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Policy analysis

What drives the illegal parrot trade? Applying a criminological model to market and seizure data in Indonesia

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ABSTRACT

High global and domestic demand for parrots (Psittaciformes) as pets, and consequent removal from the wild for the illicit trade have significantly contributed to their severe decline worldwide. While the trade is vast, not every parrot species is at equal risk of being traded, and there is controversy concerning the role of demand and the opportunity-based factors driving the illicit wildlife trade. The criminological model CRAAVED was used to analyze the factors associated with traded parrots in Indonesia, the country shown to have the highest priority for parrot conservation. We quantified the relative importance of CRAAVED components that drive trade risk by using advanced multivariate, phylogenetically controlled models. Three factors were significantly predictive of trade variation, whether the species was *disposable* (i.e. most legally exported species), *enjoyable* (i.e. most attractive), and *accessible* by people, suggesting that demand- and opportunity-based factors together can partially explain the illegal parrot trade in Indonesia. Our analysis has important implications for parrot conservation and the broader illegal pet trade, and is of considerable value for developing strategies at national and international levels for helping to control wildlife trade.

1. Introduction

The biological diversity of our planet is rapidly depleting due to the direct and indirect consequences of human activities. Direct global effects are habitat destruction, expanding urban and agricultural areas (Vergara-Tabares et al., 2020), and wildlife crime that includes the illegal killing, taking, possessing, or trading of plants and animals (Kurland et al., 2017). Wildlife trade and utilisation, whether legal or illegal, are also responsible for the potential emergence and spread of many zoonotic diseases (e.g. SARS, COVID-19, Avian flu) that can cause novel human diseases (Allen et al., 2017), which stresses the importance of regulating such activities. CITES has been regulating the international trade of threatened species since 1975 (www.cites.org), and parrots (order Psittaciformes) have become the most traded animal taxon according to their database (trade.cites.org). Parrots may thus provide the best source of data for investigating the causes and consequences of animal trade. As a result of global and domestic demand for parrots as pets, illegal trapping and removal of parrots from the wild has largely contributed to their decline (Clarke and Rolf, 2013). A global evaluation revealed that one-third of the nearly 400 parrot species are threatened by extinction, with Psittaciformes having higher aggregate extinction risk (IUCN Red List Index) than any other comparable bird group (Olah et al., 2016).

Southeast Asia is both a major hotspot for biodiversity and an epicenter for illegal wildlife trade world-wide (Nijman, 2010). Indonesia was identified as the highest priority country for parrot conservation because it has the greatest diversity of species (89 parrot species) and the highest proportion of threatened and endemic species of any nation (Olah et al., 2016). Before 2018, only 12 parrot species were listed as threatened in Indonesia and were, thus, regulated using catch-quotas (Republic of Indonesia, 1999). However, such quotas were rarely enforced and most parrot species were illicitly removed from the wild (Setiyani and Ahmadi, 2020) and trafficked to other provinces and countries (Aloysius et al., 2019). Although illicit removal from the wild

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is only the first step in the illegal wildlife trade, it is the primary activity that harms wild populations, and further understanding of its drivers is essential for understanding the broader issue of illegal trade of wildlife.

While the illegal parrot trade remains an active problem throughout Indonesia, it cannot be assumed that every species faces the same threat from illicit removal from the wild. Recent studies in the Neotropics have demonstrated that there is considerable variation among parrot species traded and sold in illicit markets (Herrera and Hennessey, 2007; Gastanaga et al., 2010). Using a criminological framework to understand variation in what is sold—and not sold—in these markets, Pires and Clarke (2011, 2012) have suggested that the illegal parrot trade is mostly an opportunistic crime. That is, species that are easier to remove from the wild are traded more frequently in illicit markets. The CRAAVED model (standing for *concealable, removable, accessible, abundant, valuable, enjoyable,* and *disposable*) was originally developed by Clarke (1999) for understanding theft variation of commonly stolen products and has been used to analyze variation of parrot species involved in the live pet trade (Pires and Clarke, 2011, 2012). CRAAVED analyses suggest that "hot products", or those products that are stolen often and re-sold in illicit markets, tend to be highly attractive to thieves and consumers alike, but are often also the easiest to steal (Clarke, 1999). Univariate CRAAVED analysis of Neotropical parrots showed that species that were more common in the wild (i.e. *abundant*), had larger distributions especially in closer proximity to illicit markets (i.e. *accessible*), and were easier to remove from nests (i.e. *removable*), were traded significantly more often than other species (Pires and Clarke, 2011, 2012; Pires, 2015). Conversely, species that were more *enjoyable* (i.e. attractive) or *valuable* (i.e. rare), otherwise known as demand-side components, were traded significantly less often. Unfortunately, these studies suffered from data limitations and could not control for competing explanations using multivariate models.

Using a multivariate statistical model on CRAAVED variables, a study found that the most *attractive* and *valuable* species were actually captured more often when controlling for relative abundance and accessibility (Tella and Hiraldo, 2014). This study concluded that demand-side components were the main driving force behind illicit trade. In addition, a more recent study of parrot trade in Colombia also found wildlife crime to be driven by selective removal of attractive species from the wild, not opportunity (Romero-Vidal et al., 2020). These studies were limited, however, because they did not operationalize each component of the CRAAVED model in order to control for all competing explanations, nor did they account for phylogenetic relationships in their statistical models. Controlling for phylogenetic dependence among the studied species is important in these multivariate analyses in order to truly understand the driving factors behind trade without inflating the sample size due to multiple representation of similar species in the dataset (Olah et al., 2016).

