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# Current threats faced by Neotropical parrot populations

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## ABSTRACT

Psittaciformes (parrots, cockatoos) are among the most endangered birds, with 31% of Neotropical species under threat. The drivers of this situation appear to be manifold and mainly of anthropogenic origin. However, this assessment is based on the last extensive consultation about the conservation situation of parrots carried out in the 1990s. Given the rapid development of anthropogenic threats, updated data are needed to strategize conservation actions. Using a population approach, we addressed this need through a wide-ranging consultation involving biologists, wildlife managers, government agencies and non-governmental conservation organizations. We gathered up-to-date information on threats affecting 192 populations of 96 Neotropical parrot species across 21 countries. Moreover, we investigated associations among current threats and population trends. Many populations were affected by multiple threats. Agriculture, Capture for the Pet Trade, Logging, each of them affected > 55% of the populations, suggesting a higher degree of risk than previously thought. In contrast to previous studies at the species level, our study showed that the threat most closely associated with decreasing population trends is now Capture for the local Pet Trade. Other threats associated with decreasing populations include Small-holder Farming, Rural Population Pressure, Nest Destruction by Poachers, Agro-industry Grazing, Small-holder Grazing, and Capture for the international Pet Trade. Conservation actions have been implemented on < 20% of populations. Our results highlight the importance of a population-level approach in revealing the extent of threats to wild populations. It is critical to increase the scope of conservation actions to reduce the capture of wild parrots for pets.

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## 1. Introduction

The order Psittaciformes (parrots and cockatoos; hereafter parrots) is among the most threatened avian orders (i.e. Critically Endangered, Endangered, and Vulnerable sensu International Union for Conservation of Nature, IUCN, 2012; Bennett and Owens, 1997, Butchart et al., 2004, Olah et al., 2016). Although figures vary among sources, the Parrot Action Plan and BirdLife International agree that 28 to 29% of parrot species are threatened (Snyder et al., 2000; BirdLife International, 2017). Moreover, the IUCN Red List considers that more than half of all parrot species are currently experiencing population declines (BirdLife International, 2017). The deterioration in conservation status of parrots can be traced back to well before the 1980s (Pasquier, 1980; Beissinger and Snyder, 1992; Collar, 1996; Snyder et al., 2000; Wiley et al., 2004). The drivers of the current population declines appear to be manifold, but include a mix of intrinsic biological factors and external threats, the latter often of anthropogenic origin (e.g., Wright et al., 2001; Bush et al., 2014; Martin et al., 2014). At the time of its publication in 2000, the IUCN Parrot Action Plan (Snyder et al., 2000) highlighted that the main threats to parrots were habitat loss and degradation (70 species), capture of birds for the pet trade (30 species), introduction of exotic species (15 species), persecution as alleged crop pests (10 species), and disease (2 species). A similar scenario has also been described in many studies of individual species, in country-based action plans, and in recent comparative studies and reviews (Masello et al., 2010; Botero-Delgadillo and Páez, 2011; Schunck et al., 2011; Marsden and Royle, 2015; Olah et al., 2016). However, the last extensive consultation with wild parrot experts and conservation organizations from around the world was carried out in the late 1990s during the preparation of the Parrot Action Plan. Since then, Birdlife International has solicited input on threatened species, but information from many parrot experts, including many of the current authors, has not made its way into recent status reviews. Given the rapid development of many anthropogenic threats, such as habitat loss, climate change, and the spread of disease (Hansen et al., 2012, 2013; Regnard et al., 2015), information compiled over 15 years ago is now unlikely to be valid, and studies based on present day field information are urgently needed.

During the 25th International Ornithological Congress (22 – 28 August 2010) in Campos do Jordão, Brazil, the Working Group Psittaciformes (WGP) of the International Ornithologists' Union (http://psittaciformes.internationalornithology.org) was formed, comprising specialists in parrot research and conservation. One of the first objectives of this group was to update and increase our knowledge of the threats affecting parrots. A regional approach was adopted to evaluate threats facing Psittaciformes and a review of the conservation status of large Afrotropical parrots has been completed (Martin et al., 2014). The present study evaluates current threats faced by Neotropical parrots following a population-based approach. We adopted this approach as 1) threats may vary considerably among populations of the same species (Rusello et al., 2010; Masello et al., 2011, 2015; Wenner et al., 2012), 2) adopting populations as the unit for conservation may help identify and reverse conservation problems while species are still common and ensures that genetic variation is preserved (Lindenmayer and Burgman, 2005), and 3) the population-level conservation approach is less affected by changes in organismic taxonomy. Consequently, we report here novel information on the severity and scope of threats affecting 192 Neotropical parrot populations of 96 species across 21 countries. We also investigate underlying associations among current threats and population trends, and relate them to conservation actions and priorities.

## 2. Methods

### 2.1. Data sources

A questionnaire regarding the threats affecting parrot populations was distributed among the co-authors, which include researchers who published in the field during last ten years, members of the WGP, and active wildlife managers and conservationists from 33 non-governmental and governmental conservation organizations in the Neotropics. In order to facilitate the proper interpretation of our results, a tabulated version of the information delivered by each contributor is provided in Table A1 of Appendix A.

