Can local ecological knowledge establish conservation baselines for the Critically Endangered Blue-crowned Laughingthrush?

Rosalind A. Gleave[1,2], Sarah K. Papworth[2], David Bauman[3,4,5], Steven J. Portugal[2], Weiwei Zhang[6], Yikang Liu[7], Zhiming Cao[6], Xiaojin Cheng[8] & Samuel T. Turvey[1]

1) Institute of Zoology, Zoological Society of London, London, NW1 4RY, United Kingdom.

2) School of Life Sciences and the Environment, Royal Holloway University of London, Egham, TW20 0EX, United Kingdom.

3) AMAP, Univ Montpellier, CIRAD, CNRS, INRAE, IRD, Montpellier, France.

4) Environmental Change Institute, School of Geography and the Environment, University of Oxford, Oxford, UK.

5) Plant Ecology and Biogeochemistry lab, Faculty of Sciences, Université libre de Bruxelles, Brussels, Belgium.

6) Center for Wildlife Resources Conservation Research, Jiangxi Agricultural University, Nanchang 330029, China.

7) School of Foreign Languages, Huazhong University of Science and Technology, No. 1037, Luoyu Road, Wuhan, China.

8) School of Economics and Business Administration, Chongqing University, Chongqing 400044, China.

Corresponding author: samuel.turvey@ioz.ac.uk

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Abstract

1. Designing conservation interventions for rare species can be hindered by a lack of relevant data. Local ecological knowledge (LEK) has potential to provide rapidly-collected, cost-effective data across large spatio-temporal scales, but has rarely been used as a source of conservation-relevant information for the Asian Songbird Crisis.

2. The Blue-crowned Laughingthrush (*Pterorhinus courtoisi*; BCLT) is a Critically Endangered passerine found only in southeastern China. It is unclear why the species' breeding range and global population are extremely small, as it occurs in human-occupied forest-agricultural landscapes similar to surrounding environments across southern China.

3. We conducted systematic range-wide interviews on BCLT (n=519) to collect novel information on the species' temporal and spatial distribution, and on potential human activities and landscape changes associated with its presence or absence. Recognition of BCLT was moderate (45.0% of respondents reported sightings), with sightings within the previous 18 months across the study area, within and beyond their known distribution. Over half of known breeding villages were confirmed by LEK data, and nesting was reported from two villages with no previous breeding records.

4. BCLT trapping was reported across the study landscape, mostly from the last decade and associated with trappers from urban centres. BCLT trapping and lack of *fengshui* forest were associated with sites where BCLTs did not breed. Breeding sites were associated with increases in vegetable gardens over respondents' lifetimes, and other sites within the species' range were associated with decreases in bush/scrub.

5. We demonstrate that LEK can identify potential threats, new breeding sites, and landscape changes correlated with species presence or absence for threatened birds affected by the Asian songbird crisis. This study provides the first evidence of ongoing trapping as a threat to BCLT, and remedial measures are urgently required across the region.

Introduction

Efforts to halt biodiversity loss must be underpinned by an understanding of species' status and threats, and diagnosing mechanism(s) responsible for declines, low population sizes or range restrictions is critical (Williams et al., 2020). Designing interventions without knowledge of these factors risks inefficient use of resources (Sutherland et al., 2004), continued population decline or extinction (Caughley, 1994), or other unintended consequences (Larrosa et al., 2016). However, identifying threats and population constraints for highly threatened species may be difficult with standard ecological techniques, necessitating employment of alternative approaches to provide conservation evidence (Turvey et al., 2014). One potential data source is Local Ecological Knowledge (LEK), representing first-hand information from people's interactions with their environment (Newing, 2011). LEK can provide information on current and past species status, human-wildlife interactions, and conservation-relevant patterns of local awareness, perceptions and attitudes (Bonfil et al., 2018; Bessesen & Gonzalez-Suarez 2021). It has established novel baselines on population parameters and threats for many species (Turvey et al., 2013; Parry & Peres, 2015), which can inform practical conservation interventions (Archer et al., 2020).

LEK has been used to guide conservation of large charismatic or economically important taxa, notably mammals (Archer et al., 2020; Zanvo et al., 2020). It has also provided insights into bird ownership and trapping (Biddle et al., 2021) and bird declines (Mallory et al., 2003). However, its usefulness for addressing other bird conservation priorities is largely unexplored. In particular, many Asian songbirds have declined severely through exploitation for trade (Nijman et al., 2017; Heinrich et al., 2021). Within this region, threats to songbirds in China are high (Nijman, 2010), with songbird markets in many Chinese cities (Huo et al., 2009; Dai & Zhang, 2017; Cheng, 2019), and widespread songbird hunting and trade (Kamp et al., 2015). However, the dynamics and impacts of these activities remain incompletely understood, with limited baselines on Chinese wildlife hunting, consumption, or trade (Zhang et al., 2008; Liang et al., 2013; Cheng, 2019). The Asian songbird crisis has been studied mainly through market surveys, with limited assessment of wild populations (Sykes, 2017; Putri et al., 2021). LEK has high potential to supply information about exploitation of commercially significant species (Jones et al., 2008), but may be less useful for smaller-bodied species (Turvey et al., 2014). It is therefore important to investigate the potential usefulness of LEK to establish new conservation baselines on this major threat to regional biodiversity.

The Blue-crowned Laughingthrush (*Pterorhinus courtoisi*; BCLT) is a highly threatened Chinese songbird, with a global breeding population restricted to a small region of northeast Jiangxi Province (He et al., 2017). It is classified as Critically Endangered by IUCN (BirdLife International, 2018), due to its restricted and fragmented range (extent of occurrence: 610 km^2) and small population (c.323 individuals in 2016). Its past range is unknown; a second population (sometimes treated as the subspecies *P. c. simaoensis*) was historically known from Yunnan Province (c.2,000 km from Jiangxi) but is now considered extinct (He et al., 2017). It was listed under Class I protection on China's List of Protected Species in 2020 (Ministry of Agriculture and Rural Affairs of the People's Republic of China, 2021).

