

Spatial, temporal and age sources of variation in parrot poaching in Bolivia

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Summary

Parrot poaching and the subsequent illegal trade in the Neotropics are exacerbating the decline in parrot populations. Little is known, however, on where, when and how parrots are poached. The goals of this study were to identify the spatio-temporal patterns of parrot poaching in order to identify ways in which poaching could be reduced, using parrot data (9,013 individuals from 27 species) collected daily in a major illicit wildlife market in Santa Cruz de la Sierra, Bolivia, in 2005. Parrot data identified the individuals by species, age, date of arrival at market, and the poaching location. Parrot poaching strongly varied seasonally, with differences among municipalities, species, and age classes. While almost 90% of parrots were poached within a 234 km radius of the market, 84% originated from seven municipalities in which two of them accounted for 56% alone. With regard to species, six of the 27 market species accounted for nearly 90% of total individuals. A disproportionate share of parrots (47%) arrived between July and September. Poaching of adults and juveniles peaked however at different times of the year, offering valuable information for species where very little is known about their breeding phenology. Contrary to the idea that most parrot trade comes from nest poaching, most poached parrots (c.70%) were adults, which outnumbered juveniles in 21 out of the 26 native species. Therefore, the detrimental effects of parrot poaching are higher than simple trade numbers would suggest when considering that harvesting of adults has a stronger impact on the population viability and risk of extinction of long-lived species. Based on the findings, we recommend the allocation of police and conservation resources to patrol particular areas at particular times of the year in order to reduce the likelihood of poaching by species, age classes, and conservation status.

Resumen

La captura y comercio ilegal de loros está acelerando el declive de sus poblaciones en la región neotropical. Sin embargo, se conoce poco sobre dónde, cuándo y cómo son capturados ilegalmente. Los objetivos de este estudio fueron identificar los patrones espacio-temporales en la captura ilegal de loros para identificar las formas de atenuarlo, usando datos de 9,013 individuos pertenecientes a 27 especies registrados diariamente en 2005 en el principal mercado de fauna salvaje situado en Santa Cruz de la Sierra (Bolivia). Los individuos fueron identificados según su especie, edad, fecha de llegada al mercado y según dónde fueron capturados. La captura ilegal varió fuertemente entre estaciones, difiriendo también entre municipios, especies y clases de edad. Mientras que casi el 90% de los loros fueron capturados dentro de un radio de 234 km en torno al mercado, el 84% provenían de sólo siete municipios, dos de ellos acumulando el 56% de todas las capturas. Por otro lado, casi el 90% de los individuos correspondieron a 6 de las 27 especies capturadas. Un número desproporcionado de loros (47%) llegó al mercado entre julio y septiembre. Los picos de captura de adultos y juveniles ocurrieron sin embargo en diferentes momentos del año, ofreciendo una información valiosa sobre la poco conocida fenología reproductora de las especies.

Contrariamente a la idea de que la mayor parte del comercio de loros procede del robo de nidos, la mayor parte de los individuos capturados (70%) fueron adultos, siendo su número mayor que el de juveniles en 21 de las 26 especies de loros nativos. Los efectos negativos de la captura de loros son entonces más graves de lo que las simples cifras pueden sugerir, considerando que la captura de adultos tiene un mayor impacto que la de juveniles en la viabilidad de las poblaciones y riesgo de extinción en especies de larga vida. Los resultados de este estudio permiten concentrar los recursos disponibles en controlar áreas concretas en momentos concretos del año para reducir más eficazmente el riesgo de captura ilegal de loros según sus especies, clases de edad y estado de conservación.

Introduction

Wild flora and fauna are disappearing at record rates from the planet. Their depletion has major implications for agrarian societies that rely on them for immediate survival and industrialised nations (Schneider 2012). One Order of fauna which has been over-trapped and poached extensively since at least the 1970s is the Psittaciformes, or parrots (Juniper and Parr 1998). Parrots are in demand as household pets worldwide (Beissinger 2001, Tella and Hiraldo 2014) because of their playful behaviour, colourful plumage, and ability to imitate human speech, which add to their overall attractiveness (Juniper and Parr 1998, Tella and Hiraldo 2014). This demand, along with habitat loss, has contributed to parrots becoming one of the most endangered groups of birds in the world, with nearly one-third of the species being threatened with extinction (Clarke and de By 2013, Donald *et al.* 2010, IUCN 2014). Despite the high demand, parrots are relatively inexpensive commodities to buy with many individuals being locally sold for approximately US\$5–10 each, although a few species can be sold for much higher prices (Herrera and Hennessey 2007, Pires and Clarke 2011).

