

Informing decisions on an extremely data poor species facing imminent extinction

MATTHEW J. GRAINGER, DUSIT NGOPRASERT
PHILIP J.K. MCGOWAN and TOMMASO SAVINI

Abstract Some of the species that are believed to have the highest probability of extinction are also amongst the most poorly known, and this makes it extremely difficult to decide how to spend scarce resources. Assessments of conservation status made on the basis of loss or degradation of habitat and lack of records may provide compelling indications of a decline in geographical range and population size, but they do not help identify where conservation action might be best targeted. Methods for assessing the probability of extinction and for modelling species' distributions exist, but their data requirements often exceed the information that is available for some of the most urgent conservation cases. Here we use all available information (localities, expert information, climate and landcover) about a high-priority Vietnamese bird species (Edwards's pheasant *Lophura edwardsi*) to assess objectively the probability of its persistence, and where surveys or other conservation action should be targeted. It is clear that the species is on the threshold of extinction and there is an urgent need to survey Bach Ma National Park (including the extension) and to consider surveying Ke Go Nature Reserve. This approach has potential to help identify where conservation action should be targeted for other Critically Endangered species for which there is an extreme scarcity of information.

Keywords Data, Edwards's pheasant, extinction, *Lophura edwardsi*, optimal linear estimator, Siamese fireback, silver pheasant

Introduction

Species that are considered to be close to extinction are often a target for conservation action. This may involve dedicated action by conservation organizations, working nationally or internationally (e.g. the Alliance for Zero Extinction, and BirdLife International through its Preventing Extinctions Programme), or the establishment of global policy targets, such as Aichi Target 12 of the

Convention on Biological Diversity's Strategic Plan for Biodiversity 2012–2020 (Secretariat of the Convention on Biological Diversity, 2010) and target 15.5 of the UN's Sustainable Development Goals (UN Sustainable Development Knowledge Platform, 2016). Our understanding of how high the probability of extinction is for individual species is variable, as is our ability to identify places that should be priorities for action. In some instances, species are well known and easily detectable, meaning that there is a sound basis for identifying where and how to act. For other species, however, it is extremely difficult to be confident about their proximity to extinction, let alone decide where searches should be focused or where conservation interventions should be implemented. This variation in our understanding is typically a result of variable information about species, across both space and time, which, in turn, is attributable to factors such as detectability (Bibby et al., 2000), search effort (Boakes et al., 2016) and how well information is documented and made accessible (Boakes et al., 2010b).

South-east Asia has been highlighted as a region where there is both a high risk of extinction of many vertebrate species (e.g. Hoffmann et al., 2010) and a severe lack of information on where and how to act to prevent their extinction (Duckworth et al., 2012). These concerns led to a call for urgent action to address the threats facing tropical Asia's species, at the 2012 World Conservation Congress (IUCN, 2012), and the establishment of the Asian Species Action Partnership (ASAP, 2016).

For many of these species the available data on location or ecology are few, and they are often considered to be of poor quality, which typically refers to old records for which the date and location are uncertain. Using these records without critical appraisal of the nature of this uncertainty could result in subjective assessments of where a species may still occur, what its habitat is and where searches should be focused.

Since Edwards's pheasant *Lophura edwardsi* was re-categorized as Critically Endangered on the IUCN Red List in 2014 there has been increasing attention to its conservation. It is vital, therefore, that as much information as possible, even if of unknown quality, is used as the basis for defining the species' status and deciding what conservation action should be undertaken. Here we make use of all available information to model the potential for extinction of Edwards's pheasant and compare this with the two other *Lophura* species inhabiting the same area. We then examine the spatial

MATTHEW J. GRAINGER and PHILIP J.K. MCGOWAN (Corresponding author) School of Biology, Newcastle University, Newcastle upon Tyne NE1 7RU, UK
E-mail philip.mcgowan@newcastle.ac.uk

DUSIT NGOPRASERT and TOMMASO SAVINI Conservation Ecology Programme, King Mongkut's University of Technology Thonburi, Bangkok, Thailand

Received 3 January 2017. Revision requested 24 February 2017.
Accepted 6 May 2017. First published online 18 August 2017.

uncertainty associated with the location data to determine if a species distribution model could be produced to guide survey effort. Finally, we produce a Bayesian model to predict current habitat availability and identify sites where the species may still occur.

