



## Using market data and expert opinion to identify overexploited species in the wild bird trade



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### ABSTRACT

The wildlife trade involves thousands of vertebrate species and now rivals habitat loss as an extinction driver in some regions. However, its impacts are poorly known because field monitoring of wild populations is expensive, localized, and requires specialized expertise. We examined whether market data and expert opinion could be used to identify bird species that may be at risk from the trade in Indonesia. We asked expert ornithologists to characterize population trends of 38 species of Indonesian birds, including many heavily traded species. They identified 14 species as having undergone population declines, all of which are regularly traded, and only two of which are restricted to old-growth forests. Conversely, none of the untraded species was classified as declining. We combined the expert-derived population trends with data on changes in price and trade volume from Indonesian wildlife markets to see if market data could identify declining species. We found that severely declining species have a significantly different price–volume signal than stable/increasing species; the former are characterized by increasing market prices and declining volumes. Market data are much cheaper to collect than field data, roughly 1/30th the cost of a representative field study. We recommend a two-step approach to assess trade impacts on wild birds in Southeast Asia: coordinated market monitoring followed by field studies of species whose market signals indicate declining populations. Our findings, however, require further validation with higher resolution wild population and market data.

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## 1. Introduction

The illegal wildlife trade is worth c. \$10 billion per year, making it comparable in value to the trafficking of weapons, drugs, or people (Wilson-Wilde, 2010). In recent years, dramatic increases in the illegal trade of elephant ivory and rhinoceros horn have garnered international attention (Environment News Service, 2013). However, the wild animal trade extends far beyond the few charismatic species that have received extensive press coverage. Approximately one third of the world's birds and thousands of

reptile and mammal species, sourced from most of Earth's ecosystems, are traded (BirdLife International, 2008; Bush et al., 2014; Butchart, 2008; Nijman, 2010). Each year, vast numbers of animals, many of which are drawn from thousands of kilometers away, are sold openly in wildlife markets, especially in Asia (Crookes et al., 2005; Duckworth et al., 2012; Nash, 1993; Nijman, 2010; Root et al., 2006; Shepherd and Nijman, 2007; Shepherd et al., 2004).

The scale of the trade suggests that many species may be at risk. For example, hunting and trapping are considered to be the third most important threat to the world's birds after habitat disturbance and invasive species (BirdLife International, 2008). The wildlife trade is known to be driving declines of a limited number of species in all major vertebrate groups in Asia, South America, and Africa (Alves et al., 2013; Butchart, 2008; Cowlishaw et al., 2005; Lee et al., 2004; Nijman and Shepherd, 2007; van Balen et al., 2013; Shepherd et al., 2013), but the effects of trade on the vast majority of trapped species are unknown because monitoring of wild animal populations is expensive, localized, and requires

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specialized scientific expertise (Bush et al., 2014; Phelps et al., 2010; Smith et al., 2011). The potential for trapping-related losses of ecosystem functions such as seed dispersal and insect control in natural and agricultural landscapes (Dirzo et al., 2014; Harrison et al., 2013; Van Bael et al., 2003) makes it all the more important to determine the impacts of trapping on as many species as possible.

Biologists and decision makers need cost-effective ways to identify species that are being overexploited. This need may be most acute in Southeast Asia, where an intense animal trade and widespread deforestation are interacting to threaten numerous endemic species (Wilcove et al., 2013). However, long-term field monitoring of wild populations of any taxon is virtually non-existent in Southeast Asia (Collen et al., 2008; Sodhi et al., 2004). The seriousness of the trade threat necessitates an evaluation based on the incomplete data available, comparable to analyses of sustainability for data-poor fisheries (Costello et al., 2012). Here we examine the use of expert opinion and market data as a means of assessing the impact of the wildlife trade on bird populations in Sumatra, Indonesia.

Indonesia is a global center of the pet bird trade. In Indonesia at least 300 bird species are traded, 22% of households own pet birds, and the trade contributes nearly \$80 million to the national economy annually (Jepson and Ladle, 2009; Jepson et al., 2011; Nash, 1993; Shepherd et al., 2004). Sumatra, which is slightly larger than California, hosts 620 species of birds and is an important hotspot of the Indonesian bird trade (Shepherd et al., 2004). Despite the island's avian diversity, no systematic, long-term bird surveys have been done, and Sumatra is seldom visited by birdwatchers.

Given the active trade and the lack of information on Sumatran bird populations, we surveyed expert ornithologists to characterize population trends of traded and untraded bird species. We then analyzed changes in market price and trade volume to see if market data could identify species in decline. We also compared species' global conservation status and population trends (BirdLife International, 2014) to the expert-derived population characterizations for Sumatra alone. Our objective in doing so was to call attention to any regional declines in species that might otherwise be classified as globally secure.

Finally, we wanted to evaluate whether our predictions regarding a relationship between market data and wild population size were matched by other historical information sources. The yellow-crested cockatoo *Cacatua sulphurea* and Bali myna *Leucopsar rothschildi* are two Southeast Asian species that have been pushed to the brink of extinction by trapping. There exist many years of historical data on wild population size, price, and trade volume for both (and for few, if any, other species in the region). This information allowed us to look at relationships among the three variables over time and perform a second test of the use of market data to identify declines.

