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PARENTAL CARE OF THE ENDANGERED CHACO EAGLE (*BUTEOGALLUS CORONATUS*) IN CENTRAL ARGENTINA

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ABSTRACT.—Sexual differences in parental care investment may affect individual survival or performance, and also demography. We investigated parental-care behavior of the endangered Chaco Eagle (*Buteogallus coronatus*) to evaluate implications for population conservation in semiarid habitats of central Argentina. From 2004 to 2012, we monitored three breeding attempts using video recording (275 hr) during the incubation period, and nine pairs during the nestling-rearing period by means of video recording (1087 hr) and focal observations at nests (232 hr). Chaco Eagles showed a strong division of parental care by sex. Females contributed significantly more than males to incubation, shading/brooding, and feeding of the nestling, whereas males provided prey to females during incubation and to nestlings during the early nestling-rearing period. Foraging males, which spend more time away from the nest, may be more exposed to anthropogenic activities and negative interactions with humans. If males are more vulnerable to such effects, this could decrease the survival of breeding males and potentially increase the recruitment of immature males to the breeding population. In this event, the ability of the inexperienced immature males that replace the adult eagles to cope with the food and care demands of the mate and offspring is critical for ensuring Chaco Eagle population maintenance.

KEY WORDS: *Chaco Eagle, Crowned Eagle, Crowned Solitary Eagle, Buteogallus coronatus; Argentina; breeding; nest; nestling rearing; parental care.*

CUIDADO PARENTAL DE LA ESPECIE EN PELIGRO DE EXTINCIÓN *BUTEOGALLUS CORONATUS* EN EL CENTRO DE ARGENTINA

RESUMEN.—Las diferencias sexuales en el cuidado parental pueden afectar la supervivencia o el desempeño individual y también la demografía. Investigamos el comportamiento de cuidado parental de la especie en peligro de extinción *Buteogallus coronatus* para evaluar las implicaciones en la conservación poblacional en hábitats semiáridos del centro de Argentina. De 2004 a 2012, utilizando el registro en video, monitoreamos tres intentos reproductivos durante el periodo de incubación (275 horas), nueve parejas durante el periodo de cría de pollos (1087 horas) y realizamos observaciones focales en nidos (232 horas). *B. coronatus* evidenció una fuerte división por sexo del cuidado parental. Las hembras contribuyeron significativamente más que los machos en la incubación, empollando o dando sombra, y en la alimentación de los pollos, mientras que los machos proveyeron de presas a las hembras durante la incubación y a los pollos durante el periodo inicial de

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cría. Los machos en busca de alimento, que pasan más tiempo lejos del nido, pueden estar más expuestos a actividades antropogénicas y a interacciones negativas con los humanos. Si los machos son más vulnerables a estos efectos, esto podría disminuir la supervivencia de los machos reproductivos e incrementar potencialmente el reclutamiento de machos inmaduros en la población reproductiva. En este caso, la habilidad de los machos inmaduros poco experimentados que reemplazan a las águilas adultas en la obtención de alimento y en el cuidado de la pareja y los pollos es crítica para asegurar el mantenimiento de la población de *B. coronatus*.

[Traducción del equipo editorial]

For altricial species, the survival of newborn individuals is influenced by the parents' ability to provide food and care to the young. Most bird species, and particularly raptors, share parental duties between both adults (Newton 1979, Clutton-Brock 1991, Cockburn 2006, Webb et al. 2010). Although shared parental care maximizes fitness in some species (Emlen and Oring 1977), different parental-care strategies also exist. Among some raptors that exhibit little or no sexual-size dimorphism (e.g., vultures, condors), the division of roles is minimal (Margalida and Bertran 2000), whereas in other species the division of duties during breeding, including the hatching, nestling-rearing, and fledging periods, is more marked (Newton 1979).

