Understanding retail dynamics of a regionally important domestic bird market in Guangzhou, China

Sicily Fiennes1,2 | Mingxia Zhang3 | Fuping Sun4 | Tien Ming Lee1

1Schools of Life Sciences and Ecology and State Key Laboratory of Biological Control, Sun Yat-sen University, Guangzhou, Guangdong, China
2Durrell Institute of Conservation and Ecology, School of Anthropology and Conservation, University of Kent, Canterbury, Kent, UK
3Guangxi Key Laboratory of Rare and Endangered Animal Ecology, Guangxi Normal University, Guilin, Guangxi, China
4Chengdu Zhucai Science and Technology Company Limited, Chengdu, China

Correspondence
Tien Ming Lee, Schools of Life Sciences and Ecology and State Key Laboratory of Biological Control, Sun Yat-sen University, Guangzhou, Guangdong, China.
Email: leetm@mail.sysu.edu.cn

Funding information
Guangdong Provincial Research Fund, Grant/Award Number: 42150016; Guangxi Key Laboratory of Rare and Endangered Animal Ecology Grant, Grant/Award Number: 20-A-01-03; National Talent Research Program in China, Grant/Award Numbers: 41180944, 41180953

Abstract
The prevailing methodology of noncontinuous wildlife market surveys contributes little to our understanding of the spatiotemporal variations of markets and their supply. Here, we investigate trends in bird trade in a large regional domestic market. Near-continuous monthly surveys at a pet market in Guangzhou, China discovered over 95,000 individuals of 147 species between 2011 and 2013. We analyzed optimal survey frequency, finding that autumn is the best season to detect maximal species diversity. In a mixed-effects model, we found that species-specific purposes for trade controls the occurrence of species across shops in a market. A buffer analysis showed that 13 of the 15 most abundant species are distributed within 200 km of the market. However, hotspots of range overlap for wild-caught, native species were found at great distances from the market within China and along China’s borders. Identifying the location of theoretical trapping bottlenecks (areas where trapping levels are high) from this market data can help identify regions (e.g., southwest China) that are affected by trade, where local bird populations may be experiencing residual impacts from harvesting. Our results provide insights to improve methodologies for monitoring wildlife markets and identify priority regions for population surveys of in-demand wild bird species.

KEYWORDS
bird trade, China, hotspots, monitoring, pet markets, retail dynamics, species richness, trapping bottlenecks, wildlife markets, wildlife trade

1 | INTRODUCTION

Wildlife market surveys are a common method to monitor place-specific markets (Barber-Meyer, 2010; Bušina...
et al. 2020; Pires, 2015). These usually include recording species inventories, shop/stall trading information, and collecting price data (Chng, Guciano, & Eaton, 2016; Eaton, Leupen, & Krishnasamy, 2017; Shepherd, 2006). Wildlife markets are dynamic systems, subject to import and export flows, seasonality, consumer demand, and law enforcement (McNamara et al., 2016). Market composition can be driven by current fashions (Harris et al., 2015). Species sold in few shops could indicate the species most in demand, due to their rarity (Courchamp et al., 2018; Harris et al., 2015), conversely, species that appear in many shops may be the most in-demand. Alternatively, the composition of markets may be explained by the seasonal changes in the phenology of wild, migratory species sold there.

In repeated surveys, popular or widely sold species in a market can act as proxies for consumer preference (Buruvalova et al., 2017; Hinsley, Verissimo, & Roberts, 2015) and market abundance has been used to approximate the numbers of wild populations (Eaton et al., 2015; Harris et al., 2015). However, the clandestine nature of wildlife trade renders repeat surveys difficult, as traders may notice repeated visits by certain individuals (Barber-Meyer, 2010; Souto et al., 2017). As a result, most market surveys are only snapshots of trade (Chng et al., 2016; Eaton et al., 2017; Shepherd et al. 2016a) or even the “tip of the iceberg” (Busína et al. 2020). Thus, “snapshot” market data typically do not capture the spatio-temporal variation and turnover of wildlife products. Therefore, regular monitoring remains crucial to uncover market dynamics.

In Asia, place-specific wildlife markets are (partially) open street markets, which sell wildlife and their associated parts (Arena, Steedman, & Warwick, 2012). Daily markets act as consistent, attractive advertisements for wildlife (Yiming & Dianmo, 1998). Within Asia, China’s growing consumer power (Li, 2007) and increasing gross domestic product (GDP) have allowed the market for wildlife to rapidly amplify (Liang, Cai, & Yang, 2013; Zhang, Hua, & Sun, 2008; Zhang & Yin, 2014). In urban areas, consumers are now following fashionable trends, such as owning cats, dogs, and more exotic pets such as reptiles and birds (Liang et al., 2013). In the late 1990s, local urban markets for wild meat started to develop and subsequently, urban pet markets began to appear (Liang et al., 2013), though pet markets may also be visited for the purposes of buying meat. Birds are widely affected by wildlife trade in China and are engrained in traditional subcultures, such as for food, in Buddhist prayer release, singing and fighting competitions, and as pets or ornaments (Dai & Hu, 2017; Dai & Zhang, 2017; Li & Jiang, 2014; Severinghaus & Chi, 1999; Shiu & Stokes, 2008). There is a huge and growing demand for birds as pets in China (Zhang et al., 2008; Zhang & Yin, 2014), but the extent of trade is relatively unknown.

Environmental regulation relating to birds in China is in theory robust. In 1988, the first version of the Law of the People’s Republic of China on the Protection of Wildlife was introduced. Under this law, it was forbidden to hunt, sell or export wild-caught native birds, unless with a license administered by the National or Provincial Forestry and Grassland Administrations (FGA). In the 1990s, the FGA also directed a shift of the pet market to non-native, farmed species, such as African lovebirds (Agapornis spp.) (Li & Jiang, 2014). In 2003, the FGA released a Checklist of Commercial Use of 54 species with Matured Breeding Technology (2003, No. 121), which can be commercially traded after applying a license from the local FGA department.

In recent pre-COVID-19 years, one of the largest pet and aquarium markets in China was Huadiwan Flower and Pet Market, in Guangzhou city, the capital of Guangdong province (south China) (Gong, Chow, Fong, & Shi, 2009; Wang, Wang, Bowler, & Xiong, 2016). Although Guangdong is historically famous for its wildlife consumption culture, there has been growth in the number of markets supplying the pet trade since the early 2000s (Zhang et al., 2008; Zhang & Yin, 2014). Huadiwan was opened in 2001 as a daily, permanent “brick-and-mortar” market (Nijman, Langgeng, Birot, Imron, & Nekaris, 2018) in Liwan district. Permanent locations likely have consistent supply and enough commerce to provide the people that work there with a permanent occupation. In early autumn 2020, the Liwan location was permanently closed, and the market has since reopened in another location.