Information for each of the 192 parrot populations includes the following: 1) identity and geographical area of expertise of the contributor, 2) the population's historic (before 1970), recent (1970–2000) and current (since ca. 2001) occurrence and abundance, 3) current (since ca. 2001) population trend, 4) current threats affecting parrot populations, and 5) current conservation and research activities in each population (Table A1 and Table A2 of Appendix A). Occurrence and abundance information was classified in six categories: unknown, absent, vagrant, occasional, fragmented populations, and widespread. Population trend information comprised four main categories: decreasing, stable, increasing, and uncertain. The category "decreasing" was split in four sub-categories: minor decrease if the population reduction was under 30% since ca. 2001, moderate decrease (30–50% since ca. 2001), major decrease (50–80% since ca. 2001) and extreme decrease (> 80% since ca. 2001; Table A1 of Appendix A; Fig. 1). To aid assessment of data quality, we provided details of data sources for population trend and current threats in Table A2. Data provided by the contributors to our study originated mostly in peer review papers but also in reports, thesis, monographies, national action plans, and some *in litt.* communications (references available in Table A2 of Appendix A). To further help comparisons between our study and previous work, we also provide the Red List Status, the IUCN-BirdLife International Population Trend, and information sources used for all species included in this study (Table A2 of Appendix A, BirdLife International, 2017).

We defined a population as a cluster of individuals with a high probability of mating with each other compared to their probability of mating with a member of some other population (Pianka, 1994). For instance, the burrowing parrot *Cyanoliseus patagonus* colony located in El Cóndor, north-eastern Patagonia was considered one population, the burrowing parrot in the Coquimbo region of Chile was considered another population, and the like (Table A1 of Appendix A). Locality details, country, and biological species identity for all our 192 Neotropical

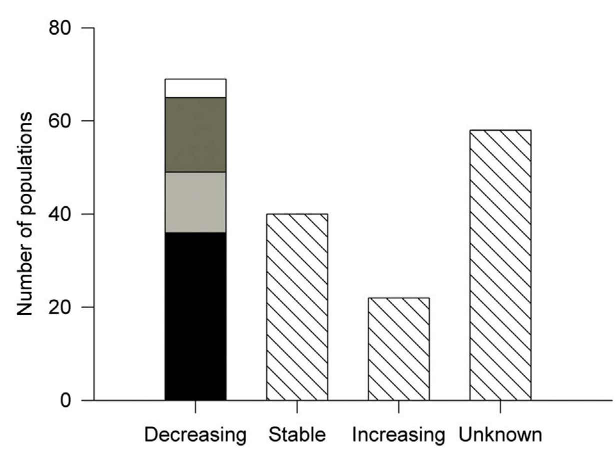


**Fig. 1.** Current population trends for the 192 parrot populations studied across the Neotropical zoogeographical region. Different levels of decrease are denoted by different shades. Black: minor decrease, light grey: moderate decrease, dark grey: major decrease, and white: extreme decrease. The population trend for each of the 192 studied populations is provided in Table A4 of Appendix A.

**Table 1**
The relationship between declining population status and 25 different threat types reported for 192 parrot populations across the Neotropical zoogeographical region. The "Distance" represents the Euclidean distance between population decrease and presence of most closely associated threat variable calculated using a multiple correspondence analysis. Smaller distances and ranks signify a greater association between threat categories and population decline, suggesting that these may be more instrumental in driving the population decline. The specific threat categories used in this study are given together with the corresponding IUCN-CMP threat categories. The order in which the threat categories are given follows the numeration used by IUCN-CMP. Some of the IUCN-CMP categories have been split in order to account for specific threats affecting parrots in the Neotropics.

| IUCN-CMP threats — Level 1 | IUCN-CMP threats — Level 2 | IUCN-CMP threats — Level 3 | Major threat categories used in this study | Specific threat categories used in this study | Distance | Rank |
|---|---|---|---|---|---|---|
| Agriculture & aquaculture (2) | Annual & perennial non-timber crops (2.1) | Small-holder farming (2.1.2) | Agriculture | Small-holder farming | 0.38 | 2 |
| | | Agro-industry farming (2.1.3) | | Agro-industry farming | 0.88 | 10 |
| | Wood & pulp plantations (2.2) | | | Wood & pulp plantations | 3.23 | 22 |
| | Livestock farming & ranching (2.3) | Small-holder grazing, ranching or farming (2.3.2) | | Small-holder grazing | 0.65 | 6 |
| | | Agro-industry grazing, ranching or farming (2.3.3) | | Agro-industry grazing | 0.63 | 5 |
| Energy production & mining (3) | Oil & gas drilling (3.1) | | Energy production & mining | Oil & gas drilling | 4.11 | 25 |
| | Mining & quarrying (3.2) | | | Mining & quarrying | 2.48 | 20 |
| Transportation & service corridors (4) | Roads & railroads (4.1) | | Transportation & service corridors | Road construction | 1.23 | 13 |
| Biological resource use (5) | Hunting & collecting terrestrial animals (5.1) | Intentional use (5.1.1) | Hunting | Hunting for traditional ceremonies | 3.21 | 21 |
| | | | | Hunting for food | 2.02 | 16 |
| | | | Pet trade | Capture for pet trade: local | 0.15 | 1 |
| | | | | Capture for pet trade: international | 0.66 | 7 |
| | | Unintentional effects (5.1.2) | | Nest destruction by poachers | 0.48 | 4 |
| | | Persecution/control (5.1.3) | Hunting | Persecution/control | 3.60 | 23 |
| | Logging & wood harvesting (5.3) | Intentional use: subsistence/small scale (5.3.1) | Logging | Small-scale logging | 1.37 | 14 |
| | | | | Large-scale logging | 0.73 | 8 |
| | | | | Selective large-scale logging | 0.90 | 11 |
| Human intrusions & disturbance (6) | Recreational activities (6.1) | | Human intrusions & disturbance | Recreational activities | 2.21 | 18 |
| | Work & other activities (6.3) | | | Rural population pressure | 0.44 | 3 |
| Natural system modifications (7) | Dams & water management/use (7.2) | | Natural system modifications | Dam construction | 2.00 | 15 |
| | Fire & fire suppression (7.1) | Increase in fire frequency/intensity (7.1.1) | | Increase in fire frequency/intensity | 1.02 | 12 |
| | | Suppression in fire frequency/ intensity (7.1.2) | | Suppression in fire frequency/ intensity | 4.06 | 24 |
| Invasive other problematic species, genes & diseases (8) | Invasive non-native/alien species/diseases (8.1) | | Invasive non-native/alien species | Invasive non-native/alien species | 2.42 | 19 |
| Climate change & severe weather (11) | Habitat shifting & alteration (11.1) droughts (11.2) | | Climate change & severe weather | Droughts/desertification | 0.87 | 9 |
| | Storms & flooding (11.4) | | | Storms & flooding | 2.15 | 17 |

