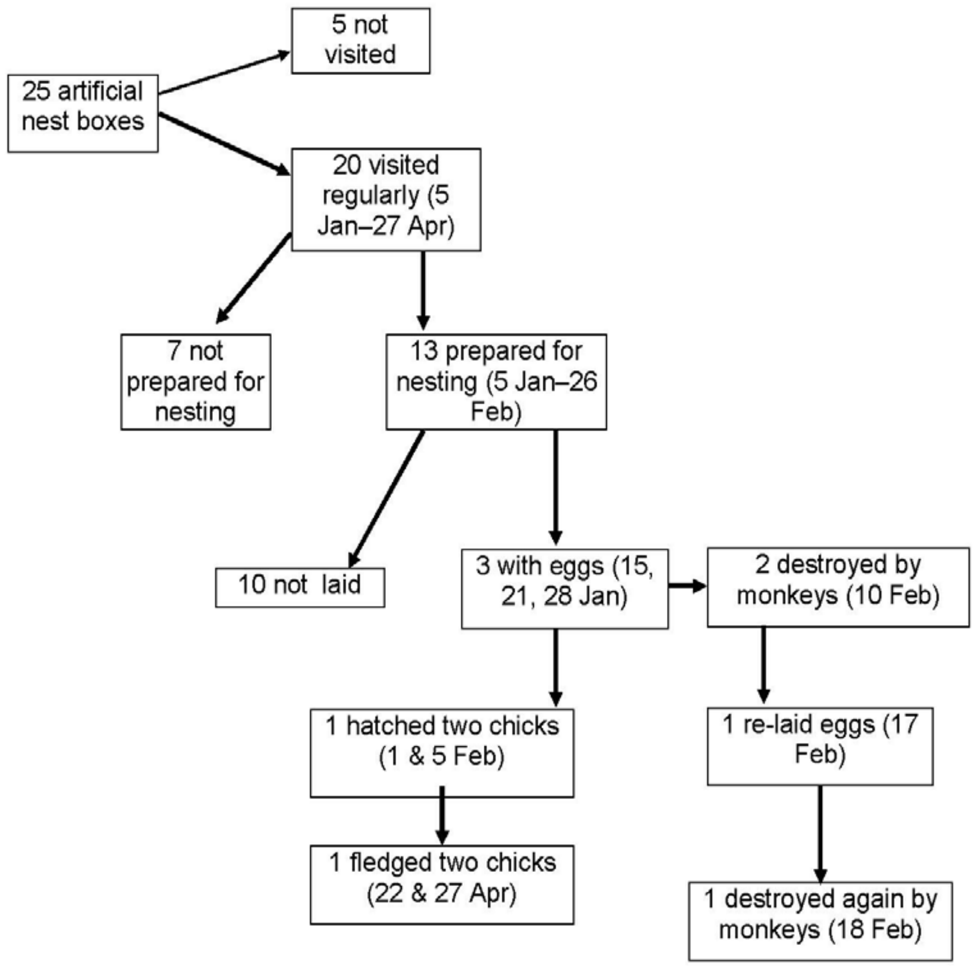

FIG. 2. Study of Scarlet Macaw use of 25 artificial nest boxes in Central Pacific Region, Costa Rica (5 January–27 April 2000).

ers, or fruits. All other trees were considered alive. Nests were located in tree trunks or branches originating from the trunk. From 1993 to 1997, 27 nest trees (19 living, 8 dead) were monitored to determine annual rate of cavity loss resulting from tree fall.

A nest was considered on public property if it was within a national park or other government-managed area; otherwise, it was on private property. Poaching risk was classified for each nest as follows: a) high risk of poaching if the tree had signs of past poaching (climbing spur marks, makeshift ladders nailed to the tree, ropes hanging close to nest), or was mentioned by local inhabitants; b) intermediate risk of poaching if the nest cavity was 30 to 40 m above ground level, difficult to climb, and showed none of the aforementioned signs of poaching; and c) low risk of poaching if the nest tree was found in an area difficult to access, appeared difficult to climb (nest high off the ground, on a thin branch, spines on the bark), or was located within a well protected area (Marineros & Vaughan 1995).