Contrary to the conventional wisdom that organised crime groups run most illegal wildlife trafficking (UNODC 2013), recent research shows that illegal parrot trade in the Neotropics does not involve organised crime nor is it very sophisticated (Pires and Clarke 2011, 2012). Rather, parrot trade in the Neotropics is largely a domestic problem with a simple supply chain. Often, poor rural people, or “campesinos”, will poach locally found parrots and sell them to an itinerant middleman who visits villages periodically. From here, the middlemen travel to a local city where they will sell their wildlife products to an illicit market vendor (Pires 2012, Pires and Clarke 2011, 2012). Poaching and related illegal activities are seen as a way to earn supplementary income, especially for farmers who often see these birds as crop pests (Pires 2014). Four recent studies in Mexico (Cantú *et al.* 2007), Bolivia (Herrera and Hennessey 2007), Peru (Gastanaga *et al.* 2011) and Brazil (Regueira and Bernard 2012) have shown that tens of thousands of parrots are poached and sold routinely in illicit markets in order to fulfil domestic, rather than international demand. As such, a diminishingly small proportion of individuals and species actually traverse national borders (Cantú *et al.* 2007, Herrera and Hennessey 2007, Gastanaga *et al.* 2011), thus challenging the notion that the parrot trade is mostly a transnational crime.

Bolivia is a signatory party (1979) to CITES, which mandates that countries develop national laws to prohibit the illegal taking and harvesting of protected species. Bolivian law number 12301, the 1975 Law on Wildlife, National Parks, Hunting and Fishing, aims to protect the country's natural wild resources. Included in this law is “the protection, management, utilization, transportation, and selling of wildlife and their products; the protection of endangered species; habitat conservation of fauna and flora; and the declaration of national parks, biological reserves, refuges, and wildlife sanctuaries, tending to the preservation, promotion, and rational use of these resources” (Decree Law No. 12301 1975; Environmental Law Alliance [2003], U.S. Department of Interior [2011]). In addition to Law 12301, Bolivia passed another environmental law (No. 1333) in 1999, which intends to protect and conserve the environment and its natural resources, as well as to promote sustainable development. This law criminalizes

the “unauthorized trade, capture, and transportation of wild animals” (U.S. Department of Interior 2011). Violators can be sentenced up to two years in prison and be fined up to 100% of the value of the animal (Herrera and Hennessey 2007, U.S. Department of Interior 2011).

Despite Bolivia being a signatory party to CITES and criminalizing the wildlife trade, including the trapping and trafficking of all parrot species, parrot poaching continues to threaten their populations (Rivera *et al.* 2010, Tella *et al.* 2013). Herrera and Hennessey (2007) were among the first to monitor the illicit trade of parrots in Bolivia by examining the Los Pozos market in Santa Cruz from August 2004 to July 2005. They had a seller within the market count the number of parrots brought to the market on a daily basis for a one year period and found 7,279 individuals from 31 species offered for sale (Herrera and Hennessey 2007). Their study showed that wild parrots were by far the most frequently brought to market (94%), and that international trade was negligible since most traded species – and individuals – were native to Bolivia. Pires and Clarke (2011) used these data to test whether the distribution of Bolivian parrot species contributed to the offer of parrots for sale at the Los Pozos market. They found the majority of species in the market had distributions within 80 km of Santa Cruz, and nearly all market species were within 161 km of the city. Yet most Bolivian species not poached for this Santa Cruz market were distributed outside a 161 km radius. Thus, Pires and Clarke (2011) concluded that the Los Pozos market’s catchment area, or where most parrots are theoretically being poached, is roughly within a 161 km radius around the city.

Both the Herrera and Hennessey (2007) and the Pires and Clarke (2011) studies examined the spatial relationship between an illicit market and the wildlife products that are sold within it, considering broad international and national scales respectively. However, no market study has ever examined the exact poaching location, the months when poaching occurs, and the age classes of poached parrots. Wildlife market research has ignored the age composition of traded parrots and when juvenile parrots arrive at the market. Examining market data on space, time, and age classes provides information and insights on poaching techniques. A common poaching technique in the Neotropics is nest poaching of juvenile birds (Collar and Juniper 1992, Monterrubio *et al.* 2002, Wright *et al.* 2001). Adult parrots, however, are more likely to be caught by other techniques like mist netting (Rivera *et al.* 2010), or the use of *hondas*, an inexpensive apparatus similar to a slingshot (Guerrero and Arambiza 2004). The breeding phenology of particular species can be better understood by tracking the arrival of juveniles at markets, an area of research where little is known for Neotropical parrot species (Juniper and Parr 1998).

The purpose of this study is to provide a better understanding of the illegal parrot trade in Bolivia by examining poaching by space, time, species, and age classes. There are three research goals that drive this study: 1) to determine if parrot poaching is concentrated in space or if it is randomly distributed throughout Bolivia; 2) to demonstrate the temporal concentration, if any, of parrot poaching, and to determine if it varies among species and localities; and 3) to study the age composition and its seasonal variation of poached parrots sold in the Los Pozos market. This study of the illegal parrot trade from a spatio-temporal and parrot age perspective may help to determine where, how and when policy and conservation actions would more effectively reduce parrot poaching.