BCLTs are colonial and cooperative breeders, nesting near or within villages (Wilkinson et al., 2004). Their breeding landscape is characterised by low forested hills and riverine valleys converted to agriculture (rice, oilseed rape and tea plantations), containing villages surrounded by vegetable plots (Richardson, 2005; He et al., 2017) and *fengshui* forests (small locally protected mature broadleaf or mixed-forest stands; Coggins et al., 2012). BCLT nest in *fengshui* forest, bamboo, fruit trees and fir, foraging mainly within broadleaf and *fengshui* forest, bush/scrub, tea plantations and vegetable plots when breeding (Hong et al., 2006; Wilkinson et al., 2004; Wilkinson & He, 2010b; He et al., 2017; Zhang et al., 2017; Liu et al., 2020). It is unknown where BCLTs spend their non-breeding season, although they may use nearby hills and mountains (Cheng & Lin, 2011; He et al., 2017).

As the BCLT's breeding landscape is similar to other Chinese human-occupied landscapes, it is unclear why the species is not widespread. Building developments and traffic are known to affect breeding sites (He et al., 2017; Li et al., 2021), but it is unknown whether local land-use differs between areas occupied and unoccupied by BCLT. The potential impact of exploitation is also unclear. Captive collections have existed since the 1990s (Long et al., 2004; Pasini et al., 2004), but most captive individuals are *P. c. simaoensis* (Wilkinson et al., 2004; Wilkinson & He, 2010a). Only one report of captive birds originates from Jiangxi (Yu, 2003), with no other evidence of BCLT trapping in this region (Richardson, 2005; Wilkinson & He, 2010b).

Recent conservation-oriented research has investigated BCLT habitat use (Shi, 2017; Huang et al., 2018; Liu et al., 2020) and responses to tourist disturbance (Zhang et al., 2017), but the potential information-content of LEK has not been investigated. The BCLT is a distinctive, attractive species both visually and aurally, with call detection used by researchers in monitoring (He, 1994; Richardson, 2005), and it is of local cultural and socio-economic importance (Zhang et al., 2017). It may therefore be familiar to people living within its range.

Here, we explore the ability of LEK to provide information on three key issues for BCLT conservation: can LEK identify (1) BCLT breeding sites and seasonal distributions; (2) threats and habitat changes associated with BCLT presence/absence; (3) priority areas for further research and conservation. By investigating the usefulness of LEK for informing management parameters for a threatened passerine, our findings also provide broader lessons on using LEK to establish baselines for species that have not traditionally been the focus of social-science research.

Methods

Field survey

Community-based surveys were conducted between 4 June and 31 July 2019 in Wuyuan, Dexing and Leping counties (Jiangxi Province) and Xiuning County (Anhui Province). These counties encompass the known BCLT breeding range, including known breeding sites in Wuyuan and Dexing and other breeding-season observations (data from unpublished 2000-2017 censuses and www.eBird.org; F. He 2019, personal communication), and nearby unsurveyed and unoccupied regions. We digitised and labelled >900 villages across this region using the Google Satellite plugin in QGIS v.2.18 (QGIS Development Team, 2021). Villages are defined as any named group of domestic buildings. Villages were digitised within a core area comprising all BCLT records (1434 km^2 minimum convex polygon (MCP) generated in QGIS), and within a 25 km buffer around this area. A separate core area comprising a convex hull around all recorded breeding locations from 2000-2017 (725 km^2 Extent of Occurrence (EOO)) was also generated, with its own 25 km buffer (**Figure 1**).

We conducted interviews in 18 villages where BCLT bred between 2000-2018 (representing all but one known site, which was only learnt about after fieldwork), and in 21 ‘control’ villages with no breeding records, chosen by: (1) randomly selecting 12 villages within the combined core and buffer polygons; (2) selecting nine villages closest to BCLT localities on eBird or in field reports (He, 1994). Of these villages, 25 were within the EOO and 14 were within its buffer. Breeding and randomly-selected control villages showed minor differences in environmental characteristics based upon data from a Google Satellite layer within QGIS, with control villages on average 557m closer to rivers (**Table 1**). However, as BCLT breed close to rivers (Richardson 2005), this was not anticipated to cause undue bias.

A target of ≥10 interviews was conducted per village, based on the estimated data saturation threshold (Guest et al., 1995). Village household plans were unavailable, so respondents were selected opportunistically in villages and surrounding farmland. Respondents were thus sampled on an approximately random basis, which aims to be broadly representative of wider baselines across the study region and allows comparability between localities (Newing 2011). Village leader(s) or other appropriate individuals were first located to request permission for research and obtain information on village population sizes (number of individuals/families).

Interviews were conducted on a one-to-one basis in Mandarin or local dialect (Wuyuanhua) by local field assistants trained in interview methods (local university students or high-school graduates). Research aims were explained before each interview (**Figure S1,**

Supplementary Information), with respondents informed that their responses were anonymous, they could stop interviews at any time, and could decline to answer questions without explanation. Interviews were then only conducted following verbal consent of participants; written consent was not appropriate as some respondents may have been illiterate and/or suspicious of signing written declarations. Individuals below 18 were not interviewed, but respondents were otherwise interviewed irrespective of sex, age, occupation or other characteristics. Research was permitted by Jiangxi Wuyuan National Forest Bird Nature Reserve Management Office, with project design approved by the Royal Holloway University of London ethics committee (1536-2019-02-21-16-10-PEBA015).