Management of artificial nest boxes. We based our design and strategy for placement of artificial nests on natural nest cavity characteristics observed during our study, as well as on information resulting from work in the Manu Biosphere Reserve and the Tambopata-Candamo Reserved Zone, Peru (Nycander *et al.* 1995). We built various models, altering design based on study results. Our designs included 46 cm diameter, 1.0 m high 55-gallon poly-acryl amide (PA) barrels, 1.0, 1.5 and 2.5 m 14-inch poly-vinyl chloride (PVC) tubes, and 1.0 m x 0.6 m wood nest boxes made of 2.5 cm thick wood from *Cedrela* sp. or *Hura crepitans.* We placed wood shavings and sawdust in nests during the 1995–1996 nesting season, and replaced the shavings with wood chips (2–3 cm diameter chips; 20–30 cm full from the bottom of the nest) from 1997 to 2000. Prior to each nesting season, we cleaned out active nests and replaced decayed, dampened wood chips with fresh chips. In 1999–2000, we placed metal strips from 1–2 m high around the base of artificial nesting trees as an additional effort to protect them.

Artificial nests had one or two entrance holes per nest. Entrance holes were approx. 25 cm high x 20 cm wide, and wood nests had wooden perches on the lower lip so that macaws could enter easily, whereas earlier models (PVC and PA) did not have wooden perches outside the cavity entrance. Nests were placed from 10–15 m high, with cavity entrances oriented toward the west, away from am sunlight.

We nailed or strapped nest boxes (n = 38) to tree trunks at approx. 10–20 m height in five different sites, including Punta Leona Private Biological Reserve, CNP, Hotel Villa Lapas, Hacienda Quebrada Bonita, and Bijagual (Fig. 1). We observed artificial nests weekly during the early nesting season while, later in the nesting season, we concentrated our efforts on nests that we knew were occupied by Scarlet Macaws. During the 2000 nesting season (5 January–29 April), we monitored 25 artificial nests weekly at CNP, Punta Leona, and Hacienda Quebrada Bonita by ground inspections for presence of adult macaws, and by climbing nests to document nest contents (Fig. 2). Finally, we climbed trees containing artificial nests weekly to weigh, measure and evaluate health of chicks (Vaughan unpubl. data).

Nest poaching. Poaching was considered a major threat to our study population (Marineros & Vaughan 1995), and through research assistants living within communities from 1995–2000, we were informed of some level of poaching events. In some cases, poachers informed us of their own activities, or of those of other poachers in a current or past nesting season. Additionally, park guards monitoring poaching activity reported poaching information to us.

Environmental education and ecotourism at active nests. From 10 February to 29 March 2002, approx. 175 children from four nearby elementary schools (Tarcoles, Playa Azul, Quebrada Ganado, and Bijagual) were bused to an active artificial nest in the center of a pasture to observe chicks being weighed and measured.

RESULTS

Nest cavities and nesting attempts. The Scarlet Macaw nesting season lasted approx. 96 days, with approx. 22 days dedicated to egg incubation, and 74 days dedicated to rearing young. Chicks fledged from late March (eggs laid in late December) to late May (eggs laid in late February). Macaws in this study were not reproductively synchronous (Marineros &

TABLE 1. Tree species and habitat types used by nesting Scarlet Macaws in Central Pacific Costa Rica.

