

Positive demographic effects of nest surveillance campaigns to counter illegal harvest of the Bonelli's eagle in Sicily (Italy)

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Abstract

Illegal trade in wildlife has been identified as one of the main challenges to wildlife conservation. In 2010, an illegal trade-ring trafficking in birds of prey was uncovered in Sicily (southern Italy). This illegal trade targeted the three most endangered species in Italy: Bonelli's eagle *Aquila fasciata*, Lanner falcon *Falco biarmicus* and Egyptian vulture *Neophron percnopterus*, all of them long-lived territorial raptors threatened with extinction across their European distribution. Illegal harvest primarily involved young birds and eggs taken from nests. After the discovery of these activities, surveillance camps and camera traps connected to the mobile Global System for Mobile communications network were established in nine Bonelli's eagle breeding sites in which illegal harvest was reported. Surveillance activities resulted in a sharp reduction in illegal harvest that has contributed to the recent increase in population size and number of breeding pairs of Bonelli's eagle in the island. This population represents 95% of the entire Italian population and is catalogued as Critically Endangered in this country. Importantly, our results highlight the impact of illegal harvest on the population dynamics of endangered species as demonstrated by a population viability analysis. This is particularly important in the case of insular species for which demographic recovery due to immigration from other geographic areas is unlikely. Systematic patrols by forestry police authorities, a resolute application of Convention on International Trade in Endangered Species legislation via legal punishment, and the requirement of including all live captive specimens used for falconry in an obligatory DNA data bank would contribute to reducing the risk of extinction for small populations of endangered species of birds of prey.

Introduction

Unsustainable trade in wildlife has been identified as one of the main challenges to wildlife conservation (Warchol, 2004; Wyler & Sheikh, 2008; Zhang, Hua & Sun, 2008; Pires, 2012). Among vertebrates, mammals (46% of taxon reports), followed by reptiles (24%) and birds (19%), are the most important group of species involved in wildlife trade (Baker *et al.*, 2013). The Convention on International Trade in Endangered Species (CITES) is the most important

international agreement to which 183 countries adhered voluntarily (<https://www.cites.org/>). CITES regulates legal wildlife trade and it aims to ensure that international trade of specimens of wild animals and plants does not threaten their survival. However, along with legal trade, literature shows that there is an increasing black market of illegal wildlife trade that is mostly focused on species used as luxury goods and for food, as well as for traditional medicine, pets and entertainment (e.g. Baker *et al.*, 2013; Buij *et al.*, 2016; Whytock *et al.*, 2016). For example, annually, hundreds of

raptors are legally and illegally traded for falconry and collecting in Asia (World Wide Fund for Nature (WWF) Vladivostok, 2006; Wyatt, 2011). The main destinations of these animals are Europe, North America and Gulf States (Wyatt, 2011). European Mediterranean countries hold some of the most important populations of threatened raptors, such as Spanish Imperial eagle *Aquila adalberti*, Bonelli's eagle *Aquila fasciata* and Lanner falcon *Falco biarmicus*, among others. These species are highly prized for collection and falconry and are consequently included in CITES Appendix I and II. The former includes species threatened with extinction and the trade in specimens of these species is permitted only in exceptional circumstances, whereas the latter includes species that are not necessarily now threatened with extinction but that may become so unless trade is closely controlled.

Importantly, an illegal trade-ring trafficking in birds of prey was uncovered in Sicily (southern Italy) in 2010, involving mostly young birds and eggs taken from nests for falconry and illegal trafficking. This illegal trade specifically targeted Bonelli's eagle, Lanner falcon and Egyptian vulture *Neophron percnopterus* (López-López, Sarà & Di Vittorio, 2012; Di Vittorio *et al.*, 2015a,b). At least nine breeding sites of Bonelli's eagle had been subjected to continuous illegal harvest and led to the confiscation of a large number of raptors by law enforcement authorities, including nine Bonelli's eagles (Italian Forestry Police and regional CITES office, unpubl. data). The discovery of this illegal trade-ring trafficking in raptors was alarming and triggered conservation actions including surveillance activities whose effectiveness is detailed and proved in this paper.