A standard questionnaire comprising 52 closed and open-ended questions was used, which took 15-20 minutes to complete (**Figure S1, Supplementary Information**). After questions collecting demographic information, respondents were asked about landscape changes around their village over their lifetime. Land types included rice paddy, vegetable gardens, tea plantation, oilseed rape, fir forest, pine forest, bamboo forest, *fengshui* forest, broadleaf forest, bush/scrub, and fruit trees; example photographs of land types were shown as necessary. Subsequent questions asked about change in local human population, number of houses, and construction of roads, bridges and highways.

Respondents were then asked if they recognised BCLT (*languan zaomei*) and four bird species locally common across the study area based on direct experience by the survey team: Hwamei *Garrulax canorus* (*huamei*), Masked Laughingthrush *Pterorhinus perspicillatus* (*heilian zaomei*), Light-vented Bulbul *Pycnonotus sinensis* (*baitoubei*), and Tree Sparrow *Passer montanus* (*maque*) (MacKinnon & Phillipps, 2018). Species were always mentioned in the order above, with BCLT last. Respondents were asked if they recognised each bird from its Mandarin or Wuyuanhua name. They were then shown colour photographs of all species individually (**Figure S2, Supplementary Information**; obtained through Google Images designated for non-commercial reuse) and asked if they recognised and/or could name them. All species are sexually monomorphic. Finally, respondents were played an audio recording of wild BCLT calls recorded by the lead author in July 2018. Respondents who recognised BCLTs were asked about their last BCLT encounter (year, time of year, location, breeding activity). Respondents were expected to recognise sparrows, which are locally abundant and included as a positive control. Including a range of species was intended to allow comparisons (to assess respondents' ability to identify BCLT in relation to knowledge of other species), and functioned to obscure the possible importance of BCLTs within interviews, increasing the likelihood that respondents might disclose sensitive knowledge or activities associated with BCLTs (Turvey et al., 2015).

Final questions were about bird-related threats and conservation (awareness of local bird capture/killing and legal protection). If respondents identified BCLTs, they were asked about specific captures of this species. Reports of BCLT captures were investigated further with separate key informant interviews, including questions on trapping location/methods and origin of trappers (**Figure S3, Supplementary Information**).

Analysis

Quantitative analysis

First, we wanted to understand basic descriptive patterns in the dataset, so chi-squared and Fisher's exact tests were used to investigate differences in: (1) number of respondents who recognised BCLT from name, photo or audio recording, between breeding versus control villages, and between EOO versus buffer villages; (2) number of recent (2018-2019) reports of BCLT sightings, between the same groups of villages; and (3) number of BCLT sightings in breeding (spring-summer) and non-breeding (autumn-winter) seasons, between breeding versus control villages. To account for possible pseudoreplication (non-independence of responses within same village), a Bayesian logistic regression was built in *brms* (Bürkner, 2017) to model BCLT sightings as a function of different village types (breeding and control; EOO and buffer) with village name as a random effect, using default priors. All analyses were performed in R v.3.5.2 (R Core Team, 2021). BCLT last-sighting dates were converted to calendar years where possible (**Table S1**, **Supplementary Information**); dates with low precision were excluded (n=12 excluded, n=149 retained).

Next, we wanted to explore the relationship between BCLT presence/absence and sighting metrics, and local landscape changes and/or human threats. For this, we built a set of regression models. Multiple Correspondence Analysis using the *factoextra* package (Kassambara & Mundt, 2020) was performed on landscape-change variables to reduce the number of model covariates; however, because a low proportion of total variance was described by axes 1-4 (19%), covariates were not separated. Variation in respondent demographics between response types was investigated using chi-squared tests (occupation, sex) or univariate frequentist GLMs (age) with a Gaussian error structure using the *lme4* package in R (Bates et al., 2015), and with response variables treated as binary predictors.

Sampling units are at the respondent level. Factor levels for landscape change are increase/no change in/decrease/lack of land types. These were not collapsed into increase/decrease as this would combine two opposing environmental changes, and fail to capture the range of land type change. Factors were re-levelled for each covariate, making reference levels either ‘No’ or ‘No change’. A Bayesian inference framework was used for all models, to account for unbalanced data design and to capture and report model coefficient uncertainty. Bayesian frameworks are used as an alternative approach to frequentist frameworks and give model outputs in the form of probability distributions.

Modelling BCLT breeding responses

Our first question was to explore which landscape change or threat variables could predict whether responses came from breeding or control villages, or within the EOO or its buffer (binary response variables). A modelling approach using a consensus of all responses per village was not possible, as responses for some land-use variables were contradictory (respondents in the same village sometimes reported differing directions of change for the same variable). For example, in one village, 36% of respondents stated there was more broadleaf forest, 27% each stated there was no change or no broadleaf forest, and 9% said they did not know. Data were thus analysed at the village level, using generalised linear models (GLMs) with binomial error structure (logit link). These responses within the same village were allocated identical binary outputs for breeding/control and EOO/buffer models. For this approach, each categorical predictor was split into its separate factor levels, with each level analysed as a proportion of responses per village (treated as a new separate variable for each land type covariate), i.e. percentage of ‘increase’, ‘no change in’, ‘decrease’ or ‘lack of’ for each village. Individual GLMs were then run using these levels (one

GLM per predictor, and one data point per village). This process was repeated for all seven *a priori* categorical predictors.

Past BCLT breeding was reported in two villages with no previous breeding record, so two separate ‘breeding/control’ models were built, alternately assigning these villages as ‘breeding’ or ‘control’ to compare model outputs. This provided 14 regression models.