Tree species	Number (%)[1]	Number of trees in			
		Primary forest	Secondary forest	Pastures	Mangrove
Schizolobium parahybum	17(37)	6	9	2	0
Ceiba pentandra	10(22)	3	2	5	0
Unknown species	10(0)	6	1	3	0
Astronium graveolens	3(7)	1	1	1	0
Hura crepitans	3(7)	1	2	0	0
Rhizophora mangle	3(7)	0	0	0	3
Terminalia oblonga	3(7)	0	1	2	0
Sterculia apetala	2(4)	0	0	2	0
Brosimum utile	2(4)	0	2	0	0
Avicennia nitida	1(2)	0	0	0	1
Anacardium excelsum	1(2)	0	0	1	0
Myroxylon balsamom	1(2)	0	1	0	0
Totals	56(100)	17	19	16	4

[1]% is calculated by dividing number of known individuals of a species by 46, the number of identifiable trees.

Vaughan 1995).

We found 56 natural nest cavities from 1992 to 1996; 34 nests were found from 1992 to 1993 (Marineros & Vaughan 1995), and 22 were found from 1994 to 1996. Local residents, usually poachers, showed us all but four of these nests. From 1992 to 1997, 61 nesting attempts were recorded during nesting seasons in 42 individual trees, representing eight known tree species, as well as unidentified tree species. These nesting attempts included the repeated annual use of certain nests. Five different nests in our study were occupied for three years and nine nests were occupied for two years, while 28 nests were occupied for a single year. We confirmed the fledging of three chicks from one nest by radio telemetry.

Tree species and habitats. Of 46 nest cavity trees identified to species, 17 (37%) were in *Schizolobium parahybum* and 10 (22%) were in *Ceiba pentandra*. Additional tree species represented the remaining 41% of nests in identified tree species. Nest cavities were found in primary forest (30%), secondary forest (34%), pasture (29%), and mangrove swamp (7%). The majority of *S. parahybum* nests (9 of 17) were in secondary forest (Table 1).

Nest and nest tree characteristics. Mean nest heights from the lower nest lip to the ground varied from 8 m high in *R. mangle*, to nests in *C. pentandra* and *Sterculia apetala*, which were up to 40 m from the ground. Dead trees represented 14 of 56 nest trees (25%), ten of which were unidentifiable to species. Nest cavities in tree trunks (35 of 56; 63%) were more common than nests in branches (21 of 56; 37%) in this study (Table 2). Orientation of cavity entrances was nonrandom among quadrants (0–90°, 91–180°, 181–270°, 271–360°) ($\chi^2 = 10.16$, df = 3.0, $P < 0.01$). The largest proportion of nests was oriented from 0–90° (n = 18; 38%) and 181–270° (n = 16; 34%). Five nest entrances were oriented vertically, while all others were oriented horizontally. The direction of three nests was not recorded.

TABLE 2. Characteristics of trees containing 56 nests used by the Scarlet Macaw in Central Pacific Costa Rica.

Tree species	Number of nests	Height (m) (Mean ± SD)[1]	Number of cavities in		
			Alive trees	Branches	Trunks
Schizolobium parahybum	17	20.3 ± 5.2	15/17	8	9
Ceiba pentandra	10	27.0 ± 8.6	7/10	3	7
Unknown species	10	20.4 ± 9.5	2/10	4	6
Astronium graveolens	3	23.7 ± 5.5	3/3	0	3
Hura crepitans	3	25.3 ± 5.0	3/3	1	2
Rhizophora mangle	3	8.0 ± 0.0	3/3	1	2
Terminalia oblonga	3	18.0 ± 8.2	3/3	1	2
Sterculia apetala	2	26.5 ± 19.1	2/2	1	1
Brosimum utile	2	27.5 ± 3.5	2/2	0	2
Avicennia nitida	1	27.5	1/1	1	0
Anacardium excelsum	1	11.0	1/1	1	0
Myroxylon balsamom	1	20.0	0/1	0	1
Totals	56	—	42/56	21	35

[1]Distance from ground to lower lip of nest cavity entrance.