The study species: Edwards's pheasant

In 2014 Edwards's pheasant was uplisted to Critically Endangered (BirdLife International, 2014) because of the lack of recent records (the last being a poached individual in 2000; one record in 2009 is unconfirmed and another is of a captive individual with an unknown history; S.P. Mahood & J.C. Eames, pers. comm.), extremely high hunting pressure, and habitat fragmentation and degradation throughout its known range (BirdLife International, 2015). All of this led to increasing concern for the survival of the species. Since 2011, searches have been conducted at some potential sites but no evidence of the species' existence has been found, although other Galliformes species have been recorded (Pham & Le, 2015). First described in 1896, records of the species are restricted to central Vietnam (Ha Tinh, Quang Binh, Quang Tri, Thua Thein Hue Provinces), an area long considered to be of conservation concern because of high endemism and the high level of threat to which species are subjected (Eames et al., 2001). Two other forms of *Lophura* were thought to be closely related species until recently, but are now considered to be conspecific: the imperial pheasant *L. imperialis* has been shown to be a naturally occurring hybrid of Edwards's pheasant and the silver pheasant *L. nycthemera* (Hennache et al., 2003), and the Vietnamese pheasant *L. hatinhensis* is now considered to be an inbred form of Edwards's pheasant (Hennache et al., 2012). Henceforth we refer to all forms of the species as Edwards's pheasant. The species went unrecorded between the early 1960s and late 1980s, during which time much of its suspected habitat was further defoliated and degraded (BirdLife International, 2015).

Methods

Location data

Geo-referenced location data for Edwards's pheasant were extracted from the Galliformes database of Boakes et al. (2010a). As noted above, records previously ascribed to *L. hatinhensis* and *L. imperialis* were extracted for inclusion in the study, in addition to those of *L. edwardsi*. The records consist of reported locations from historical notebooks, peer-reviewed publications, books and specimen records (Mahood & Eames (in press) provide a detailed assessment of the records, including those without spatial locations).

Modelling time to extinction

The optimal linear estimator (Cooke, 1980; Roberts & Solow, 2003; Solow, 2005), or Cooke's estimator (Collen et al., 2010), is a non-parametric extinction date estimator. The approach is based on the Weibull distribution, a two-parameter model that has its origin in engineering risk analysis (Solow, 2005; Collen et al., 2010). The technique is considered robust where the probability of observing a species is low, and it does not assume that sighting effort has been equal over time (Rivadeneira et al., 2009). Even when the assumptions are not met fully because of the realities of search effort and data availability, the optimal linear estimator is broadly accurate (Collen et al., 2010; Clements et al., 2013). Its prediction of time to extinction (T_E) based on the k most recent sightings is described by Solow (2005).

There is uncertainty regarding how best to determine k . In theory it should be only the most recent sightings (Solow, 2005), but Collen et al. (2010) showed that increasing the number of sightings used (tested to a maximum of 18 sightings) increases the accuracy of prediction. However, the large gap in the sighting record of Edwards's pheasant during the First Indochina War and the subsequent Vietnam War (1946–1975) invalidates the assumptions of the optimal linear estimator if applied to a series of records that spans this gap (C. Clements, pers. comm., 4 December 2013) and so we used only the most recent records (1988 onwards). The data for this analysis consisted of the year of each confirmed observation and a test year (2016). We used the package *sExtinct* (Clements, 2013) in *R* v. 3.0.3 (R Development Core Team, 2013) to calculate the optimal linear estimator for Edwards's pheasant and two congeneric species, the silver pheasant and the Siamese fireback *L. diardi*, which are extant in the region. Data for these other *Lophura* pheasants were also extracted from Boakes et al. (2010a), with more recent records extracted from the Global Biodiversity Information Facility (GBIF, 2016).

