Contributed Paper

Measuring the impact of the pet trade on Indonesian birds

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Abstract: *The trade in wild animals involves one-third of the world's bird species and thousands of other vertebrate species. Although a few species are imperiled as a result of the wildlife trade, the lack of field studies makes it difficult to gauge how serious a threat it is to biodiversity. We used data on changes in bird abundances across space and time and information from trapper interviews to evaluate the effects of trapping wild birds for the pet trade in Sumatra, Indonesia. To analyze changes in bird abundance over time, we used data gathered over 14 years of repeated bird surveys in a 900-ha forest in southern Sumatra. In northern Sumatra, we surveyed birds along a gradient of trapping accessibility, from the edge of roads to 5 km into the forest interior. We interviewed 49 bird trappers in northern Sumatra to learn which species they targeted and how far they went into the forest to trap. We used prices from Sumatran bird markets as a proxy for demand and, therefore, trapping pressure. Market price was a significant predictor of species declines over time in southern Sumatra (e.g., given a market price increase of approximately $50, the log change in abundance per year decreased by 0.06 on average). This result indicates a link between the market-based pet trade and community-wide species declines. In northern Sumatra, price and change in abundance were not related to remoteness (distance from the nearest road). However, based on our field surveys, high-value species were rare or absent across this region. The median maximum distance trappers went into the forest each day was 5.0 km. This suggests that trapping has depleted bird populations across our remoteness gradient. We found that less than half of Sumatra's remaining forests are >5 km from a major road. Our results suggest that trapping for the pet trade threatens birds in Sumatra. Given the popularity of pet birds across Southeast Asia, additional studies are urgently needed to determine the extent and magnitude of the threat posed by the pet trade.*

Keywords: decline, overexploitation, Sumatra, trapping, wild population, wildlife trade

Medición del Impacto del Mercado de Mascotas sobre las Aves de Indonesia

Resumen: *El mercado de animales silvestres involucra a un tercio de las especies de aves del mundo y a miles de otras especies de vertebrados. Aunque algunas especies se encuentran en peligro como resultado del*

mercado de vida silvestre, la falta de estudios de campo complica la estimación de cuán seria es esta amenaza para la biodiversidad. Utilizamos datos sobre los cambios en la abundancia de aves a través del espacio y el tiempo y la información de entrevistas de trampeadores para evaluar los efectos del trampeo de aves silvestres para el mercado de mascotas en Sumatra, Indonesia. Para analizar los cambios en la abundancia de aves a lo largo del tiempo utilizamos los datos recolectados durante 14 años de censos repetidos de aves en un bosque de 900-ha en el sur de Sumatra. En el norte de Sumatra, censamos aves a lo largo de un gradiente de accesibilidad para el trampeo, desde las orillas de las carreteras hasta 5 km dentro del interior del bosque. Entrevistamos a 49 trampeadores de aves en el norte de Sumatra para aprender cuáles especies son sus objetivos y cuán lejos se adentraron en el bosque para atraparlas. Utilizamos los precios de los mercados de aves de Sumatra como sustitutos para la demanda y, por lo tanto, de la presión de trampeo. El precio del mercado fue un pronosticador significativo de la declinación de las especies a lo largo del tiempo en el sur de Sumatra (p. ej.: dado un incremento en el precio del mercado de aproximadamente $50, el cambio en el registro de abundancia por año disminuyó en un promedio de 0.06). Este resultado indica una conexión entre el mercado de mascotas basado en la venta y las declinaciones de especies a nivel de la comunidad. En el norte de Sumatra, el precio y el cambio en la abundancia no estuvieron relacionados con la distancia desde la carretera más cercana. Sin embargo, con base en nuestros censos en el campo, las especies de alto valor fueron raras o estuvieron ausentes en esta región. La distancia máxima media que los trampeadores se adentraron en el bosque cada día fue de 0.5 km. Esto sugiere que el trampeo ha mermado a las poblaciones de aves a través de nuestro gradiente de la distancia a la carretera más cercana. Encontramos que menos de la mitad de los bosques que permanecen en Sumatra están a >5 km de una carretera principal. Nuestros resultados sugieren que el trampeo para el mercado de mascotas amenaza a las aves en Sumatra. Dada la popularidad de las aves mascotas en el sureste asiático, se necesitan urgentemente estudios adicionales para determinar la extensión y la magnitud de la amenaza generada por el mercado de mascotas.

Palabras Clave: declinación, mercado de vida silvestre, población silvestre, sobre-explotación, Sumatra, trampeo

Introduction

The trade in wild animals is worth billions of dollars annually (Wilson-Wilde 2010) and encompasses one-third of the world's bird species and thousands of reptile, amphibian, mammal, and fish species (e.g., Schlaepfer et al. 2005; Butchart 2008; Nijman 2010; Raghavan et al. 2013). A small number of species have been added to the International Union for Conservation of Nature Red List of imperiled species due to trapping for the pet trade (e.g., Spix's Macaw [*Cyanopsitta spixii*] in South America; Bali Myna [*Lecopsar rothschildi*], greater slow loris [*Nycticebus coucang*], and red line torpedo barb [*Sahyadria denisonii*] in Asia; and radiated tortoise [*Astrochelys radiata*] in Madagascar) (Collar et al. 1992; IUCN 2015), but they constitute severe cases involving well-studied species. Scientists have not assessed the impact of the pet trade on wild populations for the vast majority of vertebrates sold in markets.