Nest cavity internal measurements. External and internal nest cavity dimensions were measured for 10 nests in five tree species (*Astronium graveolens*, *C. pentandra*, *R. mangle*, *S. parahybum*, and *Terminalia oblonga*). Average height of cavity entrances measured from the lower lip was 24.8 ± 12.5 cm (range 13 to 50 cm) and the average width was 18.7 ± 4.4 cm (range 13 to 25 cm). Internal nest cavity measurements averaged 34 ± 13.3 cm wide (range 20 to 60 cm), and 21.5 ± 17.2 cm deep from the lower lip of the entrance hole (range 5 to 60 cm). Finally, cavities were 69.5 ± 37.4 cm (range 20 to 120 cm) long from the lower lip of the nest entrance to the floor.

Nests on public/private property and poaching risk. The number of nests on private property (37 of 56; 66%) was greater than those on protected lands (19 of 56; 34%). Concerning habitat distribution of nests on public and private lands, 10 of 16 nest trees (63%) in primary forest were on public land, while 6 of 16 (38%) were on private land (Table 1). The poaching risk distribution of nests was as follows: 36 of 56 nests (64%) at high risk, 13 (23%) at intermediate risk, and 7 (13%) at low poaching risk. No statistical tests were performed on these data because sampling was predominantly based on poacher information.

Individual poaching efforts were recorded as local people and park guards offered information to us. In 1993, a 14-year old boy poached 17 chicks, including 12 in one day (Marineros & Vaughan 1995). In 1997, poachers reported at least 20 chicks poached from within the study area (M. Myers pers. com.).

Finally, several Scarlet Macaw pairs congregated at the closed nest cavity in an *A. graveolens* tree in late December and early January 1997. Several birds made unsuccessful attempts to remove the thin roofing that blocked the nest entrance. However in 1998, re-nesting occurred in this high poaching risk cavity after the roofing had fallen.

TABLE 3. Characteristics of artificial nest boxes placed for Scarlet Macaw and nesting success.

Sites	Number of artificial nests (1995–2000)	Successful nests	Number of chicks and years in successful nest	Date chicks fledged[a]	Tree species used for successful nest
Punta Leona Private Wildlife Refuge and Resort	12 PVC, 5 wood	# 14-PVC	1-1999[b]		*Schizolobium parahybum*
Carara National Park	3 PA, 3 PVC	# 20-PVC	2-1996[a], 2-1997[c]	1996-20 May, 22 May	*S. parahybum*
Hacienda Quebrada Bonita	4 wood	# 25-wood	2-1996[d], 2-1997[a,e]	1997-25 April, 28 April	*Ceiba pentandra*
Hacienda Quebrada Bonita	9 PA	# 27-PA	2-1996[d]		*Aspidosperma spruceanum*
Hacienda Quebrada Bonita	9 PA	# 30-PA	2-1997[a], 2-1998[d], 2-1999[d], 2-2000[a]	1997-25 April, 29 April; 2000-22 April, 27 April	*A. spruceanum*
Hacienda Quebrada Bonita	9 PA	# 33-PA	2-2000[d]		*Anacardium excelsum*
Hacienda La Catarata	2 PA				
Total	38	4	21		

[a]Chicks were tracked by radio telemetry.
[b]Chick taken into captivity when it fell from a PVC nest.
[c]Chicks fledged according to guards in Carara National Park.
[d]Herimides Sirio Jimenez, administrator of Hacienda Quebrada Bonita and head of macaw protection program for macaw nests, observed chicks fledging.
[e]One chick confiscated from a poacher and placed in nest occupied by single chick.