Spatial uncertainty

We suspect that there is positional uncertainty associated with some, if not all, of the location points and that for some records this is up to 30 km (some locations were reported as the nearest commune, village or district centre). Positional uncertainty in species distribution models has been evaluated for cases in which errors were known and relatively small (< 5 km), and found to have little effect (Graham et al., 2008; Johnson & Gillingham, 2008).

Naimi et al. (2011, 2014) showed that high levels of spatial heterogeneity in environmental predictor variables leads to reduced model performance. We used a distance of 30 km (the maximum suspected error in point locations) to determine the reference values (using the *usdm* package (Naimi, 2015) in *R*) and compared these to each of the 27 location

points. K values > 0 imply that spatial similarity is lower than expected (high spatial heterogeneity) and values < 0 imply that spatial similarity is higher than expected (low spatial heterogeneity).

The ability of the model to discriminate between occupied and unoccupied areas was estimated from the area under the curve (AUC) of the receiver operating characteristics (Phillips et al., 2006). We used 1,000 random points within the BirdLife–NatureServe shapefile for Edwards’s pheasant and the Vietnamese pheasant (a single shapefile for the species has not yet been produced) as background points. We executed the MaxEnt procedure in the *dismo* package (Hijmans et al., 2016) in *R*.

Belief network

We developed a Bayesian belief network to account for the suspected uncertainty in the spatial locations. The resulting Bayesian model provides a logical expert (IUCN Red List) derived map of potential Edwards’s pheasant habitat, albeit one that cannot be evaluated empirically, based on the habitat description in the account of the species on the IUCN Red List (BirdLife International, 2015), namely:

‘It was said to inhabit exceedingly damp mountain forests up to an estimated 600 m, favouring thick underbrush and lianas. However, all early collecting localities were in the forested level lowlands, and there is no evidence that it can live above 300 m. It is most abundant in areas with thick undergrowth and liana covered hillsides (N. Brickle, in litt., 2004). Records in the 1990s came from lowland areas which have been selectively logged (N. Brickle, in litt., 2004).’

We interpreted this as increased probability of habitat suitability for Edwards’s pheasant in areas that were forest, in areas that were at low elevation and had high monthly rainfall (Table 1). A review of published literature and assessment of the substantial body of grey literature generated since ecological fieldwork restarted in Indochina in the late 1980s (Brickle et al., 2008) has provided no information on habitat suitability that altered this understanding.

To parameterize the model we extracted monthly rainfall values from the WorldClim climatic dataset (WorldClim, 2016) version 1.4, which has a spatial resolution of 1 km² (for more details see Hijmans et al., 2005) and to this added an elevation and forest coverage layer using the *Raster* package in *R* (Hijmans, 2015).

A raster dataset at 1 km resolution combining data on the precipitation of the driest month (WorldClim, 2016), elevation and forest cover was developed in *R* using the *Raster* package. Values for each layer at each raster pixel in the region were then exported to be used as a case-file in *Netica 5.2* (Norsys Corp, 2016). The case-file was then run through the belief network and the probability of high habitat suitability calculated. This was then converted back into a raster in *R* and displayed graphically in *ArcGIS 10.2.1* (ESRI, Redlands, USA).

TABLE 1 Conditional probabilities of habitat suitability for Edwards’s pheasant *Lophura edwardsi*, based on the IUCN Red List account of the species (BirdLife International, 2015).