Data and methods

Los Pozos market in Santa Cruz was selected for study for two main reasons. First, it is the largest open-air market in the Santa Cruz department with a robust supply of wildlife for sale. Second, the Santa Cruz department is the home to some of the most abundant and diverse wildlife in all of Bolivia due to its close proximity to the Amazon basin and rainforest to the north, the Andes to the west and the Chaco dry forest to the south (Ibisch and Mérida 2008). The market itself is comprised of seven pet stalls and some street vendors (Herrera and Hennessey 2007). We paid a Bolivian market seller who had worked in the wildlife trade at the Los Pozos market for over a

decade to document the arrival of all parrots and their poaching origins. Given his long-term experience, this person had a good knowledge of parrot species and their age identification, as well as the people involved in the clandestine trade (Herrera and Hennessey 2007). Juvenile parrots are easily identifiable based on their fresh plumage, compared to the worn and often moulting plumage of adults; in some species, juveniles also differ in colouration from adults. Data for this study were collected daily for one full calendar year by the market seller in the Los Pozos market from January 1, 2005 through to December 31, 2005. A digital camera was supplied to the market seller in order to verify the identification of unusual species (Herrera and Hennessey 2007). Here, nomenclature and conservation status of each species follows the most recent IUCN Red List (IUCN 2014).

The market seller completed a standardised form noting the quantities of parrots by species, age (adult or juvenile), and origin on the day they arrived to the market (Herrera and Hennessey 2007). To obtain poaching origin information, the market seller would simply ask the handlers where parrots originated. The market seller was part of the clandestine trade so handlers would not be suspicious when asked about the origin of the parrots. The market seller being an insider increases the likelihood that handlers disclosed correct information. Many handlers were middlemen who collected parrots from trappers at their villages. We know that trappers gather parrots in close proximity of their homes (authors' pers. obs.) increasing the likelihood that the data are accurate.

Parrot poaching locations were mapped using GIS shapefiles of Bolivia's administrative units obtained from ArcGIS software 10.2. Parrot poaching locations were rank ordered from largest to smallest administrative unit: country, department, province, and municipality. Aggregated data were inputted into each administrative level of Bolivia and then turned into a choropleth map to illustrate spatial variation in poaching. As a proxy for the distances from poaching localities to the Los Pozos market, we calculated the straight-line distance from the geographical centre of each municipality from which parrot poaching was reported to Santa Cruz (in km).

Temporal data was aggregated by month and analysed by species and by age (juvenile or adult). Univariate relationships between parrot poaching, distances to poaching localities, number of poached species by locality, and age classes were assessed through Spearman correlations given the non-parametric distribution of poaching data. After examining univariate relationships, we built two generalized linear models (GLM) to assess 1) monthly variations in the numbers of parrots poached while controlling for variations among municipalities; and 2) monthly variations related to species and age classes. As the response variable in both models was number of parrots poached, we first used a Poisson distribution and log link function since they are adequate for analysing count data. The resulting conditional variances were, however, much larger than the conditional means, causing data overdispersion and inflation of parameter estimates, and thus data were better fitted to a negative binomial distribution (a particular case of the Poisson distribution); see Tella and Hiraldo (2014) for a similar approach. The models presented here, using the negative binomial distribution and log link function, did not show data overdispersion and the distribution of residuals were adequate in both models. All analyses were performed using SPSS v. 15.0.

Results

A total of 9,013 parrots from 27 species were brought to the Los Pozos market in the year studied. Table 1 shows the number of parrots varied from 1 to 2,437 (median = 54, quartiles: 9-175) per species.

Spatial patterns

Apart from two Bronze-winged Parrots *Pionus chalcopterus* (Table 1) that were poached in Peru, 99.98% of parrots traded in the Los Pozos market were native to Bolivia. The municipalities

Table 1. Number of individuals, percentage of adults, % of the total, and cumulative percentage of the total of parrots recorded at Los Pozos market between January and December 2005. Species are ranked in descending order. English and scientific names, as well as conservation status (CS: LC: Least Concern, NT: Near Threatened, VU: Vulnerable, EN: Endangered) follow the 2014 IUCN Red List.