Variables included within models were: bamboo (Bamboo_change), *fengshui* forest (Fengshui_forest_change), bush/scrub (Bushscrub_change), tea plantation (Tea_plant_change) and vegetable gardens (Veg_garden_change); building or not of new roads (Roads), and awareness of people catching BCLT (Catching_BCLT); see **Table 2**. Land type variables were chosen *a priori* through basic data exploration (**Table S2, Supplementary Information**), and because all are suggested to impact BCLT breeding or have potential to influence BCLT populations (Yu, 2003; Hong et al., 2006; Wilkinson & He, 2010b; He et al., 2017; Zhang et al., 2017; Liu et al., 2020). Missing data were checked using *visdat* and *nanair* (Tierney 2017; Tierney & Cook 2023). No modelled predictors were missing excessive values (>6% of total sample size) so none were removed from the dataset.

Responses from each village for each factor level were summed and scaled (subtracting variable mean and dividing by variable standard deviation) to improve model performance (Zuur et al., 2009; McElreath, 2016). Collinearity between factor levels was checked using the R package *corrplot* (Wei & Simko, 2021), using pairwise correlations with a threshold of 0.70; all correlations were below this threshold. Most ‘do not know’ responses were excluded, but were retained for questions about people catching BCLT (response could indicate withholding of sensitive information); we also excluded increases in *fengshui* forest (if this habitat type increased within living memory, new trees might not yet be mature, creating uncertainty over potential increase). Regularising priors were used to avoid overfitting of parameter estimates.

Modelling BCLT sighting responses

Our second question was to explore which landscape change or threat variables could predict whether respondents had seen BCLTs, or had seen them within the previous 18 months (binary response variables). These were investigated using generalised linear mixed models (GLMMs) with binomial error structure. All models included varying intercepts for Interviewer and Village. To reduce model overfitting, biases from unsupervised addition of covariates, and stepwise variable selection issues (Mundry & Nunn, 2009; McElreath, 2020), a global model was compared to four reduced models (**Table 2**) to identify the most parsimonious model and examine different combinations of habitat change and threat covariates.

For overall sightings, the global model contained the same covariates as in the previous breeding/EOO models to enable direct comparison, together with respondent age to control for the length of time that people had lived in their village. The first two reduced models contained fewer habitat covariates (removing change in tea plantation and then bush/scrub, as these showed weaker importance for breeding BCLT); the third contained only threat covariates (new roads, trapping); the fourth contained all habitat covariates.

For recent sightings, the global model contained the same covariates as the previous global model but excluded changes in *fengshui* forest, bush/scrub, or new roads (all suggested to have specific relationships to breeding sites rather than general BCLT distribution; Liao et al., 2007; Wilkinson & Gardner, 2011; Liu et al., 2020), and included reported types of locally-caught birds (songbirds, gamebirds, waterfowl, and sparrows or other birds considered pests). Overall, 94.2% of respondents had lived in their village for at least two years; respondents who lived there for <2 years were still included in the models.

The global model was of the form:

$$Y_{i,s} \sim Bernoulli(p_{i,s})$$

$$logit(p_{i,s}) = \beta_{00} + \beta_{0_i} + \beta_{0_s} + \sum_{j=1}^{8} \beta_j \times x_{j_{i,s}}$$

$$\beta_{00} \sim Normal(0, 1)$$

$$\beta_{0_i} \sim Normal(0, \quad \sigma_{interviewer})$$

$$\beta_{0_s} \sim Normal(0, \quad \sigma_{village})$$

$$\beta_{1-8} \sim Normal(0,1)$$

$$\sigma_{interviewer} \sim Half - Student(3, 0, 2.5)$$

$$\sigma_{village} \sim Half - Student(3, 0, 2.5)$$

Where: β_{00} is the overall intercept, β_{0i} is the random intercept for interviewer *i*, and β_{0s} is the random intercept for village *s*. Where x_1 to x_8 correspond to the fixed effect covariates in **Table 2**.

Model comparison was performed through the estimated out-of-sample expected predictive accuracy, using Leave-One-Out (LOO) cross-validation. Adaptive regularising priors were used to avoid overfitting of parameter estimates (McElreath, 2020). Models were run with and without Gaussian process regression to test and control for spatial autocorrelation in residuals, allowing varying effects of 'Village' to be treated as a continuous category by incorporating spatial coordinates, thus correcting the potential for nearby villages to share more features than expected from independent observations (e.g. topography; McElreath, 2020). We present models with best expected out-of-sample predictive accuracy (LOO), together with outputs from alternative models with similar levels of accuracy. A pseudo R^2 was obtained for these models (Gelman et al. 2018).

Bayesian updating of model parameters was performed through the No-U-Turn Sampler in Stan, using the R package *brms* (Bürkner, 2017). Models were fitted using 3,000 iterations on four chains, with 1,500 warm-ups/chain. Model convergence was checked using Rhat values, with posterior distributions assessed using the R package *tidybayes* (Kay, 2022). All models converged and had sufficiently high effective sample sizes. Posterior predictive checks were performed using *tidybayes* to assess how well models retrodicted real observations. We only report covariates where the 90% credible interval of the slope posterior distribution excludes zero, i.e., whose effect was either clearly positive or clearly negative.

Results

We interviewed 519 respondents in 39 villages (Wuyuan: 281; Dexing: 189; Leping: 16; Xiuning: 33; mean of 13.3 interviews/village), with 496 respondents answering all questions

(**Table S3, Supplementary Information**). Based on population estimates provided during fieldwork, 1.1% of the local population was surveyed. Nearly all respondents (95.2%) lived in survey villages, and most (80.1%) had been residents their whole lives (mean duration respondents had lived in their villages: 49.9 years, SD=19.4, n=516). Respondents were more likely to be farmers in control villages than in breeding villages (X^2=5.26, df=1, p=0.022), and respondents were older inside the EOO than the buffer region (effect size=2.51, SE=1.28, p=0.05) and in control villages than breeding villages (effect size=3.02, SE=1.24, p=0.01).