Elevation	Probability of habitat suitability (%)		
	Low	Medium	High
Forest cover; monthly rainfall never < 30 mm			
< 100 m	20	40	40
100–300 m	50	20	30
300–500 m	70	20	10
500–700 m	80	10	10
> 700 m	90	5	5
Forest cover; monthly rainfall never < 40 mm			
< 100 m	10	40	50
100–300 m	20	40	40
300–500 m	50	20	30
500–700 m	70	20	10
> 700 m	80	10	10
Forest cover; monthly rainfall never < 50 mm			
< 100 m	10	30	60
100–300 m	20	30	50
300–500 m	20	40	40
500–700 m	50	20	30
> 700 m	70	20	10
Forest cover; monthly rainfall never < 60 mm			
< 100 m	10	20	70
100–300 m	10	20	70
300–500 m	10	30	60
500–700 m	20	30	50
> 700 m	50	30	20
No forest; monthly rainfall never < 30 mm			
< 100 m	70	20	10
100–300 m	70	20	10
300–500 m	70	20	10
500–700 m	70	20	10
> 700 m	70	20	10
No forest; monthly rainfall never < 40 mm			
< 100 m	70	20	10
100–300 m	70	20	10
300–500 m	70	20	10
500–700 m	70	20	10
> 700 m	70	20	10
No forest; monthly rainfall never < 50 mm			
< 100 m	70	20	10
100–300 m	70	20	10
300–500 m	70	20	10
500–700 m	70	20	10
> 700 m	70	20	10
No forest; monthly rainfall never < 60 mm			
< 100 m	70	20	10
100–300 m	70	20	10
300–500 m	70	20	10
500–700 m	70	20	10
> 700 m	70	20	10

Results

Modelling time to extinction Using the optimal linear estimator, Edwards's pheasant is estimated to have gone extinct in 2004, with a lower confidence interval (CI; i.e. earliest estimated date of extinction) of 2000 and upper CI (latest estimated date of extinction if no further sightings are made) of 2023. With the upper interval falling post 2016 (the test year), we can interpret this result as showing that it is probable, given the nature of the historical records, that Edwards's pheasant is still extant in the wild (Rivadeneira et al., 2009). Our low sample size may, however, have inflated the value of the upper CI (Strauss & Sadler, 1989) and thus our estimated date of extinction. The two congeners known to be extant in the region had estimated extinction dates post 2016, with an upper CI of 2024 and 2021 for the Siamese pheasant and silver pheasant, respectively.

Species distribution model Within the area bounded by the BirdLife–NatureServe (2012) extent of occurrence for Edwards's pheasant the AUC was 0.3, meaning that the model was worse than random in predicting the presence of Edwards's pheasant. Therefore, no further analyses were conducted that sought to link locations of Edwards's pheasant to environmental variables.

Belief network Maximum habitat suitability values in the belief network did not exceed 0.7 (because of the uncertainty expressed in the conditional probabilities). Areas with probability of habitat suitability of > 0.63 were found in Khe Net and Ke Go Nature Reserves in the north, and there were few grid squares of high probability of suitable habitat located in the south (Fig. 1).

Discussion

Edwards's pheasant may still survive in the wild, but the small number of records that exist for this species may mean that our assessment is optimistic. Whether the latter date for re-sighting (the upper CI, in this case 2023) is optimistic or not, what is clear is that the existing records indicate that Edwards's pheasant is on the threshold of extinction. The low detectability of the species offers hope that it may exist but be recorded rarely, but our most pessimistic prediction is that the species went extinct in 2004.

Given the uncertainty in the spatial locations for the species we could not be confident that we would produce a meaningful species distribution model. The belief model, which is based on the qualitative description given in the IUCN Red List account, clearly suggests that the most suitable habitat will be in the northern part of the species' range.