Common Name	Scientific Name	CS	No. of Parrots	% Adults	% of Total	Cumulative % of Total
Yellow-chevroned Parakeet	<i>Brotogeris chiriri</i>	LC	2437	32.7	27.0	27.0
Monk Parakeet	<i>Myiopsitta monachus</i>	LC	1772	73.2	19.7	46.7
Blue-winged Parrotlet	<i>Forpus xanthopterygius</i>	LC	1435	91.8	15.9	62.6
Turquoise-fronted Amazon	<i>Amazona aestiva</i>	LC	1296	80.7	14.4	77.0
Blue-crowned Parakeet	<i>Psittacara (Aratinga) acuticaudatus</i>	LC	754	100.0	8.4	85.4
Mitred Parakeet	<i>Psittacara (Aratinga) mitratus</i>	LC	288	100.0	3.2	88.6
Green-cheeked Parakeet	<i>Pyrrhura molinae</i>	LC	175	81.7	1.9	90.5
Blue-headed Parrot	<i>Pionus menstruus</i>	LC	160	98.1	1.8	92.3
Peach-fronted Parakeet	<i>Eupsittula (Aratinga) aurea</i>	LC	109	71.6	1.2	93.5
White-eyed Parakeet	<i>Psittacara (Aratinga) leucophthalmus</i>	LC	93	11.8	1.0	94.5
Blue-and-yellow Macaw	<i>Ara ararauna</i>	LC	89	47.2	1.0	95.5
Yellow-collared Macaw	<i>Primolius auricollis</i>	LC	74	89.2	0.8	96.3
Dusky-headed Parakeet	<i>Aratinga weddellii</i>	LC	59	93.2	0.7	97.0
Chestnut-fronted Macaw	<i>Ara severus</i>	LC	54	51.9	0.6	97.6
Scaly-headed Parrot	<i>Pionus maximiliani</i>	LC	42	57.1	0.5	98.1
Tucuman Amazon	<i>Amazona tucumana</i>	VU	42	100.0	0.5	98.6
Red-and-green Macaw	<i>Ara chloropterus</i>	LC	36	52.8	0.4	99.0
Red-fronted Macaw	<i>Ara rubrogenys</i>	EN	32	65.6	0.4	99.4
Southern mealy Amazon	<i>Amazona farinosa</i>	NT	17	70.6	0.2	99.6
Cobalt-winged Parakeet	<i>Brotogeris cyanoptera</i>	LC	17	0.0	0.2	99.8
Northern red-shouldered Macaw	<i>Diopsittaca nobilis</i>	LC	9	0.0	0.1	99.8
Orange-winged Amazon	<i>Amazona amazonica</i>	LC	8	75.0	0.1	99.9
Black-legged Parrot	<i>Pionites (leucogaster) xanthomerius</i>	LC	5	100.0	0.1	100.0
Scarlet Macaw	<i>Ara macao</i>	LC	4	100.0	0.0	100.0
Yellow-crowned Amazon	<i>Amazona ochrocephala</i>	LC	3	100.0	0.0	100.0
Bronze-winged Parrot	<i>Pionus chalcopterus</i>	LC	2	100.0	0.0	100.0
Yellow-faced Amazon	<i>Alipiopsitta (Amazona) xanthops</i>	NT	1	100.0	0.0	100.0
Total			9013		100.0	

where Bolivian parrots were poached could not be obtained for 228 individuals (2.5% of the total poached), although we know that 76 of them came from unknown municipalities within the Beni department. Within Bolivia, the majority of parrots (at least 94%, $n = 9,011$) were poached within the Santa Cruz department, which encompasses the Los Pozos market. This is not surprising given (1) the expected catchment area (within a 161 km radius) is within the Santa Cruz department, and (2) three other Bolivian cities west of Santa Cruz have their own established parrot markets (Figure 1).

Figure 1 also reveals the locations of parrot poaching at the municipality unit of analysis. These birds originated from 21 municipalities spanning three departments; 19 are situated in the department of Santa Cruz, one in the department of Tarija (Villamontes) and one in the department of Cochabamba (Mizque). Seven municipalities within the Santa Cruz department (11% of the total) were responsible for most of the parrot poaching incidents (84%). Moreover, 56% of all the parrots traded at the market came from just two municipalities - Pailón and Charagua (Figure 1). The number of species poached varied among municipalities (range 1–21) and was correlated with the total number of parrots poached per municipality (Spearman correlation, $r = 0.72$, $P < 0.001$, $n = 21$).

Poaching counts at the municipal level were not significantly related to distance from the market ($r = -0.27$, $P = 0.30$, $n = 21$, Figure 2A). Similarly, there were no significant relationships between municipality poaching counts (all $P > 0.20$) and age classes (adults and juveniles), even when excluding the two municipalities (Pailón and Charagua), which disproportionately contributed to overall trade (Figure 2A). Although 66% of parrots originated from municipalities that were within the 161 km radius surrounding the Los Pozos market, the vast majority (88%) originated from a larger distance of 234 km (Figure 2B).

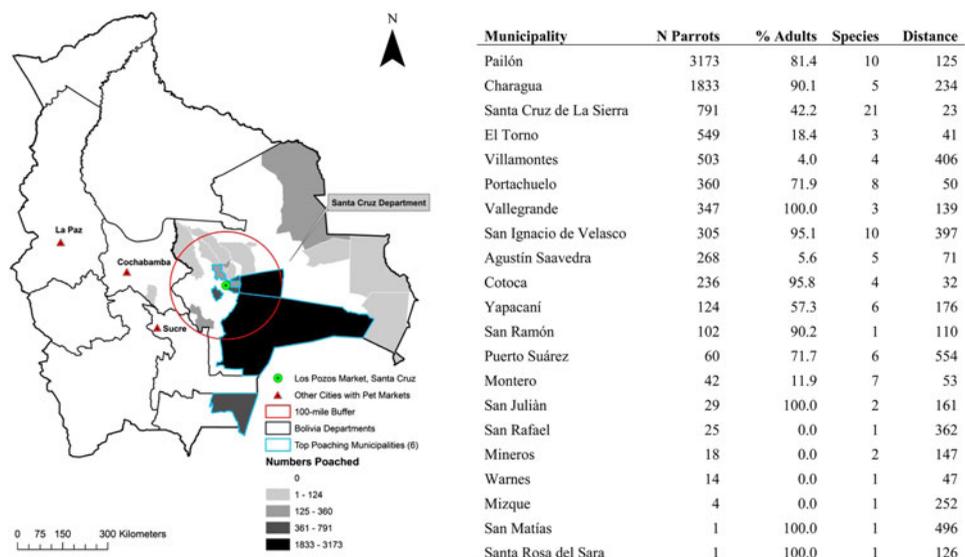


Figure 1. Number of parrots, percentage of adults, and number of parrot species poached related to the municipality where they were captured, and distance (in km) from the municipality to the Los Pozos market (Santa Cruz de la Sierra, Bolivia). Calculating the proportion of parrots poached within particular municipalities uses the denominator of 9,013 parrots, which represents all parrots found in the Los Pozos market. The total number of parrots originating from identifiable municipalities equals 8,785 because 2.5% of the sample has no origin information at the municipality level.