Divergent results in studies to date suggest that it is not yet clear whether opportunity, demand, or both drive the illegal parrot trade. It is often assumed that offenders disproportionately target highly valuable and charismatic species, which is thought to be driving the anthropogenic Allee effect that hastens the risk of extinction (Courchamp et al., 2006). This theory predicts that under a critical population size (Allee threshold), the elevated value of rare species can provide financial incentives for targeted poaching and eventually lead to accelerated extinction (Holden and McDonald-Madden, 2017). At the same time, the finding that the illegal parrot trade is an opportunistic activity is consistent with a number of recent wildlife crime studies that can explain why particular species of flora and fauna are poached (Kurland et al., 2017; Haines et al., 2012; Maingi et al., 2012; Pires et al., 2016; Kurland et al., 2018; Petrossian, 2018). For example, Maingi et al. (2012) found bodies of water, roads, and abundance of elephants were spatially predictive of where elephant poaching occurred in south-eastern Kenya. This line of research suggests opportunity structures both in the built (e.g. roads) and natural environment (e.g. bodies of water) facilitate the illicit removal of species from the wild.

The present study has the broad objective of furthering our understanding of the forces driving the illegal parrot trade in Indonesia by quantifying the relative importance of opportunity and demand-based factors. We use sophisticated multivariate models, controlling for phylogeny, to assess all CRAAVED factors that could potentially drive the illegal domestic and international parrot trade originating from Indonesia, a task that has not been accomplished to date.

2. Methods

2.1. Trade data

This study used a combination of seizure data and previously published market surveys of parrots from Indonesia to gather information for species at risk of being removed from the wild. Six data sources were used in total to gather a complete picture of which species are more commonly traded within Indonesia. These data were obtained from six different provinces spanning the archipelago (Fig. 1). Species traded were shown to be consistent across data sources (ICC = 0.804, 95% confidence interval 0.732–0.861; $F(89,356) = 5.104$, $P < 0.001$) giving us confidence these data are reliable and representative (Fig. 2).

Seizure data were obtained from the Natural Resource Conservation Center of the Ministry of Forestry (Balai Konservasi Sumber Daya Alam, BKSDA hereafter; Setiyani and Ahmadi, 2020) and the Regional Police of East Java (Reskrimsus Polda Jatim). BKSDA confiscated illicitly obtained parrots between 2016 and 2018 in the provinces of North Maluku and Maluku, and the Regional Police in East Java in 2018 (District Court of Jember, Indonesia, 2019). Market survey data were obtained from four sources. The first was based on Shepherd's (2006) survey of three markets in Medan, North Sumatra, where monthly market surveys were conducted between 1997 and 2001, and again in 2005, finding a total of 27 parrot species for sale. The second was based on extended field surveys on Obi Island in North Maluku in 2012, where they found eight species for sale (Cottee-Jones et al., 2014). The third was a published report by TRAFFIC (Chng et al., 2015) that documented the number of birds per sale in three of the largest markets in Jakarta in 2014, registering 14 parrot species for sale. In the fourth study, Chng et al. (2016) surveyed the Sukahaji wildlife market in Bandung, West Java in 2016 and found nine parrot species for sale.

Given the wide time-scale of the source data (1997–2018), we divided the sources into two periods for the analyses: (1) a 'past' dataset with Shepherd's (2006) extensive survey between 1997 and 2005 containing 27 traded species, and (2) a 'recent' dataset with all the other sources recorded between 2012 and 2018 containing 23 parrot species in the trade (Fig. 2). Trade patterns may have changed over time in Indonesia and we wanted to isolate these two time periods as well as combine them to get a fuller picture.

First, we analyzed the data separately in the two time-periods and then altogether as an 'overall' dataset. We measured CRAAVED components following the methods used by recent studies of illegal parrot trade (see Pires, 2015), summarized in Table 1, and details are given in the Appendix A. We conducted a Pearson correlation test among the components to explore potential multi-collinearity issues. The complete dataset is available in FigShare (https://doi.org/10.6084/m9.figshare.13681393).

2.2. Statistical analysis

Utilizing studies and data with different methodologies meant that the exact number of birds observed in markets or confiscated was not always comparable. For example, some market surveys were monthly, while others were conducted over a 3-day or 1-day period at wildlife markets. Hence, we treated our response variable as a binary measure to simply reflect whether the species was traded ('1') or not traded ('0'). In addition, data were assembled according to which species were traded within the past, recent, and overall time-periods. First, we fitted a binary

