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LETTER

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SIBLICIDE IN BONELLI'S EAGLE (*AQUILA FASCIATA*)

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Siblicide occurs when dominant siblings kill a subordinate sibling by injury or starvation, or when a subordinate falls from the nest in an attempt to escape from its attackers (Newton 1979, Mock and Parker 1997, Morandini and Ferrer 2015). This behavior occurs in a wide range of bird species including raptors, Ciconiformes, Gruiformes, Pelecaniformes, and Charadriiformes, among others. In some species and/or populations, this behavior happens occasionally, usually associated with situations of food scarcity or long interval between the hatching of siblings, and then it is called "facultative siblicide." In contrast, when the lowest ranking sibling is routinely killed by its dominant broodmate, this is termed "obligate siblicide" (reviewed in Mock and Parker 1997, Morandini and Ferrer 2015).

Among raptors, siblicide has been recorded in species of the genera *Cybaetus*, *Neophron*, *Aquila* (including species of the former genus *Hieraetus*), *Harpia*, *Stephanoaetus*, *Elanoides*, *Milvus*, *Buteo*, and *Accipiter*, among others. This behavior is more common among eagle species, in which it is sometimes called cainism (Meyburg 1974), and it has been described as obligate in some populations of Lesser Spotted Eagle (*Clanga pomarina*), Tawny Eagle (*Aquila rapax*), Verreaux's Eagle (*A. verreauxii*), Wahlberg's Eagle (*Hieraetus wahlbergi*), African Hawk-Eagle (*A. spilogaster*), Booted Eagle (*H. pennatus*) and Crowned Eagle (*Stephanoaetus coronatus*). In the present letter, we describe the occurrence of two events of siblicide caused by aggressive behavior in one population of Bonelli's Eagle (*Aquila fasciata*) located in Catalonia (northeastern Iberian peninsula). Siblicide has been reported in a closely related species, the African Hawk-Eagle, and some populations demonstrate obligate siblicide (Meyburg 1974, Steyn 1983, Simmons 1988). In Bonelli's Eagle, siblicide involves enforced starvation of the smallest nestling, particularly when hatching is very asynchronous (Real 1987). In this sense, Real et al. (2000) found that among 179 nestlings in our study population (1987–1993), 2.2% died as a

consequence of very asynchronous hatching (22.2% of dead nestlings). However, to our knowledge the events we describe here are the first reported records of siblicide caused by injury in Bonelli's Eagle. We contextualize these events in the framework of a long-term monitoring carried out in this population over the last 35 yr.

Bonelli's Eagle is territorial raptor distributed from southeastern Asia and the Middle East to the western Mediterranean (del Hoyo et al. 1992). The European Bonelli's Eagle population is estimated at 920–1100 pairs and that population is classified as near-threatened (BirdLife International 2004) and is protected by special conservation measures (Directive 2009/147/EC of the European Parliament). The main threats appear to be decreased fertility and increased mortality (Hernández-Matías et al. 2013), driven by persecution, electrocution, deterioration and loss of suitable habitat, decreasing prey availability, and interspecific competence (Real 2004). In Europe, this species is strongly associated with the Mediterranean region, where it mainly nests on cliffs, although in southern Portugal, most pairs nest in trees (Real 2004). Females lay one or two, rarely three, eggs per clutch and mean productivity rates range between 0.6 and 1.4 fledglings per pair per year (Hernández-Matías et al. 2013).

During 1980–2015, we measured productivity for 1506 nesting attempts in territories occupied by a pair of eagles; of these nesting attempts, 65.7% resulted in at least one fledged young. Of these successful nesting attempts, 39.8% fledged one young, 59.7% two young, and 0.5% three young. We also ringed 419 nestlings of this population in 1986–1992 and 2008–2015. Monitoring effort in terms of surveyed territories was particularly intense and constant after 1990 (1980–1990: mean \pm SD: 23.3 \pm 7.5 territories; 1991–2015: 49.4 \pm 4.3 territories), though the time and nature of observations varied. In general, we made three visits at the time when young were in the nests (just after hatching, at the age of approximately 20 d, and just prior to fledging). More effort was expended in 1980–1993 and 2008–2015 when, respectively, 165 and 388 nesting attempts were monitored at least five times during the nestling stage. Additionally, in 1984–1988, four territories (10 nesting attempts) were intensively observed from a blind for 1230

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hr during the nestling stage and in 2003–2015, three territories (15 nesting attempts) were continuously observed during the nestling stage using webcams.