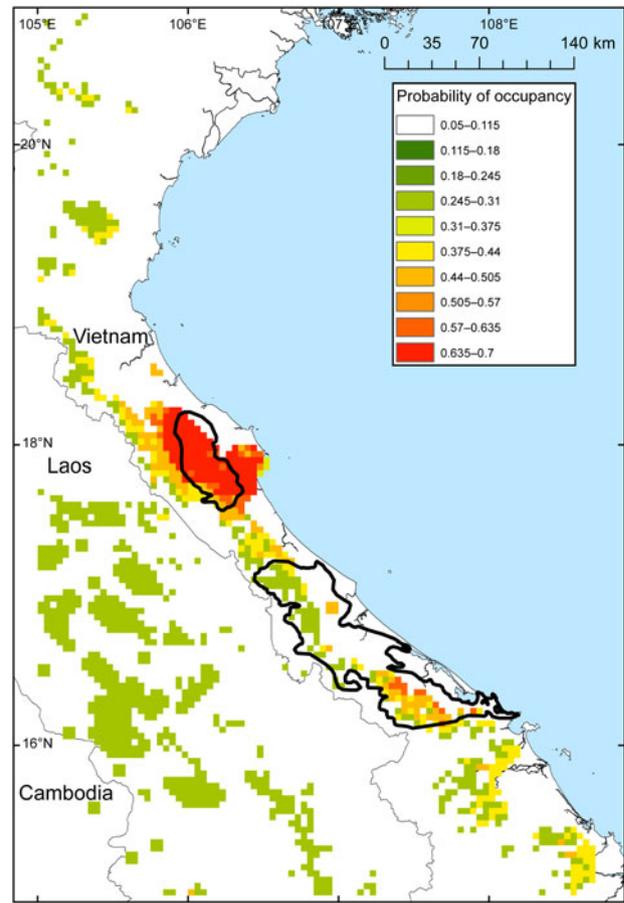


FIG. 1 Spatial representation of the results of our belief network based on the IUCN Red List habitat description for Edwards's pheasant *Lophura edwardsi* (see Methods). High probability of occupancy based on altitude, climatic conditions (monthly rainfall) and presence of forest is indicated in warmer colours. The species' range according to the BirdLife–NatureServe shapefile (2012) is delineated in black.

There is very little suitable habitat remaining for the species. Exceedingly damp forest falls into two blocks, which largely coincide with the distribution of locality records of Edwards's pheasant. The form previously known as the Vietnamese pheasant was reported mostly from the northern block and only during 1964–1999 (Hennache et al., 2012), the only exception being a single record south of Hue (Mahood & Eames, in press). As the Vietnamese pheasant is now considered to be an inbred form of Edwards's pheasant, these few observations suggest that the population has been declining for some time and is likely to have suffered considerably from heavy deforestation in Central Vietnam from the early 1970s (Müller & Zeller, 2002).

Other ecological knowledge suggests that the survival prospects of Edwards's pheasant are very poor. Species with small ranges tend to be scarce within those ranges (Brown, 1984), making them more susceptible to hunting

compared with sympatric, widely distributed species. The congeneric silver pheasant and Siamese fireback both have larger geographical ranges and would be expected to suffer similar levels of hunting given that none are particular targets for poachers. Furthermore, narrow endemism in vertebrate species is considered to be an indicator of limited flexibility to habitat disturbance (Wijesinghe & Brooke, 2005), mainly as a result of edge effects of fragmented habitat (Williams & Pearson, 1997; Brooks et al., 1999). The claim that Edwards's pheasant inhabits degraded habitat has not been confirmed (Eames, 1996) and could be a misinterpretation of its presence in bamboo patches in pristine habitat with abundant palms and rattan understorey (Robson et al., 1989). The Siamese fireback is commonly found in heavily degraded acacia and eucalyptus plantation (Suwanrat et al., 2015) and was found during the 2011 survey in Central Vietnam when Edwards's pheasant was not, suggesting that the habitat may have been too degraded for Edwards's pheasants but not for its more tolerant congener.

Following our analysis, the fragments that should be searched as a matter of urgency are Ke Go Nature Reserve, Bach Ma National Park (site of the most recent confirmed and unconfirmed records) and the extension to Bach Ma National Park. Although camera-trap surveys for other species have yielded little evidence of Galliformes at these sites (Willcox, 2015), and at Ke Go the most recent records were of the inbred Vietnamese form, these sites offer the best prospects for conservation action because of the most recent records and the relative suitability of remaining habitat.