Given that many Southeast Asian birds have large geographic ranges, we hypothesized (H1) that some species would show declines in Sumatra but not globally. And given the positive feedback between rarity and demand for wildlife products (Courchamp et al., 2006), we hypothesized (H2) that species that were increasing in market price but decreasing in trade volume would be declining in the wild. Third, we hypothesized (H3) that species showing increases in both price and volume would be increasingly in demand and therefore would also be declining. Fourth, we predicted (H4) that species with falling market prices would be under reduced demand and therefore should have stable population trends in the wild in Sumatra. Fifth, we hypothesized (H5) that the well-known cases of the yellow-crested cockatoo and Bali myna would show similar market patterns as the species declined due to trapping: prices and volumes would first increase as trappers intensified their efforts in response to growing demand, and

then prices would continue to increase while volume and population size decreased as trappers exhausted the supply of wild birds. Finally, we hypothesized (H6) that market surveys would generate information on large numbers of bird species at lower cost than field studies.

## 2. Methods

### 2.1. Characterizing population trends

We studied markets in Medan, Sumatra, which is one of the primary hubs of the Asian wildlife trade with >200 species of birds regularly sold. Most birds in the Medan markets are wild caught, some from as far away as China and New Guinea, and most are bound for the domestic market (Jepson and Ladle, 2005; Shepherd, 2006; Shepherd et al., 2004). Pet markets may be more informative of population declines than other consumptive wildlife markets (e.g., bushmeat) because pets are expected to have lower substitutability than species used for bushmeat or fisheries (Courchamp et al., 2006). Buyers are more likely, therefore, to continue to demand desired species even as their prices rise, rather than switching to more common (and less expensive) ones (Courchamp et al., 2006). That certain species of captive birds serve as status symbols in Indonesia (Shepherd et al., 2004; Collar et al., 2012) further supports the idea of low substitutability. Therefore, we felt justified in testing for population declines based on price and trade volume without reliable information on source or trapping methods used (which are rarely available) (Crookes et al., 2005; Ling and Milner-Gulland, 2006).

Based on our knowledge of the community of ornithologists and bird-tour leaders working in Sumatra, combined with internet searches of all of the major bird-tour companies, we assembled a list of 29 experts whom we regarded as the most experienced and active ornithologists visiting or living on the island. We then prepared a list of 38 species of Sumatran birds that included 32 of the most popular species in the pet trade (this list was developed based on market data—see below) plus six species that rarely, if ever, appear in the markets (see under “Rarely traded species” in Table 1). We included the six untrapped species to check if any declines observed by the experts were part of a widespread decline of all of Sumatra's birds.

We sent the ornithologists the list of birds and asked them to (1) summarize their birdwatching experience in Sumatra (places visited, years spent birdwatching in Sumatra); (2) their impressions of the current status and changes in status of the 38 species; and (3) whether changes in populations of each species were uniform or widespread among the places in Sumatra they had visited. We did not ask them to provide their opinions on the causes of any reported changes in bird populations, although some volunteered such information. If no reply was received, we sent a reminder email after one week. Ultimately, ten respondents with experience at several sites covering at least two years separated by at least five years sent informative replies. Most respondents had extensive experience studying birds in Sumatra, the average time span being 17 years of experience (range of 5–27 years; Table S1).

Respondents stated if species were stable, declining, or of unknown status, and they appeared to give answers only if they were confident about the population trend (i.e., some species were either not commented upon, or respondents specified that they were unsure about that species' status). Some added unsolicited qualifiers to their characterizations of declining species, such as “rapidly declining” or “seriously declining.” We used these responses to classify each of the 38 species as Stable/Increasing, Declining, Severely Declining (when observers added such qualifiers) or Unknown in Sumatra. Including the Severely Declining category enabled us to

**Table 1**  
 Respondents' opinions on Sumatran population trends and price and trade volume data for (a) regularly traded bird species for which historical and contemporary price and volume data were available, (b) regularly traded species for which incomplete market data were available, and (c) rarely traded species.