Subsequently, given that demand for pets in China has increased, Huadiwan may have been on par with other megadiverse urban bird markets in Southeast Asia (e.g., Pramuka market in Jakarta, Indonesia, and Chatuchak market in Bangkok, Thailand [Techachoochert & Round, 2013]). In 2017, due to the decline of several populations of songbird species in Asia, the Asian Songbird Extinction Crisis was declared (Lee, 2016; Shepherd & Cassey, 2017). One of the most well-documented declines due to unsustainable trade in China has been the Yellow-breasted Bunting, Emberiza aureola (Heim et al., 2021; Kamp et al., 2015). Trade at Huadiwan (and demand for pet birds across southeast Asia) may have been an important and under-reported element in driving this crisis. This current study will focus on the bird trade at Huadiwan between 2011 and 2013, during which time Huadiwan was likely Guangzhou’s most important pet market (Gong et al., 2009).

Many bird markets have been surveyed across Southeast Asia, with either a geographical or species-specific focus, although most of the survey effort has been concentrated on the megadiverse markets of Indonesia, particularly on the island of Java (Chng et al., 2016; Chng &
Eaton, 2016; Marshall et al. 2020). In recent years, more data on the spatiotemporal nature of the wildlife trade has become available. Indraswari et al. (2020) collated media-reported bird seizures over a 10-year period in Indonesia, and Heinrich et al. (2020), analyzed 17 years of confiscation records in Cambodia for several taxa, with particularly high rates of songbird trafficking recorded. Of the studies on bird markets in China, very few have consistently visited markets over long periods of time. One comparable study is from Dai and Zhang (2017), who performed monthly surveys of markets in Guiyang city, Southwest China, for 2 years. Huadiwan market was in a unique location due to its proximity to major port cities such as Shenzhen and Hong Kong, which also function as major wildlife trafficking hubs (Wong, 2017), whereas Guiyang is further inland.

Landbird trapping hotspots are well known in China along migratory flyways on the eastern coast (Kamp et al., 2015; Yong et al., 2015), in Yunnan province, in the southwest of China (Chang et al., 2019), and on Hainan island in south China (Liang et al., 2013). However, it is unclear if these hotspots are also linked to pet trade in the southeast of China. In research on domestic bird trade in Bolivia, Pires and Clarke (2011) hypothesized that wild species whose range is far from the market are highly unlikely to be sold there. Hence, we can explore the distances at which wild-caught species could be transported to Huadiwan. We would expect Huadiwan to behave like other typical regional bird markets, where wild-caught, native species naturally occur close to the market, to supply the market with enough birds.

Here, we address three interlinked research questions to describe how a geographically important bird market operates. We test for a high season in bird trade at Huadiwan, by analyzing market data to search for seasonal trends in the number of species sold. Second, our dataset is used to predict important variables that control the occurrence of wild bird species in the market shops. Last, to investigate potential market species hotspots in China, we plotted the ranges of wild-caught species sold in the market, across East and Southeast Asia, to visualize theoretical trapping bottlenecks for species. Trapping bottlenecks are areas where trapping levels are high, in part due to their richness in species in demand, for wildlife retail or otherwise (Kamp et al., 2015). This data can strengthen our understanding of market structure and functionality and understand the dynamics of wildlife retail, using monthly market survey data from 2011 to 2013.

2 | METHODS

The data were collected at Huadiwan market in the city of Guangzhou, China between October 2011, and June 2013 for 20 months. The market was surveyed each month (apart from May 2013) and random days within a month were chosen, including weekdays and weekends. Birds were recorded by counting openly displayed individuals offered for sale at individual shops, using the widely practiced direct counting method (DCM) (Busín et al. 2020). Species were identified by two skilled observers (alternating between authors MZ and FS). In each survey, abundance was only estimated at the whole market level to avoid suspicion from the shopkeepers; however, the number of shops in which a species occurred was recorded. Where possible, the source of birds and the age (adult, juvenile) were estimated, and the protection status, conservation status, and price were recorded.

International and national regulatory and protection mechanisms for birds were identified, such as the Convention on International Trade in Endangered Species (CITES) status (Appendix I, II or III) and whether the species was listed as Animals under the State Key Protection under the 2010 version of the China Wild Animal Protection Law (CPL). This law was split into two categories of Class 1 (141 species) and Class 2 (202 species) protection species. A third addition to this law is a list of important species of beneficial or economic and scientific value (includes over 707 bird species [Li, 2007]), hereafter referred to as the “third level” of protection. These laws have now been revised. Although the captive-bred list was abolished in September 2012, for the duration of the survey the list was still effective.

Following Nijman et al. (2018), we assumed that birds are not transferred between shops and that observations between surveys are independent. Species occurrence (i.e., how many shops a species is present in the market, during a complete survey) can be used to estimate popular species in the market and provide more information on market structure than market abundance. Hence, “species occurrence among shops” is the proportion of shops in which a species was observed during one survey. For example, a species recorded in one out of 54 shops has a proportion of 0.019 for that survey.

2.1 | Identifying the peak season of bird trade at Huadiwan market

A species accumulation curve was built for the whole market, to see over how many surveys the richness of the market becomes saturated, in other words, to validate the effectiveness of the surveying method in terms of detecting most of the species available for sale in the market. (Indraswari et al., 2020).

The high resolution of this data enables the determination of the optimal time of the year to visit the market.
and perform a survey. Survey incidence data were transformed into a species-by-sampling unit (with shops as unit) matrix, for each season (autumn, winter, spring, summer) starting from Autumn 2011 to the beginning of summer 2013. Seasonal diversity estimates and associated 95% confidence intervals were computed, using three measures of Hill numbers of order q: species richness \( (q = 0) \), Shannon diversity \( (q = 1, \text{the exponential of Shannon entropy}) \) and Simpson diversity \( (q = 2, \text{the inverse of Simpson concentration}) \) in the R package “iNEXT” (Hsieh, Ma, & Chao, 2016).

### 2.2 Predicting species occurrences among shops in market

Of the birds in the market, there are 15 species on the captive breeding list (Fischer’s lovebird, *Agapornis*

| TABLE 1 | Summary of the all the variables considered for the model, their definition, and their categories |
|------------------|-------------------------------------------------|-------------------------------------------------|
| **Variables** | **Definition** | **Categories** |
| Survey timing (SU) | The time of the month when the survey was performed | Middle of the month on a weekday, middle of the month on the weekend, end of the month on a weekday and end of the month on the weekend |
| Price (PR) | The price of the species in the market, when available in RMB | The price was either in RMB or not recorded |
| Season (SE) | The season in which the surveys take place | Autumn (the first), winter, spring, summer |
| Year (Y) | The years in which the surveys took place | 2011, 2012, 2013 |
| Distance (DIST) | Minimum distance from the edge of the species range to the market | There is one category, measured in degrees |
| IUCN status (IUCN) | The International Union for Conservation of nature (IUCN) assigns a species listing status based on the risk of extinction of a given species | Least concern, near threatened, vulnerable, endangered and critically endangered |
| National and international status (ST) | The protection status of each species at the international trade level of the convention on international trade in endangered species (CITES) and at the national level within the China's wildlife protection law | CITES listed (only Appendix II or higher was considered), both CITES and, on the CPL, CPL only or unprotected |
| International Union for the Conservation of Nature (IUCN) use of bird in trade (IUCN.PURP) | The consumptive, end use of a species harvested from the wild | Food, pets/display animals, handicrafts/jewelry, sports hunting |
| Our purpose (OUR.PURP) | Mutually exclusive categories for why customers purchase birds at markets, based on the local knowledge of the authors | Good looking, songbird, prayer release, falconry, fighting, intelligence, fortune, food |
| Age (AD) | This was the suspected age of birds offered for sale. Sometimes both adults and juveniles for both species were seen, in which case this was recorded as yes for both categories for that observation. | Adult or juvenile |
| Population trend (POP) | The current population trend of a species as defined by the International Union for the Conservation of nature | Stable, increasing, decreasing, or unknown |