Southeast Asia is a global hotspot for the wild bird trade; >1000 species are sold (J. B. C. H., personal observation) for pets, song competitions, religious animal release, traditional medicine, and food (e.g., McClure & Chaiyaphun 1971; Jepson 2008; Chng et al. 2015; Su et al. 2015). Indonesia is the largest importer and exporter of wild birds in Asia (Nash 1993). Indonesian bird trappers use mist nets, bird lime (an adhesive made from tree sap), snares, and traps baited with decoy birds to catch target species (Shepherd et al. 2004), and mist nets appear to be increasingly popular (J. B. C. H., et al., personal ob-

servation). The deep cultural roots of bird keeping in Indonesia have contributed to the country's active bird trade, whereas human population growth and the rise of bird-song competitions have intensified the pressure on Indonesia's wild birds (Jepson 2010). For example, the highly prized Straw-headed Bulbul (*Pycnonotus zeylanicus*) has been extirpated from Java, has not been seen in Sumatra since 2009, and is in steep decline in Indonesian Borneo (Shepherd et al. 2013; BirdLife International 2015; Eaton et al. 2015). Many wild birds of multiple species sold in Javan markets are now sourced from Sumatra because trapping has depleted Javanese bird populations (Jepson & Ladle 2009; Shepherd 2012).

In Sumatra and Java, the ubiquity of trapping, including inside national parks, complicates efforts to assess the impact of the bird trade on wild populations. Possible ways forward are to analyze time series of systematic survey data, which are very scarce in Indonesia; study how bird abundance changes across remoteness gradients, which can serve as proxies for trapping intensity; and use population models to estimate extinction risk based on an estimate of the number of birds caught and the species' life-history traits. Given the lack of high-quality demographic information for virtually all Indonesia's birds, we focused on the first 2, field-based methods to examine the effects of trapping on bird communities in lowland and highland forests. We then related changes in bird abundance to species trait predictor variables to weigh the evidence for the relative effects of trapping, hunting, and habitat change. We also interviewed trappers to

determine how far they typically travel in search of valuable birds and their impressions of long-term changes in the catch rates of sought-after species. Finally, we estimated how much of Sumatra's forests may be safe from intensive trapping pressure. Given the high levels of trapping in Sumatra, we hypothesized that commercially valuable species would decline over time and as their proximity to roads increased.

Methods

Study Areas and Field Sampling

We studied changes in bird abundance from 1998 to 2011 at the Way Canguk Research and Training Area, Bukit Barisan Selatan National Park, Lampung province, southern Sumatra (Figs. 1 & 2). The Way Canguk area is one of the few remnants of lowland forest on level terrain in Sumatra (Whitten 2000; Miettinen et al. 2011). Way Canguk consists of 900 ha of lowland forest (50-m elevation and 4000-mm annual rainfall) that includes primary forest (currently 50% of the area) and forest disturbed by fire, drought, and logging (Kinnaird & O'Brien 1998). El Niño-related drought and fires damaged approximately 165 ha of forest in 1997 and 1998 (Kinnaird & O'Brien 1998; Adeney et al. 2006). Understory avian insectivore abundance is significantly lower in burned forest than in unburned forest, and open-field species have colonized burned areas in Way Canguk (Adeney et al. 2006). Way Canguk remained fire-free until 2015, and the forest has recovered, although some exotic plants have invaded (Kinnaird & O'Brien 1998). The site has been subject to trapping for the bird trade since at least the late 1990s (O'Brien & Kinnaird 1996), and trapping has continued up to the present time despite the presence of a research station and national park staff. The most commonly used trapping methods we observed in Way Canguk were attracting birds to branches covered in bird lime with a song recording or a decoy bird in a cage, mist nets combined with decoys or recordings, and snares for catching pheasants.

We quantified bird abundance at Way Canguk with 10-min, unlimited-radius, visual, and aural point counts in 1998–2002, 2007, and 2011 (Supporting Information). Sampling for this study was restricted to unburned forest and forest that was subject to only light ground fires in 1997–1998. Light fires burned dead leaf litter and damaged saplings slightly (leaving most with green leaves); large trees were unaffected (Adeney et al. 2006). We included the lightly burned areas in our survey so that we could increase our statistical power to detect changes in the avifauna over time.

We sampled bird communities along remoteness gradients in the Tanah Karo region of North Sumatra province (Karo, Deli Serdang, Langkat, and Dairi regencies) from March to November 2013 (Fig. 1). We sampled 2 areas of humid montane forest, one near Mt. Sinabung in the north and another near Lake Toba in the south (Supporting Information). These montane forests are important sources of wild birds for the Medan markets (Shepherd et al. 2004) and are therefore under heavy trapping pressure, but there are also remote forests far from roads that may have less trapping. In North Sumatra, we encountered trappers using bamboo traps with live decoys, bird lime placed on perches near live decoys and in fruiting trees, and pheasant snares. Sampling at the northern sites was done before the 2014 eruption of Mt. Sinabung.

We sampled birds aurally by walking transects from 0600 to 1030 in sunny or cloudy weather without wind or rain. Our transects were sections of forest trails approximately 400-m long separated by points spaced 300-m apart (straight line distance) (Fig. 2). Transects were surveyed in March and April (n = 74), June (n = 28), and November and December (n = 54) of 2013. We used the number of minutes spent walking each transect as a measure of survey effort. Transect elevation was approximated by averaging the elevation of the points at each end of each transect. Elevations sampled ranged from 1018 to 1875 m (average 1550 m) (Supporting Information). Approximately 92% of transects were in old-growth forests; the remaining transects were in secondary forests with large remnant trees. Open fields were not sampled. Remoteness was estimated by taking the straight-line distance from the center of the transect to the nearest major road (see Supporting Information for details). Transects ranged in remoteness from 0.1 to 4.9 km from the nearest road (average 1.8 km). Our field sampling was done under RISTEK permit 75/SIP/FRP/SM/III/2013. All data are archived at www.datadryad.org (doi:10.5061/dryad.jm607).

