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ARTICLE

Age and gender related plumage variation of psittacofulvine pigments: the case of the Yellow-faced Parrot *Alipiopsitta xanthops*

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ABSTRACT: The Yellow-faced Parrot *Alipiopsitta xanthops* presents considerable phenotypic variation with a belly coloration that may vary from green to yellow-red. Though it has been hypothesized that this variation could be related to sex or age, these possibilities remain untested. We therefore tested these hypotheses by verifying geographical, sexual, and age-related trends in coloration based on museum specimens, wild populations, and captive developing juvenile birds. We found colored belly parrots (CBP) throughout the species distribution of *A. xanthops*. We found no differences in the proportion of CBP individuals between the two wild populations sampled (overall mean of 8.7%), but the proportion of CBP in museums was higher (32%) indicating that specimens were probably not randomly collected. We also found a skewed sex ratio in museums, as females represented only 25% of the specimens. We found that 37% of museum males had colored bellies, in contrast with only 18% of females; furthermore, colored bellied males presented a greater area of yellow-red patch on their bodies. None of the 16 observed fledglings presented colored bellies. The yellow head coloration slowly grew over the 14 days of observation of 16 nestlings. Together, our results suggest that color variation in the Yellow-faced Parrot seems to be related to both age and gender.

KEY-WORDS: Arinii, dichromatism, feather coloration, morphology, Psittacidae, sexual dimorphism.

INTRODUCTION

Among the myriad explanations for bird plumage variation, sexual selection is the most studied (Savalli 1995). Plumage may convey information that could be used by females to choose a high quality partner (Fitzpatrick 1998; Perrier *et al.* 2002; Siitari & Huhta 2002; Saks *et al.* 2003; Masello *et al.* 2004). However, there are alternative hypotheses to explain the remarkable plumage variation found in birds. For instance, feather coloration may be used for individual recognition (Whitfield 1986, 1987; Rohwer & Røskaft 1989), flock cohesion (Røskaft & Rohwer 1987; Selander & Hunter 1960), species recognition (Sibley 1957; Pierotti 1987), or dominance relationships (Rohwer 1977, 1985; Parsons & Baptista 1980; Fugle *et al.* 1984; Ryan *et al.* 1987; Holberton 1990).

Unlike most birds that sediment carotenoid-based compounds on their feathers, most Psittacidae derive their yellow-red coloration from psittacofulvins, a family of lipochromes pigments found exclusively within the family (McGraw & Nogare 2005). Unlike carotenoids (the pigments responsible for similar colors in most avian species), which are obtained through the diet, psittacofulvins seem to be endogenously produced. Parrots are very unlikely to absorb the pigments directly from diet, especially if we consider that no pigment was found in blood samples of 44 Psittacidae species (McGraw & Nogare 2005), or that most species maintain their color in captivity despite diet restrictions (Nemesio 2001).

Sexual plumage dimorphism or dichromatism is not common in Psittacidae, but it may be observed in some parrot species. For instance, males of the Blue-winged Parrotlet (*Forpus xanthopterygius*) exhibit primary and secondary violet-blue wing-coverts (Forshaw 1989); males of the Burrowing-parrots (*Cyanoliseus patagonus*) are slightly larger and exhibit larger red patches on their chest (Masello & Quillfeldt 2003); males of the Blue-bellied Parrot *Triclaria malachitacea* exhibit a bluish-violet bely (that may turn red as they age), and males of the Red-capped Parrot *Pionopsitta pileata* exhibit a conspicuous red crown (Sick 1997). But what would be the roles of such a conspicuous plumage among parrots?

It has been shown that plumage may vary according to body-condition in *Cyanoliseus patagonus*, as feathers reflect body-condition during feather development (Masello *et al.* 2004). Furthermore, the size of the red patch exhibited by males is positively correlated to body condition, and males with large red patches will produce higher quality offspring. Hence, plumage coloration seems to be a reliable signal of body condition that indicates higher male fitness accurately (Masello & Quillfeldt 2003). Biogeography may also lead to plumage differences, as isolated populations could be under distinct selection pressures ultimately leading to distinct plumage patterns. In fact, the Cuban Amazon (*Amazona leucocephala*) exhibits plumage variation among different island populations (Reynolds & Hayes 2009). However, plumage dichromatism has not been properly addressed among parrot species, leading to many competing hypotheses related to age, gender, genetic, or ecological explanations (Sick 1997, Masello *et al.* 2004).