Blue-crowned Laughingthrush recognition and sightings

Bird recognition ranged between 2.1-86.1% by name and 27.8-82.9% by photo, with sparrows recognised most widely (**Figure 2**). Three species (BCLT, Masked Laughingthrush, Light-vented Bulbul) were better recognised by photo than name (**Figure 2**). Overall, 45.0% (232/516) of respondents recognised BCLT, either by name (11.6%, n=27/232), photo (78.4%, n=182/232), or recording (60.3%, n=140/232), and two further respondents said they did not recognise the species based on these prompts but provided detailed last-sighting information (**Figure S4, Supplementary Information**). No respondents recognised BCLT by name in control villages (n=162) or buffer villages (n=186), representing a different pattern of recognition compared to breeding villages (X^2=27.55, df=1, p>0.001) and EOO villages (X^2=15.86, df=1, p>0.001). There was higher BCLT recognition from photos in EOO villages (46.1%, n=130/282) versus buffer villages (30.4%, n=52/171) (X^2=10.26, df=1, p=0.001), but minor difference between breeding and control villages (X^2=3.18, df=1, p=0.07). There was also no clear difference in BCLT recognition from recordings in breeding versus control villages (X^2=2.89, df=1, p=0.08), or EOO versus buffer villages (X^2=0.79, df=1, p=0.370).

Overall, 234 respondents reported BCLT sightings. While 232 respondents reported recognising BCLT from the name, photo or recording, 234 were considered to have seen a BCLT if they recognised the species and/or gave pertinent last sighting information (two respondents said they did not recognise the species from the above prompts but then went on to give detailed last sighting information). Sightings were more likely to be reported by men than women (X^2=6.05, df=1, p=0.013), but there were small differences between breeding versus control villages (X^2=0.36, df=2, p=0.835) or EOO versus buffer villages (X^2=0.46, df=1, p=0.493). Of respondents who reported sightings, 69.4% (n=161) provided a last-sighting date, with 45.7% (n=106) of sightings considered recent (dating within the previous 18 months) (**Figure S5, Supplementary Information**). There were some differences in proportions of respondents reporting recent sightings in breeding versus control villages (estimate=0.32, 95% CI: -0.39, 1.00), and EOO versus buffer villages (estimate 0.02, 95% CI: -0.66, 0.73). More recent mean last-sighting dates were reported in breeding villages (2015.73, n=69 respondents) versus control villages (2013.21, n=73 respondents), and in EOO villages (2015.86, n=97 respondents) versus buffer villages (2012.38, n=52 respondents).

Sighting frequencies varied between seasons (X^2=56.32, df=3, p<0.001), with more last sightings reported from spring/summer (75.2%, n=161) compared to autumn/winter (24.7%, n=53). Seasonality differences were slightly different between breeding and control villages (X^2=7.42, df=3, p=0.059), with a higher proportion during the breeding season in breeding villages (breeding villages=75.9%, control villages=63.7%), and a higher proportion during the non-breeding season in control villages (breeding villages=14.8%, control villages=29.8%).

Overall, 14 respondents across 11 villages had seen BCLTs nesting near their village. Nine sites were known breeding villages (56.3% of known breeding villages), and two ('village 1' and 'village 2') were previously unknown breeding sites. In village 1 (in buffer, close to a past eBird sighting), birds were reported nesting in camphor trees within the village. In village 2 (within EOO, close to a past eBird sighting and other breeding sites), they were reported nesting in old trees in a field. Respondents reporting past or present nesting did not provide exact locations, but stated that birds used high trees, huge trees near the village, old trees, fruit trees, camphor (*Cinnamomum camphora*), pomelo (*Citrus maxima*), Chinese yew (*Taxus chinensis*), or 'all kinds of trees'.

Landscape changes and threats

Respondents reported various local land-use changes during their lifetime (**Figure 3; Table S4, Supplementary Information**), 81.5% (n=423) reported changes in number of houses (99.1% reported an increase), and 72.1% (n=374) reported new road construction.

A quarter (25.5%; n=129/506) of respondents reported hearing of people catching wild birds, of which 24.8% (n=32) reported birds caught by villagers, 56.6% (n=73) by outsiders, and 8.5% (n=11) by both groups. Mean last bird-catching date was 2014 (range: 1995-2019). Overall, 6.5% (n=34) of respondents said people kept songbirds locally. Respondents from Wuyuan said people came from the copper mine area near Sizhou (Dexing County) to trap wild birds. One respondent in Xiuning had seen 1-2 people trapping BCLT and Hwamei in forested hills near his village, and could tell the trappers were from the Huangshan region by their accents; they had come to trap birds once or twice a year for the previous several years, luring and netting flock members using caged birds. Reports of Hwamei trapping and keeping were corroborated by our observation of a caged Hwamei near one BCLT breeding site.

Overall, 3.3% (n=16/487) of respondents, from 10 villages across all counties, reported having heard of people catching BCLT (Wuyuan, n=6; Dexing, n=4; Leping, n=3; Xiuning, n=3) (**Figure 4**). All these respondents reported having seen BCLT. Nine of these villages contained respondents who reported BCLT sightings within the previous five years and during the breeding season; five villages were outside the EOO, with two in Xiuning, a region not surveyed regularly for BCLT. Reports referred to BCLT being caught between spring 2019 and 15 years earlier; seven reports dated from the previous 10 years (mean reported last-catching event: 2012). No direct evidence of BCLT trapping was observed.