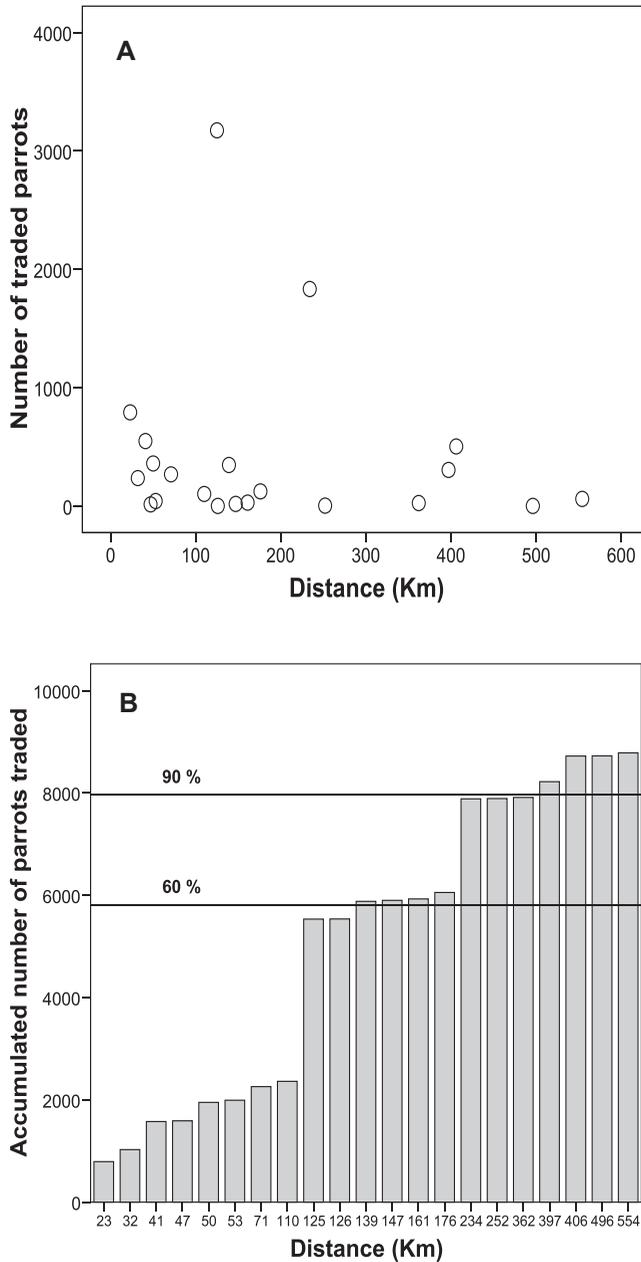


Figure 2. Number of parrots poached in each municipality (A) and accumulated number of parrots poached (B) in relation to the distances of municipalities to Los Pozos market. The two outlier municipalities in relation to the number of poached parrots in A are Pailón and Charagua. Horizontal lines in B represent 60 and 90 % of the accumulated number of parrots poached with distance to the market.

Temporal patterns

The number of parrots poached varied spatially and seasonally. There was a strong seasonal effect (GLM, Wald $\chi^2_{11} = 150.62$, $P < 0.001$) while controlling for differences among municipalities (Wald $\chi^2_{20} = 18.87$, $P = 0.063$). Poaching occurred disproportionately between July and September when 47% of all parrots were poached for the Los Pozos market (Figure 3). The uneven distribution of data among months and municipalities did not lend itself to a GLM analysis where this interaction effect was included; however, Figure 3 clearly shows the different contributions of municipalities to overall parrot trade in the year studied. Pailón and Charagua contributed mostly to the poaching peaks in July and August, while poaching increased in Santa Cruz de la Sierra in September and October, in El Torno in September, and in Villamontes in December; the remaining municipalities contributed fewer poached parrots and more consistently across the year (Figure 3).

