Ecological Modelling 361 (2017) 74–79

Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

Evaluating management strategies in the conservation of the critically endangered Blue-throated Macaw (*Ara glaucogularis*)

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ARTICLE INFO

Article history:
Received 21 March 2017
Received in revised form 17 July 2017
Accepted 24 July 2017
Available online 9 August 2017

Keywords:
Blue-throated Macaw
Conservation strategies
Life cycle graphs
Matrix model
Reintroduction

ABSTRACT

We model the dynamics of the remaining wild population of the Blue-throated Macaw (*Ara glaucogularis*), a critically endangered and Bolivian endemic species exposed to different management strategies. The model becomes a tool to quantify how effective management actions may be. We construct a birth-pulse, post breeding census, deterministic, stage structured projection matrix model to describe the population dynamics. The model shows that population growth is sensitive to changes in the probability of survival in the adult stage, followed by changes in fertility. We describe the long-term behavior of the population as result of the combination of the maternity function and the nestlings' survival probability. Under the scenarios of increasing population, the number of years that are necessary to double the current wild population varied between 33 and 215 years without reintroduction, and between 7 and 46 years if 50 adult macaws are reintroduced ten years later since the simulation starts. Stakeholders of the Blue-throated Macaw Conservation Project may profit from a simple graphical tool based on this model for management decision making. By knowing the adult population size and the number of hatched eggs at the beginning of each breeding season, the field team could assess the necessary effort on nestlings' management to increase the chances of a positive population growth. Evaluating beforehand the impact of management actions on Blue-throated Macaws could contribute to the improvement and effectiveness of conservation actions on the critically endangered Blue-throated Macaw population.

1. Introduction

Macaws are the most endangered group of the Psittacidae family, counting one extinct species, three critically endangered ones. Habitat loss, trade and the hunting for indigenous ornamental feathers dresses are the main causes of macaws' population decline (Snyder, 2000; Birdlife International, 2016). More than 50% of macaw species are included in the Red List as Endangered, Vulnerable, or Near Threatened species (Birdlife International, 2016). Rediscovered in the savannahs of Bolivia in 1992, the Blue-throated Macaw *Ara glaucogularis* is the last critically endangered macaw still sustaining a wild population (Birdlife International, 2016; Forshaw, 1989; Hesse and Duffield, 2000).

The wild population of the Blue-throated Macaw is unlikely to count more than 115–125 individuals (Birdlife International, 2016). A number of conservation actions aimed to recover the wild population were conducted during the last 15 years. However, our knowledge of the species' biology is limited to descriptions and estimations of range, habitat use, population size, and some basic reproductive parameters, recently described (Hesse and Duffield, 2000; Yamashita and Barros, 1997; Herrera et al., 2007; Berkunsky et al., 2014).

The conservation initiatives on the Blue-throated Macaw focus on actions aimed at providing long-term solutions (Berkunsky et al., 2014). As it occurs in many small populations, the limited number of individuals is one of the most serious threats, and all the efforts are addressed to boost the reproductive output by managing the wild population, and to reinforce it by reintroductions of captive-bred individuals. How effective these management actions will be, must be related to how precisely current threats and limiting factors, such as nest predation, nest flooding, brood reduction and nest site availability (Berkunsky et al., 2014; Kyle, 2006), can be identified. These actions include the protection of natural nests, the provision and protection of nest boxes, the use of defenses against predators and drainage systems for the boxes, and the hand-feeding of nestlings during first weeks of life (Berkunsky et al.,

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http://dx.doi.org/10.1016/j.ecolmodel.2017.07.023
0304-3800/

2014). Although the relative effectiveness of management actions is known, yet these were never analyzed in the global context. As part of a management strategy, knowledge of the impact and scope of each action facilitates decision-making and optimizes resources for conservation.

Modeling results in an effective tool for quantifying how effective management actions may be, and can help to better understand how accurately the current threats and limiting factors are being identified (Noon and Sauer, 1992; Simons, 1984). Strem (2008) developed a demographic model of the Blue-throated Macaw population in 2008 conducting a population viability analysis (PVA) using individual-based (VORTEX 9.72) and cohort-based (RAMAS GIS 4.0) programs. The accumulation of new data and plans for reintroduction since 2008 indicate that it is time to reassess the population and conservation projects (Berkunsky et al., 2014). Deterministic models can be a useful and simple tool for the management of endangered species (Caswell, 2001). A small number of input variable still providing good estimates of the effects of anthropogenic perturbations on species near the threshold of extinction. Also it can provide insight into the potential consequences of threatening processes and highlight the urgency with which management authorities need to act (Otway et al., 2004).

In this work we model the dynamics of the wild Blue-throated Macaw population under different management strategies. By quantifying the impact of management actions on Blue-throated Macaws we hope to contribute to the improvement and effectiveness of Blue-throated Macaw conservation projects and measures.