When asked whether BCLT is a protected species, 17.1% of respondents (n=89) said yes, 34.9% (n=181) said no, and 47.2% (n=245) did not know.

Predictors of BCLT breeding sites and sightings

For comparisons between breeding and control villages, GLMs indicated that villages with higher proportions of respondents reporting decreases in bush/scrub and increases in vegetable gardens were more likely to be in breeding villages, higher proportions of respondents reporting no *fengshui* forest were more likely to be in control villages, and higher proportions of respondents reporting BCLT trapping were less likely to be in breeding villages (**Table 3**). When villages with uncertain BCLT breeding status were included as breeding rather than control villages, results varied only slightly, with respondents reporting no change in tea plantations more likely to be in breeding villages, and with no strong relationship with changes in vegetable gardens (**Table S5, Supplementary Information**). For comparisons between the EOO and its buffer, respondents reporting decreases in bush/scrub were more likely to be within the EOO, and respondents reporting increases in bamboo forest, no change in bush/scrub, or increases in road building were less likely to be within the EOO (**Table 3**).

Respondents who knew of people catching BCLTs were more likely to have seen BCLT in the optimal candidate GLMM (**Figure 5a**). Respondents reporting no tea plantations were less likely to have seen BCLT recently in the optimal candidate GLMM (**Figure 5b**). Respondents who knew of people catching BCLTs were also more likely to have seen BCLT recently in the next most plausible GLMM, however this effect was weak (**Figure S6, Table S6, Supplementary Information**). R^2 estimates were 0.32 and 0.16 for the seen and recently seen BCLT models, respectively (**Table S7**). Models also showed between-interviewer variation (**Figure 5a-b**).

Discussion

This study provides the first large-scale, systematically-collected LEK dataset for the BCLT, one of China's most threatened birds, which requires robust evidence for conservation planning. With previous data limited to site-scale observations, our comprehensive LEK data analysis provides important insights into BCLT distribution and seasonal occurrence, and identifies threats and habitat change associated with local BCLT presence or absence. More generally, our study also promotes the usefulness of LEK for rapid gathering of novel wide-scale data, and demonstrates its application for informing conservation of distinctive passerines.

Our data are consistent with existing baselines on BCLT status and distribution, supporting their usefulness for conservation planning. Almost half of respondents recognised BCLT, with no recognition by name outside breeding sites or breeding range (EOO). In addition, demographic differences were recorded within respondent awareness of BCLT: men were more likely to report seeing a BCLT. Similar patterns have been observed in other studies (Boissière et al. 2013; Archer et al. 2020) which may be caused by differences in gender-based divisions of labour and thus interactions with nature. Mean last-sighting dates were more recent at breeding sites and within the EOO, probably reflecting regular local presence when breeding and/or greater likelihood of opportunistic local observations during the breeding season. Accuracy of using LEK to identify known breeding sites was nearly 60%, and where breeding BCLTs were reported, respondents described nesting trees consistent with known characteristics of nesting sites (Zhang et al., 2017; Huang et al., 2018). These combined findings demonstrate that LEK can provide accurate data on BCLT presence and breeding activity, although we acknowledge it may be more effective when combined with other techniques. Conversely, the moderate accuracy of LEK in identifying breeding sites suggests that this data-type should not replace standard monitoring of breeding sites, and might indicate that further villages could also support undetected past or present BCLT colonies.

BCLT sightings were made year-round and across the entire study landscape, including outside the known breeding range. Reported sightings were higher in the breeding season, although this may reflect that interviews took place during summer. Similarly, more sightings during the breeding season were made at breeding sites, although these occurrences are non-independent: sightings are more likely to be recent (and during the breeding season) at breeding sites. However, numerous autumn-winter sightings support previous suggestions that BCLTs spend the non-breeding season in a similar area to the breeding season, but away from breeding sites (He et al., 2017). Notably, recent (2014-2019) breeding-season sightings were reported outside the known breeding range in Xiuning County, Anhui, highlighting the importance of further surveys in this region. Our respondents also identified two overlooked breeding sites: one within a few miles of a known long-term site, and the other outside the known breeding range, along the same river network as many other sites and in an area containing many *fengshui* forest trees. Although these sites have not yet been independently verified, our findings suggest future surveys could reveal further potential breeding locations. Conversely, limited sighting differences between breeding and control sites and landscapes might provide evidence of wider BCLT distribution than previously thought, but may also reflect that these data are based on memory and perception.

Disturbance from vehicle traffic, photographers, and infrastructure construction are regarded as primary BCLT threats (He et al., 2017; Zhang et al., 2017), with trapping in Jiangxi previously reported only once in the 1990s (Yu, 2003). However, our results indicate that bird trapping is widespread across the study region, with BCLT trapping reported across its range and multiple BCLT trapping events reported within the past decade. Local awareness of people catching BCLT was an important factor in many of our models, supporting the likely influence of trapping on BCLT presence. Even a few trapping events could still substantially impact the species due to its cooperative breeding behaviour, restricting its breeding range and suppressing recovery (Yu, 2003). Indeed, sustainable harvesting of wild populations can be difficult to achieve in traded bird species (Valle et al., 2018), and even species traded in low numbers can experience slow decline (Nijman et al., 2021).