Specific patterns

While 27 species of parrots were recorded in the Los Pozos Market in 2005, just six species (*Brotogeris chiriri*, *Myiopsitta monachus*, *Forpus xanthopterygius*, *Amazona aestiva*, *Psittacara*

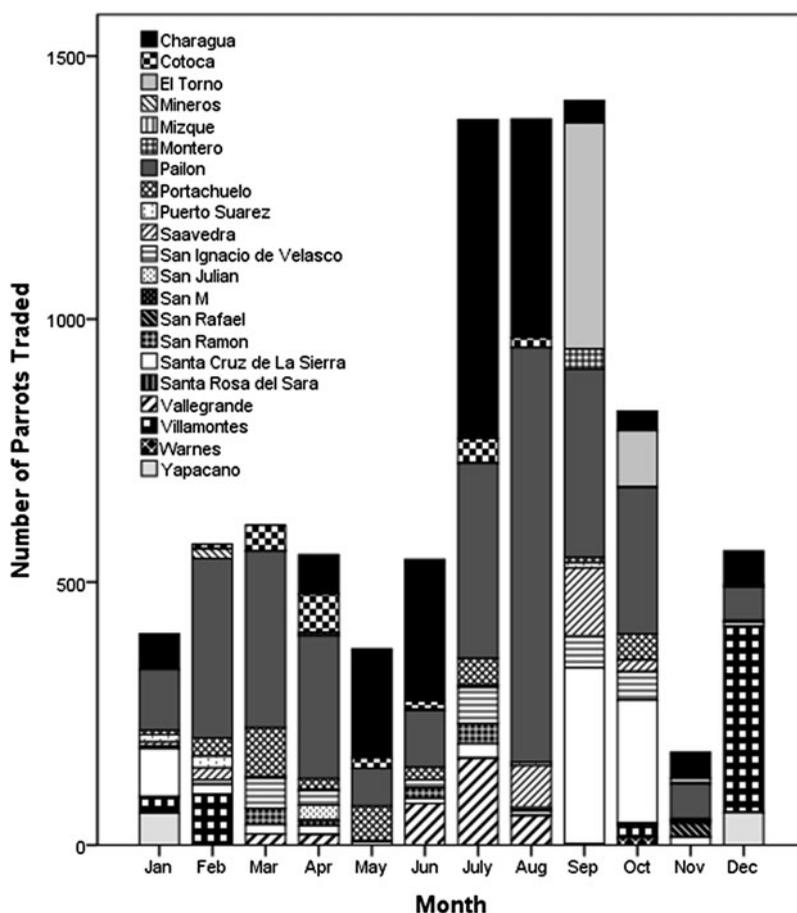


Figure 3. Monthly variation in number of poached parrots according to the municipality where they were poached.

acuticaudatus, and *Psittacara mitratus*) contributed almost 90% of all poached individuals (Table 1). Four of the poached species are globally threatened (*Amazona tucumana* and *Ara rubrogenys*) or 'Near Threatened' (*Amazona farinosa* and *Aliopsitta xanthops*), although none of them were among the most heavily traded species (Table 1).

Age patterns

Adults accounted for 69% of all parrots traded in the Los Pozos market. There was no relationship between the number of adults and the number of juveniles poached across municipalities ($r = 0.34$, $P = 0.12$, $n = 21$), with some municipalities providing more adults than juveniles to the market and vice versa (Figure 1). Among the seven municipalities that contributed 84% of all poached parrots (Figure 1), four provided more adults (range % adults: 72-100) and three provided more juveniles (range % juveniles: 58-96).

The number of adults was positively correlated with the number of juveniles poached across species ($r = 0.43$, $P = 0.023$, $n = 27$). With the exception of five species (range % juveniles: 53-100) (*Brotogeris chiriri*, *Psittacara leucophthalmus*, *Ara ararauna*, *Brotogeris cyanopectera*, and *Diopsittaca nobilis*), adults outnumbered juveniles in the remaining 22 species (range % adults: 52-100) (Table 1).

Seasonal changes in species and age-classes poached

A GLM showed that the number of poached parrots varied among species (Wald $\chi^2_{26} = 457.47$, $P < 0.001$), age classes (Wald $\chi^2_1 = 32.79$, $P < 0.001$) and by months (Wald $\chi^2_{11} = 36.08$, $P < 0.001$) (Figure 4). The highest temporal concentration of poached species over the year was: from January to April, *Forpus xanthopterygius*; May to June, *Amazona aestiva*; July to August, *Psittacara acuticaudatus* and *Myiopsitta monachus*. By September, *Brotogeris chiriri* had the highest temporal concentration of any species throughout the year. In November, the market has the least number of parrots with no real concentrations of any species. *Myiopsitta monachus* is the most targeted species in December, but only at a fraction of its August peak.