The Chaco Eagle (formerly known as the Crowned Eagle or Crowned Solitary Eagle; *Buteogallus coronatus*) is one of the largest birds of prey in South America. It inhabits open semiarid forests from southern and central Brazil, Bolivia, and Paraguay to northern Patagonia in Argentina (Ferguson-Lees and Christie 2001). It is classified as endangered by the International Union for Conservation of Nature, with a global population estimated at <1000 reproductive individuals (BirdLife International 2016). Mortality factors appear to include human persecution (Sarasola and Maceda 2006, Sarasola et al. 2010, Barbar et al. 2016), electrocution at power lines (Galmes et al. 2017), and consequences of habitat loss (Bellocq et al. 2002, Fandiño and Pautasso 2013).

The ecology of the Chaco Eagle is poorly known. The species seems to have low productivity, laying a single egg per breeding attempt (Giai 1952, Maceda 2007, Carvalho Filho et al. 2009, Berkunsky et al. 2012, Fandiño and Pautasso 2013). In addition, Chaco Eagles probably do not breed until 3–5 yr of age, as is true for other large eagles (Newton 1979, Del Hoyo et al. 1994), and the species may breed only every 2 or 3 yr (Maceda 2007, Berkunsky et al. 2012). There is no information about Chaco Eagle

parental care behavior and the roles of pair members during breeding.

The division of labor between the sexes during breeding and its possible effects on adult survival may have implications for the conservation of long-lived bird species with deferred maturity, such as the Chaco Eagle. In other eagle species, a high proportion of immature individuals in the breeding population may be an indicator of a population decline (Balbontín et al. 2003, Ferrer et al. 2003). Underlying the relationship between the replacement of one of the members of a pair by a subadult individual and possible negative population trends is the inability of a young and inexperienced parent to cope with food and care demands of the mate and offspring. Thus, subadult individuals that attempt to breed are often unsuccessful, which may reduce productivity, particularly in small populations (Penteriani et al. 2003); in those cases, nesting failure could be higher than expected, with more severe consequences on population demography of those small or threatened populations.

Here we examine the parental-care behavior of the endangered Chaco Eagle in breeding territories of central Argentina. We evaluated the roles of males and females during the incubation and nestling-rearing periods to assess whether a marked division in parental roles occurs and to evaluate future implications for population conservation.

STUDY AREA

We studied Chaco Eagles in the southernmost part of their range in western La Pampa province, central Argentina (Fig. 1) (approx. 37°S, 66°W). The study area included approximately 18,000 km², with an elevation ranging between 220–340 masl, within the Espinal and Monte Desert ecoregions (Brown et al. 2006). Vegetation types within the Espinal ecoregion include deciduous xerophytic forests of *caldén* (*Prosopis caldenia*), grassy savannahs, grassy steppes, and bushy steppes. Typical vegetation in the Monte Desert ecoregion is represented by communities of high shrub-steppe (characterized mainly by *Larrea*