Species Trait Data

We related changes in abundance to species traits associated with 3 potential drivers of population change: the pet trade, subsistence hunting, and habitat change. We used market price as a proxy for demand for pets and, therefore, trapping pressure on a species (e.g., Crookes et al. 2005). Data on sale prices came from surveys in the 4 markets of Medan, North Sumatra, from July to September 2012 (Harris et al. 2015). Medan has the largest and most diverse wildlife markets in Sumatra; species are sold that come from across the island and the rest of Indonesia (Shepherd et al. 2004; Shepherd 2006). A group of Indonesian researchers asked sellers for bird prices during the market surveys (initial asking price, not negotiated) (Harris et al. 2015). When there were multiple prices for a species, we used the average price. We used body size as a proxy for hunting pressure, assuming that hunters would be more likely to target large-bodied species (e.g., Cardillo et al. 2005). Body sizes were the average body
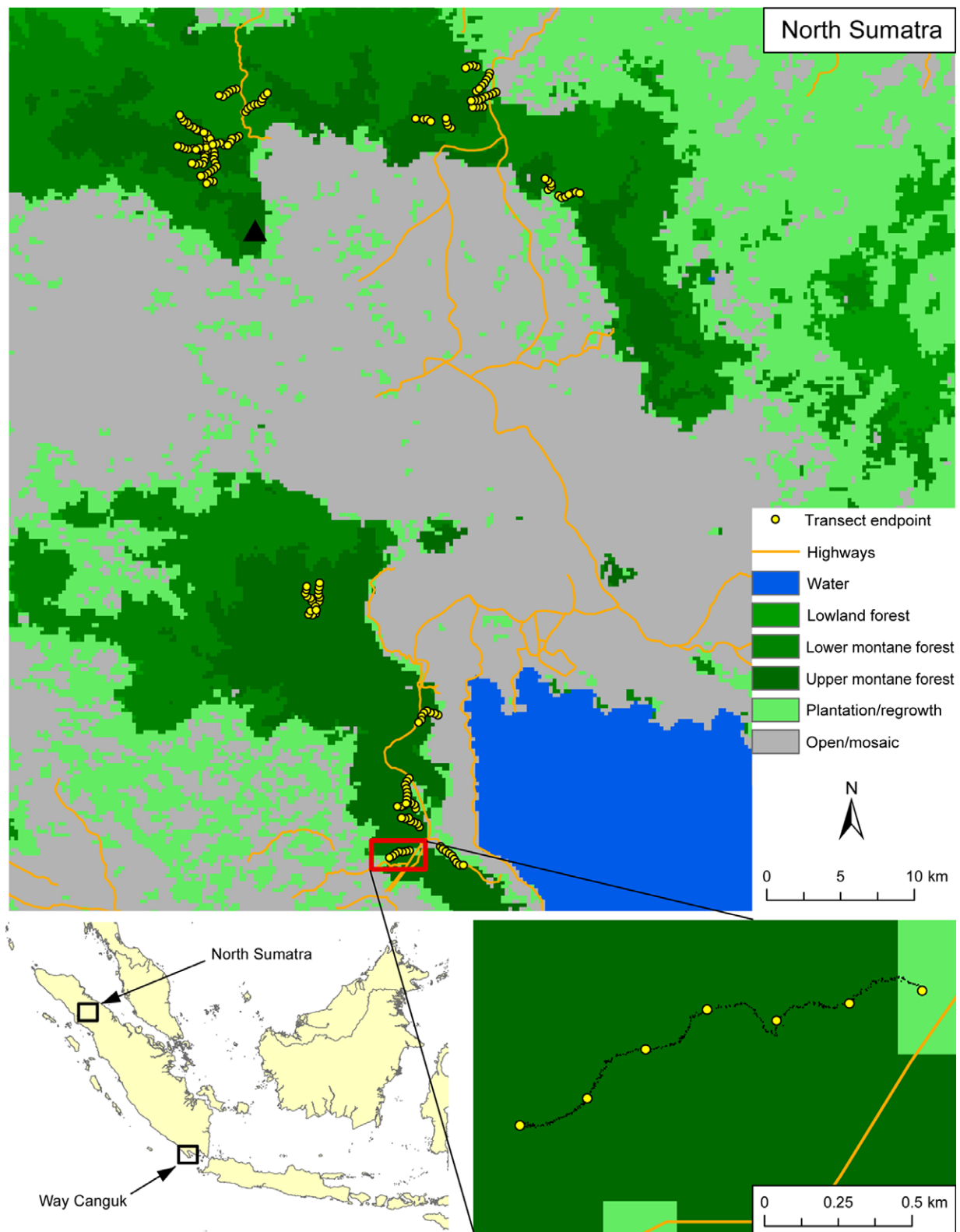
Figure 1. Locations of bird sampling sites within Sumatra (bottom left), locations of sampling sites and land cover (Miettinen et al. 2011) in northern Sumatra (main panel), and an example of a sampling transect in North Sumatra (bottom right) (black triangle, Mt. Sinabung).
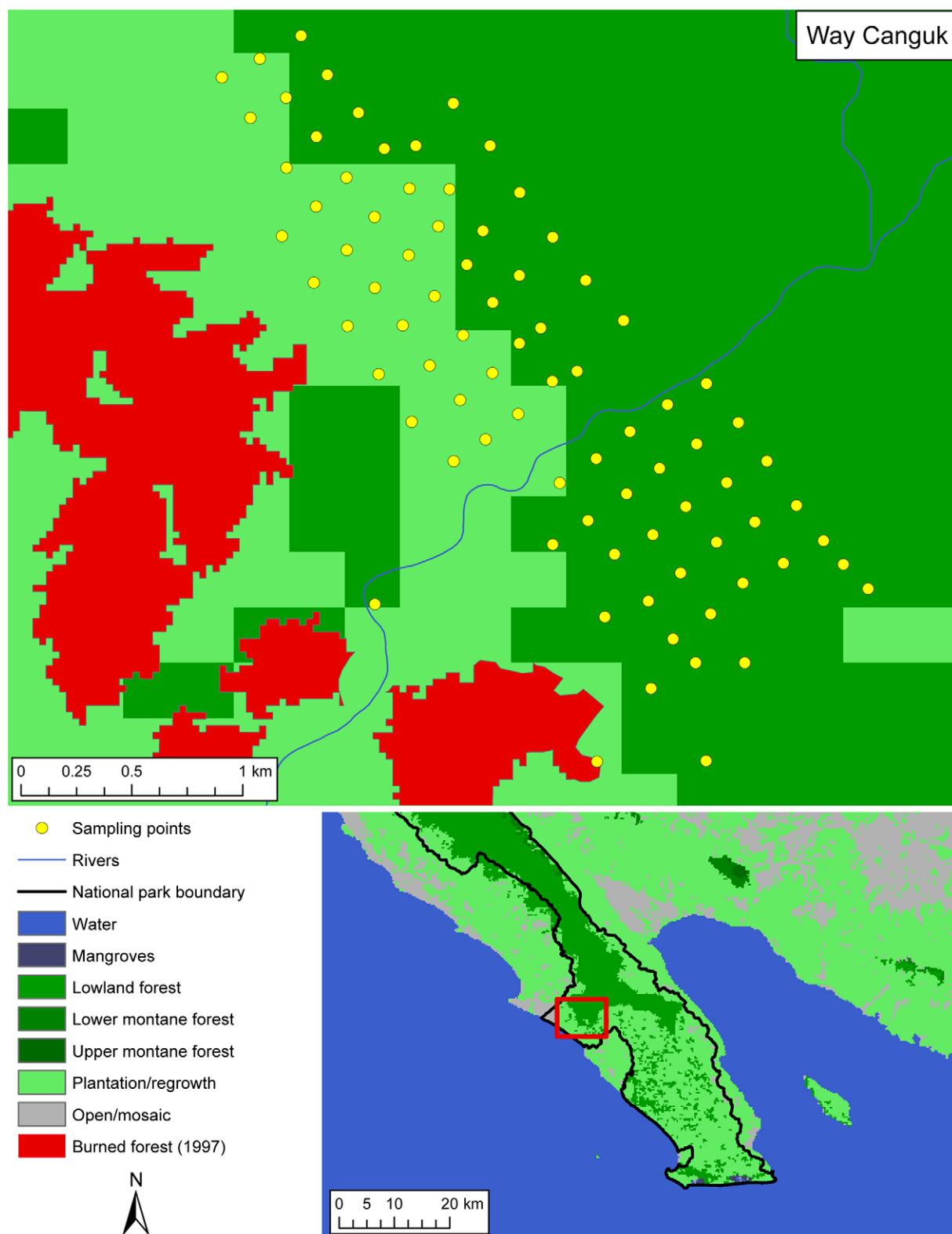
Figure 2. Location of bird sampling sites and land cover (Miettinen et al. 2011) in Way Canguk, Bukit Barisan Selatan National Park, Sumatra.