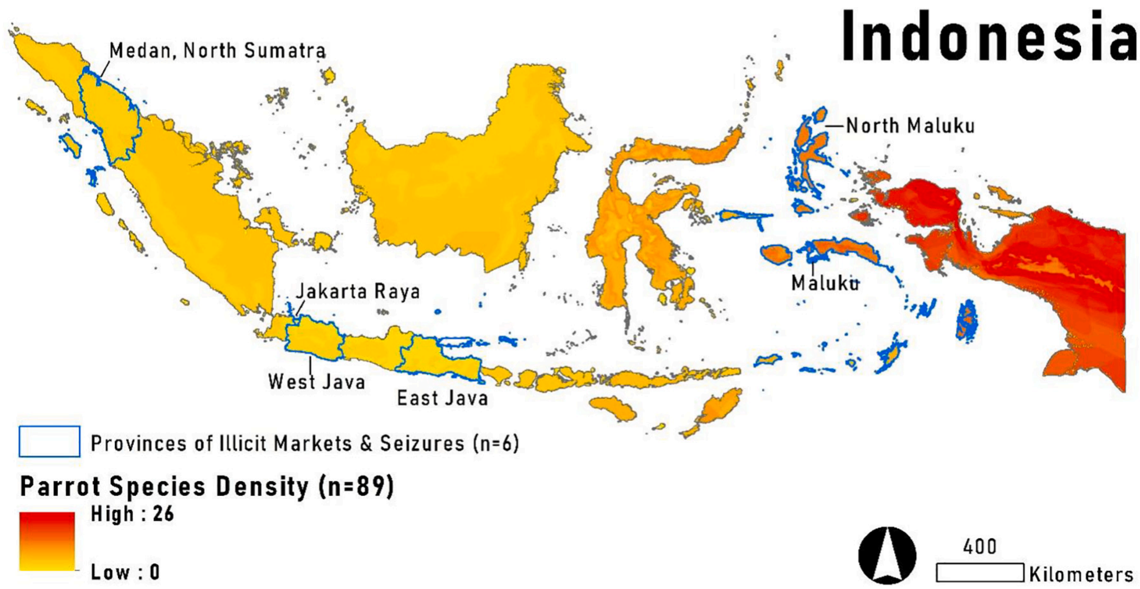

Fig. 1. Locations of illicit markets and seizures used in this study along with the distribution of parrot species density in Indonesia.

logistic regression model using the 'GLM' function in R statistics (R Core Team, 2019) to calculate *P* values for the seven explanatory variables. Then, we compared the Akaike information criterion (AIC) of all combinations of the seven variables without interactions and selected the best model with the lowest AIC (i.e. including features that maximize the predictive ability of the model) using the 'MuMIn' package in R (Barton, 2019). We repeated these steps for each of the time-periods.

For phylogenetic relatedness control, we downloaded 1000 possible

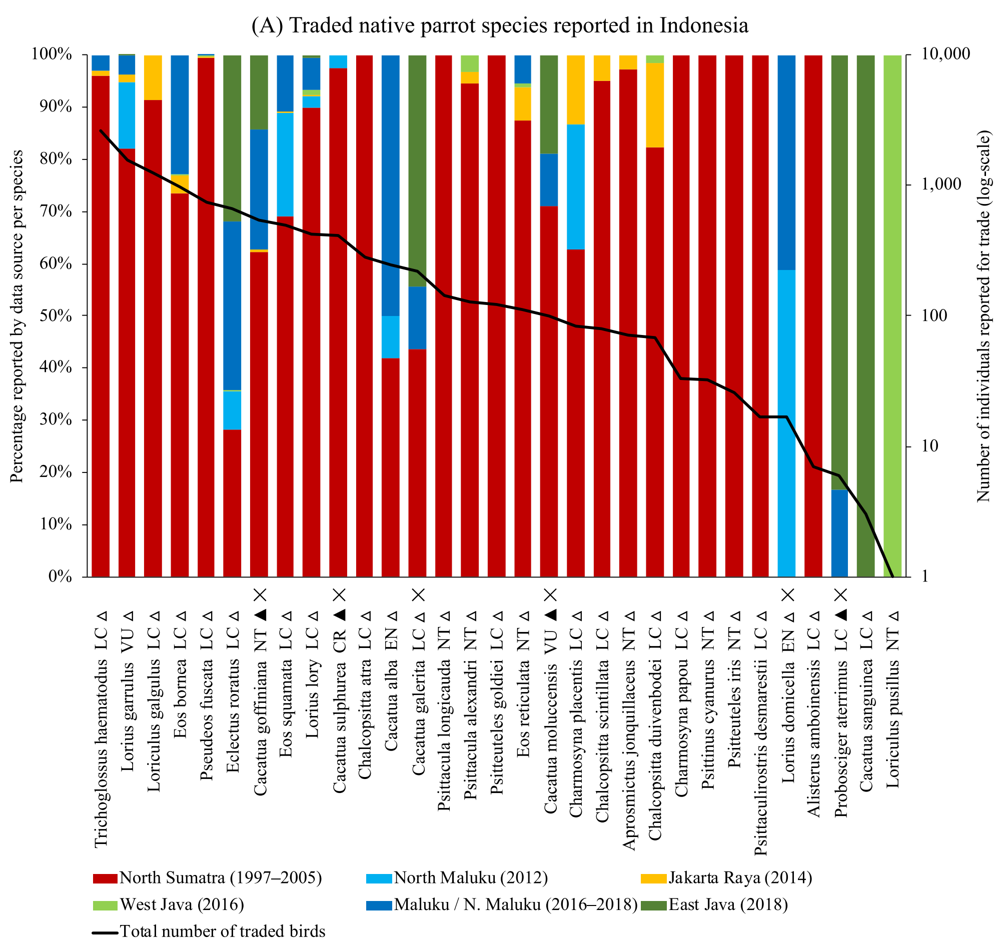

Fig. 2. Traded native parrot species reported by six sources in Indonesia for (A) an overall period of two decades (1997–2018), and (B) a recent time-scale between 2012 and 2018. Each column represents a species and its relative appearance in market/confiscation data sources (different colors indicate the percentage of total individuals reported by species; left axis). Species are sorted by the total number of individuals reported for trade shown by the continuous line and the right axis. After the species name are their IUCN RedList (2018) status (CR = Critically Endangered, EN = Endangered, VU = Vulnerable, NT = Near Threatened, and LC = Least Concern), CITES listing (▲ = Appendix I and △ = Appendix II), and protection in the national level in Indonesia pre-2019 (✕).