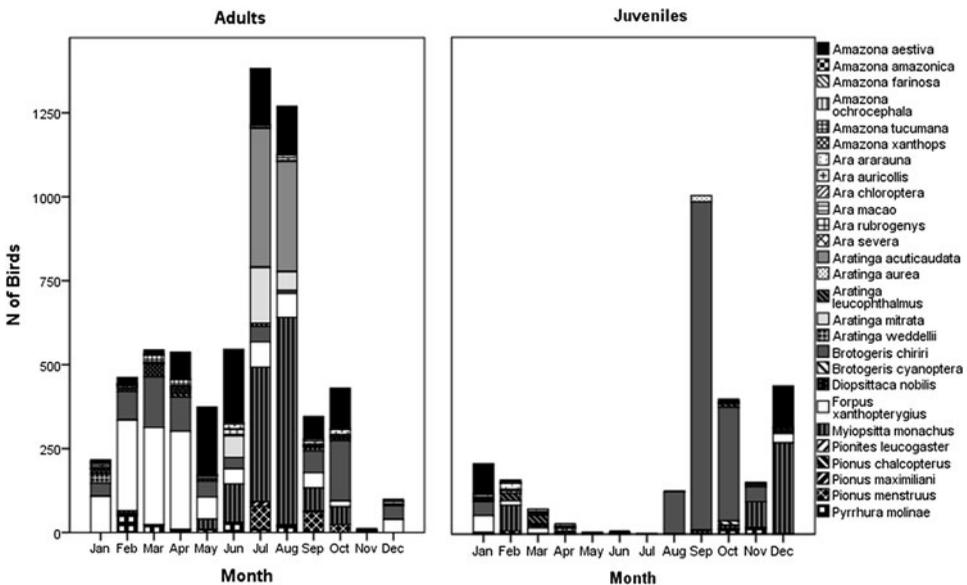


Figure 4. Monthly variation in number of poached parrots according to species and age classes.

Data structure did not allow a GLM analysis when including a three-way interaction; however, Figure 4 clearly shows a temporal mismatch in the capture of adult and juvenile parrots, which varied among species. Most adults were caught between February and October, with a peak in July and August. These two months accounted for 43% of all adults caught throughout the year, primarily concentrated in two species (*Psittacara acuticaudatus* and *Myiopsitta monachus*). The capture of juveniles peaked in September, when 38% of all the juveniles were caught. This peak was mostly due to the capture of a single species (*Brotoogeris chiriri*, 97%), while juveniles of the remaining species were caught more often between November and February with only one species (*Myiopsitta monachus*) peaking in December (Figure 4).

Discussion

Detailed illicit market data on wildlife product origins illustrates spatio-temporal patterns of parrot poaching as well as providing insight on the breeding phenology of target species and poaching methods. These results provide important implications for understanding and addressing poaching as a conservation problem.

Spatial patterns

Our results suggest that parrots are obtained from a larger catchment area than previously expected (Pires and Clarke 2011). While 66% of parrots originated from municipalities located within the 161 km radius surrounding the Los Pozos market, most (88%) originated from larger distances (within a radius of 234 km). However, parrot poaching was not randomly conducted within this large area, since 84% of poached individuals came from just seven municipalities.

Species-specific patterns and conservation status of poached species

As reported in earlier parrot-poaching studies (Pires and Clarke 2011, 2012, Pires 2014), the most commonly traded species in the Los Pozos market were not actually those threatened on a global scale. Six species, out of 27 in the market, accounted for nearly 90% of poached individuals and none are considered globally threatened. Four globally threatened or nearly threatened species, however, were poached for the Los Pozos market, which includes the Red-fronted Macaw *Ara rubrogenys* that has a global population of <1,000 individuals (Tella et al. 2013). Other globally threatened species such as the Blue-throated Macaw *Ara glaucogularis*, Lear's macaw *Anodorhynchus leari* and Hyacinth Macaw *A. hyacinthinus* were also recorded for sale in previous surveys conducted at the Los Pozos market (Herrera and Hennessey 2007, 2008). Efforts to protect species should be focused on those at greatest risk of extinction even if poaching numbers are relatively low. In addition to threatened species, conservation efforts should focus on protecting species that are highly attractive (i.e. a combination of colouration, size and mimicry ability) to consumers. Prior research has found the most attractive species, such as amazons and macaws, have an increased risk of extinction due to disproportionate poaching (Tella and Hiraldo 2014). One such attractive species commonly poached for the Los Pozos market is the Turquoise-fronted Amazon *Amazona aestiva*, which has been noted to be unsustainably overharvested in Bolivia (Herrera and Hennessey, 2008).

Temporal and age patterns

Parrot poaching varied seasonally, and this variation differed among species and age classes. These seasonal patterns can be used to focus conservation actions in particular months to protect specific species and ages, and target corresponding trapping techniques. Juveniles are poached from nests located in cliffs, trees and termitariums with ropes or by cutting nesting trees for easier access (Guerrero and Arambiza 2004). In Bolivia, mist nets has been used to catch Tucuman Amazons

Amazona tucumana when concentrated in large communal roosts (Rivera *et al.* 2010), but most adults are caught individually by using *hondas* (locally termed “flechas”, A. Rojas, F. Hiraldo, and J. L. Tella, unpubl. data). While this method is considered time-consuming, *hondas* have been used to capture 2,000–3,000 *A. aestiva* annually in the Isoso region (Guerrero and Arambiza 2004), which emanate from the municipalities of Charagua and Pailon (A. Rojas, F. Hiraldo and J. L. Tella unpubl. data).

In addition to conservation implications, the concentrations in time of those juvenile parrots trafficked to the Los Pozos market contribute to the poorly-known breeding phenology of most parrot species in Bolivia and in the wider Neotropical region (Juniper and Parr 1998). The fact that our temporal patterns of juvenile parrot poaching match data from the breeding phenology of some species in Bolivia (Tella *et al.* 2013, Juniper and Parr 1998, A. Rojas, F. Hiraldo and J. L. Tella unpubl. data) suggests that the arrival of juveniles to the Los Pozos market is a reliable reflection of their breeding phenology.