Nest cavity loss and competition. We observed an annual loss rate of 8% for nests in living trees, and 22% for those in dead trees, represented by 6 of 19 (32%) living trees and 7 of 8 (88%) dead trees that fell during the study. Therefore, the minimum estimated lifetime for a nest cavity was the inverse of the loss rate, or approx. 4.5 years for nests in dead trees and 12.5 years for nests in live trees. It has been shown that interspecific competition among cavity nesters can have a negative impact on breeding bird densities (Brawn & Balda 1988). In our study, nest competitors observed in potential macaw nests included the Chestnut-mandibled Toucan (*Ramphastos swainsonii*), black iguana (*Ctenosaura similis*), Barred Forest Falcon (*Micrastur semitorquatus*), Yellow-naped Parrot (*Amazona auropalliata*), kinkajou (*Potos flavus*), and wasps (unknown species). Locals reported that the former three species were also macaw egg and chick predators.

Quality nest sites seem to be in demand among macaws based on high turnover data for nest trees, and because we observed as many as four macaw pairs competing for one nest cavity. Additionally, macaws explored 12 of 14 artificial nest boxes in CNP and Hacienda Quebrada Bonita within three days of placement, late in the nesting season (August–September 1996).

Management with artificial nest boxes. Macaws visited most of the 38 artificial nests we placed within the study area. From 1996 to 2000, 11 broods hatched in six artificial nests made from wood (1 nest, 2 broods), 14-inch PVC-tubes (2 nests, 3 broods), and 55-gallon PA barrels (3 nests, 6 broods). Scarlet Macaw chicks fledged from wood, PVC and PA artificial nests during our study (Table 3). However, macaws in our study area did not nest in the 2.5-m PVC tubes, as they did in Peru (Nycander *et al.* 1995).

During the year 2000, macaw pairs visited 20 of 25 (80%) artificial nests observed from 5 January to 29 April, and defended 13 of 25 (52%) nests from 5 January to 26 February. Of the 13 nests defended, two made from PVC pipe and one from PA barrel contained eggs in January. Two chicks hatched from one of these artificial nests, on 1 and 5 February. White-faced monkeys (*Cebus capucinus*) apparently destroyed eggs from two of the nests. Eggs were re-laid by 17 February in one of these nests, but were found destroyed on 18 February; evidence again suggested *C. capucinus* as the cause. Chicks fledged from the second nest on 22 and 27 April, and were tracked by radio telemetry. Thus, only one nest (4%) of the 25 monitored (and 5% of the 20 nests investigated) in 2000 was successful in fledging chicks that year (Fig. 2). Between 1994–1997, Sanz *et al.* (2003) observed an overall success rate of 5.6% (5 nests used vs. 88 nests available) for artificial wooden nests used by Yellow-shouldered Parrots (*Amazona barbadensis*) in Isla de Margarita, Venezuela; they observed high poaching rates for artificial nests, and artificial nests were also used by various competitor species, including the Robinson's mouse (*Marmosa robinsoni*), dark tree rat (*Echimys semivillosus*), gecko (*Thecadactylus rapidcaudus*), tropical rat snake (*Spilotes pullatus*), and honey bees (*Apis mellifera*).

Management with environmental education and ecotourism at active nests. When school children were transported to the artificial nest site to observe an active pair of nesting macaws and their chicks, the consensus by both children and their teachers was that the trip was an exciting learning experience. Tourists voiced the same opinion.

DISCUSSION

We recommend detailed, long-term data on macaw nest site selection and nesting success to aid in managing natural and artificial nests to increase recruitment rates. The study population of Scarlet Macaws has shown limited recruitment over the past ten years, and the current and future status of this population is of concern (Vaughan 2002). Our highest chick:adult ratios were 0.123 on 24 September 1996 (211 adults, 26 young), 0.114 on 20 August 1996 (225 adults, 29 young), and 0.113 on 14 July 2000 (211 adults, 27 young). The population declined (l = 0.97) from 1990–94 when at least 73 young were added to the population; it grew (l = 1.04) from 1995–2000 when at least 117 young were added to the population. This comparison suggests that our Scarlet Macaw management efforts since 1994 resulted in some level of population growth (Vaughan 2002), although it has not been quantitatively demonstrated.