One example of a wildlife species that is currently being unsustainably poached is the Bonelli's eagle. It is a long-lived territorial bird of prey distributed across the Palearctic, Indo-Malayan and, marginally, the Afro-tropical regions (Ferguson-Lees & Christie, 2001). The western Palearctic population is distributed across the circum-Mediterranean area, including countries of northern Africa (Morocco, Algeria and Libya) and southern Europe (Portugal, Spain, France and southern Italy) (Ferguson-Lees & Christie, 2001). Since the second half of the 20th century, abundance of the species has decreased sharply throughout its European range due to habitat modification and unnatural high mortality, mainly due to direct persecution (i.e. hunting, poaching, and poisoning), electrocution on electric pylons and collisions with power lines (Birdlife International, 2016). As a consequence, the species is listed as endangered in Europe (Birdlife International, 2011), where <1500 pairs still breed; 80% of these breeding pairs occur in Spain. The species is also listed as threatened by international laws such as the Annex I of the EU Wild Birds Directive, Appendix II of the CITES and Bern Conventions, as well as on the Bonn Convention.

In Italy, Bonelli's eagle was recorded historically in Sardinia and Sicily and irregularly in the southern Apennines (Cortone & Mirabelli, 1987). In Sardinia, where the species was moderately abundant in the past (Arrigoni Degli Oddi, 1929), only 3–4 pairs remained by the late 1970s (Lo Valvo & Massa, 1992) and there is no evidence of current presence (H. Schenk, pers.

comm.). In Sicily, breeding pairs of Bonelli's eagle were regularly recorded since the 19th century (Doderlein, 1869–1874; Massa & Schenk, 1983). In the 1960s, the species disappeared from south-eastern Sicily due to heavy poaching (Lo Valvo & Massa, 1992; Lo Valvo *et al.*, 1993; López-López *et al.*, 2012). In the mid-2000s, surveys recorded 22–25 breeding pairs (Di Vittorio, 2007; Di Vittorio, López-López & Sarà, 2012; López-López *et al.*, 2012) which represent nearly 95% of the entire Italian population (López-López *et al.*, 2012). Bonelli's eagle faces local threats such as loss of prey species and increased human pressure on breeding habitats (Barov & Derhé, 2011; Scher & Lecacheur, 2011; Di Vittorio *et al.*, 2012), and also illegal nest robbery by falconers and collectors (Di Vittorio *et al.*, 2015b). Furthermore, direct persecution by poaching constitutes one of the main causes of mortality of adult and juvenile Bonelli's eagles in Sicily, where at least 14 cases were recorded in the last 20 years (López-López *et al.*, 2012). Because of a low population size and reduced distribution, the species is currently catalogued as Critically Endangered in Italy (Calvario *et al.*, 1999).

Since the dismantling of this network of illegal trade could influence the Bonelli's eagle population in Sicily, the main goals of this paper are: (1) to provide new information on the status of Bonelli's eagle in Sicily, for which there has been a recent population recovery; (2) to compare breeding parameters before and after the episodes of illegal harvest; (3) to highlight the impact of illegal trafficking on the Bonelli's eagle population in Sicily; and (4) to suggest useful management actions to improve the conservation status of endangered species subject to unnatural sources of mortality.

Materials and methods

Field monitoring

We monitored Bonelli's eagles from 1990 to 2016 as a part of an intensive field survey (Di Vittorio, Greci & Campobello, 2000; Di Vittorio, 2007; Di Vittorio *et al.*, 2012, 2015b). Every year, all known eagle territories were surveyed by remote observation using telescopes and binoculars to assess territory occupancy and breeding performance. Territory occupancy was recorded from at least three visits per site during each breeding season (López-López *et al.*, 2012). We assessed the number of fledglings/monitored pair (i.e. productivity), the number of fledglings/successful pair (i.e. flight rate) and the percentage of successful pairs/monitored pairs (i.e. breeding success) following the standard methodology of breeding performance monitoring for raptors (Steenhof & Newton, 2007; e.g. López-López, García-Ripollés & Urios, 2007).