English name	Scientific name	Number of stable/increasing responses	Number of declining responses	Number of severely declining responses	Total number of responses when trend was known	Expert opinion on Sumatran population trend	Historical trade volume	Contemporary trade volume	Historical price (Indonesian Rupiah in 2013)	Contemporary price (Indonesian Rupiah in 2013)	IUCN status	Global population trend (BirdLife International, 2014)
<i>A. Regularly traded species for which historical and contemporary price and volume data were available</i>												
Red-breasted parakeet	<i>Psittacula alexandri</i>	1	0	0	1	Unknown	23	34	57,272	2,963,333	NT	Declining from trade
Long-tailed shrike	<i>Lanius schach</i>	3	4	0	7	Unknown	117	593	34,363	153,549	LC	Unknown
Black-naped oriole*	<i>Oriolus chinensis</i>	0	2	0	2	Declining	250	229	137,453	248,403	LC	Unknown
Straw-headed bulbul	<i>Pycnonotus zeylanicus</i>	0	0	2	2	Severely Declining	299	117	372,270	7,462,500	VU	Declining from trade
Ruby-throated bulbul	<i>Pycnonotus dispar</i>	1	4	2	7	Severely Declining	305	235	22,909	60,164	LC	Declining from trade
Sooty-headed bulbul	<i>Pycnonotus aurigaster</i>	2	2	0	4	Declining	588	1525	57,272	35,329	LC	Declining from trade
Orange-spotted bulbul*	<i>Pycnonotus bimaculatus</i>	1	4	0	5	Unknown	240	270	114,544	73,333	LC	Stable/increasing
Yellow-vented bulbul	<i>Pycnonotus goiavier</i>	3	2	0	5	Unknown	186	2091	57,272	42,679	LC	Stable/increasing
Grey-cheeked bulbul	<i>Alophoixus bres</i>	2	2	0	4	Unknown	10	243	40,091	260,143	LC	Stable/increasing
Chestnut-backed scimitar babbler*	<i>Pomatorhinus montanus</i>	3	1	0	4	Stable/increasing	1	34	114,544	75,000	LC	Stable/increasing
Oriental white-eye	<i>Zosterops palpebrosus</i>	2	3	0	5	Unknown	254	809	20,045	29,706	LC	Declining from habitat loss
Asian glossy starling	<i>Aplonis panayensis</i>	4	1	0	5	Stable/increasing	422	786	28,636	83,350	LC	Unknown
Common hill myna	<i>Gracula religiosa</i>	0	5	0	5	Declining	352	440	572,722	1,137,813	LC	Declining from trade
Daurian starling	<i>Agropsar sturninus</i>	1	0	0	1	Unknown	1579	264	91,636	345,250	LC	Unknown
Orange-headed thrush	<i>Geokichla citrina</i>	0	0	0	0	Unknown	50	25	229,089	480,000	LC	Causing a decline
Oriental magpie-robin*	<i>Copsychus saularis</i>	1	3	4	8	Severely Declining	2500	1145	183,271	347,362	LC	Stable/increasing
White-rumped shama	<i>Copsychus malabaricus</i>	0	2	4	6	Severely Declining	2055	1492	171,817	2,500,000	LC	Declining from trade
Greater green leafbird	<i>Chloropsis sonnerati</i>	0	3	0	3	Declining	5	842	314,997	868,405	LC	Declining from habitat loss
Pin-tailed parrotfinch	<i>Erythrura prasina</i>	1	0	0	1	Unknown	270	90	25,773	107,500	LC	Stable/increasing
Scaly-breasted munia	<i>Lonchura punctulata</i>	4	0	0	4	Stable/increasing	6270	6438	2,864	1,158	LC	Stable/increasing
White-headed munia	<i>Lonchura maja</i>	3	0	1	4	Stable/increasing	4870	5151	4,868	8,704	LC	Stable/increasing
<i>B. Regularly traded species for which incomplete market data were available</i>												
Fire-tufted barbet	<i>Psilopogon pyrolophus</i>	5	4	0	9	Unknown	1163	229	Unknown	162,083	LC	Declining from habitat loss
Common green magpie*	<i>Cissa chinensis</i>	0	4	1	5	Declining	127	135	Unknown	325,000	LC	Stable/increasing
Cinereous tit	<i>Parus cinereus</i>	3	0	0	3	Stable/increasing	49	160	NA	77,258	LC	Stable/increasing
Ochraceous bulbul	<i>Alophoixus ochraceus</i>	2	3	0	5	Unknown	32	446	NA	196,071	LC	Stable/increasing

(continued on next page)

Table 1 (continued)

English name	Scientific name	Number of stable/increasing responses	Number of Declining responses	Number of Severely Declining responses	Total number of responses when trend was known	Expert opinion on Sumatran population trend	Historical trade volume	Contemporary trade volume	Historical price (Indonesian Rupiah in 2013)	Contemporary price (Indonesian Rupiah in 2013)	IUCN status	Global population trend (BirdLife International, 2014)
Sumatran laughingthrush*	<i>Garrulax bicolor</i>	0	4	5	9	Severely Declining	Unknown	1080	Unknown	211,143	VU	Declining from trade
Sunda laughingthrush*	<i>Garrulax palliatus</i>	1	2	3	6	Severely Declining	400	820	Unknown	124,375	LC	Declining from habitat loss
Chestnut-capped laughingthrush*	<i>Garrulax mitratus</i>	0	3	3	6	Severely Declining	310	614	Unknown	119,778	LC	Declining from habitat loss
Black laughingthrush*	<i>Garrulax lugubris</i>	2	4	1	7	Unknown	13	59	Unknown	Unknown	LC	Declining from habitat loss
Silver-eared mesia*	<i>Leiothrix argentauris</i>	0	4	2	6	Severely Declining	138	184	Unknown	225,833	LC	Declining from habitat loss
Blue-winged leafbird	<i>Chloropsis cochinchinensis</i>	2	3	1	6	Unknown	220	847	Unknown	280,720	LC	Declining from habitat loss
Sumatran leafbird	<i>Chloropsis media</i>	0	3	1	4	Severely Declining	Unknown	Unknown	Unknown	Unknown	LC	Declining from habitat loss
C. Rarely traded species												
Grey-headed canary-flycatcher	<i>Culicicapa ceylonensis</i>	6	0	0	6	Stable/increasing	Not sold	Not sold	Not sold	Not sold	LC	Stable/increasing
Pygmy wren-babbler	<i>Phoenopyga pusilla</i>	6	0	0	6	Stable/increasing	Not sold	Not sold	Not sold	Not sold	LC	Declining from habitat loss
Mountain leaf warbler	<i>Phylloscopus trivirgatus</i>	5	1	0	6	Stable/increasing	Not sold	1	Not sold	30,000	LC	Stable/increasing
Yellow-breasted warbler	<i>Setercercus montis</i>	5	0	0	5	Stable/increasing	Not sold	Not sold	Not sold	Not sold	LC	Stable/increasing
Grey-throated babbler	<i>Stachyris nigriceps</i>	5	0	0	5	Stable/increasing	Not sold	Not sold	Not sold	Not sold	LC	Declining from habitat loss
Golden babbler	<i>Stachyridopsis chrysaea</i>	4	1	0	5	Stable/increasing	Not sold	Not sold	Not sold	Not sold	LC	Declining from habitat loss

\* These species are primary forest obligates (del Hoyo et al., 1992–2009).