mass from a global database of avian ecological traits based on the ornithological literature (Sekercioglu et al. 2004; Sekercioglu 2012) updated with data from recent publications (del Hoyo et al. 1992–2009). We ranked species tolerance of anthropogenic disturbance on a scale from 1 to 6. For example, species with a disturbance tolerance of 1 were found only in the interior of primary forest, species with a score of 3 were found in both primary and disturbed secondary forests, and species with a score of 6 were nonforest species. We calculated these scores by combining habitat characterizations from Wells (1999, 2007) with the expert opinion of D.L.Y. (see Supporting Information for details).

In North Sumatra, drongos (*Dicrurus* spp.) and white-eyes (*Zosterops* spp.) were heard commonly, but we could not assign their calls to species. Because Sumatran Drongo (*D. sumatranus*) and Black-capped White-eye (*Z. atricapilla*) were the most commonly seen members of their respective genera in this area, we assigned the trait variables of those 2 species to the genus-level records.

Statistical Analyses

We used hierarchical Bayesian models to simultaneously model changes in abundance over time (Way Canguk) and space (North Sumatra) for each species and to relate these parameters to species traits to weigh the evidence for drivers of change in abundance (Gelman et al. 2013). We limited analyses to the set of species for which we had complete data on these traits and excluded species without price data (i.e., species which we did not find for sale in the Medan markets). We did not assume that species without price data had zero value because prices were derived from current markets, and there are many reasons why species with no price data may not be present in current markets (e.g., supply or demand).

For both Way Canguk and North Sumatra, we modeled the expected change, μ, in log-abundance over time (or change in abundance with distance from road; parameter $\beta 1$) for species i as a linear function of 3 variables representing distinct hypotheses:

$$\mu_{\beta 1,i} = \alpha_0 + \alpha_1 \text{price}_i + \alpha_2 \text{disturbance tolerance}_i$$
$$+ \alpha_3 \text{body size}_i, \qquad (1)$$

where α is a slope parameter. For both sites, we inferred the strength of each hypothesized driver of change by evaluating the sign, effect size, and 95th percentile Bayesian credible interval (BCI) of each of the slope parameters ((1)–3). All 3 variables were standardized to an SD 1 prior to modeling so that effect sizes would be directly comparable.

Although the general model structure and basis of inference is the same across the 2 locations, due to differences in data collection and other study-specific factors, the 2 models were parameterized slightly differently. For example, we controlled for transect elevation in North Sumatra in our estimates of $\mu_{\beta 1,i}$ because sites there spanned a montane gradient and bird abundance in Indonesia is related to elevation (e.g., Harris et al. 2014). The overall Bayesian model structure and the differences between the 2 models are described in Supporting Information.

To evaluate our statistical power to detect a trapping effect, we did 2 retrospective (a posteriori) power analyses. These analyses explored the probability of rejecting the null hypothesis that there is no relationship between market price and either temporal or spatial trends in bird abundance (H_0: $\alpha_1 = 0$) for Way Canguk and North Sumatra, respectively. In both cases, we used the posterior means for all other hyperparameters (α_0, α_2, α_3, and σ_α) and a range of values for α_1 in order to probabilistically simulate trends, $\mu_{\beta 1,i}$, for each of the species in both data sets. In both cases, we simulated 5000 sets of $\mu_{\beta 1,i}$ for each of 25 potential values of α_1, ranging from –0.01 to –0.25. We then ran a linear model (identical in parameterization to the formal analysis) on each simulated set of $\mu_{\beta 1,i}$ to determine the proportion of simulations where H_0 would be rejected by finding a 95% credible interval (CI) of α_1 that did not include 0.