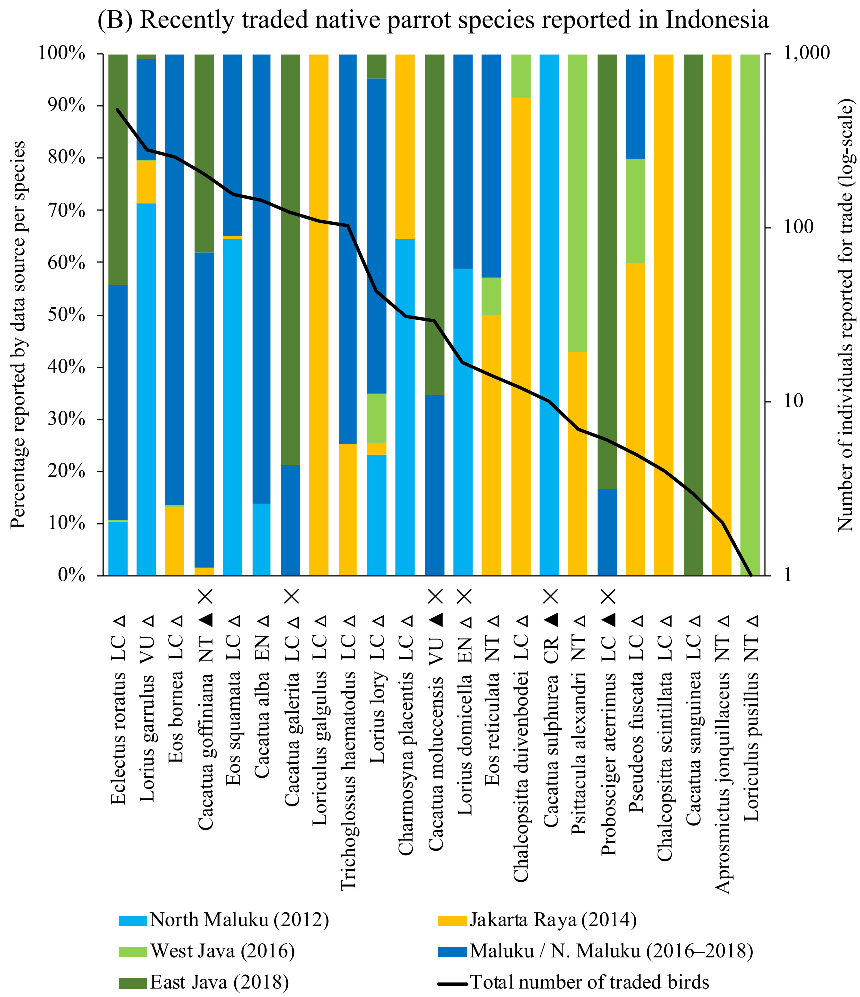

Fig. 2. (*continued*).

phylogenetic trees with the Ericson taxonomic backbone of parrot species distributed in Indonesia from birdtree.org (Jetz et al., 2014) to account for the branch lengths in addition to nodes separating species (available with our FigShare dataset). For each tree we ran a phylogenetic generalized least squares (PGLS) regression using the 'caper' package in R (Orme et al., 2018).

The explanatory and response variables were the same as those used in the logistic regression model. We ran the PGLS model with all seven variables in the three time-periods, and then with the variables represented in the best models from the previous step. For each explanatory variable, we report the modified P value accounting for phylogenetic relatedness, the estimates, and for each model we also report the λ transformation that improves the fit of phylogenetic data. Greater λ values indicate that the relationship between response and explanatory variables correlates with the phylogeny, and that the values of the explanatory variables are more similar for closely related species.

We used the random forest machine learning (RFML) algorithm (Breiman, 2001) in the 'randomForest' package of R (R Core Team, 2019), to model the relationship between the traded parrots and CRAAVED variables. RFML is a computational machine learning approach that fits multiple decision trees to our trade dataset using a random subset of the CRAAVED input variables for each tree constructed for the parrot species. For each model, we present the percentage of variance explained in traded species, and for each CRAAVED component the mean decrease in Gini (i.e. higher decrease meaning that a particular predictor variable plays a greater role in partitioning the data into traded/not traded) and their relative importance in each time-period.

3. Results

Indonesia hosts a total of 89 parrot species, of which two are Critically Endangered, four are Endangered, seven are Vulnerable, 16 are Near Threatened, and 60 are of Least Concern (IUCN, 2019). Based on the six data sources reviewed by this study, 31 parrot species (34% of total in Indonesia) were reported as traded species (one CR, two EN, two VU, eight NT, and 18 LC). Four species are listed in CITES Appendix I: *Cacatua goffiniana*, *C. moluccensis*, *C. sulphurea*, and *Probosciger aterrimus* (Fig. 2).