+ These declining birds have subspecies that are endemic to Sumatra or nearby offshore islands. The historical trade volume is the median annual total from Shepherd et al. (2004). The contemporary trade volume is the annual estimate from co-author Giyanto's 2012–2013 data (see Supplementary material; price and volume data sources for details on this calculation). The historical price is the price from Basuni and Setiyani (1989) adjusted for inflation. The contemporary prices are median prices from the three contemporary sources (see price and volume data sources). The annual percent changes in price shown in Fig. 1 are the median of each price change calculated from the three price data sources. For white-headed munia, the overall trend is a slight decrease in price even though the median contemporary price is higher than the historical price.

identify the species that appear to be in most immediate need of conservation attention. To be placed into a category, a species had to have reports from a minimum of two observers. If only two observers commented on the status of a species (a situation that arose twice), both observers had to agree on its status. For species with >2 responses, we considered the trend to be known if  $\geq 75\%$  of responses were in agreement. If  $\geq 75\%$  of responses were Declining or Severely Declining, and at least 25% of responses were Severely Declining, we considered the species to be Severely Declining. We used the 25% threshold for Severely Declining because not all respondents qualified declines. The mean number of responses for species with enough responses to assign a trend was  $5.1 \pm 1.7$  SD (Table 1).

We tested the effect of using a stricter threshold (requiring 50% of responses to be Severely Declining rather than 25%) on our results. We could not test the effect of using a more liberal threshold (e.g., requiring just one Severely Declining response to be placed into that category) because four of the five species that received any Severely Declining responses were already classified as Severely Declining, and the remaining species, white-headed munia *Lonchura maja*, showed insufficient evidence of being in decline (Table 1).

We used del Hoyo et al. (1992–2009) to characterize the habitat preferences of our study species and identify which, if any, of the declining species were old-growth forest obligates. Bird names follow the taxonomy of Gill and Donsker (2014).

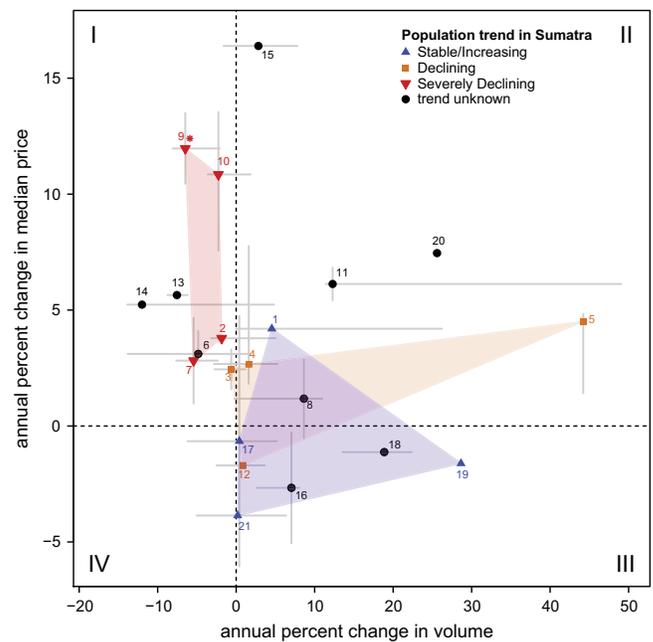
## 2.2. Relating changes in price and trade volume to population trends

We obtained price and trade volume data for 32 species of birds that are native to Sumatra and were sold primarily as pets from 1987–2013 in Medan's bird markets (Table 1). Historical and contemporary price and volume data came from the literature and from market surveys in Sumatra and Java (see Supplementary material for details). In Table 1, the 21 study species for which we found complete market data are listed under the heading "regularly traded species for which historical and contemporary price and volume data were available". The vast majority of individuals of these 21 species in the markets are wild-caught (99.9%; JBCH unpubl. data), so we believe any effects of sales of captive-bred individuals on prices are small. Eleven species for which we could find only partial market data are listed under the heading "regularly traded species for which incomplete market data were available".

We used the market data to plot species in price–volume change space as a function of the expert-derived Sumatran population trends (Fig. 1). To ease interpretation we designated four quadrants within the plots: I, increasing price, decreasing volume; II, increasing price and volume; III, decreasing price, increasing volume; IV, decreasing price and volume. To compare data from different years we present annualized changes in price and volume. For species with >2 years of data, we calculated the median annual change and we plot the range of values with whiskers (Fig. 1).

To evaluate whether changes in price and volume related to population trends, we plotted minimum convex hulls for species in each known population trend category and interpreted the graphical results. In addition, we formally tested whether species in each population trend category were different from species in other categories in price–volume change space using a permutational multivariate ANOVA (Anderson, 2001; see Supplementary material for details).

We used two approaches to compare expert-derived Sumatran population trends to global conservation status. First, we compared Sumatran trends to global International Union for the Conservation of Nature (IUCN)'s Red List status (BirdLife International, 2014). Second, we plotted our market data as a function of BirdLife



**Fig. 1.** Annual changes in price and trade volume in Indonesian markets of bird species as shown by their population trend in Sumatra (deduced from interviews with ornithologists; see Methods). The quadrants are labeled with large Roman numerals in the corners. If multiple years of data are available, medians are plotted and gray bars show the range of values based on multiple years of price and volume data (i.e., variability, not uncertainty). A red asterisk denotes the one species (*Pycnonotus zeylanicus*) that is classified by BirdLife International (2014) as globally imperiled. The minimum convex hulls show groups of species based on their population-trend categories. Key: 1 *Aplonis panayensis*, 2 *Pycnonotus dispar*, 3 *Oriolus chinensis*, 4 *Gracula religiosa*, 5 *Chloropsis sonnerati*, 6 *Geokichla citrina*, 7 *Copsychus saularis*, 8 *Zosterops palpebrosus*, 9 *Pycnonotus zeylanicus*, 10 *Copsychus malabaricus*, 11 *Lanius schach*, 12 *Pycnonotus bimaculatus*, 13 *Erythrura prasina*, 14 *Agropsar sturninus*, 15 *Psittacula alexandri*, 16 *Pycnonotus aurigaster*, 17 *Lonchura maja*, 18 *Pycnonotus goiavier*, 19 *Pomatorhinus montanus*, 20 *Alophoixus bres*, 21 *Lonchura punctulata*.