Perhaps the most striking result, and one with deeper conservation implications, is the high percentage of adults poached. Most research on the illegal parrot trade has focused on nest poaching and its potential effects on parrot populations (Wright *et al.* 2001, González 2003, Pain *et al.* 2006, Briceño-Linares *et al.* 2011). This study reveals, however, that most parrots trafficked in the Los Pozos market were adults (c.70% of the total), and adults outnumbered juveniles in 22 out of 27 species. Both theoretical and empirical studies show that the non-natural mortality (in this case harvesting) of adults, increases the risk of extinction in those species that are long-lived (with delayed maturation periods) than in short-lived species (Sæther and Bakke 2000, Beissinger *et al.* 2008, Jeppsson and Forslund 2012, Sanz-Aguilar *et al.* 2015). Although parrots in general are considered long-lived species, larger species, such as macaws and amazons, show higher lifespans and take longer to mature (Young *et al.* 2012). The population health of larger species is more affected by poaching of adults than by juveniles. Therefore, the detrimental effects of parrot poaching are more complex than simple poaching numbers would suggest, especially when considering the high proportion of adults poached in species such as *A. rubrogenys* and *A. aestiva*.

Conservation criminology: implications for policy and law enforcement

Wildlife, like other goods, is acquired and then sold through a variety of ways. In Bolivia, as well as in many other Latin American countries, the trade in wildlife products is widespread, especially via open-air street markets. Even though a police headquarters is located within one street block of the Los Pozos market, local police do not appear to enforce existing laws regarding illegal wildlife trading. The sale of endangered species and other illicitly obtained species takes place publicly, by local residents. The fear of being arrested and subsequently prosecuted appears to be a relatively small worry for these illegal traders and poachers. Further, the existence of so many un-policed, public-sale outlets allows for the proliferation of illegal trading of wild flora and fauna to take place and thrive.

Police and other governmental officials should realise that the existence and acceptance of illicit markets enables higher levels of poaching to occur (Pires and Guerette 2014), and may create demand where there was none before (Langworthy 1989). Poachers, who are generally locals and not organised criminals, are savvy about how to dispose of parrots quickly for fast money, to supplement their legitimate and legal income (Pires and Clarke 2011). If police were to enforce existing laws, the poachers may have a more difficult time disposing of the contraband and consumers may be thwarted from purchasing poached parrots. Active enforcement would make the activity more risky and may discourage would-be offenders and consumers to partake in the crime (Schneider 2005, 2008).

If poaching were evenly distributed across Bolivia, law enforcement and conservation resources would also have to be distributed evenly across the country. Since only seven municipalities are responsible for most poached parrots in the Los Pozos market, law enforcement and conservationists can efficiently address the problem. Further, temporal patterns of parrot species and age classes

appearing in the market allude to opportunities to concentrate actions at particular locations during certain periods of the year depending on the species targeted for conservation. To the authors' knowledge, this is the first parrot conservation study that demonstrates that the size and scale of the trade could be reduced by concentrating efforts and resources in specific areas and times most vulnerable to poaching.

Based on this paper's findings, we recommend shutting down illicit sales-points in cities and implementing hot spot patrolling during peak times in order to have the greatest effect on parrot-poaching reductions. These policies would specifically increase the risk and effort, along with reducing the rewards of poaching for all actors in the trade (Clarke and Eck 2005). Poachers would have more difficulty in obtaining parrots without being caught, and with the added difficulty of disposing of parrots quickly and conveniently. Middlemen in the trade might not find it economically rewarding if they have to travel to more distant cities to dispose of parrots, thus increasing their risk of police detection on a major road. Finally, the market seller would be left with the alternative to sell parrots in underground urban locations or leave the trade. A market seller going underground would be a positive form of displacement since there are fewer possible customers to serve, which could potentially drive down demand and therefore reduce potential profits. Research on disrupting open-air drug markets in the U.S. finds that displacement to private homes can reduce overall drug usage because customers find it more difficult to access drugs (Haracopos and Hough 2005).

While this research has provided policy makers an effective analytical toolkit that can be used to combat illegal trafficking in parrots, there are limitations that can be addressed in future studies. Firstly, mapping poaching concentrations in Bolivia was constrained by the absence of more accurate data on poaching locations. Some municipalities are fairly large and poaching may only occur in a certain area within a municipality. Hot-spot patrolling would be aided by micro-targeting particular areas (Braga 2005, Braga and Weisburd 2010). Secondly, measuring distances from poaching municipalities to markets could be further improved in the future by using Google street directions if poaching geo-coordinates are known. Parrots are often transported through a complex web of unpaved secondary roads and trails (M. Herrera and J. L. Tella pers. obs.), which is not accounted for by a standard straight-line measure of distance between municipality and the city of Santa Cruz used in this study. Finally, quantitative data could be supplemented with qualitative interviews with various sellers, consumers, and police officials in order to provide researchers and policymakers a more thorough understanding of the illegal practices of poaching and trafficking in parrots. Patterns identified through both quantitative and qualitative studies would help formulate intervention techniques that would have sustained impact on the illegal trade.

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Received 3 April 2015; revision accepted 10 September 2015;

Published online 14 December 2015