The approach that we have used to critically and objectively assess the data that exist on Edwards's pheasant, a poorly known and highly threatened species, has brought temporal and spatial focus to the need for action. The species may already be extinct, and if not it is surely close. Historical records and remaining habitat that is thought to be suitable make it clear where effort should be targeted. Combining all available evidence within these temporal and spatial frameworks provides direction for where searches should be conducted and conservation action considered for this species. Given the crisis facing many similarly poorly known species that are believed to be on the verge of extinction, in South-east Asia and elsewhere, we believe that this approach may prove useful in distilling conservation direction from limited data.

The modelling approaches we have used here have potential to be useful for other species in the region and across other regions where data are scarce. All models are only as good as the data on which they are based, and it is important to recognize that the data available in this case and many others (e.g. the saola *Pseudoryx nghetinhensis*) may not fit well with the particular assumptions of any model. Despite this limitation, conservation managers cannot afford to wait until all of the desired data become available, particularly when funds are in short supply. All data available at the

time a decision is to be made must be gathered, assessed and, where possible, used to make inference. Bayesian networks have been shown to be effective in determining the distribution of species when there is little available ecological information (e.g. Smith et al., 2007) and few resources for conservation planning (Tantipisanuh et al., 2014). The optimal linear estimator has also been shown to be broadly accurate in the face of data realities (poor search effort and data availability; Collen et al., 2010; Clements et al., 2013).

Species distribution models based on MaxEnt have been shown to be effective at determining distribution accurately even when using few location records (14–25 records; van Proosdij et al., 2016); however, there is some evidence that models using fewer than 30 locations are less accurate, and caution must be taken in using these (Wisz et al., 2008). MaxEnt is probably better suited to species for which there are more ecological data available and a greater understanding of the most appropriate environmental variables than we have for Edwards's pheasant at present.

Researchers and managers who are faced with making decisions about what actions may be appropriate for a species for which there is only low-quality and uncertain data should consider taking the following approach to inform their decision. Firstly, gather all available data on locations from historical records, scientific sources, local communities, and any other available sources (i.e. from all stakeholders). Secondly, assess critically this information to identify potential biases and uncertainties, bearing in mind that it may not be possible to address these through modelling but they need to be highlighted. Thirdly, build a Bayesian belief network (or networks) based on the available data and assess these critically, ideally involving all stakeholders in this step whenever possible. At the same time, use an optimal linear estimator to assess the likelihood that the species still survives. Fourthly, use the model and the optimal linear estimator prediction to determine whether a survey should be conducted and, if so, at which sites. Finally, either carry out the survey or propose another course of action, such as categorization as Extinct (in the Wild), reintroduction or other, as appropriate.

Acknowledgements

We thank King Mongkut's University of Technology Thonburi, the Royal Golden Jubilee Fund (Thailand) and Newcastle University Research Committee for funding the opportunities to collaborate on this work.

Author contributions

All authors conceived the study, discussed and developed the analyses and wrote the article.