Trapping reports are more likely in villages where BCLTs have been seen at all but less likely at breeding sites. These findings might indicate that trappers are drawn to the general region where BCLT are found, but existing breeding sites may confer some protection. Conversely, some colonies might have been eliminated through trapping, BCLT might not breed where trapping occurs, or trapping might be underreported at breeding sites. Wuyuan is known for high bird diversity and abundance, which could attract trappers targeting other species (He et al., 2014); however, trappers may also be attracted by BCLT, given its popularity with photographers (Zhang et al., 2017). Respondents stated that most BCLT trapping is conducted by outsiders, with some reports that individuals from nearby urban centres were visiting to trap songbirds. Visiting trappers were reported to trap both BCLT and Hwamei; the latter species is traded in large numbers throughout China and Southeast Asia (Shepherd et al., 2020), so local trapping could be linked to both domestic and international songbird trade (Dai & Zhang, 2017; Nijman et al., 2017). Chinese Hwamei in trade are considered to be chiefly wild-caught within China (Shepherd et al. 2020; Nelson & Shepherd 2023). Further investigation into the distribution and prevalence of trapping, potentially using interview techniques developed for investigating sensitive behaviours (Hinsley et al., 2019, 2021), is thus an urgent priority for BCLT research. Concerningly, local awareness of BCLT protection status was low, highlighting the additional need for awareness-raising using locally-relevant approaches (Qian et al., 2022). BCLT were added as a Class I protected species in 2020 after these interviews took place, however all wild birds receive general protection in China (People’s Republic of China Wildlife Protection Law, 1988).

Our results also indicate substantial changes to BCLT habitat during respondents’ lifetimes, with increases in houses, bamboo, bush/scrub, broadleaf forest and fir forest, and decreases in pine and *fengshui* forest, tea plantations and vegetable gardens around villages. We recognise the potential for overlap in meaning between some responses. For example, ‘less’, ‘no change’ and ‘none’ might all mean ‘none left’, particularly for tea plantation and *fengshui* forest, which have disappeared in many places during respondents’ lifetimes; decreases in these habitats may therefore be more common than our data suggest. Importantly, several reported habitat changes are correlated in our models with varying likelihood of local BCLT occurrence, providing an indicator of potential drivers of decline or factors influencing population dynamics, with implications for landscape management.

Higher proportions of reported increases in vegetable gardens were more likely at BCLT breeding sites, and respondents who reported a lack of tea plantation were less likely to have seen BCLT recently. Reported decreases in bush/scrub were also more likely at breeding sites, and no change in bush/scrub less likely at breeding sites and within the EOO. These findings support existing evidence that these habitat types are used by foraging BCLTs disproportionately to other habitats except woodland (Liu et al., 2020), indicating that they are associated with local BCLT occurrence and breeding. Concerningly, road construction is a known source of disturbance to BCLTs (He et al., 2017), but was more likely to be reported within the EOO versus the buffer, highlighting an ongoing threat within the species' key habitat.

Further differences in land-use changes associated with varying likelihood of BCLT occurrence may be specific to breeding sites. Notably, perceived change in *fengshui* forest showed no difference between EOO and buffer regions, but reported absence of *fengshui* forest was less likely at breeding sites, suggesting that it is specifically important for breeding. This result supports previous findings that this habitat is a common feature of breeding sites, even if it is not always used for nesting (He et al., 2017; Zhang et al., 2017). *Fengshui* forests have recently received greater protection in Jiangxi (Zheng, 2003), but face continuing threats across China (Chen et al., 2018). Protection of this habitat type is thus also required across southeastern China, which may be critical for future BCLT recovery and expansion.

No independent baselines exist for habitat change across the BCLT landscape, so our model correlates are important for management and may be crucial for encouraging BCLT presence at breeding sites. LEK is shown to broadly corroborate independent data on land-cover change for better-studied systems (Chalmers & Fabricius 2007; Lauer & Aswani 2010), suggesting that respondent perceptions of landscape change can provide conservation-relevant insights. Freely available satellite data to assess fine-scale habitat change across our study region, such as Sentinel-2, was unavailable prior to 2015 (Phiri et al. 2020). However, there is potential for future diachronic-synchronic complementarity between LEK and habitat surveys, earth observation time-series data, and standard monitoring data (Moller et al., 2004); used together, these may provide more comprehensive insights into spatiotemporal changes in BCLT landscapes and their impacts on BCLT populations.

Conclusion

Our LEK data suggest that BCLT are more widespread across our study landscape, but under greater risk from trapping, than previously thought. Given the widespread songbird declines across Asia due to trade (Sykes, 2017), trapping should not be discounted as a past threat, but must be considered alongside other potential current threats to BCLTs. Respondents showed awareness of whether trappers were local or outsiders, suggesting the potential for community-based conservation to provide early warnings of trapping conducted by external actors. Wider survey work is needed to understand BCLT distribution and co-occurrence of trapping, including the possibility that BCLTs occur year-round across this landscape and may thus be affected by trapping throughout the year. Subpopulations of breeding birds may also remain undocumented, with southern Anhui as an important new area to target surveys and conservation efforts to counter potential trapping. Current landscape management also has important implications for BCLT conservation, and we provide support for *fengshui* forests and vegetable gardens being associated with BCLT breeding. Habitat loss and overexploitation form a common synergy in driving species loss (Symes et al., 2018), with these effects notoriously difficult to unpick (Brook et al., 2008; Ni et al., 2018). Further declines of important land types should be prevented across the wider region, including outside Jiangxi. Our results can help to inform this work, and give evidence that LEK data can provide important insights into correlates of BCLT presence and absence, its temporal and spatial distribution, and local people's interactions with this Critically Endangered species, assisting with future BCLT conservation. Our results thus demonstrate that LEK can provide important insights for understanding potential reasons behind species' low population size or range restriction. We also demonstrate that LEK represents a useful data source for uncommon birds, countering suggestions that it is more appropriate for large or common species (Nyhus et al., 2003), and can reveal previously undetected trapping activity to support tackling the Asian songbird crisis.