The Yellow-faced Parrot (*Alipiopsitta xanthops*) is a comparatively small species (27 cm) (Sick 1997) that presents remarkable plumage variation. It has orange ear-coverts and a variable amount of yellow on the head (Miranda-Ribeiro 1920). The belly coloration varies from green to conspicuous yellow/orange/red (Forshaw 1989; Sick 1997). The species has a wide distribution throughout the *Cerrado* in central Brazil, from southern Maranhão and Piauí States, throughout Goiás, Tocantins, Mato Grosso, Mato Grosso do Sul, western Bahia, and northern São Paulo as well as Bolivia (Sick 1997). Despite its wide distribution and high local abundance, the biology of *A. xanthops* began to be studied only recently (Bianchi 2009; de Araújo & Marcondes-Machado 2011; de Araújo *et al*. 2011, 2014; Dias 2011). However, none of these previously published studies describes the species' plumage variation, in spite of the role it may have on the species' biology (e.g. Masello & Quillfeldt 2003; Masello *et al.* 2004; Heinsohn *et al*. 2005; Hill 2006).

Authors disagree on the cause and form of the Yellow-faced Parrot's color variation. Some authors simply inform of the variation (Perlo 2009, Antas *et al* 2009, Sigrist 2009), while others relate it to age (Collar 1997, Erize *et al.* 2006, Mata *et al.* 2006, Juniper & Parr 1998, Forshaw 1989, Sick 1997) or sex (Sick 1997, Collar 1997). Still, all these studies have in common an anecdotal approach, without a formal or systematic approach to elucidate or differentiate between competing hypotheses. As a consequence, contradictory information may be found in the literature (i.e. Alderton 1991, which states that sexes actually exhibit similar plumage and no dichromatism at all).

We aim to test whether Yellow-faced Parrot's plumage variation is 1) age-related, that is, if juveniles present distinct plumage when compared to adults; 2) gender related; or 3) geographically-related, varying among distinct localities. This was accomplished through a comprehensive analysis of specimens found in museums worldwide, field observations, as well as the study of captive juveniles.

METHODS

We obtained a total of 109 ventral photographs of parrot specimens from worldwide museum collections. However, here we used only the ones that presented gender classification, so that our analysis was restricted to 65 pictures / specimens. Additionally, we used pictures of 16 chicks from the Mato Grosso do Sul rehabilitation center ("Centro de Reabilitação de Animais Silvestres" - CRAS/MS). All specimens measured in this study (n = 81) are listed in Table 1.

We used pictures to classify adult parrots (n = 65) according to the amount of yellow/reddish coloration in their bellies. If the yellow patch covered the belly completely the specimens were classified as color-bellied parrots (CBP); if they were green or presented incomplete yellow/reddish patches on their bellies, the specimens were classified as non color-bellied parrots (non-CBP). Additionally, we created a plumage index (I) that is given by the relative ratio of the longitudinal length of the colored patch on the center of the ventral region divided by the total body length (Figure 1; Index (I) = Color patch length/ body length). All measurements were made through the pictures with the help of software ImageJ. To test for index differences between sexes, we used a unilateral Fischer exact test, as it is expected that males should exhibit higher indexes as dichromatism (when present) as verified in other parrot species such as *Forpus xanthopterygius*, *Cyanoliseus patagonus*, *Triclaria malachitacea*, and *Pionopsitta pileata* (Forshaw 1989, Sick 1997, Masello & Quillfeldt 2003). We used the Ornithological Gazetteer (Paynter & Traylor 1991) to geo-reference specimens and build a map of colored belly occurrences along the Yellow-faced Parrot's distribution.

Weekly pictures from the CRAS/MS allowed for observations of nestling development (n = 16 individuals) for a period of 21 days. Pictures were taken ventrally (in order to observe the presence of yellow coloration on the belly), and laterally (in order to allow for observations of the size of the mask, and the presence of the orange patch over the ears). Nestlings were classified following the categories described above (CBP or non-CBP).