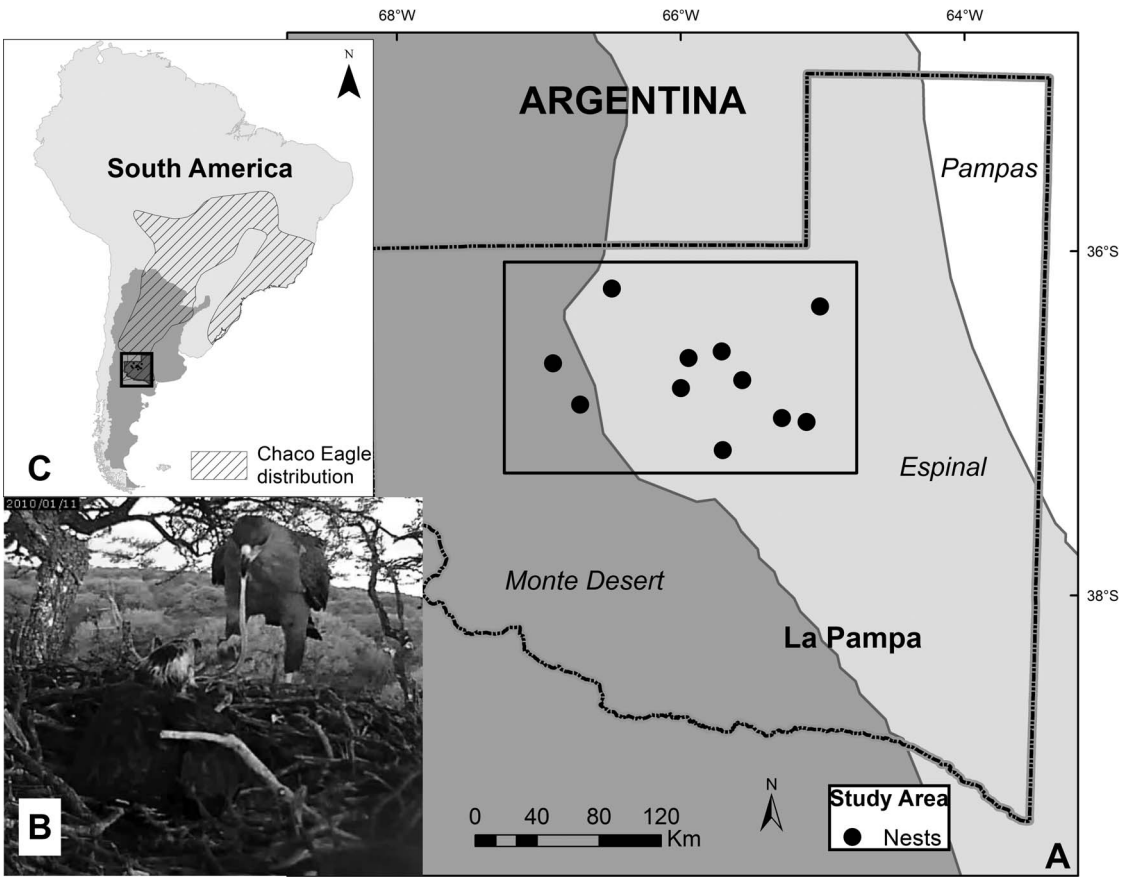


Figure 1. (A) Location of Chaco Eagle nests monitored with video cameras (B) and focal observations at our study area in (C) La Pampa Province, central Argentina, from 2004 to 2012.

spp.), with isolated trees of the genus *Prosopis*. In both ecoregions, the climate is temperate arid, with high temperatures in summer (up to 44°C) when most of the scarce rainfall occurs; annual rainfall ranges between 80–300 mm in the Monte Desert and 300–550 mm in the Espinal (Fernandez and Busso 1997).

METHODS

We searched for Chaco Eagle nests in our study area from mid-September to mid-February in 2004–2005 and 2007–2012 (Fig. 1). Eagle nests were located during field surveys by car and on foot, and by soliciting information during interviews with local people.

We conducted focal observations of individuals during the 2007 and 2008 breeding seasons. Two observers recorded behavior from a hide located

200–300 m from the nest using 10 × 50 binoculars and a 20 × 60 spotting scope. Observations were conducted daily from dawn-to-dusk (about 0630 H to 2200 H). At each nest, we recorded the time and duration of each activity performed by each member of the pair.

Although Chaco Eagles are not sexually dimorphic in plumage, like most raptor species they are sexually dimorphic in size, with females being larger than males (Newton 1979, Ferguson-Lees and Christie 2001). Thus, we determined sex visually, based on relative size. We carefully recorded particular characteristics of each individual (e.g., plumage features such as molt or incomplete adult plumage) to facilitate identification when only one member of the pair was present. When sex identification was unclear, we recorded the sex of the bird involved as unknown.

To record behavior we installed video cameras on branches of the nest tree (1–2 m from the nest). During 2004 and 2005 breeding seasons we used an analog camera connected to a time-lapse VHS video recorder (VCR Panasonic AG-1070 DC, Kadoma, Osaka, Japan), and from 2009–2012 we used a digital camera (IP Vivotek 7330, San José, CA, USA) connected to a 1TB hard disk (Network Attached Storage, LaCie, d2 Network2, Cupertino, CA, USA). All recorders were housed in a waterproof compartment. Monitoring systems were powered by a 12 V battery connected to a solar panel that allowed power autonomy of the equipment. The VCR was programmed to record during two 8-hr time blocks (0600–1400 H, 1400–2200 H) and the digital camera was programmed to record in a continuous fashion from 0600–2100 H, at which time the camera was turned off until the next day.