parrot populations are given in Table A1. In order to facilitate the identification of specific populations for each analysis in this study, we assigned a population number to each of the studied populations (see Table A1, Table A4 and Table A5). In 25 cases, we investigated more than one population per parrot species e.g. 4 populations of chestnut-fronted macaw *Ara severus*, 3 of blue-headed parrot *Pionus menstruus*, 4 of white-eyed parakeet *Psittacara leucophthalmus* (for further detail see Table A2 of Appendix A).

In our study, we used the relevant categories of the hierarchical Unified Classification of Direct Threats from the IUCN and the Conservation Measures Partnership (CMP) (hereafter IUCN-CMP categories; IUCN and CMP, 2012, Table 1). IUCN and CMP classify the threats in hierarchical levels (levels 1, 2 and 3; Table 1, IUCN and CMP, 2012). For further descriptions of the threat categories used here see IUCN and CMP (2012). In all statistical analyses, we used the IUCN-CMP threat categories in Level 3, except for a few cases where only Level 2 categories exist (Table 1; IUCN and CMP, 2012). To investigate general trends and to improve visualization and clarity, we used the IUCN-CMP threat categories in Level 1 (hereafter: major threat categories) in some of the figures in this study e.g. Fig. 2. Following Martin et al. (2014), and in order to account for specific threats that may affect parrots (Snyder et al., 2000; Martin et al., 2014), some of the IUCN-CMP categories were further subdivided. The IUCN-CMP category 'Biological Resource Use (BirdLife International, 2017)' in Level 1 was split into three categories of: Hunting, Pet Trade, and Logging. The IUCN-CMP category 'Hunting & Collecting Terrestrial Animals (5.1) Intentional Use (5.1.1)' was split into four categories: Hunting for Traditional Ceremonies, Hunting for Food, Capture for Pet Trade: local, Capture for Pet Trade: international. Additionally, we used the more specific threat category 'Road Construction' instead of the IUCN-CMP category 'Roads & Railroads (4.1)' (IUCN and CMP, 2012), as all cases in our study corresponded to the construction of new roads and not to existing roads (see Table A1). We also used a combined threat category 'Droughts/Desertification' to replace the IUCN-CMP categories 'Habitat Shifting & Alteration (11.1)' and 'Droughts (11.2)', which occurred as one combined intermingled threat in our study (see Table A1 of Appendix A). Following IUCN recommendations (IUCN, 2013), contributors indicated the timing, scope (i.e. proportion of the affected population) and severity (i.e. the overall decline) of the threats facing each population in their geographical area of expertise (see raw information in Table A1). We used ordinal categories to indicate the scope of the threat: a) minor, affects a negligible proportion of the population, b) < 50%, affects the minority of the population, c) 50 − 90%, affects the majority of the population, d) > 90%, affects the whole population, and e) unknown (Table A1). We defined the categories of severity as follows: a) none, i.e. no decline, b) minimal, causing or likely to cause negligible declines, c) fluctuating, causing or likely to cause fluctuations, d) slow decline, causing or likely to cause relatively slow, but significant, declines (< 20% over 10 years or three generations), e) fast decline, causing or likely to cause rapid declines (> 20% over 10 years or three generations), and f) unknown (Table A1). For timing we defined the categories as follows: a) 0, only in the past (and unlikely to return), b) 1, only in the past (no direct affect but limiting), c) 2, now suspended but could come back in the long term, d) 3, now suspended (could come back in the short term), e) 4, continuing, f) 5, only in the future (could happen in the short term), g) 6, only in the future (could happen in the long term), and h) uncertain or unknown (Table A1).

Details of research and conservation activities in progress in the studied populations and the priority level for those activities are also provided in Table A1. Activities reported include: population monitoring (compilation of biodiversity inventories that include parrots, bird atlases, nest record card schemes, monitoring of breeding attempts), demographic and ecological research (habitat use, feeding ecology, breeding biology), management (activities aimed at directly boosting individual survival or breeding success, provision of nest boxes, planting of food trees, direct protection of nesting/roosting sites), population reinforcement, and species re-introduction (Table A1 of Appendix A).

## 2.2. Analysis

We used Cohen's kappa coefficient (K) to test for the degree of concordance between categories of scope and severity of threats (Cohen, 1960). Index values are: no concordance (lower than 0.2), discrete (between 0.2 and 0.4), moderate (between 0.4 and 0.6), substantial (between 0.6 and 0.8) and almost perfect (higher than 0.8). For most of the threats considered (72%), we found no concordance (Table A3). Moderate concordance was observed between scope and severity for threats associated with Climate Change, Construction of dams, Decrease in the frequency of natural fires, and Small-scale logging (Table A3).