Note: These were market variables (SU, PR, SE, Y, DIST), conservation/regulatory variables (IUCN, ST), trade knowledge variables (IUCN.PURP, OUR.PURP), and life history variables (AD, POP).
Coturnix japonica; Orange-cheeked waxbill, Agapornis roseicollis; Red avadavat, Amandava amandava; Gouldian finch, Chloebia gouldiae; King quail, Coturnix chinensis; Japanese quail, Coturnix japonica; Orange-cheeked waxbill, Estrildidae melpoda; White-rumped munia, Lonchura striata; Budgerigar, Melopsittacus undulates; Cockatiel, Nymphicus hollandicus; Javan Sparrow, Padda oryzivora; Black-throated finch, Poephila cincta; Island canary, Serinus canaria; Zebra Finch Taeniopygia castanotis). Except for the Japanese quail, White-rumped munia, and Red avadavat, all the other 12 species listed are non-native.

As the captive breeding technology for these species is already successful, we removed these species from the dataset. Only the Japanese quail and White-rumped munia were retained in the dataset as it is possible for traders to catch local wild populations to support the market (Li & Jiang, 2014). We expect there may be important variables driving species occurrences, such as the uses of birds in trade, the season in which they are sold, their national and international protection status, and their average price, which constrain the occurrence of certain species in shops.

Generalized linear mixed-effects models (GLMMs) are a powerful technique for analyzing longitudinal data, which arise from recurring visits to a wildlife market (Nakagawa, Schielzeth, & Schielzeth, 2017; Thiele, 2012). The response variable, species occurrence in shops, exhibits a Poisson distribution (Zhang et al., 2017). To create a dataset where we can account for species absence, we combined the observed, survey data with create a dataset where we can account for species absence data, when native species were missing from the market in certain months.

We fitted hierarchical GLMMs with a Poisson distribution, to model species occurrence as the dependent variable, using the R package “glmmTMB” (Brooks et al., 2017) (Table 1). Fixed effects were market variables, conservation/protection status, trade knowledge, and life history variables. Market variables were price, survey timing, season, year of survey, and the minimum distance from the edge of the bird’s range to Huadiwan. Conservation and regulatory status variables were the International Union for the Conservation of Nature (IUCN) conservation status, protection status of the bird under national regulations (CPL), and international agreements (CITES). Trade knowledge variables were the IUCN categorization for each species based on use and/or trade (food, pets/display, handicrafts/jewelry, sports hunting), and each species could have multiple uses. These operate on three scales: local, national, and international levels. Another trade purpose variable was defined based on local knowledge of authors (MZ and SF) and information obtained during conversations with traders. All categories (attractiveness, songbird, prayer release, falconry, fighting, intelligence, fortune, food) were mutually exclusive, except for songbird/fortune. Life history variables were the age of the bird (juvenile or adult) and its IUCN population trend. We fitted family as a random effect, due to the taxonomic hierarchy of species (species nested as groups within families), similar to Heinrich et al. (2020).

2.3 | Model evaluation and inference

The pseudo marginal and conditional R² was calculated as an absolute value for the goodness of fit for both models (Nakagawa et al., 2017), which is the proportion of total variance explained through both fixed and random effects. The distributional variance (or observation-level variance) is based on lognormal approximation, log (1+var(x)/mu²). The model specification and fit were checked using the “DHARMa” package (Hartig, 2020). Scaled quantile residuals were calculated, where a uniform, flat distribution of the overall residuals indicates a correct model specification. Stepwise model selection was performed to iteratively select variables to achieve the most parsimonious Akaike Information Criterion (AIC) value. To complement this, models with a differing of covariates were run manually, also using the AIC as a baseline to compare models.

2.4 | Determining potential origins of traded birds

For traded species that were hypothesized as wild-caught (including the captive-bred White-rumped munia), we plotted their distribution to determine potential origins. Distributional range data were downloaded from BirdLife Datazone, using Handbook of the Birds of the World (HBW) and BirdLife Checklist version 3.0 (data available on request at http://www.birdlife.org/datazone). For these maps, the coordinate system is the World Geodetic System (WGS84), with the unit for each range of km². The legend of these maps shows the number of ranges for birds in the market, as some species occur within multiple range categories, that is, they breed in northern China and visit southern China as a non-breeding individual, so they would be represented on the legend as two, rather than one species.

Data were split into subsets to visualize market composition with respect to protection status and season, using the R package “letsR” (Vilela & Villalobos, 2015). Each of these subsets was transformed into a presence-
absence matrix (PAM), allowing the calculation of areas of range overlap, which can reveal key supply information for wild-caught birds (Vilela & Villalobos, 2015). Since many pan-Asian species appear in the market, it is necessary to look for regions of species overlap throughout Asia, not just in China. If cross-border areas of market species richness exist, this could reveal import or export flows.

Based on its reach, a wildlife market can be classified as local, feeder (distributing stock to other markets), or regional. Classifying the “trade scale” of markets allows us to prioritize locations for targeted enforcement. Hence, we can characterize the market size based on how far away species are sourced, that is, its reach, following the approach of Pires and Clarke (2011). To assess whether the most popular species (e.g., most abundant) occurred closer to the market, the ranges for these species were plotted separately. In addition, to further explore the hypothesis of whether birds found in the most shops naturally occur close to the market, the ranges of the 15 most popular species were plotted. We expected locations of species richness to occur close to the market, due to lower fuel costs for trappers and lower mortality for birds from being transported at large distances.

We also computed the distances between the market and the nearest edge of the species range, where zero indicates that Huadiwan is within the species range. We created 200, 500, and 1,000 km circular buffer areas around Huadiwan market and calculated the number of species’ ranges which overlap with these buffer areas, to infer the source of the market’s wild birds. These analyses were performed using the Distance/Azimuth Tools (version 1.6) extensions for Arc View (Jenness, 2005).

All statistical analyses were performed in R version 3.5.2 (R Core Team, 2018).

3 | RESULTS

3.1 | The peak season of bird trade

In total, between October 2011 to June 2013, 95,912 birds of 147 species (of 32 families) were recorded in the market across 60 shops. The species recorded in the highest abundance was the budgerigar, *Melopsittacus undulatus*.