During the incubation period, we recorded the number and length of incubation bouts per individual (male vs. female) per day. We also recorded deliveries of nest material (branches and grasses) made by each adult eagle to rebuild or repair nests. We assumed that nocturnal incubation was performed by the last member of the pair identified incubating at dusk.

During the nestling-rearing period, we recorded the number and length of bouts of brooding/shading of nestlings performed by each adult. We also recorded deliveries of nesting material (branches and sprigs) to the nest for this period. Finally, we recorded the number of prey deliveries to the nest by each member of the pair, the arrival time at the nest, as well as the type (snake or mammal) and size (small: ≤ 250 g; medium: between 251–500 g, and large: > 500 g) of food items. We estimated these values visually based on our experience of weights of prey taxa in the area. To explore the daily timing of prey deliveries, we divided daily video recording periods into three time blocks (0600–1100 H, 1101–1600 H, and 1601–2100 H). We recorded behavior until the young left the nest, at about 10 wk old.

Statistical Analyses. We used generalized linear mixed models (GLMMs) to test for sexual differences in the number of incubation bouts, brooding/shading bouts, nest-material deliveries, prey deliveries, and daily number of feeding bouts to nestlings during the nestling-rearing period. Models were built using Poisson distribution errors and a log-link function. For modelling, we followed a backward stepwise procedure. From a full model, which included the main effects as well as all the two-way

interaction effects of the explanatory variables, the least significant variables ($P > 0.05$) were successively eliminated until a suitable minimum model was obtained in which all the retained variables improved the adjustment level. We tested for differences between models including a variable and those not including it using ANOVA; if the difference was significant we excluded that variable. Only significant effects ($P < 0.05$) were retained in the final model. We checked for overdispersion in all models.

In the different models, the sex of the adult performing the behavior was included as a two-category factor (male or female). Daily time effect was included in the models as a three-category factor (one for each of three time blocks). The age of nestlings was included as an explanatory variable with six levels in the brooding/shading and nest-material delivery models, and with nine levels for the other models, with each level corresponding to one week of the breeding season. To evaluate whether there was variation between the sexes in food provisioning to the nestling, we tested for an interaction of sex of the food provider and age of the nestling.

To assess for variation in the timing of prey deliveries throughout the day, and sex differences in that timing, in addition to time blocks and sex, we incorporated the type of prey as a factor, grouping most prey deliveries into two classes (snakes or mammals). To assess those variations, we tested all two-way interactions among the three variables. To assess variation in size of prey delivered to the nest by sex or date, we included prey size as a three-level size class in the models (see above); we also included all two-way interactions among the three variables. Generalized linear mixed models were run with the lme4 package (Crawley 2007, Zuur et al. 2009) of R statistical software version 3.0.2 (R Development Core Team, R Foundation for Statistical Computing, Vienna, Austria, www.R-project.org) with the pair/nest identity as a random factor in all tests. We present values as mean \pm SD except when stated otherwise.

RESULTS

From 2004 to 2012, we collected information on parental-care behavior during 12 breeding attempts by Chaco Eagles at 11 different nests. The mean minimum distance between studied nests was 32.3 km (range: 16.1–69.2 km).

Incubation Period. We used cameras to monitor three breeding attempts during the incubation period: one in the 2005–2006 breeding season (28 Dec–6 Jan) and two in the 2010–2011 season (7–19 Dec 2010 [when the camera stopped working], and 23 Oct–17 Nov 2010). Adults incubated 71% of the time in 256 incubating bouts ($n = 275$ hr); eggs were left exposed 29% of the time. The length of daily mean incubation bout was 47.0 ± 24.4 min (range = 8–126, $n = 256$). All three nests failed before hatching.