Trapper Interviews

Between March and July 2013, we interviewed 49 bird trappers in 21 villages in the Karo, Deli Serdang, and Langkat regencies of North Sumatra province. Trappers ranged in age from 24 to 61 years (average 39 years; see Supporting Information for details, including the interview questions). Interview methods were approved by the Princeton University Institutional Review Board for Human Subjects research, protocol #6161 (https://www.princeton.edu/ria/human-research-protection/committee-information/). We asked trappers which species they seek, how much time they spend trapping them, and how much area they cover when looking for birds each day. We used this information to approximate the proportion of Sumatra's forests that is out of reach of the average bird trapper and to examine changes in catch of sought-after species over time.

We asked each trapper to specify how many kilometers they covered each day in search of birds to approximate how far from villages or roads trappers go to catch birds. Based on their reported distances and our own observations of trapping in the field (e.g., bird snares and perches with bird lime remnants), we estimated the percentage of Sumatra's forests that was out of reach of an average trapper. We did this by comparing the area of mature forest (lowland, montane, peat swamp, and mangroves) (Miettinen et al. 2011) near primary roads (Peta Dasar Indonesia road layers [Supporting Information]) and away from roads in ArcGIS version 10 (ESRI, Redlands, California). Given that our database included

only relatively major roads, our estimate of untrapped habitat is conservative.

We asked all 49 trappers to rank bird species based on their perceptions of the birds' sensitivity to trapping (i.e., vulnerability to population decline from trapping). We asked trappers to consider whether a particular species is easy to deplete based on how easy a species is to catch and the ability of the species' population to recover from exploitation. We then analyzed the cases of the 4 most vulnerable species that occur (or once occurred) in the montane forests we sampled in North Sumatra to see if the time spent searching for and catching these species had changed over time. To gather data on these temporal trends, we conducted in-depth interviews with 7 experienced trappers (all men with a mean of 15 years trapping experience). We began this section of the questionnaire by showing the trappers' photographs of 54 regularly traded species (selected by reviewing the native birds that are most commonly traded in Medan [Shepherd et al. 2004; Harris et al. 2015; Supporting Information]). If a trapper acknowledged catching the species in the photograph, then we asked him how long he spends searching for each species, how many he catches per day, and how these variables have changed over time. We used Gaussian mixed-effect models to test for statistical relationships between year and amount of time spent trapping and year and number of birds caught in the lme4 package in R (Bates et al. 2014; R Development Core Team 2015). We coded each trapper as a random intercept because trappers differed in their habits and their responses cannot be considered independent. We used Nakagawa and Schielzeth's (2013) method of calculating marginal and conditional R^2 of the mixed models.

Results

Bird Abundance

We recorded 154 species in Way Canguk, 78 of which had price data and were included in the analysis (hereafter traded birds). Based on posterior means of annual trends in abundance, 33 species of traded birds showed temporal trends in abundance (95% BCI for trends that did not include 0). Of these species, 23 species increased in abundance over time and 10 decreased in abundance (Supporting Information). Current market price and trends of species over time were significantly related; species with higher prices were more likely to decline over time (95% BCI on α_1 –0.10 to –0.03). This effect size indicated that given a market price increase of approximately $50 (527,706 Indonesian Rupiah), the log-change in abundance per year decreased by 0.03–0.10. Thus, above a market price of 500,000 Indonesian Rupiah (approximately $50 US), species were more likely to have declined from 1998 to 2011 than to have increased (Fig. 3). Abun-

dance trends of trapped birds at Way Canguk also showed the effects of forest succession; forest-dwelling species intolerant of disturbance increased over time (95% BCI on α_2 –0.10 to –0.03) (Table 1 & Fig. 3). The standardized effect size of price and habitat preference was approximately equal. There was no consistent evidence for a relationship between body size and population trend (weak negative relationship, 95% BCI on α_3 –0.05 to 0.02).

In North Sumatra, we recorded 70 bird species, of which 27 were traded and thus used in the analysis. Relationships between price, disturbance tolerance, or body size and bird abundance along the remoteness gradients were not significant (all 95% BCI overlapped 0) (Table 1 & Fig. 4). There was a nonsignificant trend of larger bodied species being commoner away from roads than near roads (95% BCI –0.07 to 0.23). One species was clearly more common away from roads: the Bronze-tailed Peacock-pheasant (*Polyplectron chalcurum*), which is hunted regularly (Supporting Information). Although true relationships between abundance and remoteness were uncertain in nearly all cases, parameter means indicated that most traded species (21 of 27 species or 78%) (Supporting Information) were more common at greater distances from roads.

Both abundance models showed strong posterior predictive abilities, indicating good model fit (Supporting Information), but the data provided relatively low power to reject the null hypothesis that there is no relationship between market price and either spatial or temporal trends in bird abundance. For Way Canguk, where our empirical findings rejected the null hypothesis, a standardized effect size for α_1 would have needed to be at least –0.13 to reject the null hypothesis 80% of the time. Our empirical finding for Way Canguk was an effect size of –0.064, at which point simulations rejected the null hypothesis only 31.8% of the time (Supporting Information). In North Sumatra, where our empirical findings did not reject the null hypothesis, a standardized effect size for α_1 would have needed to be –0.20 or more extreme to reject the null hypothesis 80% of the time. Our empirical finding for North Sumatra had an effect size of –0.090, at which point the null hypothesis was rejected 24% of the time in simulations (Supporting Information). The lower power for North Sumatra can be attributed to the lower number of traded species providing inference on trends.