To study the pattern of association among reported threats and population trends, a multiple correspondence analysis (MCA) was carried out using the ca package in the R statistical environment (Nenadic and Greenacre, 2007, R Development Core Team, 2016). We included a total of 26 categorical variables (i.e. the reported population trend, and the 25 specific threat categories considered in this study; see Table A4 and Table A5). For the MCA, the variable "population trend" had two character states: "stable or increasing" and "decreasing". The values used for the remaining 25 threat variables corresponded to the scope of current (i.e. threats which timing value was 4) threats pooled into two character states: 0 for scope values of 0 and 1; and 1 for scope values of 2 and 3 (Table A5 of Appendix A). The outcome of this analysis is a set of coordinates indicating the association between the different variables and their character states (population trends and threat scope). We plotted the low-dimensional Euclidean space to examine the associations among the categories: highly associated variables result in closer coordinates (Table 1, Fig. 3). Here, we selected multiple correspondence analysis based on a simple Correspondence Analysis (CA; Benzécri, 1973) of the indicator matrix (setting lambda = "indicator"), and visualized the results using symmetric maps with the row and

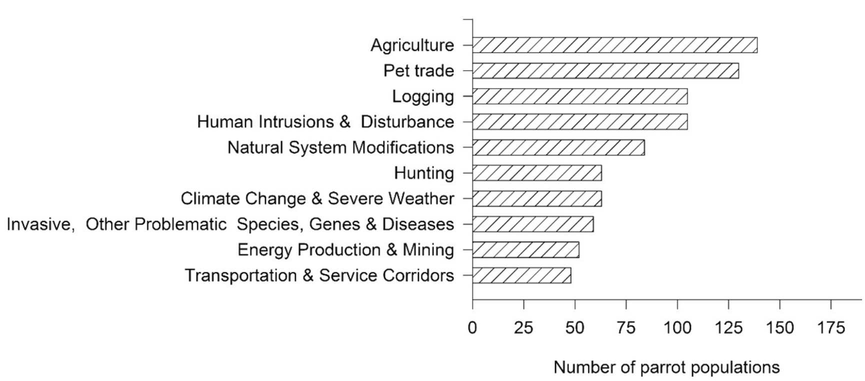


**Fig. 2.** Major threat categories currently affecting the 192 parrot populations studied across the Neotropical zoogeographical region. Data were classified according to the IUCN-CMP Level 1 threat categories, except for category 'Biological Resource Use', which was split in three categories i.e. hunting, pet trade, and logging with the aim to account for some specific threats found to affect parrots (Snyder et al., 2000; Martin et al., 2014). For raw data see column "timing", value "4" in Table A1 of Appendix A.

 

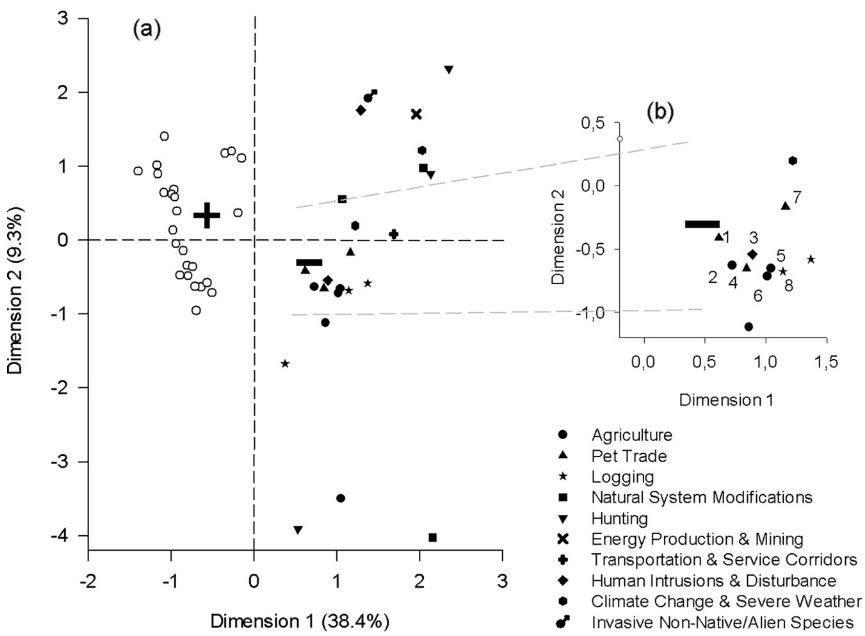


**Fig. 3.** Symmetric map of multiple correspondence analysis (MCA) on 26 categorical variables (population trend and 25 specific threat categories). The first two dimensions explained 48% of the data distribution. The left panel (a) shows the two character states of all 26 variables (black "+" for stable/increasing population trend, and black "−" for decreasing population trend; small open circles: 25 threats with character state "absence", small black symbols: 25 threats with character state "presence"). To facilitate visualization, the 25 specific threat categories were grouped in ten major groups based on the IUCN-CMP Level 1 threat categories, except for category 'Biological Resource Use', which was split in three categories i.e. hunting, pet trade, and logging with the aim to account for some specific threats found to affect parrots (Snyder et al., 2000, Martin et al., 2014; see appendix A. The close-up in the right panel (b) details the most important variables (i.e. closer than a half-distance between stable/increasing and decreasing population trend). The eight specific threat categories most closely associated to decreasing population trend are numbered according to the rank in Table 1.

column coordinates of the two dimensions with the largest eigenvalues (Fig. 3).