References

- ASAP (2016) Asian Species Action Partnership (ASAP). https://www.iucn.org/about/work/programmes/species/our_work/asian-speciesactionpartnership/ [accessed 16 November 2016].
- BIBBY, C.J., BURGESS, N.D., HILL, D.A. & MUSTOE, S.H. (2000) *Bird Census Techniques*. 2nd edition. Academic Press, London, UK.
- BIRDLIFE INTERNATIONAL (2014) Archived 2014 discussion: Edwards's pheasant (*Lophura edwardsi*) and Vietnamese pheasant (*L. hatinhensis*) are considered to be the same species and are treated as *L. edwardsi*: list as Critically Endangered? *BirdLife's Globally Threatened Bird Forums*. <http://www.birdlife.org/globally-threatened-bird-forums/2014/02/edwards%E2%80%99s-pheasant-lophura-edwardsi-and-vietnamese-pheasant-l-hatinhensis-are-considered-to-be-the-same-species-and-are-treated-as-l-edwardsi-list-as-critically-endangered/> [accessed 12 June 2017].
- BIRDLIFE INTERNATIONAL (2015) *Lophura edwardsi*. In *The IUCN Red List of Threatened Species 2015*: e.T45354985A84677778. <http://dx.doi.org/10.2305/IUCN.UK.2015.RLTS.T45354985A84677778.en> [accessed 11 May 2016].
- BOAKES, E.H., FULLER, R.A., MCGOWAN, P.J.K. & MACE, G.M. (2016) Uncertainty in identifying local extinctions: the distribution of missing data and its effects on biodiversity measures. *Biology Letters*, 12, 20150824. <http://dx.doi.org/10.1098/rsbl.2015.0824>.
- BOAKES, E.H., MCGOWAN, P.J.K., FULLER, R.A., CHANG-QING, D., CLARK, N.E., O'CONNOR, K. & MACE, G.M. (2010a) Data from: Distorted views of biodiversity: spatial and temporal bias in species occurrence data. *Dryad Digital Repository*, <http://dx.doi.org/10.5061/dryad.1464>.
- BOAKES, E.H., MCGOWAN, P.J.K., FULLER, R.A., CHANG-QING, D., CLARK, N.E., O'CONNOR, K. & MACE, G.M. (2010b) Distorted views of biodiversity: spatial and temporal bias in species occurrence data. *PLoS Biology*, 8(6), e1000385.
- BRICKLE, N.W., DUCKWORTH, J.W., TORDOFF, A.W., POOLE, C.M., TIMMINS, R. & MCGOWAN, P.J.K. (2008) The status and conservation of Galliformes in Cambodia, Laos and Vietnam. *Biodiversity and Conservation*, 17, 1393–1427.
- BROOKS, T.M., PIMM, S.L. & OYUGI, J.O. (1999) Time lag between deforestation and bird extinction in tropical forest fragments. *Conservation Biology*, 13, 1140–1150.
- BROWN, J.H. (1984) On the relationship between abundance and distribution of species. *The American Naturalist*, 124, 255–279.
- CLEMENTS, C.F. (2013) sExtinct: Calculates the historic date of extinction given a series of sighting events. R package version 1.1. <https://CRAN.R-project.org/package=sExtinct>.
- CLEMENTS, C.F., WORSFOLD, N.T., WARREN, P.H., COLLEN, B., CLARK, N., BLACKBURN, T.M. & PETCHEY, O.L. (2013) Experimentally testing the accuracy of an extinction estimator: Solow's optimal linear estimation model. *Journal of Animal Ecology*, 82, 345–354.
- COLLEN, B., PURVIS, A. & MACE, G.M. (2010) When is a species really extinct? Testing extinction inference from a sighting record to inform conservation assessment. *Diversity & Distributions*, 16, 755–764.
- COOKE, P. (1980) Optimal linear estimation of bounds of random variables. *Biometrika*, 67, 257–258.
- DUCKWORTH, J.W., BATTERS, G., BELANT, J.L., BENNETT, E.L., BRUNNER, J., BURTON, J. et al. (2012) Why South-east Asia should be the world's priority for averting imminent species extinctions, and a call to join a developing cross-institutional programme to tackle this urgent issue. *Sapiens*, 5, 77–95.
- EAMES, J.C. (1996) Ke Go Nature Reserve, the place of wood. *World Birdwatching*, 18, 6–8.
- EAMES, J.C., EVE, R., TORDOFF, A.W. (2001) The importance of Vu Quang Nature Reserve, Vietnam, for bird conservation, in the context of the Annamese Lowlands Endemic Bird Area. *Bird Conservation International*, 11, 247–285.