Trapper Interviews and Spatial Analysis

The median maximum distance covered by trappers in search of birds was 5 km (mean 7.7 km; 25 trappers provided distance estimates). We also observed evidence of trapping (human-made perches with bird lime remnants) up to 4.9 km from the nearest road. Our spatial analysis showed that 47.6% of Sumatra's remaining mature forests are within 5 km of a major road (Fig. 5).
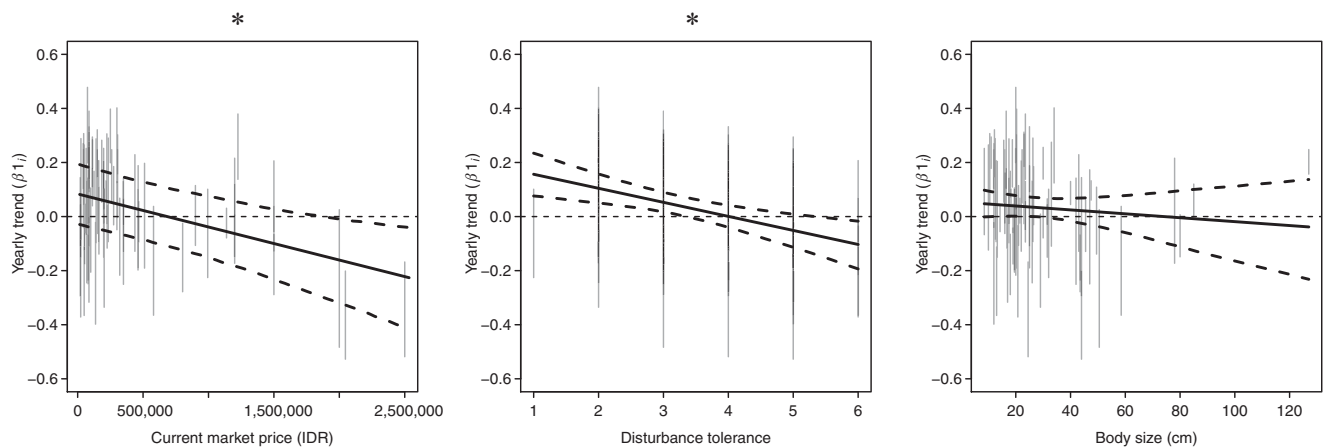
Figure 3. Relationships between bird price, disturbance tolerance, and body size and changes in abundance over time in Way Canguk, Sumatra (*, significant slopes as evidenced by 95% BCI that do not overlap 0; dashed lines, 95% credible intervals for the linear trend).

Table 1. Estimates of relative effects of price, disturbance tolerance, and body size (α parameters) on changes in bird communities over time in Way Canguk, Sumatra, and along remoteness gradients in northern Sumatra.

Parameter	Mean (95% credible interval)	SD
Way Canguk[a]		
intercept	0.256 (0.149–0.367)	0.056
price[b]	−0.064 (−0.103 to −0.026)	0.02
disturbance[b]	−0.063 (−0.101 to −0.028)	0.019
body size	−0.013 (−0.048 to 0.021)	0.017
Northern Sumatra[c]		
intercept	0.052 (−0.071 to 0.168)	0.06
price	−0.090 (−0.288 to 0.084)	0.092
disturbance	−0.070 (−0.244 to 0.103)	0.088
body size	0.083 (−0.066 to 0.231)	0.076

[a]*Lowland forest, southern Sumatra.*
[b]*Parameters with credible intervals around the coefficient estimates that do not cross 0.*
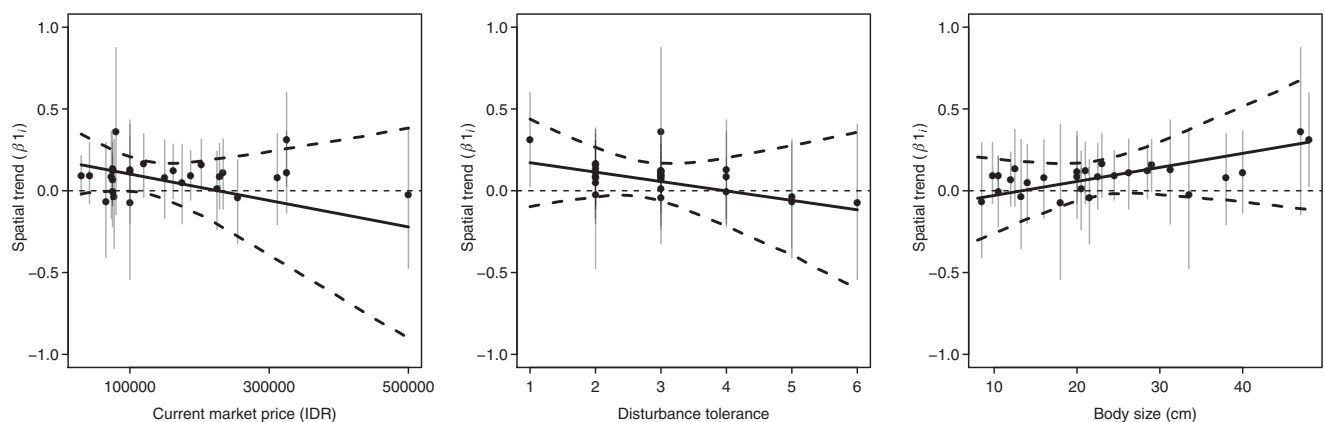[c]*Montane forest.*