During 2005, we studied wild populations of the Yellow-faced Parrot in *Cerrado* fragments of the "Cana do Reino" stream (Vicente Pires – DF, Central Brazil; 146 parrots in 9 flocks). In September of the same year we took a 20-day field trip to the Emas National Park (southern state of Goiás, Brazil), where we observed the

color bellies of 61 parrots from 7 distinct flocks. Overall, we observed 207 parrots in 16 flocks in the wild at both localities. We classified the plumage of the individuals observed in the field as CBP or non-CBP, following the criteria above described. We were thus able to determine the proportion of colored bellied individuals in both wild populations. Even though some individuals could be recounted, we expect that our final estimation represents a value very close to what may be found in these areas. Additionally, we made the observations on distinct days and (as much as possible) in distinct areas, further reducing the possibility of overlapping parrot counts.

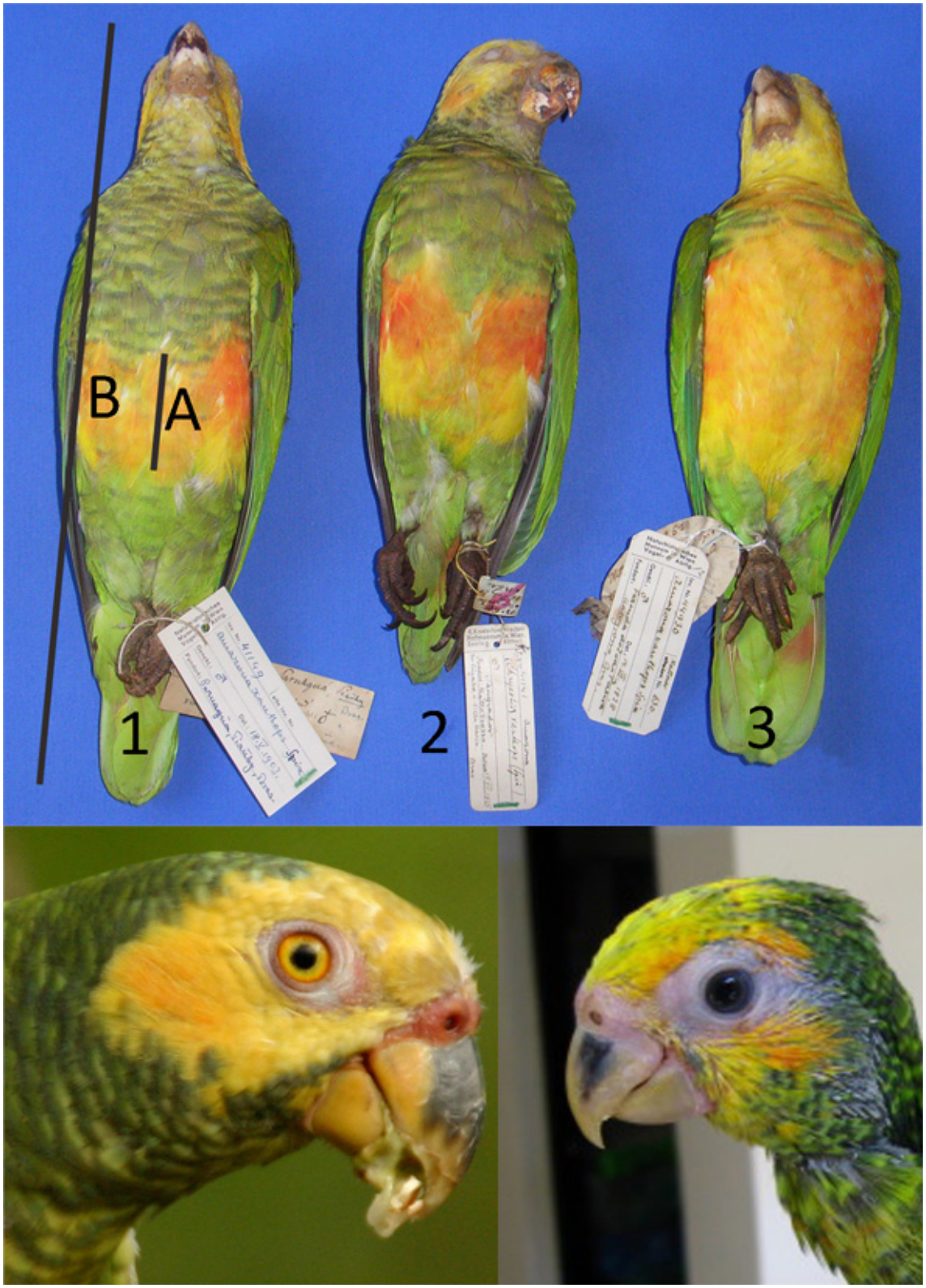

FIGURE 1. Top: some of the variation found in colored bellied parrots. A and B represent the measurements needed to calculate the plumage index (I) given by I = A/B. Parrot 3 is an example of a yellow neck parrot. (Picture by Dr. Ernst Bauernfeind, Naturhistorisches Museum Wien). Bottom left: an adult *Alipiopsitta xanthops* showing the orange ear-covert. Bottom right: an *A. xanthops* nestling with a small yellow mask, and no orange ear-covert.