## 3. Results

### 3.1. Population trends

Of the 192 Neotropical parrot populations studied, 72 (38%) were found to present a decreasing population trend since 2001 (Fig. 1, Table A4). An extreme decrease since 2001 was reported for four populations (2%): the red-tailed amazon *Amazona brasiliensis* from São Paulo and Santa Catarina, Brazil, the Spix macaw *Cyanopsitta spixii* in Bahia, Brazil, and the blue-winged macaw *Primolius maracana* in both Argentina and Paraguay (Fig. 1; populations 21, 109, 152 and 153 in Table A1 and A4). A further 16 populations (8%) experienced a major decrease, including the yellow-naped amazon *Amazona auropalliata* from Santa Rosa in Guatemala, the Cuban parakeet *Psittacara euops* from Sancti Spiritus, Cuba, and the grey-cheeked parakeet *Brotogeris pyrrhoptera* from Piura and Tumbes, Peru (Fig.1; populations 16, 100, and 160 in Table A1 and A4 of Appendix A). A moderate decrease was reported for 15 populations (8%), including the great green macaw *Ara ambiguus* in Mosquitia, Honduras, red-and-green macaw *Ara chloropterus* in Chiquitania, Bolivia, and the yellow-shouldered parrot *Amazona barbadensis* from Araya Peninsula, Venezuela (populations 53, 62, and 191 in Table A1 and A4). Finally, a minor decrease was reported for 37 populations (19%), including the hispaniolan parakeet *Psittacara chloropterus* from the Commonwealth of Dominica, and the painted parakeet *Pyrrhura picta* from Guajira, Colombia, (populations 158, and 183; Fig. 1, Table A1 and A4 of Appendix A).

Overall, 40 studied populations (21%) were considered to present a stable population trend since 2001, including the yellow-chevroned parakeet *Brotogeris chiriri* from Beni, Bolivia, the orange-fronted parakeet *Eupsittula canicularis* from Guanacaste, Costa Rica, and the scarlet-fronted parakeet *Psittacara wagleri* from Lambayeque, Piura, Tumbes and Lima, in Peru (populations 96, 117, 168; Fig. 1, Table A1 and A4 of Appendix A). An increasing population trend since 2001 was reported for 22 populations (11%), including the yellow-shouldered amazon *Amazona barbadensis* from Bonaire, Netherland Antilles, the blue-and-yellow macaw *Ara ararauna* from Mato Grosso do Sul, Brazil, and the monk parakeet *Myiopsitta monachus* from Buenos Aires, Argentina, (populations 20, 59, and 127; Fig. 1, Table A1 and A4 of Appendix A). Finally, due to the lack of complete information, the population trend could not be established for 58 of the studied populations (30%), such as the yellow-billed amazon *Amazona collaria* from Jamaica, the scarlet macaw *Ara macao* from Belize, and the red-billed parrot *Pionus sordidus* from Napo, Ecuador (populations 22, 74, and 144; Fig. 1, Table A1 and A4 of Appendix A). We found intra-specific differences in population trends in 18 out of 25 cases with more than one population per parrot species (Table A4). For instance, of the six blue-fronted amazon *Amazona aestiva* populations studied, one was stable (population number 8, Pantanal, Brazil), three experienced a minor decrease (populations: 5, Cerrado, Brazil; 6, Chaco, Argentina; and 7, Beni, Bolivia), one experienced a moderate decrease (population 3, Chiquitania, Boliva), and for another population the trend was unknown (population 4, Mato Grosso do Sul, Brazil; Table A4).

### 3.2. Current threats

On average, parrot populations were affected by 10 ± 7 threats per population ($N$ = 192 populations). For reasons of space and readability reasons, we mention here only the major results for current threats affecting Neotropical parrot populations. However, we provide complete data on all threats currently faced by each of the studied populations in the supporting information (Table A1 and Table A5).

The main threats to Neotropical parrot populations in the wild were related to human activities. Agriculture threatened 72% of populations ($N$ = 139), followed by the capture of individuals for the Pet Trade ($N$ = 130 or 68%), Logging ($N$ = 105 or 55%), and Human Intrusions and Disturbance ($N$ = 105 or 55%) (Fig. 2, Table A1 and Table A5). Nine out of ten major threat categories affected at least 50 of the parrot populations studied (Fig. 2; Table A1 and Table A5).

MCA analysis revealed that a stable or increasing population trend since 2001 generally corresponded to an absence of threats (negative values in dimension 1), while decreasing population trends were associated with the presence of one or more threats (positive values in dimension 1; based on IUCN-CMP Level 3 threats; Table 1; Fig. 3; Table A5 of Appendix A). However, a large spread of the coordinates in space among the different threats was apparent. Capture for the local Pet Trade was the threat most closely associated with population decrease (MCA analysis; number 1 in Fig. 3; rank 1 in Table 1). Our analysis suggests that the domestic trade is associated with population decrease in 102 of the 192 studied populations, including a major decrease for the yellow-naped amazon *Amazona auropalliata* from El Salvador, a moderate decrease of the yellow-shouldered parrot *Amazona barbadensis* from Lara and Falcón in Venezuela, and a minor decrease of the brown-throated parakeet *Eupsittula canicularis* on the Pacific coast of Mexico (Table A5). The 102 populations showing decreases associated with the local pet trade were from 16 countries and included 35 species of all body sizes from the following genera: *Alipiopsitta*, *Amazona*, *Ara*, *Brotogeris*, *Cyanoliseus*, *Cyanopsitta*, *Eupsittula*, *Forpus*, *Pionus*, *Primolius*, *Psittacara*, and *Pyrrhura* (Table A1 and Table A5). The threat from Small-holder Farming ranked second in association with population decrease (number 2 in Table 1 and Fig. 3), and affected 43 of the studied populations e.g. a major decrease in the yellow-headed amazon *Amazona oratrix* from Guerrero and Michoacan in Mexico, a moderate decrease of the great green macaw *Ara ambiguus* from Ecuador, and a minor decrease of the vinaceous-breasted amazon *Amazona vinacea* from Misiones, Argentina (Table A5). Populations showing a decrease associated with Small-holder Farming were distributed in 10 countries, including continental and insular localities (Table A5). Other threats closely associated with population decrease were Rural Population Pressure ($N = 65$ populations), Nest Destruction by Poachers ($N = 81$), Agro-industry Grazing ($N = 69$), Small-holder Grazing ($N = 60$), Capture for the International Pet Trade ($N = 90$), and Large-scale Logging ($N = 74$, Table 1, Fig. 3, for more information on threats to each parrot population see Table A5).