Figure 4. Relationships between bird price, disturbance tolerance, and body size and changes in bird abundance along remoteness gradients (distance from the nearest road) in northern Sumatra (dashed lines, 95% credible intervals for the linear trend). The y-axis shows the coefficient of the abundance to remoteness relationship. There were no significant relationships.
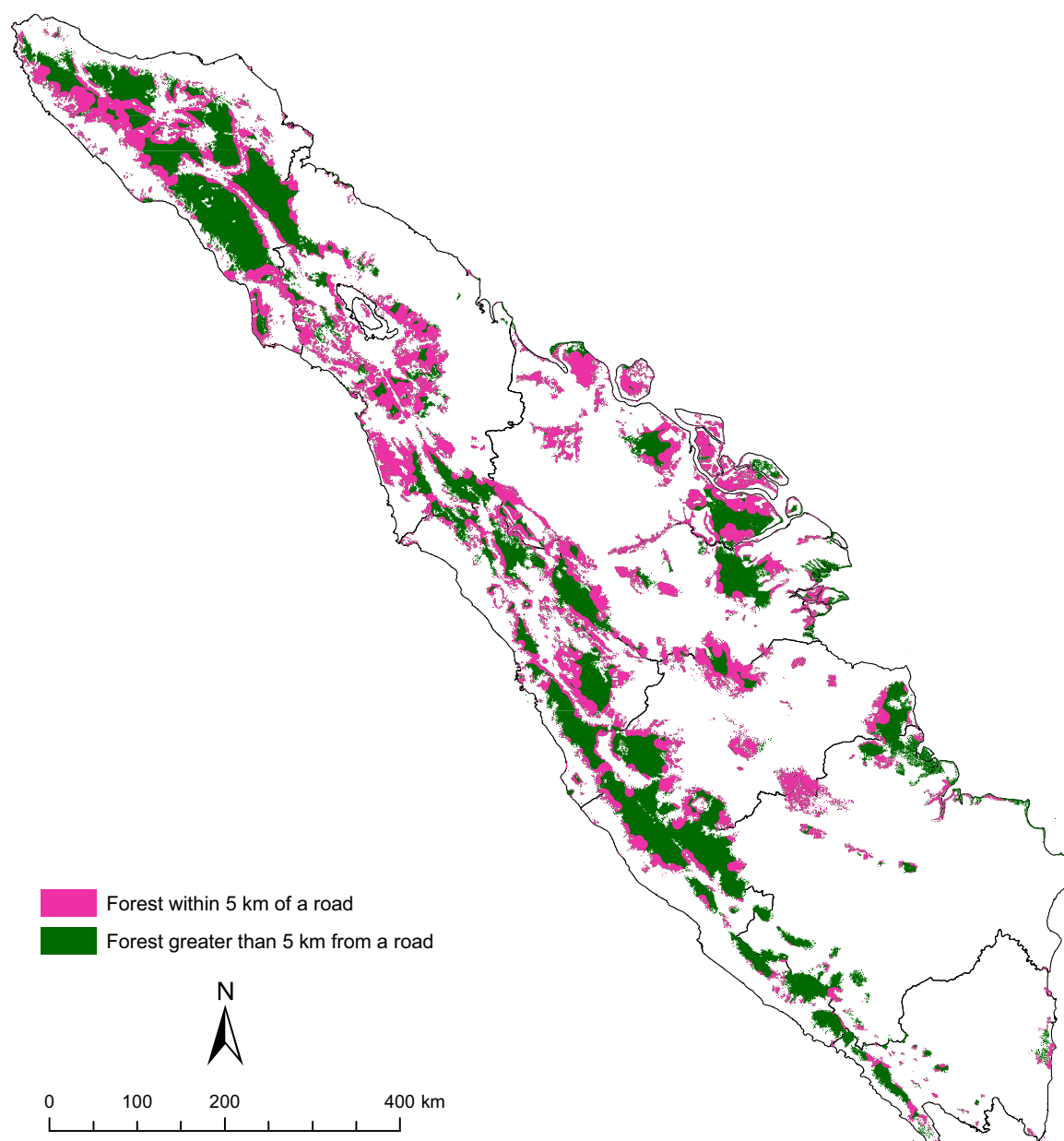
Figure 5. Sumatran forest cover in 2010 (darkest shade, forests >5 km from a road, 110,647 km^2 in area; lightest shade, forests within 5 km of a road, 52,622 km^2 in area).

Trappers caught 51 bird species and ranked, in descending order from extremely sensitive to highly sensitive, the following species as especially sensitive to trapping (i.e., vulnerable to population decline): White-rumped Shama (*Copsychus malabaricus*), Oriental Magpie Robin (*C. saularis*), Common Green Magpie (*Cissa chinensis*), Silver-eared Mesia (*Leiothrix argentauris*), Sumatran Laughingthrush (*Garrulax bicolor*), and Chestnut-capped Laughingthrush (*G. mitratus*). Based on our field work and the trapper interviews, 4 of these species occur or once occurred (before heavy trapping) in the montane forests we sampled in North Sumatra: Silver-eared Mesia, Common Green Magpie, and Sumatran and Chestnut-capped Laughingthrushes.

In-depth interviews revealed that experienced trappers are now spending more time searching for all 4 sensitive species than they did in the 1970s and 1980s (Supporting Information). Furthermore, daily catches of Silver-eared Mesia (which was once caught in large numbers according to trappers) have fallen to nearly 0 birds taken per day (only one trapper reported catching this species in 2013), and catches of the other 3 species showed nonsignificant negative trends (Supporting Information). We did not observe Silver-eared Mesias or Sumatran Laughingthrushes in any of our surveys.

Discussion

The most frequently cited threats to Southeast Asian birds are habitat loss and hunting for food (BirdLife International 2008; Wilcove et al. 2013). Here, we present multiple lines of evidence that indicate trapping for the pet trade is causing declines in populations of multiple Sumatran birds. In Way Canguk (southern Sumatra), we found a strong negative relationship between market price and population trend, which suggests that trapping is contributing to the decadal-scale declines of multiple species.