TABLE 1. Specimens of *Alipiopsitta xanthops* examined in this study.

Institution	Voucher number	Sex	Index [1]
Academy of Natural Sciences, Philadelphia, USA (ANSP)	170759	F	0.23
American Museum of Natural History, New York, USA (AMNH)	174597	F	-
AMNH	241824	M	-
AMNH	241825	F	-
AMNH	241826	M	0.24
AMNH	475312	M	0.27
Coleção Ornitológica Marcelo Bagno, Brasília-DF (COB)	404	M	-
COB	285	M	-
COB	281	M	-
COB	282	M	-
Field Museum of Natural History, Chicago, USA (FMNH)	46971	M	-
FMNH	46972	M	-
FMNH	350841	M	0.24
Forschungsinstitut Senckenberg, Frankfurt, Germany (SMF)	26282	M	0.26
Louisiana Museum of Natural History, Baton Rouge, USA (LSUMNS)	64937	F	-
LSUMNS	166429	M	-
Museu de Zoologia da Universidade de São Paulo, São Paulo (MZUSP)	4330	M	0.27
MZUSP	5078	F	-
MZUSP	5079	M	-
MZUSP	13107	M	-
MZUSP	17098	M	-
MZUSP	17100	M	0.35
MZUSP	30161	M	0.31
MZUSP	30162	M	0.22
MZUSP	30163	M	-
MZUSP	30164	M	-
MZUSP	30165	M	0.24
MZUSP	30166	M	0.29
MZUSP	30167	F	-
MZUSP	35030	M	-
MZUSP	35031	M	-
MZUSP	5081	M	-
Naturhistorisches Museum Wien, Vienna, Austria (NHMW)	44930	M	0.54
NHMW	41146	F	-
NHMW	41141	M	0.31
NHMW	41142	M	-
NHMW	41144	M	-
NHMW	41145	F	-
NHMW	41146	M	-
NHMW	41147	M (Immature)	-
NHMW	41148	F	0.12
NHMW	41149	M	0.20

Institution	Voucher number	Sex	Index [1]
Museu Paraense Emílio Goeldi, Belém (MPEG)	14810	M	-
MPEG	15589	M	0.27
Museu Nacional da Universidade Federal do Rio de Janeiro, Rio de Janeiro (MN)	3992	M	-
MN	3997	M	0.26
MN	4007	F	0.17
MN	9447	M	-
MN	9448	M	-
MN	31573	F	-
MN	31575	M	-
MN	42780	F	-
MN	43617	F	-
MN	Without accession number	M	-
Museum of Comparative Zoology, Cambridge, USA (MCZ)	160970	M	-
MCZ	198332	F	-
MCZ	198333	M	0.21
Natural History Museum of Los Angeles County, Los Angeles, USA (LACM)	32371	F	-
LACM	32372	M	-
LACM	32373	M	0.10
LACM	32374	M	-
LACM	32375	M	-
The Natural History Museum, Tring, UK (NHM)	1929.3.10.1	F	-
Museu de Zoologia da Universidade Estadual de Campinas, Campinas (ZUEC)	1015	M	-
ZUEC	0408	M	0.23
Centro de Reabilitação de Animais Silvestres, Campo Grande (CRAS-MS)	A4_2066	? (Immature)	-
CRAS-MS	A4_2067	? (Immature)	-
CRAS-MS	A4_2068	? (Immature)	-
CRAS-MS	A4_2069	? (Immature)	-
CRAS-MS	A4_2070	? (Immature)	-
CRAS-MS	A4_2071	? (Immature)	-
CRAS-MS	A4_2072	? (Immature)	-
CRAS-MS	A4_2073	? (Immature)	-
CRAS-MS	A4_2074	? (Immature)	-
CRAS-MS	A4_2075	? (Immature)	-
CRAS-MS	A4_2076	? (Immature)	-
CRAS-MS	A4_2077	? (Immature)	-
CRAS-MS	A4_2078	? (Immature)	-
CRAS-MS	A4_2079	? (Immature)	-
CRAS-MS	A4_2080	? (Immature)	-
CRAS-MS	A4_2081	? (Immature)	-

[1] For Index calculation see methods.