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Data Availability Statement: Due to the extreme vulnerability of our study species to poaching and other threats, and due to cultural and political sensitivities for the people participating in this research, the original dataset cannot be placed in a public repository.

Conflict of interest: The authors declare no competing interests.

Author contributions: RAG, STT, SKP, SJP and WZ developed study design. RAG, YL, XC and ZC collected data. YL translated the questionnaires. RAG and DB analysed data. RAG, STT, SKP and SJP contributed to interpretation of data and writing of the manuscript. All authors contributed critically to drafts and gave final approval for publication.

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Table 1. Differences between breeding and randomly-selected control villages in mean basic characteristics.

Basic characteristic	Overall	Breeding	Control
Approximate number of buildings			
Mean	150.97	195.31	106.91
Standard deviation	199.68	239.42	83.97
Distance to main road (m)			
Mean	881.37	823.52	955.00
Standard deviation	26	1185.36	1139.05
Distance to river (m)			
Mean	647.47	956.42	399.50
Standard deviation	1515	1767.41	873.79
Elevation (m)			
Mean	90.33	77.00	89.83
Standard deviation	1166	18.94	33.60

Table 2. Global and reduced GLMMs for investigating sighting responses in relation to habitat change and threat covariates. Model specification uses R notation.

	Respondent seen BCLT	**Respondent seen BCLT within last 18 months**
Global model (random intercepts)	Seen_BCLT ~ Catching_BCLT + Fengshui_forest_change + Veg_garden_change + Tea_plant_change + Bamboo_change + Bushscrub_change + Roads + Age + (1|Village) + (1|Interviewer)	Recently_seen_BCLT ~ Catching_BCLT + Tea_plant_change + Veg_garden_change + Types_caught_birds + Bamboo_change + (1|Village) + (1|Interviewer)
Reduced model 1	Seen_BCLT ~ Catching_BCLT + Fengshui_forest_change + Veg_garden_change + Age + (1|Village) + (1|Interviewer)	Recently_seen_BCLT ~ Bamboo_change + Tea_plant_change + Veg_garden_change + (1|Village) + (1|Interviewer)
Reduced model 2	Seen_BCLT ~ Catching_BCLT + Fengshui_forest_change + Veg_garden_change + Bamboo_change + Bushscrub_change + Age + (1|Village) + (1|Interviewer)	Recently_seen_BCLT ~ Tea_plant_change + Types_caught_birds + (1|Village) + (1|Interviewer)
Reduced model 3	Seen_BCLT ~ Catching_BCLT + Roads + Age + (1|Village) + (1|Interviewer)	Recently_seen_BCLT ~ Tea_plant_change + Types_caught_birds + (1|Village) + (1|Interviewer)
Reduced model 4	Seen_BCLT ~ Fengshui_forest_change + Veg_garden_change + Bamboo_change + Tea_plant_change + Bushscrub_change + Age + (1|Village) + (1|Interviewer)	Recently_seen_BCLT ~ Catching_BCLT + Types_caught_birds + (1|Village) + (1|Interviewer)

Table 3. Outputs from univariate Bayesian GLMs for breeding versus control villages, and EOO versus buffer villages. Variables where 90% credible interval (CI) range does not overlap zero (considered to have clear effects) are highlighted in bold.

Response	**Breeding/control**		**EOO/buffer**	
Covariate				
Bamboo forest change	**Estimate**	**90% CI range (lower-upper)**	**Estimate**	**90% CI range (lower-upper)**
More	-0.33	-1.13 – 0.42	**-1.04**	**-2.06 – -0.19**
No change	-0.21	-1.02 – 0.54	0.25	-0.57 – 1.12
Less	0.44	-0.26 – 1.25	0.08	-0.67 – 0.89
No bamboo forest	-0.45	-1.38 – 0.37	-0.47	-1.36 – 0.39
Catching BCLT				
Do not know	-0.29	-1.16 – 0.49	**-0.75**	**-1.61 – 0.00**
No	-0.38	-0.33 – 1.19	0.20	-0.60 – 1.07
Yes	**-0.89**	**-2.01 – 0.00**	-0.63	-1.59 – 0.22
***Fengshui* forest change**				
No change	0.09	-1.08 – 0.45	-0.25	-1.03 – 0.53
Less	-0.21	-0.73 – 0.93	-0.50	-1.28 – 0.24
No fengshui forest	**-1.26**	**-2.52 – -0.19**	-0.66	-1.57 – 0.18
Bush/scrub change				
More	0.22	-0.79 – 1.20	-0.43	-1.38 – 0.43
No change	**-2.02**	**-3.79 – -0.61**	**-1.60**	**-2.82 – -0.55**
Less	**2.78**	**1.16 – 4.93**	1.28	0.19 – 2.56
No bush/scrub	0.56	-0.40 – 1.63	0.42	-0.65 – 1.68
Tea plantation change				
More	-0.36	-1.27 – 0.43	**-1.06**	**-2.14 – -0.17**
No change	0.68	-0.13 – 1.55	0.01	-0.87 – 0.88
Less	0.15	-0.72 – 1.03	-0.36	-1.25 – 0.53
No tea plantation	-0.12	-0.97 – 0.75	-0.76	-1.73 – 0.13

Roads				
Yes	0.23	-0.48 – 0.98	-0.14	-0.88 – 0.59
No	-0.65	-1.49 – 0.09	**-0.76**	**-1.61 – 0.00**
Vegetable garden change				
Less	-0.18	-0.99 – 0.55	-0.14	-0.88 – 0.61
More	**0.88**	**0.05 – 1.96**	0.13	-0.67 – 1.02
No change	-0.65	-1.57 – 0.15	-0.69	-1.51 – 0.06
No vegetable garden	0.47	-0.30 – 1.27	0.12	-0.68 – 0.96