The best linear regression models explaining the likelihood of a parrot species being traded in Indonesia in the past (1997–2005) contained the CRAAVED components *disposable*, *enjoyable*, and *accessible*, while in a later time period (2006–2018), *concealable* was also highlighted alongside these other variables (Table 2). Species were significantly more prone to trading if they were more *disposable* in all of the time-periods analyzed (PGLS $P_{past} = 0.003$, $P_{recent} = 0.001$, and $P_{overall} = 0.009$; Fig. 3A). More *enjoyable* species were also traded significantly more in both the past and recent periods (PGLS $P_{past} = 0.026$, $P_{recent} = 0.014$; Fig. 3B) but this component was not significant when we pooled the two periods (PGLS $P_{overall} = 0.065$). Species that were more *concealable* showed up as significant only in the linear regression model in the recent time-period (GLM $P_{recent} = 0.04$) but this could not be confirmed when we controlled for phylogenetic relationships (PGLS $P_{recent} = 0.927$). The full models with all CRAAVED components are presented in Appendix A.1.

Of the total variance between traded and non-traded species data, 21% was explained by the seven CRAAVED components in the overall

Table 1
CRAAVED components used in the study to evaluate the likelihood of Indonesian parrot species being traded in past (1997–2005), recent (2012–2018), and overall (1997–2018) time-periods.

Variable	Definition	Measure	Source
Concealable	Species that could not be legally trapped and are therefore harder to conceal from law enforcement. *Opportunity-based.*	Nationally protected (1) or unprotected (0) species in Indonesia.	Republic of Indonesia PP7/1999
Removable	How easy is it to remove species from the wild? *Opportunity-based.*	Easy (1) e.g. from nests near to the ground; medium (2) e.g. using glue or mist netting; difficult (3) e.g. high nests, noose techniques.	Dudi Nandika, Dr. La Eddy
Accessible	Species found in areas where there is a greater number of people may be at an increased risk of trade. *Opportunity-based.*	Human population size within the species range in the year 2000 (past), 2015 (recent), and the average of their sum (overall time-scale).	IUCN, 2019; Schiavina et al., 2019
Abundance	How common species are. *Opportunity-based.*	To reduce variability between global and Indonesian estimates, average population sizes were converted to (1) 1–9999, (2) 10,000–49,999, (3) 50,000–99,999, and (4) over 100,000 individuals.	Juniper and Parr, 1998; IUCN, 2019
Valuable	IUCN RedList categorization as a widely used proxy for value. *Demand-based.*	(1) Least Concern, (2) Near Threatened, (3) Vulnerable, (4) Endangered, and (5) Critically Endangered.	IUCN, 2019
Enjoyable	Species attractiveness to potential customers. *Demand-based.*	Composite values (4–8) from the sum scores of low (1) or high (2) of the colorfulness, percentage of body brightly colored, body length, and ability to mimic sounds.	Juniper and Parr, 1998; Tella and Hiraldo, 2014
Disposable	The ease with which species can be sold in illicit or licit markets. *Demand-based.*	Number of exported parrot specimens between 1997 and 2005 (past), 2006–2018 (recent), and their sum (overall time-scale).	CITES trade database

analysis, while 19% in the past and 23% in the recent time-periods. Of the total effects (100%) of the components, *accessible* showed the highest relative importance in all time-periods (between 23% and 24%) followed by *disposable*, *removable, enjoyable*, *abundance, valuable*, and *concealable* (Appendix A.1, Fig. 4). When only the components from the best models were kept, 19% of the variance was explained by four variables retained in the overall analysis, while 18% in the past and 19% in the recent time-periods including three and four variables respectively. In these cases, the highest relative importance was again associated with the *accessible* component (38–41%; Table 2, Fig. 4). Some CRAAVED components were correlated (Appendix A.2); the highest correlation was between *abundance* and *valuable*.

4. Discussion

The objective of this study was to determine whether illegal parrot trade patterns in Indonesia can best be explained by demand, opportunity, or both factors using the criminological model CRAAVED (Clarke, 1999). The drivers of the illegal wildlife trade have become a common theme in the literature and this paper addresses this with specificity to the live pet trade. It is often assumed that offenders target the most valuable and attractive wildlife species for the live pet trade and two recent parrot poaching studies have supported this view (Romero-Vidal et al., 2020; Tella and Hiraldo, 2014). Some coveted species for the pet trade may have large distributions, are in close proximity to urban populations and illicit markets, and may be easier to remove. Whether this finding holds true for wildlife products, is the basis of this study. Modeling all relevant factors that could influence the decision-making process of offenders is critical to understanding how the wildlife trade operates, and to inform preventive policies.

The contributions of this paper are twofold. First, this is the only wildlife crime study that operationalizes all CRAAVED components while utilizing sophisticated multivariate models and controlling for phylogeny. Previous conservation studies have either operationalized all CRAAVED components, but were limited to univariate analyses (Pires and Clarke, 2011, 2012; Petrossian and Clarke, 2014; Petrossian et al., 2015) or ran multivariate models without operationalizing all components (Tella and Hiraldo, 2014). Second, Indonesia is home to the largest number of parrot species—roughly a quarter of all Psittaciformes—and the largest number of genera of any nation (Olah et al., 2018). As a result, findings from this context are likely to be more generalizable to other Psittaciformes found elsewhere, especially considering findings from this study have been partially corroborated previously in Mexico, Peru, and Bolivia. Altogether, accumulating knowledge based on a collection of nation-based studies is a suitable method to generalize factors that drive the illegal parrot trade more globally.