Tolerance to anthropogenic habitat disturbance was also a significant predictor of change in bird abundance in Way Canguk, where forest-dependent species tended to increase over time and open-field species decreased. We attribute these changes to recovery of the forest after the 1997 and 1998 fires. It is also possible that trapping contributed to declines in sought-after open-country species (e.g., Bar-winged Prinia [*Prinia familiaris*]); the relative importance of trapping and habitat change was probably related to the species' market value and life history. Furthermore, some forest-dwelling species that are heavily trapped declined significantly (e.g., White-rumped Shama and Blue-crowned Hanging-parrot [*Loriculus galgulus*]), which implicates trapping. The declines of sought-after species, regardless of habitat, indicated that changes in the avifauna at Way Canguk did not result only from forest regeneration. And, the lack of a relationship between body size and change in abundance suggests that hunting for food is not likely driving bird declines in the area. Population models could be used to delve into the life-history drivers underlying the population trends we observed, perhaps with the use of demographic data from related, well-known species as a proxy for Sumatra's poorly known species (e.g., Brook et al. 2002). A demographic modeling framework could then be used to test future conservation scenarios (e.g., increased enforcement or increased demand for certain species).

In North Sumatra, there were no clear relationships between any of our predictor variables and changes in abundance along the remoteness gradient. The lack of a price relationship may indicate that trapping is not affecting bird populations in the area. However, we posit that trapping has already depleted the bird community within all the forests we surveyed and we were thus unable to detect a price effect. Our reasons for this conclusion are 4-fold. First, trapping occurs regularly out to 5 km in our study area (based on trapper interviews and direct observations during our surveys). Second, 21 of our 27 study species, all of which are traded, had positive (albeit weak) relationships between distance from road and abundance. Third, 2 of the most coveted species— Silver-eared Mesia and Sumatran Laughingthrush—were once caught in large numbers in our study area (up to 30 birds/day), according to trapper interviews, but are now caught rarely. Finally, we did not encounter either of these species in our field surveys.

Our interview results indicated that trappers are spending more time searching for prized species in North Sumatra than they used to. Despite this increase in effort, the current catch of Silver-eared Mesia is near 0, and catches of the other 3 sensitive species are either stable or decreasing over time. This apparent decrease in catch per unit effort (for some species at least) is indicative of overharvesting (Baum et al. 2003; McNamara et al. 2015), which further supports the argument that bird populations have been affected by trapping in all of our field sites in North Sumatra. Indeed, our results indicate that the bird trade may be so pervasive in parts of Indonesia that ecologists and managers need to be alert to shifting-baseline syndrome caused by trapping (Papworth et al. 2009). If we had not found that trappers seek birds at least 5 km inside the forest and that the catch of sensitive species had decreased over time, we might have concluded that bird populations were unaffected by trapping in North Sumatra. Our trapper interview data could be subject to the shifting-baseline syndrome because trapping has gone on for so long in Sumatra. For example, van Marle and Voous noted that the Common Hill Myna *Gracula religiosa* was already in decline from trapping by 1988 (van Marle & Voous 1988).

By 2010, 30% of Sumatra's original forest cover remained (Margono et al. 2012). This alone constitutes a threat to many birds. However, our finding that 47.5% of the remaining forests are within 5 km of a major road, combined with the trapping impacts we detected, suggests that some of Sumatra's birds are in far greater danger than habitat-loss statistics alone would suggest. The actual extent of trapping in Sumatra's forests is likely higher than we found because our road data sets excluded most small roads, which provide trappers with access to forest birds. In addition, tropical forest fires are much more likely to occur near roads (Adeney et al. 2009), and Indonesian fires threaten biodiversity and contribute to climate change (Adeney et al. 2006; Lohman et al. 2007). Predicted increases in road development in tropical countries (Laurance et al. 2014) raise the alarming prospect that both trappers' access to forests and fire risk will continue to increase in the future.

Our results must be interpreted cautiously. It is possible that birds are declining for reasons unrelated to trapping (or hunting or habitat loss) and that their growing scarcity is driving up their prices in the markets. We assumed that price was an adequate proxy of demand for the various uses of wild birds in Indonesia and, therefore, of trapping pressure and that bird-trapper behavior in North Sumatra is reflective of trappers across Sumatra. Our historical trapper-interview data may be subject to a retrospective bias that could have led to overestimates of bird declines (e.g., O'Donnell et al. 2010). Finally, our

data provided relatively low power to detect a trapping effect in either data set.

Despite these caveats, our results highlight the urgent need for increased enforcement of trapping regulations in Indonesian protected areas. The trappers we interviewed readily stated that they often caught birds in national parks and that they rarely or never encountered park rangers.

Trapping for the pet trade occurs around the globe and involves many taxonomic groups (e.g., BirdLife International 2008; Rhyne et al. 2012; Bush et al. 2014). Our results suggest that, in Sumatra at least, trapping can have substantial effects on wild bird populations beyond the handful of species already recognized as imperiled by it. Unlike habitat loss, the impact of the pet trade cannot be seen via remote sensing and it is not visible through casual fieldwork. But, a growing body of evidence suggests the pet trade now poses a major, quiet threat to biodiversity in Indonesia and perhaps across Southeast Asia. We fervently hope that more conservation scientists will turn their attention to the pet trade to increase understanding of how widespread and serious a threat it is.

Acknowledgments

Supporting Information

Methodological details on bird sampling, remoteness estimation, trapper interviews, and statistical analysis (Appendix S1); sampling localities in Way Canguk (Appendix S2); sampling localities in North Sumatra (Appendix S3); trapper interview questions (Appendix S4); bird species shown to trappers (Appendix S5); JAGS Bayesian modeling code for Way Canguk and North Sumatra (Appendix S6); species-specific parameter estimates for Way Canguk (Appendix S7); species-specific parameter estimates for North Sumatra (Appendix S8); variance parameters from Bayesian models (Appendix S9); statistical tests of the changes in hours walked by trappers in search of sensitive species and numbers of birds trapped per day (Appendix S10); goodness-of-fit plots for Bayesian models for Way Canguk (Appendix S11) and North Sumatra (Appendix S12); number of birds caught per day by trappers when searching for sensitive species (Appendix S13); time spent by trappers searching for sensitive species (Appendix S14); and power analyses for Way Canguk (Appendix S15) and North Sumatra (Appendix S16) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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