Specific threats varied in their scope and severity across the populations (Table A6). We found that Agro-industry Farming and Agro-industry Grazing (Fig. 4a), Capture for the international and local Pet Trade (Fig. 4b), and Selective Large-scale Logging (Fig. 4c), as well as Droughts/Desertification and Storms & Flooding (Fig. 4d) were severe threats broadly affecting large proportions of the studied populations. By comparison, Wood & Pulp Plantations, Mining & Quarrying, and Road Construction had extensive impacts on the populations they threatened, but the impacts were of lower severity (Fig. 4a, c). Nest Destruction by Poachers was commonly reported, but usually involved a small proportion of each population for which it was registered (Fig. 4b). All other threats affected < 25% of parrot populations with low severity (Fig. 4; Table A1 and Table A6).

### 3.3. Research and management

Population monitoring was reported as ongoing in 121 of the 192 studied populations (Table A1). Half of the contributors (52%) agreed in their surveys that monitoring is a high priority activity, which should include population size estimates and nesting activity. Research activities were reported in 77 of the 192 populations. Main research topics included breeding biology (63 populations), feeding ecology and food availability (48), and habitat use and dispersal (48). By comparison, behavioural research (12), analyses of pet trade impact (12), genetic studies (4), and disease monitoring (4) were less frequently reported (Table A1). At least one management action was carried out in 38 of the studied populations. The most common management action was the use of nest boxes (19 populations), followed by nest and/or roost surveillance (8), habitat restoration (5), improvement of natural cavities (4), and activities aimed at directly boosting nestling survival including hand-feeding of nestlings or removal of ecto-parasites (3 populations; Table A1). Reintroduction attempts have been carried out in only a small number of the studied populations ($N = 4$), which is in line with the answer provided by 37 of 53 contributors who agreed that reintroduction was a low priority activity in their populations (Table A1). Eight of the 22 populations where reintroduction was considered high or medium priority corresponded to decreasing populations (e.g. blue-fronted amazon from Pantanal, Brazil, yellow-naped amazon from Santa Rosa, Guatemala, yellow-headed amazon from Guerrero and Michoacán in Mexico; Table A1 and Table A2). Reintroduction was also

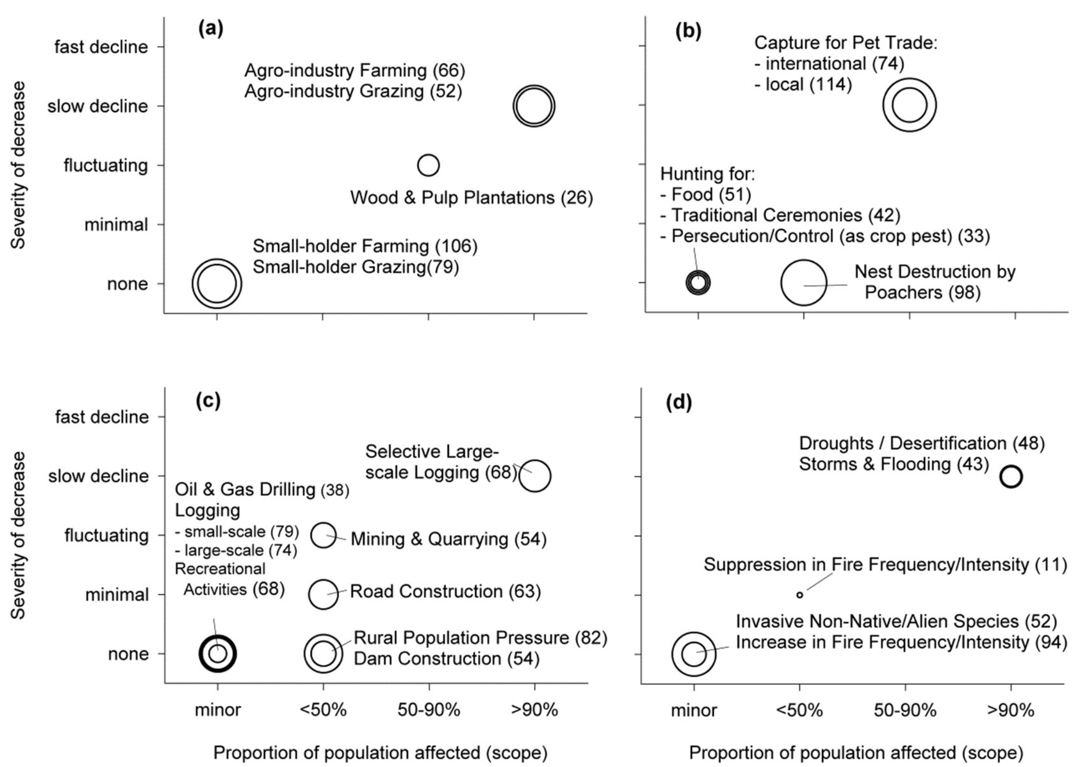


**Fig. 4.** The severity of the population decrease versus the proportion of the affected population (i.e. scope) corresponding to each current threat affecting the 192 parrot populations studied across the Neotropical zoogeographical region. The threat categories are based on the hierarchical Unified Classification of Direct Threats from the IUCN-CMP. The data are presented in four plots in order to facilitate visualization. The number of populations experiencing a particular threat at present is given in brackets. The size of the circles is directly proportional to the number of populations experiencing a particular threat at present (i.e. small circles: fewer populations; large circles: more populations). For data on timing, scope and severity of threats and the identity of the populations affected see Table A1 and Table A6 of Appendix A.

considered high priority in some stable or increasing populations with very small or extinct wild populations (i.e. blue-throated macaw in Bolivia, Puerto Rican amazon in Puerto Rico).