As a result of operationalizing all components of CRAAVED and using multivariate models, it is not surprising that our study draws

Table 2
Best models explaining the likelihood of Indonesian parrot species being traded in different time-periods: past (1997–2005), recent (2012–2018), and overall (1997–2018). Presented are results from the best models (selected based on AIC) evaluating the importance of each CRAAVED variable: the Wald statistic and chi-square *P* values (P_{GLM}) from logistic regression (GLM) models; *P* values (P_{PGLS}), estimates, and lambda (λ) values from phylogenetic generalized least squares (PGLS) regression models with corresponding standard deviation values (SD); and mean decrease in Gini and relative importance of each variable from random forest machine learning (RFML) models. *P* values lower than 5% are presented in bold.

Time-period	Variable	Wald test	P_{GLM}	P_{PGLS} (SD)	PGLS Estimate (SD)	λ (SD)	Gini	Relative Importance
Past	Accessible	1.71	0.088	0.213 (0.045)	0.002 (0)	0.127 (0.058)	10.4	38%
	Enjoyable	2.24	**0.025**	**0.026** (0.005)	0.147 (0.002)		4.9	25.7%
	Disposable	3.67	**<0.001**	**0.002** (0)	0.009 (0)		14.9	36.3%
Recent	Concealable	2.05	**0.04**	0.927 (0.061)	0.003 (0.015)	0.360 (0.041)	2.8	9.5%
	Accessible	1.88	0.06	0.218 (0.026)	0.002 (0)		11.2	40.7%
	Enjoyable	2.24	**0.025**	**0.013** (0.002)	0.152 (0.004)		4.6	19.7%
	Disposable	3.44	**0.001**	**0.001** (0)	0.016 (0)		13	30.1%
Overall	Concealable	1.83	0.067	0.752 (0.112)	−0.04 (0.021)	0.414 (0.083)	1.3	6.5%
	Accessible	1.86	0.062	0.292 (0.037)	0.002 (0)		13.1	39.9%
	Enjoyable	1.76	0.078	0.065 (0.012)	0.133 (0.005)		4.6	17.1%
	Disposable	3.75	**<0.001**	**0.009** (0.004)	0.008 (0)		19.1	36.6%

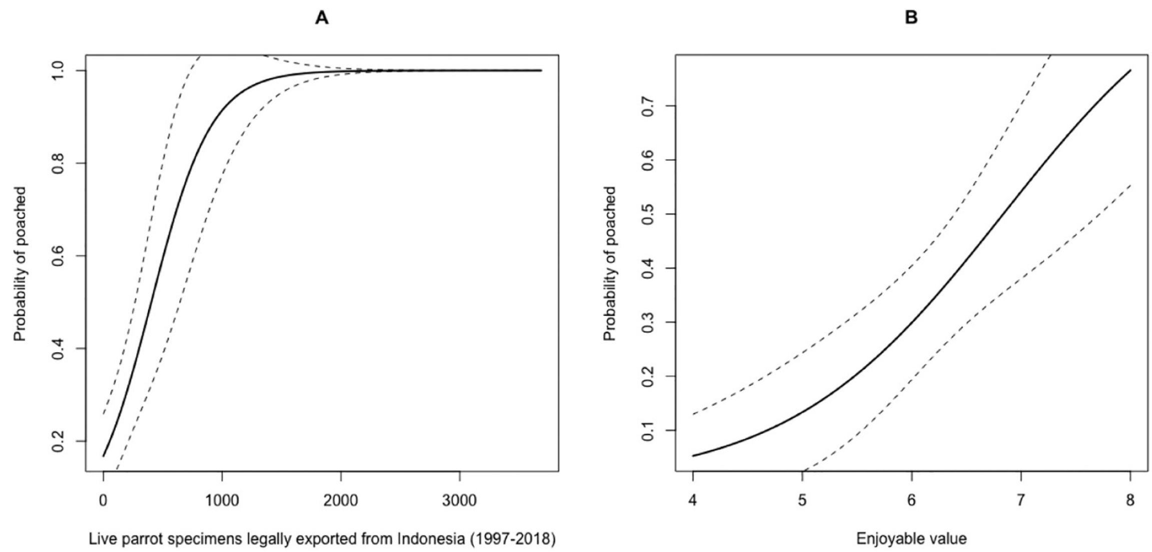

Fig. 3. Predicted effects of (A) *disposable* and (B) *enjoyable* components of the CRAAVED model on the probabilities of Indonesian parrot species being traded in the overall analysis. Continuous lines are predicted values, and dashed lines represent 95% CI upper/lower bounds.

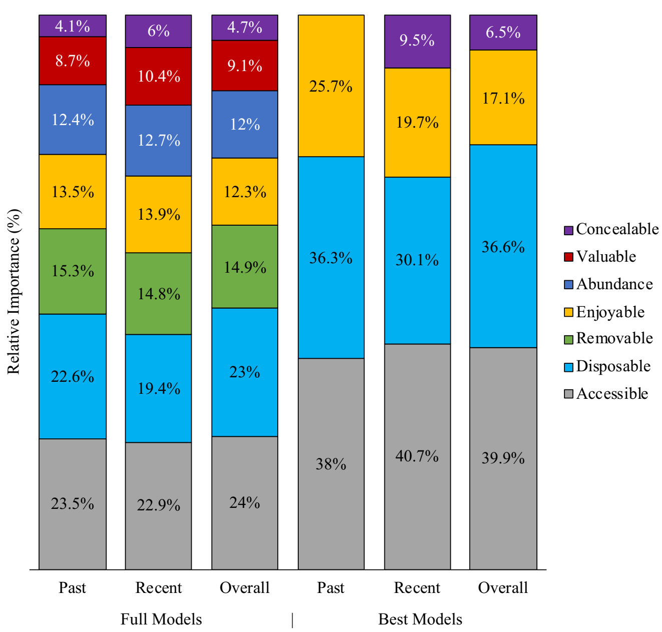

Fig. 4. Relative importance of CRAAVED components in explaining the variance of parrot species traded in Indonesia by the random forest machine learning (RFML) models in past (1997–2005), recent (2012–2018), and overall (1997–2018) time-periods. Results from full and best models (based on AIC values) are presented.