![Image](image-url)
Table 2: The generalized linear mixed effects models (GLMM) model effects from the model with the lowest Akaike Information Criterion (AIC) value, the confidence intervals (CI), p-values and the marginal and conditional $R^2$ for the overall model

| Model terms                                      | Estimate | Two-tailed 95% CI | SE  | p-value | Standard deviance of random effects | Marginal/Conditional $R^2$ |
|--------------------------------------------------|----------|-------------------|-----|---------|-------------------------------------|---------------------------|
| 2. IUCN use: food (local, national), pets (international) | 0.36     | −1.25–1.98        | 0.83| 0.66    | Family: ***                         | 0.1327589139/0.1327589143 |
| 3. IUCN use: food (local, national), pets (local, national) | 1.07     | −0.43–2.57        | 0.76| 0.16    |                                     |                           |
| 4. IUCN use: food (local, international), pets (local, national) | 0.33     | −2.88–3.53        | 1.63| 0.84    |                                     |                           |
| 5. IUCN use: food (local, national)              | −1.14    | −8.01–5.74        | 3.51| 0.75    |                                     |                           |
| 6. IUCN use: food (local, national), pets (national, international) | 1.69     | −0.42–3.80        | 1.08| 0.12    |                                     |                           |
| 7. IUCN use: (none recorded)                     | 0.62     | −2.76–4.00        | 1.73| 0.72    |                                     |                           |
| 8. IUCN use pets (international)                 | 1.58     | −0.16–3.32        | 0.89| 0.08    |                                     |                           |
| 9. IUCN use: sport hunting (local, national), food (local, national), pets (international) | 2.82     | 0.68–4.96         | 1.09| 0.01    |                                     |                           |
| 10. IUCN use: sport hunting (local, national), food (local, national), pets (local, national) | 0.44     | −2.25–3.13        | 1.37| 0.75    |                                     |                           |
| 11. IUCN use: sport hunting (local, national), pets (international) | −1.07    | −7.95–5.81        | 3.51| 0.76    |                                     |                           |
| 2. Our use: falconry                             | −2.94    | −17.37–11.48      | 7.36| 0.69    |                                     |                           |
| 3. Our use: fighting                             | −1.56    | −11.79–8.66       | 5.22| 0.76    |                                     |                           |
| 4. Our use: food                                 | −0.73    | −2.74–1.29        | 1.03| 0.48    |                                     |                           |
| 5. Our use: intelligent                          | 0.85     | −1.19–2.89        | 1.04| 0.41    |                                     |                           |
| 6. Our use: not sure                             | −0.50    | −1.54–0.55        | 0.53| 0.35    |                                     |                           |
| 7. Our use: prayer release                       | 0.39     | −1.70–2.48        | 1.07| 0.71    |                                     |                           |
| 8. Our use: songbird                             | 0.58     | −0.29–1.44        | 0.44| 0.19    |                                     |                           |
| 9. Our use: songbird/fortune                     | 2.44     | 0.79–4.10         | 0.85| ***     |                                     |                           |
| Distance (degrees)                               | 0.00     | −0.02–0.01        | 0.01| 0.61    |                                     |                           |
| Autumn 12                                        | −0.21    | −1.40–0.99        | 0.61| 0.73    |                                     |                           |
| Spring 12                                        | −0.32    | −1.54–0.91        | 0.63| 0.61    |                                     |                           |
| Spring 13                                        | −0.88    | −2.51–0.75        | 0.83| 0.29    |                                     |                           |
| Summer 12                                        | −0.19    | −1.38–1.00        | 0.61| 0.76    |                                     |                           |
| Summer 13                                        | −0.93    | −3.09–1.24        | 1.11| 0.40    |                                     |                           |
| Winter 11–12                                     | −0.57    | −1.87–0.74        | 0.67| 0.40    |                                     |                           |
| Winter 12–13                                     | −0.23    | −1.43–0.97        | 0.61| 0.71    |                                     |                           |
| Autumn 11 (intercept)                            | −4.71    | −6.44–2.98        | 0.88| ***     |                                     |                           |

Note: For each variable, there is a reference level, which was specified as the most common or meaningful/expected category: for the IUCN use, the reference level was the trade use as “1. pets (local, national). Each category of use by the International Union for the Conservation of Nature (IUCN) can be at local, national, and international scales, and each species can have multiple uses. The model terms are numbered based on the 12 different combinations of these which appeared in our dataset. P values close to 0 are indicated with ***.
species recorded in the market were listed in Appendix I; however, there were 23 non-native species, which were listed in Appendix II.

Autumn is the season in which most species in the market are detected (Figure 1a, Table S2). Winter, spring, or summer are approximately half as diverse as autumn.

FIGURE 2 The predictor effect plot, showing the fitted values for the response SPO (species occurrence) on the y-axis versus the focal predictor on the x-axis, IUCN.USE (Use of the birds in trade, where the numbers are combinations of uses, for example, 2. is IUCN Use food (local, national), pets (international), as explained in Table 2), OUR.USE (reasons birds are in trade as indicated by the authors), DIST (minimum distance from the edge of the bird’s range, in degree), and the SY (season, autumn, spring, summer and winter, and year). The model predictors were plotted using the “effects” package. This provides a separate graphical explanation of the role of each predictor and their interactions, after conditioning on all other relevant predictors. A \( p \)-value <.01 is indicated with **. For each variable, there is a reference level, which was specified as the most common or meaningful/expected category: for the IUCN use, the reference level was the trade use as “1. pets (local, national).” For the purpose based on local knowledge, the reference level was “1. it was good looking.” The pink bars indicate the 0.95 confidence levels for confidence limits.
However, after a certain number of surveys, the richness plateaus for these seasons, whereas the richness during autumn is projected to increase, if we extrapolate to more surveys. The overall species accumulation curve shows that the richness in the market has plateaued after 19 surveys and is approaching its asymptotic richness. It is likely one would have to visit the market approximately eight times to detect most of the species in the market (Figure 1b).

3.2 | Predictors of species occurrences among shops in the market

The best model showed that the IUCN trade purpose for a species, our own classification of trade purpose, the season, and the year in which the survey took place were statistically significant (p < .05) factors in predicting species occurrence. This model had the lowest AIC and highest variance explained amongst our experiments (Table 2, Figure 2). The individual effects of these predictor variables can be seen in Figure 2.

In autumn 2011, the species occurrence for wild species was the highest (Figure 1a). The IUCN use category which was most strongly associated with species occurrence for wild-caught birds at Huadiwan was a combination of sport hunting (local, national levels), food (local, national levels), pets (international levels). So, the species which were found in most shops were those which are known to be hunted for sport, consumed as food both locally and nationally in their home range, and demanded as pets internationally. For the trade purpose based on local knowledge, the most important category associated with species occurrence was the combined songbird/fortune category. However, there was only one bird identified as for songbird/fortune, the Oriental Magpie Robin, *Copsychus saularis*– which suggests that this species is predicted to occur in the most shops out of all the wild-caught species in our model.

Distance to the market was not a significant predictor of species occurrence (p = .61). Although there was an observed increase in species occurrence for species found close to the market (Figure 2c), no meaningful relationship was found.