Nest surveillance

After the discovery of an organized network of illegal harvest and trafficking of chicks and eggs in 2010, we established a working group named 'Gruppo Tutela Rapaci Sicilia' ('Sicilian Raptor Monitoring Group' in English), consisting of raptor experts that exchanged breeding information and suspected cases of illegal harvest all over Sicily.

We established surveillance activities using volunteer camps, camera traps and intensive monitoring at 17 different breeding sites, including nine sites where illegal harvest had been reported and eight sites that were suspected to be at risk. Surveillance camps were regularly organized every year since 2011 and involved 388 volunteers coming from different European countries (41 volunteers in 2011, 77 in 2012, 71 in 2013, 50 in 2014, 70 in 2015 and 79 in 2016) and different Italian Police task forces (Forestry and 'Guardia di Finanza'). Surveillance consisted of nest guarding every day from dawn to dusk during the nesting period (from egg laying, usually in early March, to the post fledging period in mid-June) from a distance of at least 700 m to avoid disturbance. Volunteers were recruited through several international associations including Birdlife Italy (Lega Italiana Protezione Uccelli), Committee Against Bird Slaughter, Euro Bird Net Italy, the French Fonds d'intervention pour les Rapaces, World Wildlife Fund and others. Volunteers were trained and supervised by a senior expert of 'Gruppo Tutela Rapaci Sicilia' in each surveillance site. During these activities, a close partnership was established with Italian Police task forces, which intervened in cases of suspicious events (e.g. cars observed near breeding sites or people in the vicinity of nesting cliffs), or when the presence of poachers was observed. In addition, camera traps connected to the mobile Global System for Mobile communications network were positioned along the possible access routes to nesting cliffs (before the start of breeding season) in 14 sites. A summary of the full surveillance scheme is available in Table 1.

Statistical analysis

We tested for spatial and temporal differences in productivity for all monitored pairs during the period 1990–2016 by

means of generalized linear mixed models (GLMM) (e.g. Carrete *et al.*, 2006; Martínez *et al.*, 2008). In order to control for the possible effects of spatial and temporal heterogeneity on reproduction and for non-independence of data (i.e. to avoid pseudoreplication; McCullagh & Searle, 2000), we considered either territory or year as random factors. GLMM were performed using the 'lme' function in 'nlme' R-package (Pinheiro *et al.*, 2016). We also tested differences in productivity up to 2010 and after 2010 using Monte Carlo ANOVA implemented in Ecosim software (Gotelli & Ellison, 2013). We analysed average productivity in the nine territories subjected to illegal harvest before and after surveillance activities by means of a *t*-test for dependent samples.

In order to check the effect of illegal harvest on Bonelli's eagle population dynamics, we simulated different scenarios in a population viability analysis (PVA) conducted for the same population in Sicily (López-López *et al.*, 2012). PVA was built using Vortex simulation software (version 10.2.7.0; Lacy & Pollak, 2017) using the same baseline demographic values (and thus under illegal harvest) reported in López-López *et al.* (2012). Scenarios simulated illegal harvest or, by contrast, supplementation of chicks in the same population (500 runs of simulation, 100 years for projection, 1:1 sex ratio and four age classes, see details in López-López *et al.*, 2012). Simulations were performed varying one parameter at a time at fixed intervals (from harvesting or supplementation of 2, 4, 6, 8 and 10 female chicks per year) while keeping the remainder of the parameters unchanged. Sensitivity was evaluated by the change in annual population growth rate (λ) resulting from a given change in demographic parameters as follows: $S_i = (\lambda_i - \lambda_b) / \lambda_b \times 100$, where S_i is the sensitivity of the model being investigated, λ_i is the population growth rate of the model i and λ_b is the

Table 1 Summary of the Bonelli's eagle surveillance scheme conducted in Sicily (southern Italy) from 2011 to 2016