RESULTS

The belly color in *A. xanthops* varied from a complete green to a yellow, orange or red coloration (Figure 1), and color belied parrots (CBP) were found throughout its entire distribution (Figure 2). The amount of color on the belly was also quite variable. Museum specimens could be completely green or present belies with yellow/red/orange patches that in some cases extended to its upper chest (Figure 1, parrot 3) reaching up to 54% of the total body length (n = 21, median = 24%). The yellow mask also presents a great deal of variation, as adults have a yellow mask that completely covers the top of the head, while younger parrots generally display smaller masks without the orange ear-coverts (Figure 1). Some individuals have much broader yellow masks, contiguous towards the breast and belly (Figure 1, parrot 3). We observed 3 individuals with this particular coloration phenotype (hereafter yellow necked parrots, YNP), and they were restricted to the southwestern distribution of the species (Figure 2).

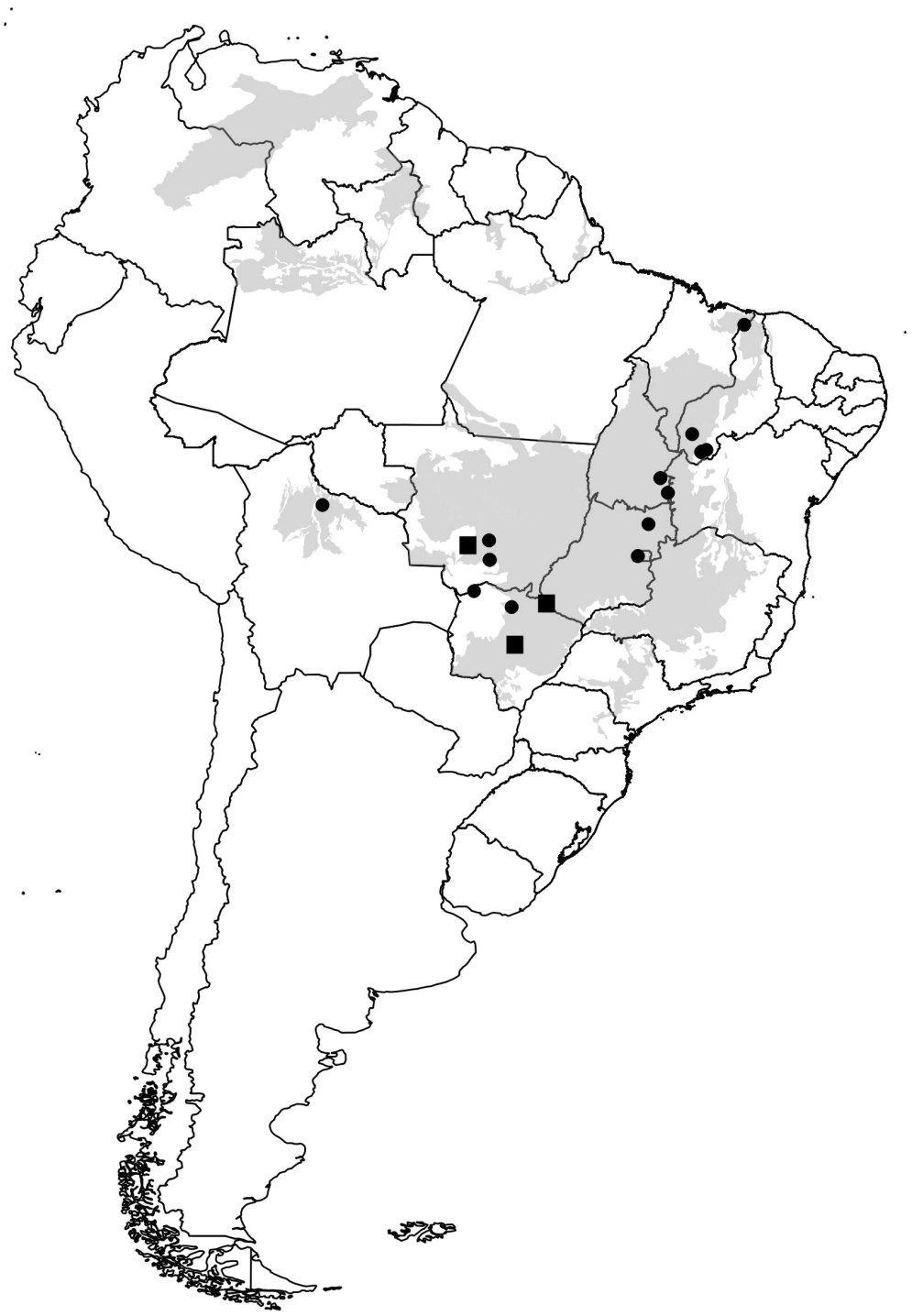

FIGURE 2. Black dots represent the occurrences of the studied colored bellied *Alipiopsitta xanthops* individuals, whereas the squares represent the locations of yellow neck individuals.