When included in the model, the random effect of Family was very small (Table 2). The best model could explain 13% of the variation in our data, with much of the variation in species occurrence explained by other factors not included in our analysis. The QQ-uniform plot for our overall species occurrence model had no significant deviations from the overall uniformity of the residuals. The simulated residuals did not differ from the observed residuals, indicating a good model fit (Figure S1a, b).

3.3 | Areas of species richness for market species

We found hotspots of market bird species richness emerge across China. Nationally protected species appear to occur in a wider buffer zone around Huadiwan than both CITES-listed nationally protected species and unprotected species (Figure 3a-c). All native CITES-listed species were also listed on the CPL, although there were not many of these species in the market. Species that are protected only nationally (Figure 3a) and the most popular species (Figure 3d), when viewed in isolation, are sourced closer to. For the 15 most abundant species (Figure 3d) in the market, 12 of these occurred in southeast China (in
Guangdong and neighboring southern Chinese provinces. In the categories besides the most popular species, this core area of species richness concentrates around a hotspot in Southwest China, spilling over into bordering countries, such as Vietnam, Laos, and Myanmar.

3.4 Buffer areas of wild species around Huadiwan

The total volume of wild birds is 43,397 birds. Of these, 34,195 (78.8%) are accounted for by the top 15 most popular native species. Of the 15 most popular species in the market, 13 out of 15 species can be found within a 200 km buffer area around Huadiwan. This reflects the green core area seen in Figure 3d.

After merging ranges, 92 native species were found in the market. Of those, 51 species (55% of wild species) can be found within the 200 km radius buffer around the Huadiwan market. Sixty-four species (70%) can be found within the 500 km radius buffer area, still within China’s borders. Seventy-nine species (86%) can be found within the 1,000 km radius buffer around the market.

4 DISCUSSION

This study represents the first in-depth review of bird trade at Huadiwan market, Guangzhou, using fine-scale wildlife market data and practical experience to evaluate key trends in bird market dynamics. These results provide evidence that autumn is likely the peak of bird trade in Guangzhou, China, and that most species traded were legal, captive-bred exotic species, though 45% of the trade volume are wild-sourced birds. Large numbers of native species were possibly caught in Guangdong or neighboring provinces to support the local market, though no significant relationship was found between distance to the market and species occurrence.

4.1 Market structure and composition

Diversity-wise, the market is largely constituted of listed, wild-caught, native species (Table S1), though those are largely species listed on this “third level” of the CPL. Our saturated curve (Figure 1b) suggests that with effective monthly wildlife market monitoring it is likely to “discover” the market’s capacity regarding species diversity and abundance (Table S1). For example, if funding were constrained for markets of a similar size, structure, and function to Huadiwan, after eight surveys (Figure 1b), one would approach a consistent rate of species discovery. By varying the survey time, as we did, this can mediate potential suspicion amongst traders, even with the same surveyors visiting the market (Barber-Meyer, 2010; Bušina et al. 2020).

Overall, few protected species (on Class 2 or higher) were found at Huadiwan during the survey period (Figure S1). These trends suggest that, at least in the open market, shops are not selling highly protected or endangered bird species, possibly because of increased enforcement between 2011 and 2013. This pattern is in sharp contrast to other key demand countries in the bird trade, such as Indonesia, species are generally found to be traded openly and in violation of Indonesian regulations (Chng & Eaton, 2016; Chng, Krishnasamy, & Eaton, 2018; Shepherd, Eaton, & Chng, 2016). It is a well-documented phenomenon that many traded Asian songbird species, are not listed on CITES, or national legislation at the time of being recorded (Shepherd, Leupen, Siriwat, & Nijman, 2020). This is largely due to a time lag on the listing of a species as endangered before it is considered for national and international protection. However, now China’s wildlife protection law has been updated, the third level has been abolished and heavily traded species, such as the Chinese Hwamei, Garrulax canorus, have been uplisted to Class 2, as well as the Yellow-breasted Bunting, which was uplisted to Class 1, which is a large improvement.

Autumn had the highest species diversity (Figure 1a) and the highest number of migratory species (Table S2). This contrasts with other reports of bird trade in Indonesia and Taiwan, which dictate that winter is the high season of bird trade (Chng et al., 2016; Su, 2016). The occurrence of species at the market likely reflects the occurrence of species in the wild, with the peak of migration in China in autumn. However, it may be the case that markets in south China receive more migrant birds trapped in northern China (Table S1). Furthermore, migratory songbirds such as the Siberian rubythroat, Calliope calliope, and the Japanese white-eye, Zosterops japonicus (Yong et al., 2015), are amongst the most abundant wild species in the market (see supplementary data). Compared with Dai and Zhang (2017, 206 species recorded), we found a lower number of species for sale overall, though a far higher volume of birds for sale over our study period.

4.2 Predictors for wild bird species occurrence at Huadiwan market

The analysis of factors suggests that it was challenging to identify significant market predictors for wild bird species occurrence at Huadiwan market. The factors which were
significant from our survey data were the use of birds in trade (both IUCN and our own assessment of use), and a seasonal effect. The significance of autumn in our model, as a driver of species occurrence in shops, complements our earlier results showing that autumn is the most diverse season during our survey. Certain species of bird were predicted to have a higher species occurrence, which includes the notoriously popular Oriental Magpie Robin, which was sold as a songbird and for fortune. This species is likely the most popular wild-caught species, after the captive-bred species.

Although 28 species did not fit into the categories of “songbird,” “for prayer release,” “intelligence,” and “attractiveness,” our classification can be used to suggest suitable categories of use according to how many shops they occur in. However, we were also unable to detect an effect on species occurrence from protection status and life history variables, such as distance to the market or IUCN population trends. Market variables such as the survey timing also had no effect, indicating that supply was likely consistent across the study period. This evidence suggests that traders will stock birds regardless of how far away from the market species are sold and their protection status.

Unlike other studies on global bird trade (Scheffers, Oliveira, Lamb, & Edwards, 2019) or bird trade in Taiwan (Su, Cassey, & Blackburn, 2014), we did not find that taxonomy had a strong effect on the variance explained by our model (Table 2, Figure 2, Figure S3). The distribution of wild birds in shops is likely indiscriminate, given that birds are sold for a higher price in pet markets, so species caught as bycatch from hunting may enter the market from all over China. Liang et al. (2013) recorded the price per kilogram for dead Oriental Magpie Robins was 50 RMB on Hainan Island, south China, whereas the price for live Oriental Magpie Robins at Huadiwan itself. However, there was no significant relationship between distance and species occurrence (Figure 2c). However, this hotspot in southwest China (Figure 3a–d), provides evidence that Huadiwan’s bird stock is not driven solely by supply or seasonal availability of wild birds (Figure S2).