Site	2011	2012	2013	2014	2015	2016
1	Surv	Surv	Surv + camera	Surv + camera	Surv + camera	Surv + camera
2	Surv	Surv	Surv	Surv	Surv	
3		Surv	Surv	Surv	Surv	Camera
4		Surv + camera	Surv + camera	Surv + camera	Camera	Camera
5	Surv	Surv + camera				
6		Surv + camera				
7		Surv + camera	Surv + camera	Surv + camera	Surv + camera	Camera
8		Surv	Surv + camera	Surv + camera	Surv + camera	Surv + camera
9					Surv	Camera
10						Surv
11						Surv
12					Surv	Surv + camera
13						Surv + camera
14						Surv + camera
15						Camera
16						Camera
17						Camera
Total	3	8	8	8	10	16

Surv, surveillance.

population growth rate of the baseline model ($\lambda_b = 0.940$). Statistics were computed in STATISTICA 6.0 (www.statsoft.com) and statistical significance was set at $P < 0.05$, with all tests being two tailed. Means are presented ± 1 standard deviation.

Results

Overall, 44 occupied Bonelli's eagle territories were surveyed in 2016. Considering the period 1990–2016, average breeding parameters were: productivity 0.87 ± 0.33 , flight rate = 1.48 ± 0.22 and breeding success = 0.58 ± 0.20 ($n = 428$ breeding attempts). Breeding parameters did not change significantly during this period (productivity: $R^2 = 0.13$, $F_{1,25} = 3.61$, $P = 0.069$; flight rate: $R^2 = 0.04$, $F_{1,25} = 1.11$, $P = 0.302$; breeding success: $R^2 = 0.09$, $F_{1,25} = 2.51$, $P = 0.126$). Considering all territories, there were no significant differences in breeding parameters before and after 2010 (productivity: Monte Carlo ANOVA, Pseudo F ratio = 1.085, $P = 0.567$; flight rate: Pseudo F ratio = 0.018, $P = 0.919$; breeding success: Pseudo F ratio = 1.014, $P = 0.918$). There were differences in productivity across years considering territory as a random factor (GLMM, year: $F_{26,362} = 2.077$, $P = 0.002$, $R^2 = 0.288$) as well as differences in productivity among territories considering year as a random factor (GLMM, territory: $F_{47,362} = 2.401$, $P < 0.001$, $R^2 = 0.289$).

Surveillance activities and nest guarding appear to have prevented further illegal harvest of eagles. Forty-six young eagles were fledged from the nine nests that were subjected to almost regular robbery before 2011. Interestingly, in these nine nests, the mean productivity increased significantly ($t_9 = -3.53$; $P = 0.008$) by 78.41%, from a value of 0.19 ± 0.34 ($n = 40$) before starting surveillance activities to a value of 0.88 ± 0.37 ($n = 46$) after surveillance activities (Fig. 1). Since the start of surveillance, population size increased by 8.39% per year, from 31 pairs recorded in 2012 to 44 pairs recorded in 2016.

Our results of the PVA showed that removing illegal harvest (while keeping all the other demographic parameters unchanged) is just enough to favour population increase, precluding the eagle population from extinction in the long term (i.e. 100 years simulation time frame). In particular, a scenario of illegal harvest of 10 female chicks per year would drive population to extinction in a mean time of 23.2 years (annual population growth rate $\lambda = 0.931$; median time of extinction = 23 years; sensitivity = -5.64) (Fig. 2). In contrast, a scenario of release of 10 female chicks per year would allow population increase ($\lambda = 1.053$) with a null probability of extinction in 100 years (sensitivity = 6.75). According to our PVA, the threshold to turn population decrease to population increase was the scenario of supplementation of two female chicks per year ($\lambda = 1.035$, sensitivity = 4.92) (Fig. 2).