different conclusions to those of previous studies. Our results reveal that both demand-side and opportunity-based factors can explain variation in trade in Indonesian parrots with approximately 20% of the variance explained in all models. While this variance statistic may seem low, it is consistent with explanatory power results published in criminology outlets (Weisburd and Piquero, 2008). More specifically, our regression models found the most *disposable* and *enjoyable* species were significantly more likely to be traded while controlling for all other potential explanations and the phylogenetic relationships of the birds (Table 2, Fig. 3). In addition, using a random forest model, the results suggest the relative importance of *accessibility*—an opportunity-based factor (Table 1)—is greater in explaining trading variation than the other components in all models (Table 2, Fig. 4), with *disposability* also highly supported by this model.

4.1. Demand-side factors

The finding that demand-side factors—*enjoyability* and *disposability*—were found to be significant suggests that people are targeting attractive species that are easier to sell in licit markets, partially supporting Tella and Hiraldo (2014). The most attractive species in Indonesia, according to our *enjoyable* metrics, were the Chattering Lory *Lorius garrulus*, Eclectus Parrot *Eclectus roratus*, and Salmon-crested Cockatoo *Cacatua moluccensis*. All three were traded in multiple provinces indicating their popularity in the trade over time. Conversely, only four of 20 species scoring the lowest on our *enjoyable* metric were traded. Related, the most *disposable* species (exported from Indonesia) were significantly more likely to be traded in Indonesia in all three models. This suggests that there is a cross-cultural preference for particular parrot species, especially ones that have been historically overexploited (Tella and Hiraldo, 2014). Similar findings have been shown for boid snakes (Frynta et al., 2011). Separately, our analysis of live psittacines exported from Indonesia between 1997 and 2018 showed a substantial decline since 2006 (mean = 1640/y) as compared to pre-2006 (mean = 6271/y), which may be due to the 2007 EU ban on imports of wild-caught birds (Reino et al., 2017).

At the international level, only four Indonesian parrot species are listed on CITES Appendix I and the remaining species are on Appendix II (Fig. 2). These four species only represent 13% of all parrot species reported from trade in this study. Many CITES Appendix II parrot species regularly appear in recent confiscation datasets and often in large quantities (Fig. 2B). For example, the Chattering Lory is one of the most traded parrots in Indonesia (Fig. 2) and it is listed as Vulnerable by IUCN with the justification that "this species is undergoing a rapid population decline that is projected to continue as a direct result of habitat loss and human exploitation for the cagebird trade" (BirdLife International, 2017). However, the species is listed under CITES Appendix II only, even though it falls into the criterion C of CITES Appendix I with "a marked decline in the population size in the wild, which has been observed as ongoing or as having occurred in the past" (www.cites.org). Indeed, the Chattering Lory was reportedly overharvested in rural areas (Tamalene et al., 2019), sold in the close locality, and was registered as the most kept pet species in North Maluku (Rosyadi et al., 2015). An urgent re-evaluation is required of the 27 parrot species traded in Indonesia that are currently listed under Appendix II of CITES.

Incidentally, the significant overlap between the domestic and international trade of certain Indonesian parrot species also suggests the possibility that a high number of wild-caught birds in Indonesia are purposefully mislabeled as 'captive-bred' in order to be legally exported. Recently, many parrots of Indonesian origin (including Sulphur-crested Cockatoo *Cacatua galerita*, Palm Cockatoo *Probosciger aterrimus*, Eclectus Parrot, Pesquet's Parrot *Psittrichas fulgidus*, Red-and-blue Lory *Eos histrio*, Rainbow Lorikeet *Trichoglossus haematodus*, Black-capped Lory *Lorius lory*) were confiscated in the Philippines and repatriated in Indonesia, including the Maluku and Papua regions (D.N. and D.A. unpublished data, 2020). Two studies have also shown a substantial number of wild-caught reptiles from Indonesia are 'laundered' via breeding facilities for the legal international trade (Nijman and Shepherd, 2009; Lyons and Natusch, 2011). In total, 420 parrots confiscated by the Regional Police of East Java—data first used in this study—were for the purpose of wild bird laundering for international trade. In this case, the owner of these parrots was unable to prove that the traded birds were captive bred, nor could they show pedigree data for the breeding facility either (District Court of Jember, Indonesia, 2019). Auditing of captive bred parrot facilities in Indonesia should follow to prevent laundering of wild-caught birds.