Our study builds on existing literature on bird trade in China (Chang et al., 2019; Dai & Hu, 2017; Dai & Zhang, 2017; Heim et al., 2021; Liang et al., 2013; Yong et al., 2015), by visualizing the possible sources of theoretical trapping bottlenecks for wild birds, particularly in southwest China. The birds of southwest China are not just destined for inland markets, such as those in Guiyang city (Dai & Hu, 2017; Dai & Zhang, 2017), but also markets on the southeast coast, such as Huadiwan. Dai and Hu (2017) found that key drivers of hunting wild birds in Guizhou province were for keeping pets both for personal ownership and selling on when hunters tire of bird keeping. However, other recent studies of hunters in neighboring Yunnan province and Hainan Island (Chang et al., 2019; Liang et al., 2013) had little mention of

4.3 Visualizing source hotspots for market species

Hotspots for wild-caught, native species were found at great distances from the market in Yunnan province and along the Sino-Vietnam, Sino- Laos, and Sino-Myanmar border (Figure 3a–d). A large hotspot is concentrated in the southwest of China, at least 1,700 km from Guangzhou (Figure 3a). This places the minimum theoretical catchment area of Huadiwan nearly an order of magnitude higher than other baseline estimates for other national bird markets in demand centers in Latin America (Pires, 2015; Pires & Clarke, 2011). Pires (2015) found in local Bolivian markets that few parrots are trafficked across borders, and most are poached within their native range (a 100-mile buffer around markets). We propose that the most common “wild” bird species in Huadiwan are collected from areas around Guangzhou city, while a few rare species could be illegally transported from southwest China or potentially southeast Asia. These include species that are range-limited to southwestern China, and are more commonly observed in southeast Asia, such as the Spot-throated Babbler, Pellorneum albitventre, which appeared in the market 12 times, and was observed in two shops.

When we plot the ranges of the most popular, non-captive-bred species, there is a hotspot closer to Guangzhou (Figure 3d). Our buffer analysis showed that 79% of wild-caught species were found within 200 km of the market. Fifty-two species (out of 92 “wild” species) had a distance of “zero,” whereby their range overlaps with Huadiwan itself. However, there was no significant relationship between distance and species occurrence (Figure 2c). However, this hotspot in southwest China (Figure 3a–d), provides evidence that Huadiwan’s bird stock is not driven solely by supply or seasonal availability of wild birds (Figure S2).

Our study builds on existing literature on bird trade in China (Chang et al., 2019; Dai & Hu, 2017; Dai & Zhang, 2017; Heim et al., 2021; Liang et al., 2013; Yong et al., 2015), by visualizing the possible sources of theoretical trapping bottlenecks for wild birds, particularly in southwest China. The birds of southwest China are not just destined for inland markets, such as those in Guiyang city (Dai & Hu, 2017; Dai & Zhang, 2017), but also markets on the southeast coast, such as Huadiwan. Dai and Hu (2017) found that key drivers of hunting wild birds in Guizhou province were for keeping pets both for personal ownership and selling on when hunters tire of bird keeping. However, other recent studies of hunters in neighboring Yunnan province and Hainan Island (Chang et al., 2019; Liang et al., 2013) had little mention of
hunting to supply live pet trade, but were more focused on local food consumption and subsistence.

In the wider context of the Asian Songbird Extinction Crisis, the Chinese bird trade may have a larger impact on wild populations than has previously been considered. Li and Wilcove (2005) suggested that just 3% of endangered wild bird species in China are threatened by the pet trade; however, our results suggest greater pressure on the wild populations in China. Despite the advanced nature of captive breeding in China, particularly for non-native, parrot species, wild birds still account for nearly half of the trade volume in our study period. Based on the “fresh” appearance of farmed birds in the market during the survey, there are likely established farms operating in Guangdong or nearby provinces. Nonetheless, farms are still supplied by wild species and may act as locations for laundering wild-caught species (Tensen, 2016). We echo the calls of Li and Jiang (2014) and Yong et al. (2015) to carry out population surveys on native bird species which are most popular.

Our analysis of market survey data provides valuable information regarding a changing enforcement and public awareness climate and leaves a legacy of demand for wild bird species in China. The recent intensification of law enforcement within China to combat the illegal trade of wildlife (Chang, 2020; Wong, 2017) has clearly been successful, forcing markets such as Huadiwan to transition from “unsustainable” to more sustainable. In terms of changing retail dynamics, this results in lower species diversity and large numbers of captive-bred species (SF, personal observation, March 2019). In turn, this success has guided updates to the Wild Animals Protection Law (2020) and national campaigns against bird trade, such as the “Let Birds Fly” campaign (Chang, 2020; Yong et al., 2015).

We need to synthesize hunting motivations, consumer motivations, and population surveys, especially given the evident complexity and multifaceted uses of birds sold in pet markets in China. Market surveys are a just a singular tool in understanding trade scenarios where species have multiple uses, even with the in-depth analyses presented here. Despite the emergence of COVID-19, provisions are in place for the continued trade in wild animals for pets (Zhu & Zhu, 2020), with monthly surveys, we can monitor trade volumes of previously unprotected species, which are now protected on the recent revision of Chinese wildlife protection law. In practice, more funding needs to be made available to increase the temporal window of data collection in wildlife markets, otherwise we may never understand the complex nuances of bird trade dynamics across Southeast Asia. Last, it is important to continually educate consumers on the environmental consequences of illegal and unsustainable bird trapping and intensify efforts such as the “Let Birds Fly” campaign.

ACKNOWLEDGEMENTS
This work was supported by research grants from the National Talent Research Program in China (grant nos. 41180944 and 41180953 to T.M.L.), the Guangdong Provincial Research Fund (grant no. 42150016 to T.M.L.) and the Guangxi Key Laboratory of Rare and Endangered Animal Ecology, Guangxi Normal University (20-A-01-03 to M.Z.).

CONFLICT OF INTEREST
The authors declare no conflict of interest.

AUTHORS CONTRIBUTIONS
S.F: Data curation, analysis, writing—original draft, visualization. M.Z: Conceptualization, methodology, investigation, writing—review and editing. F.S: Investigation, data collection. T.M.L: Conceptualization, methodology, validation, analysis, writing—review and editing, supervision.

DATA AVAILABILITY STATEMENT
All data are made available.

ETHICS STATEMENT
No animal experiment was conducted.

ORCID
Tien Ming Lee https://orcid.org/0000-0003-2698-9358

REFERENCES
Aarena, P. C., Steedman, C., & Warwick, C. (2012). Amphibian and reptile pet markets in the EU: An investigation and assessment (p. 53). Spain: Animal Protection Agency, Animal Public, International Animal Rescue, Eurogroup for Wildlife and Laboratory Animals, Fundación para la Adopción, el Apadrinamiento y la Defensa de los Animales. Barber-Meyer, S. M. (2010). Dealing with the clandestine nature of wildlife-trade market surveys: Hidden trade in wildlife market surveys. Conservation Biology, 24(4), 918–923. https://doi.org/10.1111/j.1523-1739.2010.01300.x
Brooks, M. E., Kristensen, K., Benthem, K. J., Magnusson, A., Berg, C. W., Nielsen, A., ... Bolker, B. M. (2017). glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. The R Journal, 9(2), 378. https://doi.org/10.32614/RJ-2017-066
Burivalova, Z., Lee, T. M., Hua, F., Lee, J. S. H., Prawiradilaga, D. M., & Wilcove, D. S. (2017). Understanding consumer preferences and demography in order to reduce the domestic trade in wild-caught birds. Biological Conservation, 209, 423–431. https://doi.org/10.1016/j.biocon.2017.03.005
Bušina, T., Kouba, M., & Pasaribu, N. (2021). What is the reliability of visually based animal trade census outcomes? A case study
involving the market monitoring of the Sumatran Laughingthrush Garrulax bicolor. 