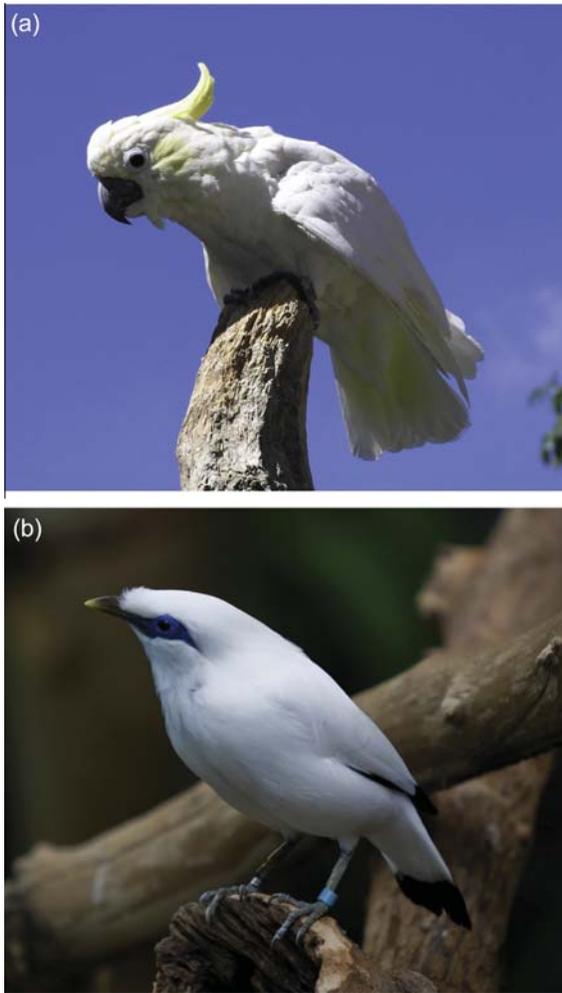
International's (2014) global population trend estimates. Some of BirdLife International's global population trends are derived from field monitoring, but most are based on expert opinion from across a given species's range. We divided the global population trends into three categories: stable/increasing; declining, with trapping specified as a contributing factor; and declining solely from habitat loss. When plotting minimum convex hulls for global trends, we compared species that were declining as a result of trapping to stable/increasing species because we were interested in examining the use of market data to identify trapping-caused declines.

## 2.3. Case studies of relationships between wild population size, price, and trade volume

To further explore whether market data can identify declining species, we studied multi-year changes in price, trade volume, and wild population size for two historically well-monitored, heavily-traded Indonesian birds, the Bali myna *Leucopsar rothschildi* and the yellow-crested cockatoo *Cacatua sulphurea* (Fig. 2). (See Supplementary material for data sources and the history of both species' declines and recovery efforts.)

## 2.4. Costs of market monitoring versus field surveys

To evaluate the efficiency of market-based versus traditional field monitoring, we compared the costs of monthly market monitoring (four days of market visits) to six continuous weeks of surveying wild populations, both done by Indonesian scientists in



**Fig. 2.** Two Indonesian birds that are highly valued as pets and Critically Endangered as a result of trapping: (a) yellow-crested cockatoo *Cacatua sulphurea* and (b) Bali myna *Leucopsar rothschildi*. Cockatoo photo by snowmanradio; myna photo by Brian Jelonek; both available on Wikimedia Commons.

Sumatra under our direction. The objective was to compare the costs of collecting information on the status of wild bird populations at one moment in time with market versus field-based methods. To look at changes over any given time period, each method would have to be employed at least twice, and therefore the costs of each method would be doubled or more. Approximately six continuous weeks of field surveys are needed to generate rough

density estimates of birds in one c. 20,000 ha patch of montane Indonesian forest (e.g., Harris et al., 2014). This level of survey effort is sufficient to obtain density estimates of most species. In a similar study, we used 10 min, 100-m radius audio/visual point counts to sample birds in two three-week field seasons on several North Sumatran mountains and observed an average of 107 species (JBCH unpubl. data). The Indonesian ornithologist hired for that project had >10 years' experience identifying Indonesian bird vocalizations; if the ornithologist needs to be trained first, the cost will increase substantially.

For the field surveys a minimum crew of an Indonesian ornithologist and three assistants were employed (Table 2), and a car was rented for eight days. In contrast, just one person is needed to record prices and volumes in market work. Food costs are higher while monitoring markets in cities, while transport costs are higher at remote field sites. Accommodation costs are not included in our analysis because residents of Medan collected our market data, and field workers stayed in tents. Thus, our comparison approximates the costs of realistic approaches for monitoring markets and wild populations in a systematic fashion. We note that our methods do not allow us to determine whether the two approaches characterize population trends with equal statistical power.