If a shortage of quality nest sites were a limiting factor in this Scarlet Macaw population, it would restrict the production of young, thereby limiting population increases (Newton 1994). We have consistently observed few successful artificial nests (Table 3), although many nests were explored. Limited successful fledging in this Scarlet Macaw population could be due to scarcity of quality nest cavities, nest cavity competitors or predators, or a combination of these factors. For Red-lored (*Amazona autumnalis*), Yellow-headed (*A. oratrix*) and Red-crowned (*A. viridigenalis*) parrots, Enkerlin-Hoeflich (1995) reported that only eight of 23 (35%) nests were reused from one breeding season to the next (1992–93). Further, only six of 42 (15%) nests were reused in 1994. In our study, only nine of 42 (21%) natural nests were reused for two nesting seasons, and five of 42 (12%) nests were reused during three different nesting seasons. Although we know that chicks fledged from most of these active nests, the fact that only one of 25 (4%) artificial nests fledged young suggests low recruitment.

Because of the low number of successful nests observed, we recommend detailed studies to quantify habitat features and nest characteristics that result in successful and unsuccessful nesting attempts in natural nest cavities. This must be a priority for future research. However, our data allowed us to design and place artificial nest boxes in environments similar to those of natural nests. For instance, in our study, nestson private lands outnumbered those on public lands two to one (37 vs. 19 nests, respectively). Mangrove habitats contained only 20–25% of nests compared to other habitats that demonstrated higher levels of macaw activity, such as pasture and forest (Table 1). Though our predominant method of nest finding induced a sampling bias toward nests known by poachers, precluding statistical comparisons, we have noticed macaws' capacity to nest in trees in pastures and the importance of private lands for macaw conservation. These are critical factors to management efforts and community efforts discussed later.

Measurements of nest parameters offered little conclusive evidence pertaining to Scarlet Macaw nest cavity preferences. Nest heights varied with tree species in our study (range 8 to 40 m) (Table 2), similarly to Scarlet Macaw height range in Mexico (10 to 51 m) (Iñigo-Elías 1996). Orientation of natural nest cav ties provided inconclusive results as well, although Iñigo-Elías (1996) found 71% of nest cavities oriented between 180–360º. Our results are consistent with those of Iñigo-Elías (1996) who found that adult Scarlet Macaws enlarged cavities in dead trees by removing rotting wood with their bills and feet. Snyder *et al.* (1987) reported nest enlargement behavior by various *Amazona* spp.

Because of the abundance and turnover rate of dead trees with nests in our study area, along with the fact that macaws do nest in live trees as well, we recommend eliminating snags with nest cavities to prevent macaws from using them for nests, and perhaps providing artificial nest boxes in the same vicinity as an alternative. The status of trees in which macaws choose to nest appeared to be an additional factor that complicated successful nesting and recruitment within this population. Annual tree nest loss was highest for dead trees in our study (22%) as compared to that of living trees (8%). Based on these results, we find it alarming that 14 of 56 (25%) of nest cavities in our study were in dead trees (Table 2), which we estimated as having a lifetime of 4.5 years (vs. 12.5 years for living trees). In 1996, twice we found broken eggshells from failed macaw nesting attempts due to fallen trees. Iñigo-Elías (1996) observed a loss of five nests when host trees were blown down by winds, though it is unknown whether these nest trees were alive or dead. White-tailed Black Cockatoos (*Calyptorhynchus funereus*) in western Australia experienced an annual nest cavity loss of 4.8% due to natural causes (Saunders 1982), and Puerto Rican Parrot (*A. vittata*) annual nest cavity loss was 6.5 to 11.4% (Snyder *et al.* 1987). Brawn & Balda (1988) found that breeding density was limited in part by nest sites when bird species relied on dead trees for nest sites in northern Arizona.