Since the removal of nest plundering, at least 11 new territories were occupied by breeding pairs (one in 2012 and 2013, three in 2014, one in 2015 and five in 2016). These breeding pairs were never observed before 2012 and were

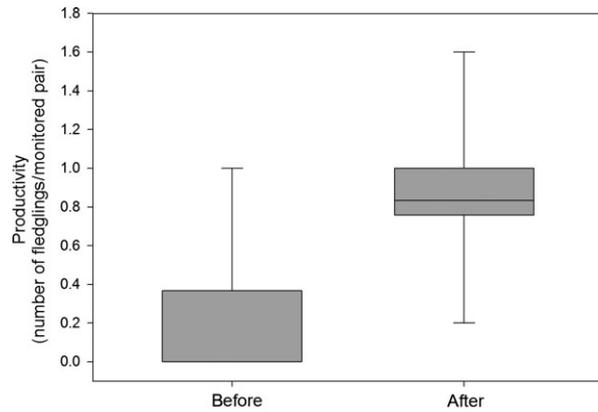


Figure 1 Productivity of nine Bonelli's eagle pairs subject to nest plundering before and after surveillance activities (see text for details). Boxplots show 25th and 75th percentiles, median (continuous line), mean (dashed line), and whiskers (error bars) above and below the box indicate the 90th and 10th percentiles.

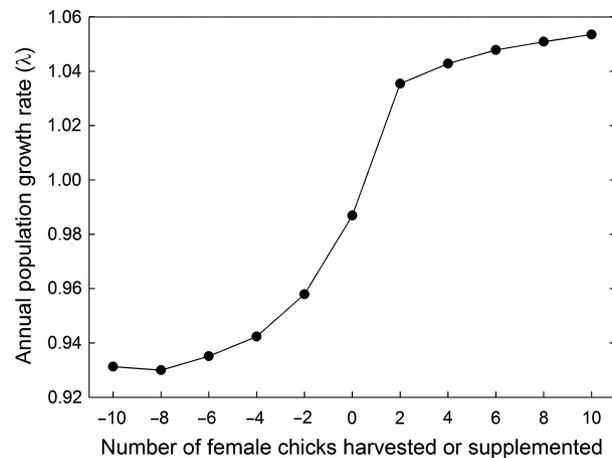


Figure 2 Annual population growth rate (λ) in relation to different scenarios of chicks harvesting or supplementation in the Sicilian population of Bonelli's eagle. Baseline values for the population viability analysis were obtained for the same population as reported in López-López *et al.* (2012). Note that $\lambda > 1$ indicates population growth.

detected during annual systematic monitoring of other cliff-nesting raptors in the study area (i.e. Lanner falcon, Egyptian vulture, Golden eagle, Peregrine falcon).

Nine Bonelli's eagles were confiscated during the operations conducted by the Italian Forestry Police between 2010 and 2015 (two fledglings, five first year juveniles and two immature birds), and at least another 10 (including immature and adults) are still under legal investigation. Ongoing investigations by the CITES team of the Forest Service ('Corpo Forestale dello Stato e della Regione Sicilia') showed that prior to surveillance activities, at least 10 chicks of Bonelli's eagle were plundered from nests in Sicily every year.

Discussion

Currently, Bonelli's eagles face several conservation problems across its range, mainly due to non-natural mortality caused by electrocution and direct persecution (Real *et al.*, 2001; Chevallier *et al.*, 2015). Other causes such as habitat loss and habitat transformation are particularly important in Sicily as well as in other Mediterranean regions (Di Vittorio, 2007; Di Vittorio *et al.*, 2012). Direct persecution is one of the main problems affecting populations of many predators throughout Europe, including Bonelli's eagle. Shooting, trapping and the harvest of eggs and chicks from nests, constitute one of the major risk factors for this species, especially because death by persecution affects similarly territorial and non-territorial birds (Rollan, Hernández-Matías & Real, 2016), indiscriminately affecting all age groups and thus constituting a strong demographic stress factor.

The sharp reduction in illegal harvest has contributed to increase in overall population size and number of breeding pairs reported in this study. Removal of illegal harvest (i.e. increasing the number of juveniles in the population) has a direct impact on demography of Bonelli's eagles. This fact is crucial because survival rate is known to be the major determinant of the persistence of populations of long-lived species, as reported specifically for Bonelli's eagle in our study area and other breeding areas across the Mediterranean region (Real & Mañosa, 1997; Soutullo, López-López & Urios, 2008; Hernández-Matías *et al.*, 2011, 2013; López-López *et al.*, 2012).