### 3. Results

#### 3.1. Regional versus global declines (hypothesis 1)

From our list of 38 species, experts identified 9 species as Severely Declining, 5 as Declining, and 11 as Stable/Increasing (trends of the remaining 13 species were unknown; Table 1). All six of the untraded species were classified as Stable/Increasing. All Declining species are able to persist outside of old-growth forest, and only two of the nine Severely Declining species (Sumatran and Sunda laughingthrushes *Garrulax bicolor* and *G. palliatus*) are old-growth forest dependent species. All 14 species that are either Severely Declining or Declining are regularly traded at moderate to high prices in the Medan markets (Table 1). Out of these 14 species, only two are recognized by BirdLife International as globally imperiled (straw-headed bulbul *Pycnonotus zeylanicus*, and Sumatran laughingthrush), and just three others (common hill myna *Gracula religiosa*, ruby-throated bulbul *Pycnonotus dispar*, and white-rumped shama *Copsychus malabaricus*) are considered to be declining from trade globally (Table 1). Two of the species that experts identified as declining in Sumatra (Sumatran laughingthrush and Sumatran leafbird *Chloropsis media*) are endemic to the island, and seven others have subspecies that are endemic to Sumatra or nearby offshore islands (del Hoyo et al., 1992–2009; Sheldon et al., 2009; Table 1).

**Table 2**

Cost comparisons from field and market bird surveys in Sumatra, Indonesia. See text for details.

Cost	Rate (Indonesian Rupiah)	Number of days	Subtotal (Indonesian Rupiah)	US dollars
<i>Field survey</i>				
Field ornithologist wage (per day)	350,000	42	14,700,000	\$1,297.78
Other wages (3 people * 100,000 per day)	300,000	42	12,600,000	\$1,112.38
Car rental (per day)	500,000	8	4,000,000	\$353.14
Food (three field meals per day * 10,000 per meal * three people)	90,000	42	3,780,000	\$333.72
			35,080,000	\$3,097.02
<b>\$3,097.02/107 species = \$28.94 per species</b>				
<i>Market survey</i>				
Market survey technician wage (per day)	250,000	4	1,000,000	\$88.28
Food (two city meals per day for one person * 50,000)	100,000	4	400,000	\$35.31
Gasoline for motorcycle	20,000	4	80,000	\$7.06
			1,480,000	\$130.66
<b>\$130.66/118 species = \$1.11 per species</b>				

The conversion rate from Indonesian Rupiah to US dollars was 8.83E–05 (XE currency converter, 3 April 2014).

The bold lines summarize the costs per species of the different monitoring methods.

### 3.2. Changes in price and trade volume compared to population trends (hypotheses 2–4)

All four species that experts identified as Severely Declining in Sumatra, and for which we have market data (straw-headed bulbul, ruby-throated bulbul, white-rumped shama, and Oriental magpie-robin *C. saularis*), were increasing in price but decreasing in trade volume over time (quadrant I; Fig. 1). Black-naped oriole, *Oriolus chinensis*, which was identified as Declining by the ornithologists, was also increasing in price but decreasing in trade volume. Of the remaining species identified as Declining, two were increasing in price and volume (quadrant II), and one was decreasing in price but increasing in volume (quadrant III). In contrast, three of the species identified as Stable/Increasing were decreasing in price but increasing in volume, and one was increasing in both price and volume. The price–volume signal of Severely Declining species was significantly different (perMANOVA;  $P = 0.03$ ,  $R^2 = 0.39$ ) from Stable/Increasing species, with Declining species intermediate between the aforementioned groups. There was no significant difference between Declining versus Stable/Increasing ( $P = 0.77$ ,  $R^2 = 0.015$ ) or Severely Declining and Declining combined compared to Stable/Increasing ( $P = 0.69$ ,  $R^2 = 0.046$ ).

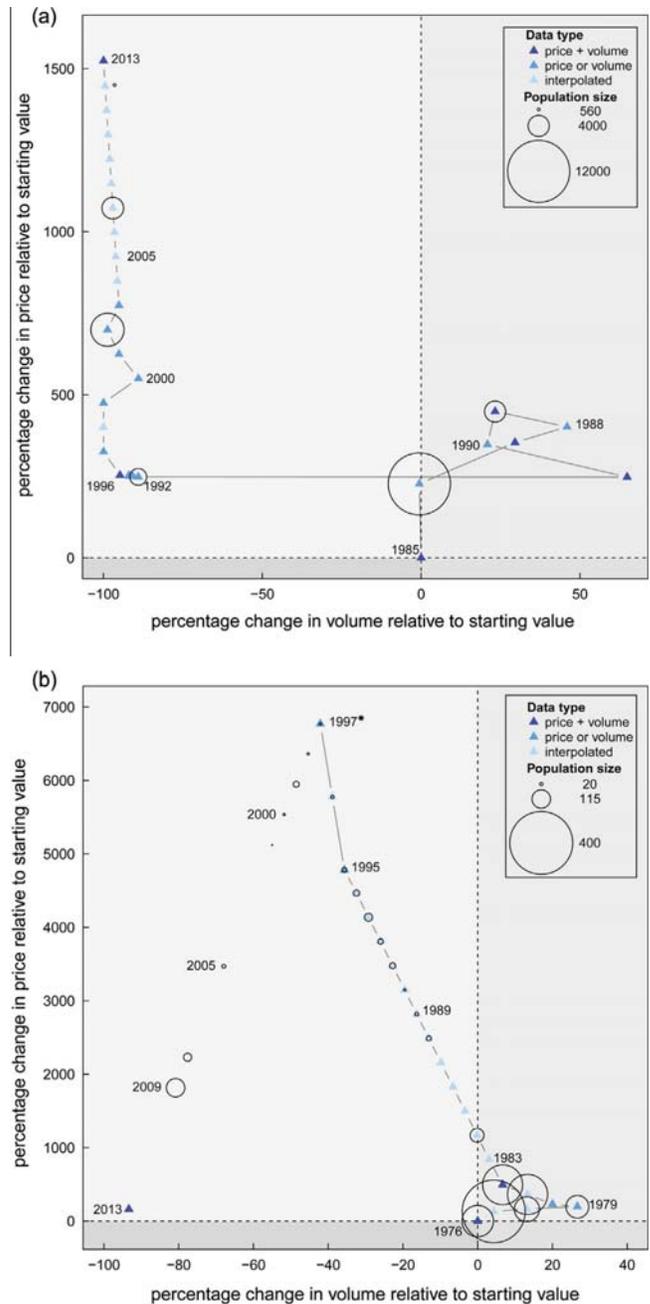
When we used a stricter threshold to designate species as Severely Declining, ruby-throated bulbul was reclassified as Declining, while straw-headed bulbul, white-rumped shama, and Oriental magpie robin remained classified as Severely Declining. When we ran the perMANOVA on this new classification, the results were similar, but there was weaker evidence for a difference in the positions of Severely Declining versus Stable/Increasing species ( $P = 0.055$ ,  $R^2 = 0.40$ ).