Incubation was shared by both members of the pair, although not equally. Females performed most of the daily incubation ($93.2 \pm 17.1\%$ of the time vs. $6.9 \pm 17.1\%$ for males; $n = 39$, $\chi^2 = 3460.6$, $df = 1$, $P < 0.01$) and throughout all nights recorded. Females performed more incubation bouts per day (6.9 ± 7.2 bouts, range = 1–31, $n = 40$) than males (0.6 ± 1.4 bouts, range = 0–6, $n = 40$; $\chi^2 = 249.85$, $df = 1$, $P < 0.01$).

During incubation, adults brought nest material 19 times, at a rate of 0.68 deliveries/d with a maximum of two deliveries in a day ($n = 28$ d). Females made most deliveries (89%) although males also contributed to this task (11%). Although nesting material was delivered throughout the day, most deliveries were in the morning.

Nestling-rearing Period. We monitored nine pairs during the nestling-rearing period for a total of 1319 hr. Most observations were obtained by video monitoring (1087 hr) with a smaller contribution from focal observations (232 hr).

Adult eagles brought nest material 32 times during the nestling-rearing period at a rate of 0.76 deliveries/d with a maximum of four deliveries in a single day. The provision of nesting material differed between males and females during the nestling-rearing period ($\chi^2 = 3.79$, $df = 1$, $P = 0.05$); as during incubation, females contributed more (72% of nest material provisions) to the maintenance of the nest than males (28%) in this period, especially in the first weeks of life of the nestling.

Nest attendance (brooding/shading) was done almost exclusively by females (96.5% of the brooding/shading bouts, $n = 57$), with males brooding or shading only twice. The length of brooding/shading bouts was 110.4 ± 110.5 min (range = 1.2–514.1, $n = 57$). Adult eagles brooded/shaded the nestling for 2.1 ± 1.5 bouts/d (range = 1–6, $n = 27$). We did not record shading events after the nestling reached an age of 7 wk. As the nestling aged, the number of shading bouts/d decreased (intercept = 3.01 ± 0.45 ;

coefficient of nestling age = -0.38 ± 0.12 , where age is expressed in weeks; $\chi^2 = 9.86$, $df = 1$, $P < 0.01$).

We recorded 238 prey deliveries to the nest, 158 (66.4%) by males, 66 (27.7%) by females; in 14 cases (5.9%) the sex of the provider could not be identified. Parent eagles delivered 2.33 ± 1.52 prey items per d (range = 1–10). Males provided more food items per day than females (males: 1.60 ± 1.23 , range = 0–6, $n = 98$; females: 0.66 ± 0.85 , range = 0–4, $n = 98$; $\chi^2 = 39.3$, $df = 1$, $P < 0.01$) during the entire nestling-rearing period; the difference was reduced after the nestling reached 4 wk old (interaction of the sex of the parent \times nestling age: $\chi^2 = 5.70$, $df = 1$, $P = 0.02$). Females rarely provided food to the nest in the first 3 wk of the nestling's life (Fig. 2).

The size of food items delivered by the adults did not change over the nestling-rearing period ($\chi^2 = 3.98$, $df = 2$, $P = 0.14$) and food size was not related to the sex of the parent providing the prey ($\chi^2 = 1.59$, $df = 2$, $P = 0.45$). Eagles brought more small and medium-sized prey items than large ones to the nest ($\chi^2 = 48.47$, $df = 2$, $P < 0.01$).

Both parents delivered food items to the nest throughout the day, from early morning (0645 H) until dusk (2045 H), with a marked peak from 0800–1000 H and a lesser peak from 1800–2000 H (Fig. 3). The number of food items delivered to the nest did not differ by sex of parent through the day (sex effect: $\chi^2 = 1.86$, $df = 1$, $P = 0.17$) or with the age of the nestling (week: $\chi^2 = 0.61$, $df = 1$, $P = 0.44$), but did change with the type of prey ($\chi^2 = 5.61$, $df = 1$, $P = 0.02$), with snakes being delivered mainly in the morning and mammals in the afternoon.

Females did more feeding of the nestlings than did males (females: 2.22 ± 1.65 feeding bouts/d, range = 0–8; males: 0.20 ± 0.47 bouts/d, range = 0–2; $n = 69$; $\chi^2 = 136.52$, $df = 1$, $P < 0.01$). The number of feeding bouts by adults decreased over time as the growing nestling began to feed itself ($\chi^2 = 5.40$, $df = 1$, $P = 0.02$; Fig. 4). The nestling started feeding itself during the fifth week of age and feeding bouts by the male ceased entirely after the nestling reached 7 wk old.