Interestingly, unlike other similar Mediterranean populations, the Sicilian population of Bonelli's eagle is isolated from a demographic point of view and its long-term persistence does not rely on immigration from other local populations. For example, a recent study conducted in France (Lieury *et al.*, 2016) showed that a population increase in Bonelli's eagles was due to a sustained immigration rate from Spain, where the largest European population of this species still persists. The French study highlighted that recovery was due by a combination of local conservation measures (e.g. correction of dangerous electric pylons), assisted by immigration. However, the immigration rate in Sicily, if any, seems to be only marginal, with no observation or information of individuals marked outside Sicily observed in the island. This total absence of immigration events recorded in Sicily is probably due to the fact that there are no populations of Bonelli's eagle close to the Sicilian one (the nearest population is recorded in North Africa; BirdLife International, 2016). Therefore, considering the isolation of Bonelli's eagle in Sicily, stopping of illegal harvest has been a determining factor favouring population recovery.

Our results of the PVA showed that removing illegal harvest (while keeping all the other demographic parameters unchanged) is just enough to favour population increase. López-López *et al.* (2012) reported that under past conditions (i.e. using demographic values computed for the period 1990–2010), this is, considering a situation in which the Sicilian population of Bonelli's eagles was subject of illegal harvest, the species was expected to become extinct in Italy

in <50 years. After taking direct measures aimed at preventing illegal harvest such as those reported in this study (i.e. nest surveillance and legal punishment of traffickers), population trend has shifted from a projected decrease to actual population increase. Therefore, the results of PVA support the observed population increase.

Conservation of birds of prey is at risk in Sicily as a consequence of the combined effects of environmental changes (e.g. habitat degradation and habitat transformation) and human impacts (e.g. poaching and illegal persecution). These factors have also resulted in a reduction in population size of other endangered species such as the Egyptian vulture *Neophron percnopterus* and the Lanner falcon *Falco biarmicus* (Sarà & Di Vittorio, 2003; Di Vittorio, 2011; Di Vittorio *et al.*, 2015a). The combination of these threats with nest plundering for falconry and collection can possibly lead to local extinction of these endangered and reduced populations in the short term (especially Bonelli's eagle and Lanner falcon). As previously reported for other species (e.g. Lyapustin, 2006; World Wide Fund for Nature (WWF) Vladivostok, 2006; Wyatt, 2011; Levin, 2011; Kenward *et al.*, 2013; Saker Falcon Task Force, 2014) illegal trade could lead to the collapse of small populations, particularly when the target species have a restricted and fragmented distribution, as does Bonelli's eagle in Sicily, which basically represents the entire Italian population (López-López *et al.*, 2012).

Our results highlight the importance of direct actions such as nest surveillance for the conservation of endangered species. For example, as a consequence of direct surveillance actions, several poachers were unable to harvest eggs and chicks (volunteers saw and photographed known poachers who made site inspections, or poachers were aware of surveillance volunteers monitoring the nest and decided not to operate). Observations of poachers at Bonelli's nest sites were immediately communicated to police task forces who conducted investigations and searches, resulting in the interception of traffickers while taking chicks and climbing the nest. Other traffickers were eventually judged and others are still under investigation and trial proceedings.

In conclusion, our findings highlight the danger of illegal harvest (either chicks or eggs) for falconry and private collection. Importantly, reducing illegal harvest of chicks through nest surveillance increases population growth rate in a highly endangered species. We suggest the combination of systematic control of the territory by forestry police authorities, a resolute application of CITES legislation via legal punishment, and the requirement to include all live captive specimens used for falconry in an obligatory DNA data bank, which is one of the actions of an undergoing LIFE project. Such measures would contribute to reducing the risk of extinction for small populations of endangered species of birds of prey.

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