When species were classified based on their global population trends, the same general patterns emerged but there was more overlap between the groups (Fig. S1). Most of the species that are declining globally from trade were in quadrants I and II, while most of the stable/increasing species were in quadrants II and III. Although a larger proportion of stable/increasing versus declining species were decreasing in price, there was no statistically significant evidence for a difference in the positions of the groups (perMANOVA;  $P = 0.11$ ,  $R^2 = 0.16$ ).

### 3.3. Changes in price, trade volume, and population of yellow-crested cockatoo and Bali myna (hypothesis 5)

With both yellow-crested cockatoo and Bali myna, the price–volume trajectory through time showed a period of concurrent increases in price and volume, followed by a decline in volume with price continuing to increase. Throughout this time, the wild population declined (Fig. 3).

In the case of the cockatoo, market prices and volumes increased rapidly from 1980–1992, during which time the wild population was depleted (Fig. 3a). In 1993 Indonesia banned export of the species, and trade decreased dramatically; however, illegal trade continued (Table S2). The population initially recovered due to the export ban, but illegal trade again depleted the population, and prices soared through the 2000s (Fig. 3a; Table S2). In the case of the Bali myna, the wild population declined in the late 1970s and early 1980s, a period in which market prices and volumes increased slowly. In the mid-1980s through 1997, prices increased rapidly, while volume declined and the wild population sank to near-extinction, reaching a low of six birds (Fig. 3b; Table S3). The subsequent drop in price from 1997–2013 resulted from the Indonesian government’s efforts to reduce demand by flooding the market with captive-bred birds, which have lower value to collectors (PHPA/BirdLife International-IP, 1997; S. van Balen, pers. comm.).



**Fig. 3.** Relationships of price, trade volume, and population size over time for two Indonesian birds that are now Critically Endangered due to the pet trade. (a) yellow-crested cockatoo *Cacatua sulphurea* and (b) Bali myna *Leucopsar rothschildi*. Percentage changes in price and volume relative to the starting value (the origin) are plotted, so patterns are not directly comparable to the quadrants of Fig. 1. The sizes of the black open circles are proportional to the population sizes of the species in the wild. Data triangles are dark blue if price and volume data were available for that year; prices and volumes were interpolated between data points. Medium blue triangles are shown when either the price or the volume data were interpolated; triangles are light blue when both were interpolated. The 2012 cockatoo population size is plotted outside the blue circle to ease interpretation. The asterisk in (b) indicates the approximate time when the market for Bali mynas was flooded with captive-bred birds, causing the price to drop. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Thus, market volume and price trends appear to accurately track wild population levels in these two well-studied species, after accounting for an intentional effort to flood the market with captive-reared birds in the case of the myna.

### 3.4. Costs of market surveys versus field surveys (hypothesis 6)

Our cost comparison found that market monitoring is much less expensive than field surveys. Field sampling in Sumatra gathered population data on 107 bird species and cost approximately \$3100 (\$29 per species), while market monitoring collected price and volume data on ~120 species at a cost of \$130 (\$1 per species) (Table 2).

## 4. Discussion

Ornithologists identified 14 of our study species as declining in Sumatra. These declines appear to be attributable in large measure to the pet trade. Each of the declining species is regularly or heavily traded. Moreover, their habitat requirements do not suggest that logging or other forms of land-use change are driving the declines: only two of the species (Sumatran and Sunda laughingthrushes) are restricted to old growth forest, three (black-naped oriole, ruby-throated bulbul, and Oriental magpie-robin) inhabit agricultural woodlands; and the remaining nine occur in forest edges or secondary forest (del Hoyo et al., 1992–2009). In addition, none of the untraded species (all of which are considered to be of Least Concern by the IUCN;  $n = 6$ ), was identified as declining by ornithologists. Therefore, we argue that the declines the ornithologists observed are not primarily due to deforestation. Nor is there evidence for a widespread decline of Sumatra's birds caused, for example, by a pathogen, inasmuch as all of the untraded species and 5 of the traded species (all of which are Least Concern) were classified as Stable/Increasing.

The fact that only five of our 14 declining species in Sumatra are on the Red List or classified as declining globally from trade suggests that most of them are facing regional, not global, declines. Nonetheless, if the declines reported by experts are real, then evolutionarily distinct lineages in the form of endemic subspecies could be at risk. For example, silver-eared mesia *Leiothrix argentauris* and orange-spotted bulbul are represented by distinctive endemic Sumatran races, with one of the bulbul's races probably meriting treatment as a separate species (J.A. Eaton, pers. comm.; N.J. Collar, pers. comm.), and both species are Severely Declining in Sumatra. Localized races are often preferred by Indonesian bird buyers (Shepherd, 2006; JBCH, unpubl. data; S. van Balen, pers. comm.), which elevates the urgency of addressing the effects of trapping. As a case in point, the Nias hill myna *Gracula robusta*, an offshore island population of common hill myna that some authors treat as a full species (Feare and Craig, 1998; Gill and Donsker, 2014), is more highly prized than its Sumatran mainland cousin because of its large size and loud voice (T. Ouhel, pers. comm.). Incessant trapping and deforestation have probably already caused this species' extinction in the wild (T. Ouhel, pers. comm.).