Before managing natural nest cavities, we recommend detailed studies comparing successful fledging from nests in softwood vs. hardwood trees. Although softwood nesting trees were probably more ephemeral than hardwood nest trees, they were 3.6 times more abundant in our study (36 vs. 10, respectively). Softwood species included *Ceiba pentandra, Schizolobium parahybum*, *H. crepitans*, *Brosimum utile*, *Sterculia apetala*, and *Anacardium excelsum* (Table 1). *C. pentandra* and *S. parahybum* comprised 27 of 46 (48%) individual nesting trees in our study, and 54% (22 of 41 nests) in a similar study in southern Mexico (Iñigo-Elías 1996). In our study, 41 of 61 (67%) nesting attempts were in softwood trees, which included one *C. pentandra* and three *S. parahybum* that were used repeatedly during a 3-year period (1994–97). In Amazonian Peru, Scarlet Macaws also nest in various softwood (e.g., *Iriarthea deltoidea* and *Erythrina* sp.) and hardwood tree species (e.g., *Dipteryx micrantha*) (Nycander *et al.* 1995). *H. crepitans* has a soft, toxic wood (Janzen 1983), and its spiny trunk dissuades poachers from climbing them.

The use of artificial nests to increase the number of breeding pairs and the overall reproductive success is a cornerstone of our management program, and is crucial to macaw conservation efforts. Successful use of artificial nests has also been documented in Puerto Rican Parrots (Snyder 1977, Snyder *et al.* 1987), Hyacinth Macaws (*Anodorhynchus hyacinthinus*) in Brazil (Guedes & Harper 1995), *Ara* spp. in Peru (Nycander *et al.* 1995), and Yellow-shouldered Parrots in Venezuela (Sanz *et al.* 2003). We based artificial nest management on natural nest parameters, and we then initiated their use for protection, environmental education, and scientific research purposes. We mounted five PA and 12 PVC nests in Punta Leona, a well-guarded resort containing several known natural nests. However, only one Scarlet Macaw pair nested in a PVC nest (# 14) (Table 3) within the resort, probably because macaw density is low in the area (Marineros & Vaughan 1995). We later placed 13 artificial nests (four wood, nine PA) close to active natural nests in a 2-ha plot of Hacienda Quebrada Bonita close to the administration center of the farm. This area consistently showed the highest macaw density in our study area (Marineros & Vaughan 1995). Quickly, artificial nests became a symbol of our Scarlet Macaw conservation project.

Because of high poaching rates, concentrating artificial and natural nests in high macaw density areas increases the probability of improving nesting success, and reduces economic and human resource costs related to protection. When we began our study, only one guard could protect each nest due to long distances between nests. Nest guarding significantly increased reproductive success of the Puerto Rican Parrot over a 17-year period (Lindsey 1992). Since 1997, we have protected an average of three active nests yearly at Hacienda Quebrada Bonita with at least six chicks fledging each year (H. Sirio pers. com.). Costs for 24-h protection during March, April and May of 2000 and 2001 was $500 per month. Nest guarding also facilitates research, environmental education, and ecotourism in pastures where the nests are easy to climb and to observe.

Likewise, closing or destroying high poaching risk nests is essential to discourage macaws from selecting these sites with a potential high risk for failure. However, this does not eliminate poaching, which has deeper socio-economic-cultural roots (Vaughan 2002). Wright *et al.* (2001) calculated an average poaching rate of 30% (range 23% to 70%) for 23 studies of Neotropical parrots. We have observed that some macaws in our study area select "safer" nests within protected areas, such as those in Hacienda Quebrada Bonita. With fewer high quality, natural, high-risk nests in an area, macaws might select safer nests.