DISCUSSION

Our results indicated a strong sex-based division of roles in the parental care of Chaco Eagles. As in other monogamous birds of prey (Newton 1979, Everett 1981, Collopy 1984, Margalida et al. 2007), females carried out most activities at the nest, including incubation, shading/brooding, and feed-

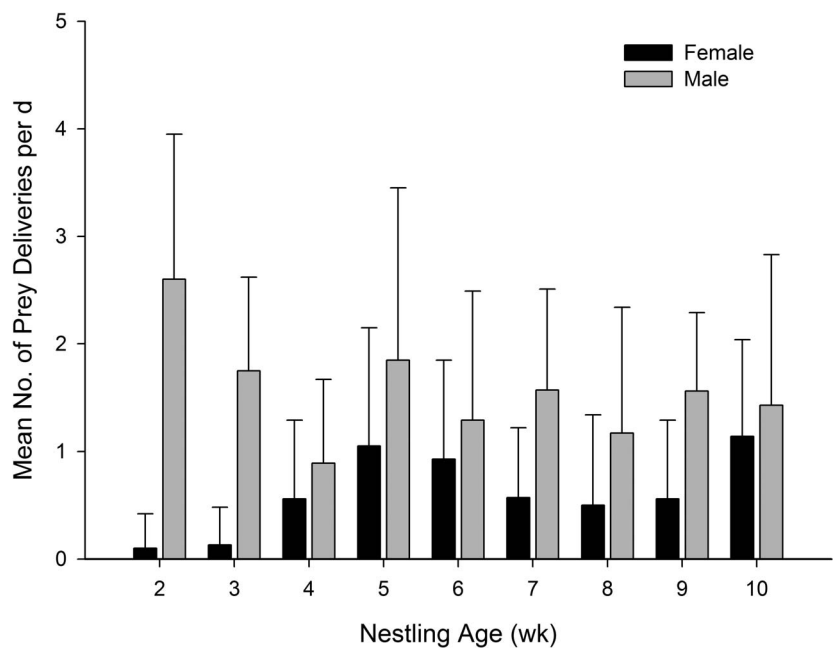


Figure 2. Mean (\pm SD) daily prey deliveries to nests by Chaco Eagles during the nestling-rearing period.

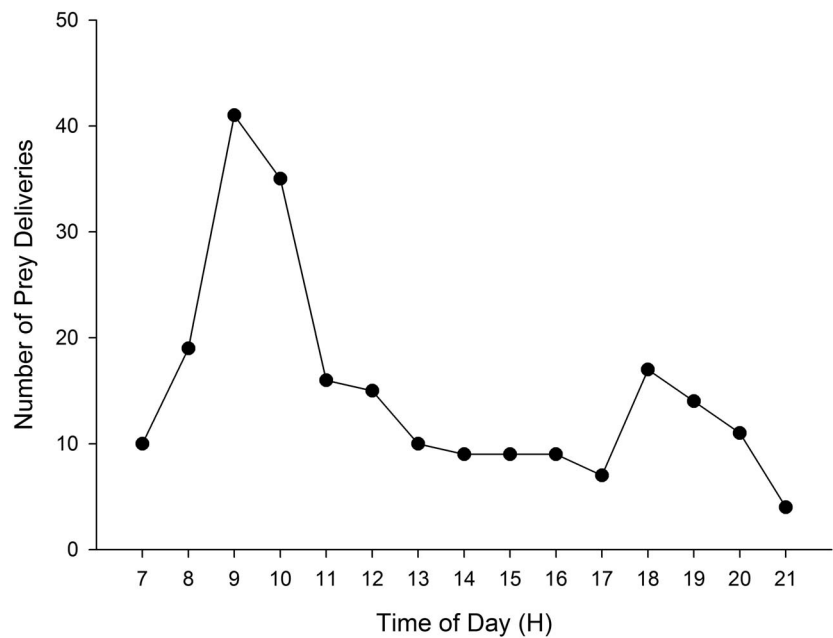


Figure 3. Hourly number of prey deliveries to Chaco Eagle nests in La Pampa Province, central Argentina.