The proportion of CBP individuals in flocks was similar in the two wild populations – 8.9% in Emas and 8.2% in Brasília (χ^2 = 0.001; d.f.=1; p = 0.98). However, museum specimens presented approximately three times more CBP individuals than the two wild populations studied (32%; $\chi 2$ =25.6; d.f.=1; p<0.01; Figure 3). We also found a skewed sex (male:female) ratio of 3:1 in museums, as 75% of the specimens were males. When we compared the proportion of CBP between sexes, we found no differences (Fischer exact test; p = 0.12; Figure 3), despite the proportion of CBP among males (37%) being more than twice that among females (17%). The comparison of the plumage indexes (I) between sexes of museum specimens revealed that males exhibit a significantly wider colored patch (t = 1.81, unilateral p = 0.04), presenting a mean index of 27%, while females presented a lower value of 16%.

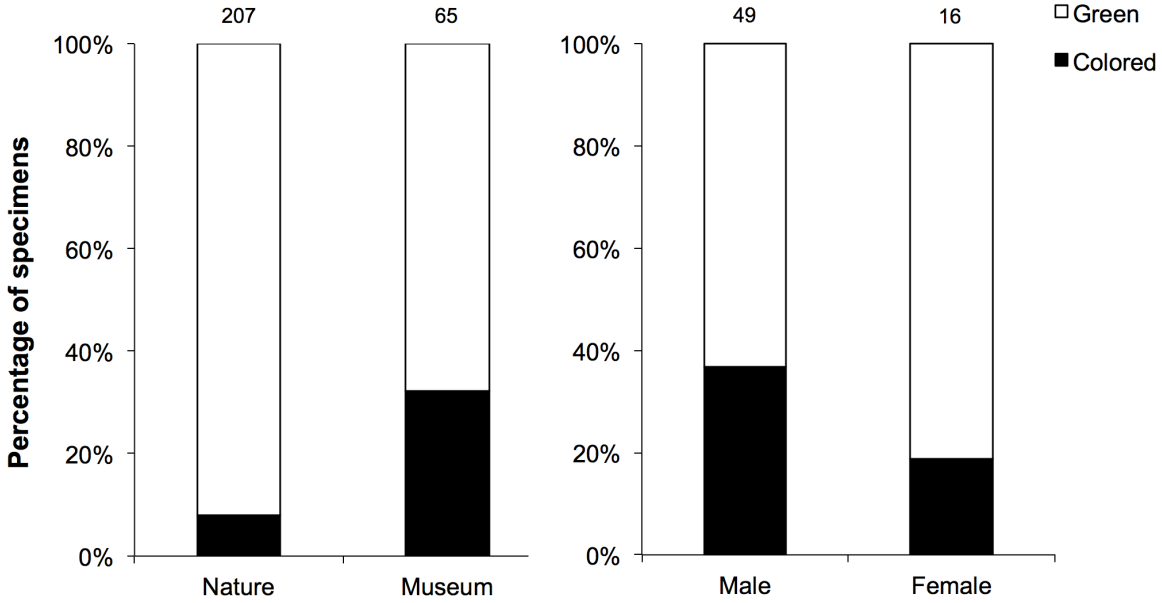

FIGURE 3. Left: proportions of adult color belied parrots in nature (Brasília and Emas National Park) and museums. Right: proportions of museum colored belied parrots specimens for each sex. Numbers over each bar represents the sample size.