## 4. Discussion

Seventy-two (38%) out of the 192 Neotropical parrot populations we studied were currently in decline, mostly due to Agro-industry Farming and Grazing and capture of individuals for the pet trade both at local and international levels. For an additional 58 populations (30%) the trend was unknown (Fig. 2), although 49 of these were also reported to be affected by at least one of the major threats and may be experiencing some degree of population decline. The results of our evaluation of Neotropical parrot populations are in strong agreement with similar studies on declines in Afrotropical (Martin et al., 2014) and Caribbean (Wiley et al., 2004) Psittaciformes, and adds to the evidence that parrots are facing high levels of threat globally (Bennett and Owens, 1997; Butchart et al., 2004; Marsden and Royle, 2015; Olah et al., 2016).

The main threats we report here corresponded in order of importance with the main threats recently reported at the species level using IUCN Red List data (Olah et al., 2016). This result suggest that the exercise of ranking threats is robust to the methods (population vs. species) used. However, in all cases, the proportion of parrot populations we report as affected by each of the main threats were substantially higher than the proportion of parrot species affected by the same threat in previous studies (Olah et al., 2016). For example, we found 72% of our study populations were threatened by Agriculture, although only 35% of parrot species were previously reported as threatened by this human activity. Similarly, capture of individuals for the pet trade reportedly impacts 68% of our study populations but was reported for just 32% of species (Olah et al., 2016).

The higher threat percentages reported in our study are likely due to a combination of factors: the level of analysis and underlying data quality. Widespread species that are highly threatened in parts of their range but not in others, may not meet the criteria for categorization as threatened in the Red List (e.g. scarlet macaws, Britt et al., 2014, BirdLife International, 2017). However, our population approach captured intra-specific variability in population trends that although relevant to the conservation status of parrots was probably lost in species-based studies (Table A4; Snyder et al., 2000, Butchart et al., 2004, Wiley et al., 2004, Lindenmayer and Burgman, 2005, Martin et al., 2014, Marsden and Royle, 2015, Olah et al., 2016). Moreover, the population approach would identify early warnings for some species, and will facilitate regional prioritization (Clements et al., 2015).

The second factor that may be influencing the higher threat levels found in our study is data quality. BirdLife works to continuously update the Red List and the list is widely recognized as the standard for assessing avian endangerment (Vié et al., 2009). Despite this, 55% of the Population, Trend, and Threat justifications in the Red List are based on information from the 1990s (marked red in Table A2; see also the references provided in the same table), while another 26% of the species trends are from information > 10 years old (marked yellow in Table A2). In addition, for approximately 25% of the 96 parrot species we analysed, the IUCN Red list classifications are supported only by *in litt.* sources (i.e. personal communications), and only 24% are backed up by peer-reviewed sources (Table A2). In contrast, our status assessment information was recently-gathered directly from experts working with local populations. As an indication of data quality, 81% of the populations analysed in this study are the subject of at least one peer-reviewed publications, and only 6% are supported by only *in litt.* information (Table A2). Additionally, 81% of peer-review publications used in our study are based on quantitative data (Table A2). As a result, our more recent and higher quality data may have captured updated population trends (Table A2 of Appendix A). Thus, the conservation status of some parrot species may be changing radically and their Red List status may change as knowledge increases as has happened with a variety of other species (Butchart et al., 2004; Tobias and Brightsmith, 2007; Tella et al., 2013; Marsden and Royle, 2015).

If the status of parrot species is truly deteriorating, then it is imperative that this information is included in the Red List. It is unclear why the information from many of our authors is not reflected in the Red List. However, we know that some of our authors have had difficulty getting their information included in the status reviews. Some other authors have also not tried to contribute their information, perhaps due to a mix of language or cultural barriers. As a result, it is important that BirdLife continue to reach out to researchers and for groups like the Working Group Psittaciformes (WGP) of the IOC to encourage their members to work more closely with Birdlife. The use of questionnaires in lots of different languages, sent them out to people in relevant areas, was an effective methodology for us.

The results of our study show that the capture of wild parrots for the local pet trade is currently the threat most closely associated with decreasing population trends, and capture for the international trade was also closely associated with declining populations. The decreases, as suggested by our data, were slow but impacted most of the individuals in the population. Capture for international trade has been one of the main threats to parrots for decades, with millions of individuals captured in the Neotropics and imported to the United States, Europe and Japan in the 1980s and 1990s (Beissinger and Snyder, 1992; Wright et al., 2001). Intensive poaching led to the endangerment and local extinction of many parrots, and was likely the main cause of the Spix's Macaw's extinction in the wild (Snyder et al., 2000; Caparroz et al., 2001). Even now, heavy trade of the grey parrot *Psittacus erithacus* has played a major role in its virtual elimination from Ghana and other regions in Africa (Martin et al., 2014; Annorbah et al., 2016).