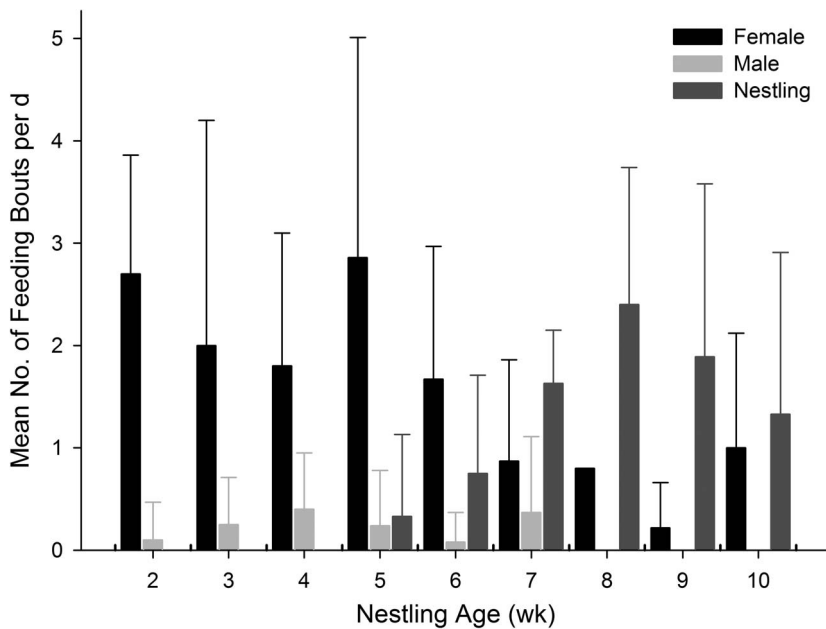


Figure 4. Mean daily number of feeding bouts to the nestling performed by females, males, and nestlings (\pm SD) during the nestling-rearing period.

ing of the nestling, while males performed most activities away from the nest. Males provided prey both to the female during incubation (M. Galmes unpubl. data) and to the nestling during early nestling-rearing, and females joined males in hunting and providing food progressively as the nestling grew. Most diurnal and all nocturnal incubation was done by the female, with males incubating only briefly, presumably while the female consumed prey delivered by the male. Therefore, as in other eagle species (Collopy 1984, Margalida et al. 2007), female Chaco Eagles remained at the nest to incubate, and self-fed from food delivered by the male.

During incubation, Chaco Eagles spent extended periods away from the nest (up to 29% of daylight hours) compared with other large raptor species in which the eggs are left exposed for no more than 10% of the time (e.g., $3.7 \pm 0.4\%$ [Collopy 1984]; $4.2 \pm 4.48\%$ [Margalida et al. 2007]). However, the roles of males and females during incubation and the differential rates of nesting-material deliveries during the incubation period were similar to those documented in other eagle species (Collopy 1984, Margalida et al. 2007), suggesting they are probably representative of the behaviors and roles of adult Chaco Eagles.

During the nestling-rearing period, as in the incubation period, parental-care tasks were not equally shared by the sexes. Females were closely associated with the nest during the first weeks of nestling rearing, while males hunted and provided food. The nestlings hatched at the end of spring or in summer, when temperatures in our study area can reach up to 44°C (Casagrande and Conti 2004). Therefore, during the first weeks after hatching, when nestlings are unable to thermoregulate, regular protection from the sun by the adults is essential. In fact, direct sun exposure during mid- and late-afternoon has been suggested as an important cause of nestling mortality in Golden Eagles (*Aquila chrysaetos*; Beecham and Kochert 1975). In Chaco Eagle pairs, most brooding and shading of the nestling was provided by the female, with only occasional assistance by the male. This behavior ended when the nestling was around 7 wk old. Similar sharing of duties during the nestling-rearing period has been described for other eagle species (Ellis 1979, Collopy 1984, Margalida et al. 2007, Watson 2010, Bakaloudis and Vlachos 2011).