2. Materials and methods

2.1. Study site

The Llanos de Moxos is a 160,000 km^2 expanse of seasonally inundated savannahs in Northern Bolivia, interspersed with a complex mosaic of forest islands and riverine gallery forests, occupying the extremely flat Beni-Mamore-Itenez basin in Southwest Amazonia, located between the Precambrian Shield to the East and the Andes to the West and South (Forshaw, 1989). The lanscape is dominated by flat, low-lying areas, which are seasonally inundated and covered by completely open treeless savannah (Langstroth, 1996). Forest islands are scarce and restricted to raised areas (mounds) which are sufficiently elevated to escape annual flooding. Most forest islands are eroded relics of natural levees or terraces of abandoned river channels, and therefore constitute fragments of former gallery forest (Hanagarth and Sarmiento, 1990).

2.2. Blue-throated Macaw's biology and management

The Blue-throated Macaw is a critically endangered parrot, endemic of Llanos de Moxos (Jordan and Munn, 1993), throughout a geographic range of 2508 km^2 in Beni Department, Bolivia (Hesse and Duffield, 2000). The habitat availability is enough to support a large population of macaws, and there is no evidence of limiting resources for the species, at least at these low numbers (Hesse and Duffield, 2000; Berkunsky et al., 2014; Strem, 2008).

The species has a monogamous mating system (Snyder, 2000; Forshaw, 1989). In captivity, an individual reaches sexual maturity, on average, at the age of five years (Bueno, 2000; Voss, 2005). In the wild, the breeding season of Blue-throated Macaws begins during the dry season (August) and extends over the rainy season, lasting until February (Berkunsky et al., 2014). In the wild, clutch size varies from 1 to 3 eggs, the latter being most common. Eggs are laid at 1–2 day intervals, incubation period is 25–26 days, and nestlings fledge approximately 90 days after hatching (Berkunsky et al., 2014). Data on sex ratio in the wild are scarce; nevertheless, the sex ratio (males/females) in the Loroparque Fundación, the largest captive population in the world counting some 150 individuals, is close to 1:1 (Bueno, 2000).

Table 1
Number of counted pairs and individuals per year and median of the monitored population of Blue-throated Macaw for the period 2004–2011 by The World Parrot Trust in Beni, Bolivia.

	2004	2005	2006	2007	2008	2009	2010	2011
Pairs laying eggs	6	6	7	10	2	8	4	3
Successful pairs	3	1	6	6	2	8	4	2
Hatched eggs	3	1	8	13	4	16	10	3
Fledglings	2	1	6	10	0	9	3	2
Juveniles and adults	50	60	60	80	65	70	70	70

Currently, there is no data on the mean lifespan of Blue-throated Macaw in the wild. We took into account the value reported by Strem (2008), who estimated it to be at least 40 years. Because there is no evidence to suggest a post-reproductive stage, age of last reproduction and maximum age were assumed to be the same.

The wild Blue-throated Macaw population is estimated to fall between 115 and 125 individuals. At least 16 breeding pairs were identified and followed over 8 years. During this study period there were no new adult pairs recruited into the breeding population. Table 1 summarizes data collected during eight consecutive breeding seasons from 2004 to 2011 (Berkunsky et al., 2014; Kyle, 2006). The variables measured were: numbers of adults and juveniles, breeding and successful pairs, hatched eggs and fledglings per nest. Each year, between 2 and 10 pairs laid eggs, with a median of 6 pairs. They produced between 0 and 10 fledglings, with a median of 2.5 fledglings.

Long term conservation management is in place for the Blue-throated Macaw in Beni, Bolivia since 2000 (Hesse and Duffield, 2000). To reduce nesting failure, drainage holes or roofs were installed in all known nests prone to flooding. Other actions aimed at avoiding nest failure included passive and active anti-predator defenses. Passive defenses are metal flashing wrapped around tree trunks and branches pruned back from cavities to abate climbing predators. Active defenses involve a high level of daily monitoring by volunteers. Most of the defenses seem to be effective given that no nests have been flooded since 2008, and that 2010 was the first year since the beginning of Blue-throated Macaw nest monitoring with no recorded predation.

The conservation project also provided nest boxes which have a good drainage and could be placed to safer positions. However, it takes time for Macaws to get used to nest boxes, since until 2014 only five pairs had used nest-boxes in fourteen different attempts.

To avoid brood reduction, the project monitors nests in a daily basis, identifying nestlings that need a boost, and helping them by hand-feeding. Since 2007, thanks to this intervention, no nestlings have died because of brood reduction and the average number of fledglings per nest has increased from one to two.

Another management action has been moving individuals who are in captivity to a Wildlife's Custody Center in Sachojere, Beni, Bolivia. Up to date, six individuals have already been recovered, whose final destination will be their reintroduction in Llanos de Moxos to strengthen existing populations. In a first stage, at least 50 individuals are expected to be reintroduced.

2.3. Matrix model development

We used a birth-pulse, post breeding census, deterministic, stage projection matrix model to describe the dynamics of the total population of the Blue-throated Macaw as proposed by Caswell (2001). The equation describing this model is of the form: $\mathbf{n}(t+1) = A\mathbf{n}(t)$, where vector $\mathbf{n}(t)$ gives the population in each stage at time t and A is a Lefkovitch projection matrix.