Turning to the markets, our results suggest that bird species that are increasing in price but decreasing in trade volume (quadrant I; Fig. 1) are likely to be undergoing population declines in the wild. The concentration of Severely Declining species in quadrant I is consistent with a positive interaction between rarity and demand, which, in some cases, can push species to the brink of extinction (Courchamp et al., 2006; Ling and Milner-Gulland, 2006; van Balen et al., 2013). The increases in price and decreases in volume for these species suggest that supply is unable to keep up with growing demand.

Less intuitive than the quadrant I results is our finding that some species that are increasing in both price and volume (quadrant II) may be undergoing population declines in the wild. It may be that changing preferences (either because of fashion or because the species is a substitute for another species that is

becoming harder to obtain) are causing a shift in demand. This demand shift may have increased the price that consumers are willing to pay and, consequently, increased the number of birds that trappers are supplying to the market. The price trend could show a growing scarcity that is not yet reflected in the trade volume: prices increasing perhaps because trappers are having to seek birds over an increasingly large area, or because supply has become more reliant on shipments from outside Sumatra. Alternatively, the pattern could be explained by cage birds being Veblen goods that do not respond to customary price signals because their demand is tied, in part, to the perception that they are status items: increases in price result in increased demand (Veblen, 1899). Regardless of the underlying mechanism, some of the species in quadrant II are probably in need conservation attention (e.g., common hill myna and greater green leafbird *Chloropsis sonnerati*). We posit that quadrant II species are liable to move into quadrant I as trade continues, and therefore merit monitoring in the field.

Our results suggest that species with falling prices are likely to have stable or increasing populations in the wild. Nonetheless, if new sources of birds are found, prices may not increase after some local populations are exhausted. Therefore, falling price should not be used as the sole indicator of a species' status in the wild.

There was a significant difference between the price/volume changes in Severely Declining compared to Stable/Increasing species, but not between Severely Declining combined with Declining compared to Stable/Increasing. This result suggests that market data work reasonably well for identifying species undergoing serious declines, but less well for species undergoing moderate declines. We emphasize that the market quadrants are not a perfect representation of the population trends reported by ornithologists. (Nor are the impressions of the ornithologists necessarily a perfect representation of trends deduced by methodical field studies.) For example, a Stable/Increasing species appears in quadrant II (Asian glossy starling *Aplonis panayensis*), while a Declining species (orange-spotted bulbul) appears in quadrant III (Fig. 1). Further tests that combine locally collected price and trade volume data with high resolution wild population estimates are needed to confirm our findings and monitoring recommendations.

The historically well-documented cases of the yellow-crested cockatoo and Bali myna support the notion of using price and volume signals as a proxy for population changes. The price/volume patterns for these two birds more or less followed the predicted trajectory: concurrent increases in price and volume, followed by further increases in price coupled with declining volume as population sizes decrease rapidly. These patterns provide additional evidence of the dangerous situation of species that are increasing in price and decreasing in trade volume. In addition, the case studies show that trade enforcement and management intervention can affect price and trade volume; such interventions should be taken into consideration when analyzing market data. Our 21 study species with market data are subject to minimal, if any, trade enforcement in Indonesia (Shepherd, 2006) so we believe that enforcement interventions played a negligible role in the patterns presented in Fig. 1.

The cost comparison of market versus field monitoring highlighted the potential efficiency of market analyses. Our cost estimates are based on our experiences in Sumatra, but we have no reason to believe that the large cost disparity between field and market surveys would not apply across Southeast Asia. Market monitoring, therefore, appears to be a cost-effective way to gather preliminary information on a large number of traded species, although it cannot replace field monitoring, which is essential to obtain accurate information on population trends. Market monitoring may best be used as an early warning system to identify species that warrant field monitoring, especially in regions where

large numbers of species are traded and where fieldwork is rarely done.

Finally, our analysis suggests that information on price trends alone is useful in characterizing population trends of traded species. If prices and trade volumes are both available, more detailed inference can be made because the dynamics of supply and demand are captured. Unfortunately, price information is much less frequently collected than volume. Admittedly, sellers may become suspicious if data collectors repeatedly ask for prices but never purchase a bird, whereas volume is more easily noted without having to interact with the seller. Nonetheless, we emphasize the importance of collecting prices to allow market data to be used to assess the effects of trapping on species. Ideally, data on price, volume, and the locations where animals are sourced would be collected systematically and stored and accessed via a secure website, thereby allowing multiple individuals and organizations to contribute to and utilize the information for conservation purposes. Countries that are major consumers of wildlife (i.e., those that create the demand) have a responsibility to assist source nations in creating market-monitoring programs and subsequent field studies (although it should be noted that Indonesia is the largest “consumer” of birds in Southeast Asia; Nash, 1993). Long-term collection of market data could provide countries with sorely needed information to better implement domestic trade regulations and the Convention on International Trade of Endangered Species of Wild Flora and Fauna (CITES) (Phelps et al., 2010). Our use of market data in this study to identify species in trouble is best viewed as a proof-of-concept, which, we hope, will be followed by other studies of markets for birds and other vertebrates.

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## Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.biocon.2015.04.009>.

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