The adult male provided most food for the nestling and in some cases for the female as well. This sex-based difference in food provisioning was greatest during the first weeks of the rearing period,

with >90% of prey items delivered by males. The rate of prey deliveries by the female increased gradually, as the necessity for brooding/shading decreased. Differences between the adults in prey delivery rates decreased by the middle of the rearing period when the young was approximately 40 d old, and remained fairly constant until the end of the rearing period (wk 10), when the contribution by the female reached a maximum of 45%. Similarly, male Golden Eagles delivered over 80% of prey during the first 2 wk of the rearing period, but females reached a maximum of 47% of prey deliveries by wk 9 (Collopy 1984).

The daily rate of prey delivery (2.36 deliveries) was similar to that of the Short-toed Snake-Eagle (*Circaetus gallicus*; Bakaloudis and Vlachov 2011), which has the same brood size (one young) and a similar diet based on snakes (Fergusson-Lees and Christie 2001). However, we did not observe variation during the nestling-rearing period as described by Collopy (1984) for Golden Eagles.

Prey deliveries to the eaglet suggest a bimodal distribution with a marked peak of deliveries in early morning and a smaller peak in late afternoon. These results are consistent with the crepuscular habits of the Chaco Eagles (Canevari et al. 1991, Collar et al. 1992). This bimodal pattern was constant throughout the rearing period and was independent of the sex of the provisioning adult. However, reptiles were delivered more often in the morning and mammals more often in the evening. Although we did not investigate hunting strategies, our results suggest that Chaco Eagles exhibit hunting activity consistent with the daily activity of its main prey. In particular, snakes should be vulnerable to capture in the morning when they are more active (Bakaloudis 2010), as suggested for the Short-toed Snake-Eagle (Bakaloudis and Vlachov 2011). Conversely, mammals such as the pichi (*Zaedyus pichi*), the main mammalian prey of the Chaco Eagle (Sarasola et al. 2010, Pereyra Lobos et al. 2011), are taken late in the day when the temperature starts to decrease (Abba et al. 2009).

In theory, the increasing requirements of food by a growing nestling could be met by an increasing number or size of prey delivered to the nest, or both (Newton 1979, Collopy 1984). However, we did not note such patterns. Although the parents delivered small prey items more frequently than larger prey, this pattern was consistent throughout the rearing period, even after the female began providing food. A likely explanation could be that prey delivered to

the nest by males in the first weeks of the nestling-rearing period is shared by both the eaglet and the female. In contrast, at the end of that period, the nestling eats alone and vigorously defends the prey, which is rarely shared with an adult.

Most of the feeding bouts were carried out by the female, especially during the first weeks of the rearing period when she was closely associated with the nest. Although the male sometimes fed the nestling, he did so only occasionally and never after the nestling reached 7 wk of age. This behavior by the male is likely related to the beginning of self-feeding by the nestling. During its first 7 wk of life, the nestling was apparently mostly dependent on its parents for handling of food. After that, the nestling was able to feed itself from food left at the nest by adults.

Conservation Implications. The role division exhibited by Chaco Eagles suggests it would be unlikely for a single adult to raise a nestling successfully if the other pair member died during incubation or shortly after hatching. Some mortality factors for the species are related to direct human persecution and electrocution (Sarasola and Maceda 2006, Galmes et al. 2017). The strong attachment of females to the nests may reduce their risk of such mortality during the nesting season, relative to the risk incurred by males, which hunt for prey over larger areas of the landscape, potentially encountering more anthropogenic threats. Conversely, the female is consistently found at the nest, and thus would be more vulnerable to shooting by a poacher aware of the nest location. If there is a sexual difference in vulnerability to mortality factors, this would potentially result in recruitment of less-experienced immatures of the more vulnerable sex into the breeding population. In this context, the ability of nonbreeding adults ("floaters") or immatures to enter the breeding population to replace adult eagles may be important for ensuring population maintenance. We recommend additional research to assess which sex is more vulnerable to mortality factors, and the potential effect of breeding experience in this species.

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