During the period 1980–2007 we did not observe any aggression between siblings that resulted in injuries and death of nestlings. Real (1987, 1991) described some aggressive behavior between Bonelli's Eagle nestlings <20 d old (also see Arroyo et al. 1976, Leshem 1977) in our study population, but the result of this behavior was never siblicide. During the period 2008–2015, we observed siblicide attributable to injuries influenced by the dominant nestling on two occasions. The first event happened in 2008 in a territory located in the Prelitoral Mountains in the north of Barcelona province, Spain. This territory had historically high productivity, but reproduction had been relatively low in the 10 yr from 2005–2014 (0.8 fledglings/year, $n = 10$). In 2008, this territory was held by a female in adult plumage (fifth year or older by calendar years) and a male in subadult plumage (fourth calendar year). The less-experienced territorial individual was the male that had been recruited (*sensu* Hernández-Matías et al. 2010) in March 2006. In 2007, the pair failed breeding during incubation. In 2008, the female laid at least two eggs in the second half of February. Hatching occurred approximately 29 March. On 14 April, we observed two nestlings were in the nest. On 2 May 2008, we accessed the nest to ring the young. The larger nestling was in good condition and had typical plumage development for its age (seventh primary = 117 mm; tarsus length = 106.3 mm; net weight = 1755 g). The smaller nestling was in poor body condition and had underdeveloped plumage (seventh primary = 55 mm; tarsus length = 88.8 mm; net weight = 1155 g). The apparent age of the larger nestling, a female based on DNA analysis, was 33.5 d (following Mañosa et al. 1995). The smaller nestling, a male based on DNA, showed an apparent age of 23.7 d. Although we did not know the exact date of hatching of the second nestling, it seems likely that the plumage development was delayed, as the typical difference in hatching between the first and second eggs is 2–3 d (Cramp and Simmons 1979). On 4 May, from 1700 to 1900 H (solar time), we observed the female and the two nestlings in the nest. The female was feeding the young a pigeon, but only the larger one obtained food. The smaller nestling was alive and able to stand, but its head was red with blood. On 5 May, from 1710 to 1900 H, we observed the female and the male flying and the two nestlings in the nest. The larger nestling was apparently fine, but the smaller one, though alive, could only be partially observed in a corner of the nest. On 7 May, we accessed the nest to rescue the smaller nestling, but it was already dead. A necropsy was carried out at an animal rehabilitation center (Centre de Fauna de Torreferrussa, Generalitat de Catalunya) and confirmed that the nestling had skin removed on the upper area of the head and injuries consistent with pecks, and its eyes were sunken. The other nestling was in apparent good condition and was observed on 28 May in the nest. Rangers (Agents Rurals de la

Generalitat de Catalunya) communicated to us that it fledged on 5 June at the approximate age of 68 d.

The second event of siblicide was observed in 2015 in a territory located on the massif of Garraf in the Litoral Mountains, in the south of the province of Barcelona. This territory had low productivity in 2005–2014 (0.4 fledglings/year, $n = 10$). The monitoring of this nest was done primarily using a webcam installed by Parc Natural del Garraf (<http://parcs.diba.cat/web/aguila-cuabarrada> and <http://www.youtube.com/aguilacuabarrada>). In 2015, the pair was composed of two individuals displaying adult plumage. The female was the less-experienced territorial individual and was recruited in spring 2011, based on observed replacements (*sensu* Hernández-Matías et al. 2011). The female laid two eggs on 14 and 18 February that hatched on 28 March and 2 April, respectively. In the second week of April, we observed a marked difference in the size and development of the two nestlings. The larger one was able to obtain much more food than the smaller one, which seemed to have delayed development. On 13 April, the larger nestling started displaying aggressive behaviors, such as climbing atop its smaller nestmate when the female attempted to feed it, causing it to be unable to obtain food. On 14 April, the aggressiveness of the larger nestling increased, and it started aggressively pecking the smaller one (the video footage can be viewed on <https://www.youtube.com/watch?v=tFpRv8YMARo>). On 15 April, the smaller nestling was severely injured on its head by its sibling and started bleeding. At 1325 H, the smaller nestling was rescued from the nest by the rangers (Grup de Suport de Muntanya dels Agents Rurals) and moved to the same rehabilitation center (above), where it finally died on 16 April. The necropsy confirmed that it died due to the head injuries and consequences. It had extremely delayed development and poor body condition (seventh primary = 10 mm; tarsus length = 28.7 mm; net weight = 94 g). On 4 May, we accessed the nest to ring the surviving nestling. It had normal development and good body condition (seventh primary = 134 mm; tarsus length = 117.2 mm; net weight = 1980 g; apparent age 36.2 d). Based on biometric measurements, it was a female. On 30 May, the young fledged at the age of 62 d.

Available evidence suggests that siblicide results from multiple causes and several hypotheses have been proposed to explain this behavior. In general, it is argued that siblicide is adaptive and that it has evolved as a mechanism to adjust brood size to available food resources (Newton 1979, Mock and Parker 1997, Morandini and Ferrer 2015). Facultative siblicide is associated with situations of food scarcity or a long interval between hatching of the young, which can be caused either by poor environmental conditions or because parents are inexperienced (Casado et al. 2008). This seems to be the case in Bonelli's Eagle in our study population. The first event we observed took place in a high-quality territory, but the male was inexperienced and this was likely its first year raising nestlings. During the years of monitoring, we detected 247 nesting

attempts (18.3%) in which the pair of territorial eagles was composed of at least one non-adult individual ($n = 1352$ nesting attempts for which we knew the plumage-age of eagles); of those non-adult pairs for which we have information, 47.0% initiated incubation ($n = 181$) and in 33.7% of attempts, at least one egg hatched ($n = 172$). Of those inexperienced pairs for which we knew the number of fledglings ($n = 237$), 75.5%, 13.1% and 11.4% raised, respectively, 0, 1, and 2 fledglings ($n = 234$), indicating that there were relatively few opportunities to observe siblicide as a consequence of inexperienced parents. In the second event, it seemed likely that the territory was low quality, as breeding success there was very low in the last ten years.

Based on our observations, although siblicide by enforced starvation of the smaller nestling may be relatively frequent in Bonelli's Eagles, particularly in situations of marked hatching asynchrony and/or food stress, siblicide by aggression seems to be a rare behavior in this species. Because we generally observe the nests from long distances and our effort in terms of time at a given nest is limited, we cannot exclude the possibility that siblicide by aggression was more frequent than we report here. However, it seems clear from our data that is not a common behavior. Additionally, this species has attracted the attention of numerous researchers (141 articles found by searching the topic "*Aquila fasciata*" or "*Hieraetus fasciatus*" in the Science Citation Index Expanded, Web of Science Core collection, during 1985–2015) and to our knowledge none of them has previously reported this behavior.

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