Bird Conservation International, 31, 326–336. https://doi.org/10.1017/S095927092000026X

Chang, C. H., Williams, S. J., Zhang, M., Levin, S. A., Wilcove, D. S., & Quan, R. C. (2019). Perceived entertainment and recreational value motivate illegal hunting in Southwest China. 

Biological Conservation, 234, 100–106. https://doi.org/10.1016/j.biocon.2019.03.004

Chang, J. (2020). China’s legal response to trafficking in wild animals: The relationship between international treaties and Chinese law. In A. Peters (Ed.), Studies in Global Animal Law. Beiträge ausländischen öffentlichen Recht und Völkerrecht (pp. 71–79). Berlin, Heidelberg: Springer.

Chng, S. C. L., & Eaton, J. A. (2016). In the market for extinction: Eastern and Central Java. Petaling Jaya, Selangor, Malaysia: TRAFFIC. Retrieved from https://www.traffic.org/site/assets/files/2393/in-the-market-for-extinction.pdf

Chng, S.C.L., Guciano, M., & Eaton, J.A., 2016. In the market for extinction: Sukahaji, Bandung, Java, Indonesia. BirdingASIA 26 22–28, p. 14.

Chng, S. C. L., Krishnasamy, K., & Eaton, J. A. (2018). In the market for extinction: The cage bird trade in Bali. Forktail, 34, 35–41.

Couchamp, F., Jaric, I., Albert, C., Meinard, Y., Ripple, W. J., & Chapron, G. (2018). The paradoxical extinction of the most charismatic animals. PLoS Biology, 16(4), e2003997. https://doi.org/10.1371/journal.pbio.2003997

Dai, C., & Hu, W. (2017). Hunting strategies employed by bird hunters with economic pursuit in the city of Guiyang, Southwest China. Journal for Nature Conservation, 40, 33–41. https://doi.org/10.1016/j.jnc.2017.09.005

Dai, C., & Zhang, C. (2017). The local bird trade and its conservation impacts in the city of Guiyang, Southwest China. Regional Environmental Change, 17(6), 1763–1773. https://doi.org/10.1007/s10113-017-1141-5

Eaton, J.A., Shepherd, R., Rheindt, F. E., Harris, J. B. C. van Balen, S. B., Wilcove, D. S. & Collar, N. J. Placeholder Text 2015. Trade-driven extinctions and near-extinctions of avian taxa in Sundac Indonesia, Forktail 31, p. 1–12.

Eaton, J.A., Leupen, B., & Krishnasamy, K. Placeholder Text 2017. Songs of Singapore: An overview of the bird species in Singapore pet shops. Malaysia: Petaling Jaya, p. 35.

Gong, S.-P., Chow, A. T., Fong, J. J., & Shi, H. T. (2009). The chelonia trade in the largest pet market in China: Scale, scope and impact on turtle conservation. Oryx, 43(2), 213. https://doi.org/10.1017/S0030605308000902

Harris, J. B. C., Green, J. M. H., Prawiradilaga, D. M., Giam, X., Giyanto, Hikmatullah, D., ... Wilcove, D. S. (2015). Using market data and expert opinion to identify overexploited species in the wild bird trade. Biological Conservation, 187, 51–60. https://doi.org/10.1016/j.biocon.2015.04.009

Hartig, F. 2020. DHARMa: residual diagnostics for hierarchical (multi-level/mixed) regression models. Retrieved from http://florianhartig.github.io/DHARMa/.

Heim, W., Hözel, N., Ktitorov, P., Mischenko, A., Kamp, J., & Kamp, J. (2021). East Asian buntings: Ongoing illegal trade and encouraging conservation responses. Conservation Science and Practice, 3, e405. https://doi.org/10.1111/csp.20405

Heinrich, S., Ross, J. V., Gray, T. N. E., Delean, S., Marx, N., & Cassey, P. (2020). Plight of the commons: 17 years of wildlife trafficking in Cambodia. Biological Conservation, 241, 108379. https://doi.org/10.1016/j.biocon.2019.108379

Hinsley, A., Verissimo, D., & Roberts, D. L. (2015). Heterogeneity in consumer preferences for orchids in international trade and the potential for the use of market research methods to study demand for wildlife. Biological Conservation, 190, 80–86. https://doi.org/10.1016/j.biocon.2015.05.010

Hsieh, T. C., Ma, K. H., & Chao, A. (2016). INEXT: An R package for rarefaction and extrapolation of species diversity (hill numbers). Methods in Ecology and Evolution, 7(12), 1451–1456. https://doi.org/10.1111/2041-210X.12613

Indraswari, K., Friedman, R. S., Noske, R., Shepherd, C. R., Biggs, D., Sulsawati, C., & Wilson, C. (2020). It’s in the news: Characterising Indonesia’s wild bird trade network from media-reported seizure incidents. Biological Conservation, 243, 108431. https://doi.org/10.1016/j.biocon.2020.108431

Jenness, J. 2005. Distance/Azimuth Tools (dist_az_tools.avx) extension for ArcView 3.x., v. 1.6. Retrieved from http://www.jennessent.com/arcview/arcview_extensions.htm.

Kamp, J., Oppel, S., Ananin, A. A., Durnev, Y. A., Gashev, S. N., Hözel, N., ... Chan, S. (2015). Global population collapse in a superabundant migratory bird and illegal trapping in China. Conservation Biology, 29(6), 1684–1694. https://doi.org/10.1111/cobi.12537

Lee, J. G. H. (2016). Conservation strategy for southeast Asian songbirds in trade: Recommendations from the first Asian songbird trade crisis summit 2015. Singapore: Wildlife Reserves Singapore and TRAFFIC Southeast Asia.