4.2. Opportunity-based factors

With respect to the opportunity-based components of the CRAAVED model (Table 1), only *accessibility* appears likely to be an important predictor based on the consistent results of the random forest models (Fig. 4). Prior studies in Mexico, Bolivia (Pires and Clarke, 2011, 2012), and Peru (Pires, 2015) found that *accessibility* was one of the leading factors explaining trade variation. Species that are disproportionately targeted are often the ones closer to more humans and open-air illicit markets. This consistent finding across nations and regions suggests that illicit removal of parrots from the wild is partly an opportunistic crime. This idea that crime is an opportunistic activity is long-standing in the discipline of criminology. Both routine activity (Cohen and Felson, 1979) and rational choice theories (Cornish and Clarke, 1986) posit that crime is a function of suitable opportunity structures. That is, crimes that are easier and less risky to commit will be committed more often, especially in certain places and times. As it relates to the parrot trade, these birds nest in predictable areas and often in specific trees, generally during the same time of year, every year. Predictable behavior and proximity to offenders make foraging for parrots and their nests relatively easy (Pires and Clarke, 2011).

Nevertheless, many opportunistic factors that were previously significantly related to trade variation were found to be unrelated in the present study. *Abundance*, or the number of estimated wild parrots, was not significantly related to the probability of being traded in Indonesia. This result could be due to the nature of our binary outcome measure or because abundance was correlated with other components (Appendix A.2). Our study also showed no significant effect of *removability* from the wild, which is supported by three previous studies (Pires and Clarke, 2011; Pires, 2015; Tella and Hiraldo, 2014). This may be because there was little variability in how parrots nested in Indonesia as in many cases they are captured on roosting trees using glue (Jepson et al., 2001).

The extent that species were *concealable* (i.e. non-protected) was also found to be unrelated to the probability of being traded, and consistently showed up as the least informative component in the random forest models (Fig. 4). This indicates that Indonesian market sellers are not fearful of law enforcement encounters and their outcomes if protected species are no less likely to appear in wildlife markets compared to non-protected species. Finally, *value* was not statistically related to being traded. This may be a result of using a proxy for monetary value (IUCN RedList status) because a limitation in the data was the absence of market prices for 83 of the 89 Indonesian parrot species.

The finding that both demand and opportunity-based factors can explain variation in parrot trade is supported by studies of other taxa. With respect to illegal, unreported, and unregulated (IUU) fishing, CRAAVED research has shown both demand and opportunity-based factors influence target choices. Petrossian and Clarke's, 2014 analysis of fish caught illegally for commercial purposes fish found that all CRAAVED components were significantly predictive of illegal fishing. In addition, Petrossian et al. (2015) found illegally caught crabs and lobsters were significantly associated with *abundant*, *valuable*, and *enjoyable* measures. Altogether, these findings indicate that the decision-making process of wildlife offenders is influenced by the ease of capturing targeted species as well as their perceived value and desirability.

4.3. Conservation and policy implications

During the period of this study, 19% of the parrot species appearing in our trade database were protected by national law, hence their trade was considered to be illegal. Although many parrot species were not protected during this period (1997–2018), our results hold important implications for their conservation especially now, that new national legislation protects all 89 native parrot species (Republic of Indonesia, 2018). In addition to protecting a greater number of species, two main strategies should be implemented to reduce the illegal trade of parrots in Indonesia.

First, interventions should focus on the species that are commonly targeted for the trade, including non-threatened species that score high on *enjoyability*, *disposability*, and *accessibility*. While such species are typically not prioritized for protection, they are at potentially greater risk of becoming threatened given their existing numbers in the trade and propensity to be targeted. For example, the Eclectus Parrot is of Least Concern (IUCN, 2019), but scored highest on *enjoyability*, is frequently exported to other countries, has a range that overlaps a population of over 7.1 million people, and was found traded in 5 of the 6 provinces in our dataset. Strategies to reduce the trade of such species could take the form of nest protection, educational awareness campaigns targeting children and consumers, and using the power of media (e.g. films) in science communication (Fernández-Bellon and Kane, 2020). Such strategies should be evidence-based and micro-target known hot spots and potentially even 'hot times' when nest poaching is likely to occur for particular species (Pires et al., 2016).

Second, place-specific illicit markets have been found to facilitate theft, and thus increase crime, by allowing illicitly obtained products to be quickly and easily exchanged for cash (Eck, 2005). Eliminating open-air illicit wildlife markets can theoretically reduce illicit removal of wildlife as offenders would be unable to dispose of parrots as easily. Some displacement to online or non-public markets could be expected if open-air markets were shut down, but a net reduction in crime should follow (Pires and Clarke, 2011).

4.4. Conclusion

The wider implications of this study suggest the criminological model CRAAVED, is suitable for analysis of other taxa commonly found in the illicit pet trade. More specifically, a CRAAVED analysis could be applied to lizards, snakes, songbirds, cacti, orchids, primates, tortoises, and turtles, which all exhibit large variation in illicit removal and trafficking among species (see Kurland and Pires, 2017). In doing so, the factors that are driving the illicit trade in pets and plants along with the *modus operandi* of offenders could be better understood across taxonomic groups. For such analyses to be conducted, more data on poaching and trafficking at the local, regional, and national levels needs to be published (e.g. by relevant NGOs), and informed by a variety of data collection methods (i.e. market surveys, offender interviews, seizure data, field observations). Our study provides a robust framework to analyze such wildlife trade data using various methods and timeframes.

Declaration of competing interest

The author(s) declare that they have no competing interests. This manuscript has not been published elsewhere and that it has not been submitted simultaneously for publication elsewhere.

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Appendix A. Supplementary data

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