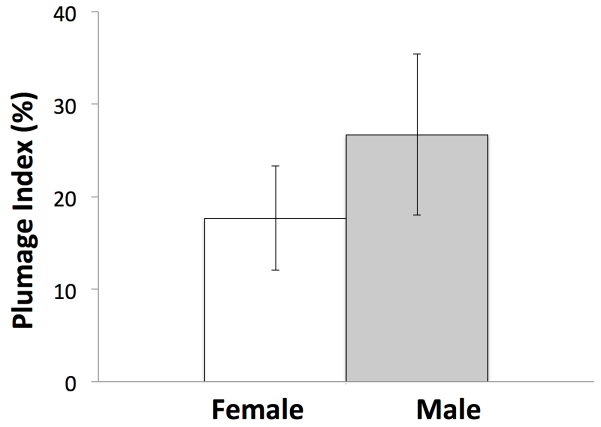

FIGURE 4. Mean and standard deviation of the plumage index (I) of color belied parrots (adults) of *Alipiopsitta xanthops* calculated from pictures for females (n = 3) and males (n = 18).

DISCUSSION

Overall, the Yellow-faced parrot presents great plumage variation throughout its distribution range. Plumage variation observed includes different colors, but also morphological differences on colored patches. We found no significant differences in the proportion of CBP between males and females, but that males have larger colored patches on the belly. Chicks did not present colored bellies and orange ear-coverts, whereas yellow masks were smaller than in adults.

Yellow coloration seems to increase in area during aging, since none of the 16 nestlings observed presented colored bellies. Also, the yellow mask, a trait observed in all adults, grew during nestling development, whereas the presence of orange ear-coverts was never observed in sub-adults. Despite these findings, our data does not allow for any further discussion on the ontogeny of the plumage patterns found. Orange ear-coverts have been reported by Miranda-Ribeiro (1920) to be absent in some individuals. As this character seems to be always present in adults and absent in young parrots, we believe that Miranda-Ribeiro (1920) probably observed young parrots to draw his conclusions.

The differences in the proportion of CBP individuals between wild and museum specimens indicate that museum sampling may be biased. This is likely to occur in species that present such conspicuous plumage variation, as naturalists may focus their sampling efforts towards rare morphs in order to obtain specimens encompassing the full color variation for the species.

Male-skewed sex ratios seem to be the norm within Psittacidae (Taylor & Parkin 2008). Still, the skewed sex ratio of 3.0 male:female found in this study is larger than what has been reported for other species in nature (maximum of 2.42 in *Pyrrhura egregia*; review in Taylor & Parkin 2008). The presence of such highly skewed sex ratio elicit three distinct possibilities: 1) the sex ratio is an actual trend in Yellow-faced Parrot's wild populations; 2) males are easier to catch (for instance, females spend more time inside the nest), or; 3) males are more colorful and thus attract additional attention from collectors. A combination of these three possibilities could also be an explanation. In spite of the fact that the difference in the proportion of CBP specimens between males and females was not significant, we cannot exclude the possibility that the observed higher proportion of CBP in males is a real biological trend, given our small sample size of females. Moreover, we have shown that colored bellies are broader in males, corroborating our hypothesis that the belly is likely to be more colorful in males.

Parrot sexual dichromatism has been described for *Cyanoliseus patagonus* , *Forpus xanthopterygius*, *Triclaria malachitacea, Pionopsitta pileata*, (Masello & Quillfeldt 2003, Sick 1997) and now for *Alipiopsitta xanthops*. Additionally, slight plumage variations may be found in species such as *Aratinga leucophthalma* (that present variable red spots) or is *Amazona pretrei*, which shows slight differences on the amount of red in their forewings (CBA pers. obs.). Thus, its necessary to further investigate the presence and function of this kind of plumage variation found within Neotropical Parrots. For instance, it has been shown that plumage color may vary according to body-condition in Burrowing-parrots as feathers reflect body-condition during feather development (Masello *et al.* 2004). Hence, future studies should incorporate well-designed experiments to elucidate the ecological role of the plumage variation described here.

It is unlikely that a single factor or hypothesis accounts for all plumage variation found in the Yellow-faced Parrot. Age seems to have a role, as chicks did not show colored bellies, neither orange ear-coverts. Sex also seems to be related, as colored belied males have wider orange-yellow patches on their bellies. Also, population genetics factors cannot be excluded, as demonstrated by the presence of yellow-necked individuals only in the southwestern part of the range of *A. xanthops*. Finally, it appears that plumage variation could have multiple functional roles in the Yellow-faced Parrot, since it seems correlated with age and sex.

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