Li, L., & Jiang, Z. (2014). International trade of CITES listed bird species in China. PLoS One, 9(2), e85012. https://doi.org/10.1371/journal.pone.0085012

Li, P. J. (2007). Enforcing wildlife protection in China: The legislative and political solutions. China Information, 21(1), 71–107. https://doi.org/10.1177/0920203X07075082

Li, Y., & Wilcove, D. S. (2005). Threats to vertebrate species in China and the United States. BioScience, 55(2), 147–153. https://doi.org/10.1641/0006-3568(2005)055[0147:TTVSIC]2.0.CO;2

Liang, W., Cai, Y., & Yang, C. C. (2013). Extreme levels of hunting of birds in a remote village of Hainan Island, China. Bird Conservation International, 23(1), 45–52. https://doi.org/10.1017/S0959270911000499

Marshall, H., Collar, N. J., Lees, A. C., Moss, A., Yuda, P., & Marsden, S. J. (2020). Spatio-temporal dynamics of consumer demand driving the Asian Songbird Crisis. Biological Conservation, 241, 108237. https://doi.org/10.1016/j.biocon.2019.108237

McNamara, J., Cowlishaw, G., Alexander, J. S., Ntiamoa-Baidu, Y., Brenya, A., Milner-Gulland, E. J., & Milner-Gulland, E. J. (2016). Characterising wildlife trade market supply-demand dynamics. PLoS One, 11(9), e0162972. https://doi.org/10.1371/journal.pone.0162972

Nakagawa, S., Schielzeth, H., & Schielzeth, H. (2017). The coefficient of determination R2 and intra-class correlation coefficient for generalized linear mixed-effects models revisited and expanded. Journal of the Royal Society Interface, 14(134), 20170213. https://doi.org/10.1098/rsif.2017.0213

Nijman, V., Langgeng, A., Birot, H., Imron, M. A., & Nekaris, K. A. I. (2018). Wildlife trade, captive breeding and the imminent extinction of a songbird. Global Ecology and Conservation, 15, e00425. https://doi.org/10.1016/j.gecco.2018.e00425
Pires, S. F. (2015). The heterogeneity of illicit parrot markets: An analysis of seven neo-tropical open-air markets. *European Journal on Criminal Policy and Research*, 21(1), 151–166. https://doi.org/10.1007/s10610-014-9426-6

Pires, S. F., & Clarke, R. V. (2011). Sequential foraging, itinerant fences and parrot poaching in Bolivia. *British Journal of Criminology*, 51(2), 314–335. https://doi.org/10.1093/bjc/azq074

R Core Team. (2018). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. Retrieved from https://www.R-project.org/

Scheffers, B. R., Oliveira, B. F., Lamb, I., & Edwards, D. P. (2019). Global wildlife trade across the tree of life. *Science*, 366(6461), 71–76. https://science.sciencemag.org/content/366/6461/71

Severinghaus, L. L., & Chi, L. (1999). Prayer animal release in Taiwan. *Conservation International* (2), 314–320. https://doi.org/10.1017/S0959270916000320

Shepherd, C. R., Eaton, J. A., & Chng, S. C. L. (2016). Nothing to laugh about —The ongoing illegal trade in laughingthrushes (Garrulax species) in the bird markets of Java, Indonesia. *Bird Conservation International*, 26(4), 524–530. https://doi.org/10.1017/S0959270916000320

Shepherd, C. R., Leupen, B. T. C., Siriwat, P., & Nijman, V. (2020). International wildlife trade, avian influenza, organised crime and the effectiveness of CITES: The Chinese hwamei as a case study. *Global Ecology and Conservation*, 23, e01185. https://doi.org/10.1016/j.gecco.2020.e01185

Shepherd, C. R., Nijman, V., Krishnasamy, K., Eaton, J. A., & Chng, S. C. L. (2016). Illegal trade pushing the critically endangered black-winged myna *Acridotheres melanopterus* towards imminent extinction. *Bird Conservation International*, 26(2), 147–153. https://doi.org/10.1017/S0959270915000106

Shiu, H., & Stokes, L. (2008). Buddhist animal release practices: Historic, environmental, public health and economic concerns. *Contemporary Buddhism*, 9(2), 181–196. https://doi.org/10.1080/14639940802556529

Souto, W. M. S., Torres, M. A. R., Sousa, B. F. C. F., Lima, K. G. G. C., Vieira, L. T. S., Pereira, G. A., ... Peralta, B. G. N. (2017). Singing for cages: The use and trade of Passeriformes as wild pets in an economic Center of the Amazon—NE Brazil route. *Tropical Conservation Science*, 10, 194008291768989. https://doi.org/10.1177/1940082917689898

Su, S. (2016). The bird trade in Taiwan. an analysis of an Eastern pathway to biological invasion. Retrieved from https://discovery.ucl.ac.uk/id/eprint/1476926/1/Theis_Sushan_FinalSub_21032016_All.pdf

Su, S., Cassey, P., & Blackburn, T. M. (2014). Patterns of non-randomness in the composition and characteristics of the Taiwanese bird trade. *Biological Invasions*, 16(12), 2563–2575. https://doi.org/10.1007/s10530-014-0686-6

Tenchachoochert, S., & Round, P. D. (2013). Red-whiskered bulbul: Are trapping and unregulated avicultural practices pushing this species towards extinction in Thailand? *BirdingASIA*, 20, 49–52.

Tensen, L. (2016). Under what circumstances can wildlife farming benefit species conservation? *Global Ecology and Conservation*, 6, 286–298. https://doi.org/10.1016/j.gecco.2016.03.007

Thiele, J. (2012). Potential of GLMM in modelling invasive spread. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources*, 7(16), 1–10.

Vilela, B., & Villalobos, F. (2015). letsR: A new R package for data handling and analysis in macroecology. *Methods in Ecology and Evolution*, 6(10), 1229–1234. https://doi.org/10.1111/2041-210X.12401

Wang, H., Wang, Q., Bowler, P., & Xiong, W. (2016). Invasive aquatic plants in China. *Aquatic Invasions*, 11(1), 1–9. https://doi.org/10.3391/ai.2016.11.1.01

Wong, R. W. Y. (2017). The role of reputation in the illegal purchase of protected wildlife in China. *Deviant Behavior*, 38(11), 1290–1302. https://doi.org/10.1080/01639625.2016.1248716

Yiming, L., & Dianmo, L. (1998). The dynamics of trade in live wildlife across the Guangxi border between China and Vietnam during 1993±1996 and its control strategies. *Biodiversity and Conservation*, 7(7), 895–914. https://doi.org/10.1023/A:1008873119651

Yong, D. L., Liu, Y., Low, B. W., Española, C. P., Choi, C. Y., & Kawakami, K. (2015). Migratory songbirds in the east Asian-Australasian flyway: A review from a conservation perspective. *Bird Conservation International*, 25(1), 1–37. https://doi.org/10.1017/S0959270914000276

Zhang, L., Hua, N., & Sun, S. (2008). Wildlife trade, consumption and conservation awareness in Southwest China. *Biodiversity and Conservation*, 17(6), 1493–1516. https://doi.org/10.1007/s10531-008-9358-8

Zhang, L., & Yin, F. (2014). Wildlife consumption and conservation awareness in China: A long way to go. *Biodiversity and Conservation*, 23(9), 2371–2381. https://doi.org/10.1007/s10531-014-0708-4

Zhang, X., Mallick, H., Tang, Z., Zhang, L., Cui, X., Benson, A. K., & Yi, N. (2017). Negative binomial mixed models for analyzing microbiome count data. *BMC Bioinformatics*, 18(1), 4. https://doi.org/10.1186/s12859-016-1441-7

Zhu, A., & Zhu, G. (2020). Understanding China’s wildlife markets: Trade and tradition in an age of pandemic. *World Development*, 136, 105108. https://doi.org/10.1016/j.worlddev.2020.105108

**SUPPORTING INFORMATION**

Additional supporting information may be found online in the Supporting Information section at the end of this article.