Adaptive management is necessary to ensure that natural and artificial nests are successful and utilized by macaws. This involves monitoring active nests and actively experimenting with them. Sanz *et al.* (2003) attributed a poor success rate of artificial nests used by Yellow-shouldered Parrots to nest design, and concluded that cavities were not a limiting resource. In our study, we have continually attempted to modify unsuccessful nest designs to better attract macaws. For instance, when 2.5 m PVC tubes were unsuccessful, we experimented with other sizes and materials until they were explored and used by macaws for nesting (Table 3). When wood shavings and sawdust within nests apparently contributed to nest rejection, we replaced these materials with wood chips. Macaws appeared to more readily accept the wood chips as nesting material, using them to actively "excavate" within their nest cavity. An additional measure we adopted to dissuade climbing nest predators, such as black iguanas and common opossums (*Didelphis marsupialis*), was the use of metal "skirts" placed around the tree base.

Aggressive management options might include attempting to decrease the density of black iguanas from around nesting sites, or to eliminate Africanized bee (*Apis mellifera*) colonies. When macaws nested in artificial nest # 30 (Table 3) in 2000, we visited the tree regularly with local school children because the nest was visible and accessible. For four years, this nest was active and produced up to eight chicks (Table 3). Unfortunately, in 2000, an Africanized bee colony established itself in a cavity approx. 5 m above artificial nest # 30. This ended our research and environmental education program for safety reasons. Bees killed chicks in nest # 30 in 2002 (H. Sirio pers. com.). Iñigo-Elías (1996) documented the failure of three of 41 active nests (two with eggs, and one with an egg and two chicks) because of bee attacks and nest takeover. Bees attacked the adults when they approached the nest. Oldroyd-Benjamin *et al.* (1994) reported extensive overlap between psittacines and feral honey bees (48%) when choosing cavities.

Environmental education within local communities has been promoted to a top priority for psittacine conservation (Snyder *et al.* 1992), and has been heavily incorporated into our management strategy as well. Forming future conservation stewards has consistently been an objective of our conservation work in the region. We have had success in community projects such as creating forestry nurseries to plant macaw feeding and nesting trees, encouraging children to count macaws flying over their village, and establishing enough trust with community members that they have reported poachers to us or authorities. Observing a young Scarlet Macaw in the wild draws strong approval from observers, which include school children, teachers, community leaders, and tourists (Vaughan 2002). Courses on Scarlet Macaw ecology and conservation are given yearly in public schools in the region, and visiting the chicks in an artificial nest now forms part of the course.

We feel that it is important to promote macaw nesting as part of ecotourism and environmental education programs in the region. Tourism is a growing industry in Costa Rica, and in the last decade has become one of the most important sources of economic income for Costa Ricans (Damon & Vaughan 1995). Tour guides lead groups to specific nesting and fruiting trees to observe macaws and other wildlife species (Vaughan *et al.* 1991, Munn 1992). However, local communities have not benefited from the estimated 40,000 visitors to CNP who spend an average $125/day to observe the Scarlet Macaw and other wildlife species in their natural environment (Vaughan 1999). We have participated in activities where landowners and local tour guides cooperate, so that visitors can pay to see macaws in nest boxes. This can benefit farm owners, local tour guides, and perhaps local craftsmen, and in turn help motivate locals to conserve Scarlet Macaws. We have not observed alterations in macaw activity due to human presence near nests or feeding sites. However, we recognize that such activities have the potential to affect activity, and should not be over-used. This has included extensive use of pastures with trees used for macaw nesting, feeding and roosting.

We recommend detailed, long-term data collection on macaw nest site selection and nesting success to aid in managing natural and artificial nests, and ultimately increase recruitment rates. This would include: a) quantifying habitat features or nest characteristics of successful nests cavities; b) eliminating snags with nest cavities so macaws cannot nest in them; c) comparing successful fledging from nests in softwood vs. hardwood trees; d) using artificial nests to increase number of breeding pairs and reproductive success; e) concentrating nests so several nests can be protected together to reduce economic and human resource investment; f) closing high poaching risk nests; g) utilizing adaptive management to ensure that natural and artificial nests are successful and utilized by macaws; and h) when scientists are measuring chicks, coordinating visits to nests by children and tourists to promote environmental education and local ecotourism.

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