Some progress has been made towards reducing international trade, as the passage of the U.S. Wild Bird Conservation Act and the permanent ban on wild-bird trade by the European Union (European Union, 2007; Pain et al., 2006) have reduced the traffic in to these huge markets. However, ten years after the EU ban, South America, Southeast Asia, and the Middle East continue to play major and increasing roles in the legal and illegal trade of wild parrots (Weston and Memon, 2009; Pires, 2012; Alves et al., 2013; Bush et al., 2014; Low, 2014; Daut et al., 2015). Some progress has also been made as some countries have enacted new legislation to protect wild parrots including (e.g., Mexico, Nicaragua). However, thriving domestic parrot trade has been reported for Bolivia (Herrera and Hennessey, 2007), Brazil (Alves et al., 2013), Mexico (Cantú Guzmán et al., 2007), and Peru (González, 2003; Weston and Memon, 2009; Gastañaga et al., 2011; Daut et al., 2015), with additional reports of continued poaching in several other countries (Wright et al., 2001; Zager et al., 2009; Masello et al., 2011; Monterrubio-Rico et al., 2014; Rivera et al., 2014). Our data were not designed to detect historical changes in threats, but few authors reported domestic pet trade only as a historical threat. As a result, we cannot determine if the threat from domestic trade has been increasing or if it has just been traditionally underestimated. Regardless, the literature and our data suggest that the threat from the domestic pet trade is probably much more widespread and serious than previously thought. As a result, governments and conservationists should redouble their efforts to reduce the capture and trade of wild birds both nationally and internationally.

As with previous studies (Snyder et al., 2000; Wiley et al., 2004; Martin et al., 2014; Olah et al., 2016), our analyses revealed that threats like increasing Rural Population Pressure (i.e. increase in rural population), Agro-industry Grazing, and Large-scale Logging were closely associated with decreasing parrot populations. However, unlike these previous studies our findings suggest an important role for Small-holder Farming and Small-holder Grazing in parrot population declines. The close relationship between these two threats and decreasing population trends might be explained by the fact that parrots can be more common in agricultural frontiers where crop and cattle are produced at small scales rather than in sites where large-scale agriculture dominates the landscape (Tella et al., 2013; Monterrubio-Rico et al., 2014; Sánchez et al., 2016). In agricultural frontiers, parrots may find isolated cavity-bearing trees for nesting, as well as isolated native trees with heavy fruit set, and abundant agricultural crops, particularly spilled grain, as food resources (Botero-Delgadillo et al., 2013; Sánchez et al., 2016). When nesting in pasture trees parrots may be more obvious and accessible to potential poachers; when feeding in fruiting trees in open areas they may be more exposed to hunters and trappers (Botero-Delgadillo and Páez, 2011); when feeding on crops they may have less nutritional diets and face retaliatory killings by farmers (Bodrati et al., 2006). As a result, agricultural frontiers may become ecological traps for many parrot species (Carrete et al., 2009; Tella et al., 2013). However, our analyses found a weak association between the persecution of parrots as crop pest and decreasing population trends. This suggests either that survey respondents did not perceive direct persecution in proportion to its occurrence or that the mechanisms driving this trend involve poaching, nutrient deficiencies in diets, or other factors not studied here (e.g. quality of available nest sites).

Regarding conservation, analysis of the IUCN Red List for parrots identified site protection and management as the most important conservation actions needed in the Neotropics, followed by awareness and communication, and ex-situ conservation (Olah et al., 2016). Our questionnaires revealed that management actions were being implemented on $<$ 20% of the 192 Neotropical parrot populations studied (Chassot and Monge-Arias, 2012). However, our sampling scheme suggests that this is in fact an over-estimate, as most of our surveys were filled out by parrot researchers and conservationists who in many cases were the ones conducting the management actions. As a result, the overall percent of parrot populations being studied or managed is likely much lower than reported here. The most common management actions reported in our questionnaires were the use of nest boxes, nest and/or roost surveillance and habitat restoration. Half of contributors consulted in the Neotropics agreed that monitoring is a high priority activity, and that monitoring should include population size estimates and nesting activity. Importantly, more than half of the studied populations were directly or indirectly monitored at present, a fact that allowed us to perform the detailed statistical analyses on the population trends reported here. Research activities were reported in about half of populations, and the most common research topics were related to breeding biology, feeding ecology, and habitat use.

### 4.1. Conclusions and perspectives

Our population level study suggests that at least 38% of parrot populations in the Neotropics may be declining. However, we suspect that this is an underestimate as 84% of the species with unknown population trends were reported as affected by at least one of the major threats and for this reason may also be declining. In addition, our findings show that 72% of populations face at least one major threat. Unfortunately, a similar worrying conservation scenario was found in a previous study in Africa (Martin et al., 2014). Both studies suggest that the global conservation situation for parrots may be even worse than previously evaluated and that the need for conservation actions is urgent. Our study also suggests that priority should be given to conservation actions aimed at reducing the capture of wild parrots for the pet trade, mainly domestic use but also international trade, as well as the conservation of parrot populations located at agricultural frontiers. Finally, it is also important to point out that our extensive survey was unable to find any data on population trends or threats for over a third of studied Neotropical parrot populations. We were also unable to find population trend data for any parrot populations from a number of Neotropical countries, including Panama, Guyana, Surinam, French Guiana, Uruguay, and many islands of the Lesser and Greater Antilles. These species and regions should be targeted especially for future research and monitoring of free-living parrot populations in the Neotropics.

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In addition to Appendix A, we provide the questionnaires as received from the contributors in https://data.mendeley.com/submissions/evise/edit/kxswp5wd33?submission_id=S0006-3207(17)30629-8&token=568e86be-c871-4356-80d5-90d995205f8e. In this way, we would like to facilitate full data access that could serve as a baseline for future conservation efforts. The questionnaires may offer additional useful information for some species, such as specific details on agricultural practices, logging, etc. Contact details of the contributors were masked in the questionnaires in order to respect privacy. However, the identity of each contributor for each studied population is provided in Table A1, Appendix A.Conflict of interest declaration

The authors declare that they have no competing interests.Consent for publication

Not applicable.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.biocon.2017.08.016.

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