- GBIF (2016) Global Biodiversity Information Facility: Free and Open Access to Biodiversity Data. <http://www.gbif.org/> [accessed 30 June 2015].
- GRAHAM, C.H., ELITH, J., HIJMANS, R.J., GUISSAN, A., PETERSON, A.T. & LOISELLE, B.A. (2008) The influence of spatial errors in species occurrence data used in distribution models. *Journal of Applied Ecology*, 45, 239–247.
- HENNACHE, A., MAHOOD, S.P., EAMES, J.C. & RANDI, E. (2012) *Lophura hatinhensis* is an invalid taxon. *Forktail*, 28, 129–135.
- HENNACHE, A., RASMUSSEN, P., LUCCHINI, V., RIMONDI, S. & RANDI, E. (2003) Hybrid origin of the imperial pheasant *Lophura imperialis* (Delacour & Jabouille, 1924) demonstrated by morphology, hybrid experiments, and DNA analyses. *Biological Journal of the Linnean Society*, 80, 573–600.
- HIJMANS, R.J. (2015) *Introduction to the 'raster' package (version 2.5–2)*. <http://cran.r-project.org/web/packages/raster/vignettes/Raster.pdf>. [accessed 11 May 2016].
- HIJMANS, R.J., CAMERON, S.E., PARRA, J.L., JONES, P.G. & JARVIS, A. (2005) Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology*, 25, 1965–1978.
- HIJMANS, R.J., PHILLIPS, S., LEATHWICK, J. & ELITH, J. (2016) dismo: Species Distribution Modeling. <https://cran.r-project.org/web/packages/dismo/index.html> [accessed 11 May 2016].
- HOFFMANN, M., HILTON-TAYLOR, C., ANGULO, A., BÖHM, M., BROOKS, T.M., BUTCHART, S.H.M. et al. (2010) The impact of conservation on the status of the world's vertebrates. *Science*, 330, 1503–1509.
- IUCN (2012) WCC-2012-Res-027 Conservation of tropical Asia's threatened species. http://portals.iucn.org/library/sites/library/files/resrecfiles/WCC_2012_RES_27_EN.pdf. [accessed 11 May 2016].
- JOHNSON, C.J. & GILLINGHAM, M.P. (2008) Sensitivity of species-distribution models to error, bias, and model design: an application to resource selection functions for woodland caribou. *Ecological Modelling*, 213, 143–155.
- MAHOOD, S.P. & EAMES, J.C. (in press) Is Edwards's pheasant *Lophura edwardsi* extinct in the wild? *Forktail*.
- MÜLLER, D. & ZELLER, M. (2002) Land-use dynamics in the Central Highlands of Vietnam: a spatial model combining village survey data with satellite imagery interpretation. *Agricultural Economics*, 27, 333–354.
- NAIMI, B. (2015) usdm: Uncertainty analysis for species distribution models. R package version 1.1-15. <https://CRAN.R-project.org/package=usdm>.
- NAIMI, B., HAMM, N.A.S., GROEN, T.A., SKIDMORE, A.K. & TOXOPEUS, A.G. (2014) Where is positional uncertainty a problem for species distribution modelling? *Ecography*, 37, 191–203.
- NAIMI, B., SKIDMORE, A.K., GROEN, T.A. & HAMM, N.A.S. (2011) Spatial autocorrelation in predictors reduces the impact of positional uncertainty in occurrence data on species distribution modelling. *Journal of Biogeography*, 38, 1497–1509.
- NORSYS CORP (2016) Netica 5.2 for MS Windows (2000 to 2007). <https://www.norsys.com/netica.html>.
- PHAM, T.A. & LE, T.T. (compilers) (2015) *Action Plan for the Conservation of the Edwards's Pheasant Lophura edwardsi 2015–2020 with vision to 2030*. Viet Nature Conservation Centre, Hanoi, Vietnam. <http://thienhienviet.org.vn/ep/wp-content/uploads/2015/01/EP-Action-Plan-VN-EPWG.pdf> [accessed 11 May 2016].

- PHILLIPS, S.J., ANDERSON, R.P. & SCHAPIRE, R.E. (2006) Maximum entropy modelling of species geographic distributions. *Ecological Modelling*, 190, 231–259.
- R DEVELOPMENT CORE TEAM (2013) *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria.
- RIVADENEIRA, M.M., HUNT, G. & ROY, K. (2009) The use of sighting records to infer species extinctions: an evaluation of different methods. *Ecology*, 90, 1291–1300.
- ROBERTS, D.L. & SOLOW, A.R. (2003) Flightless birds: when did the dodo become extinct? *Nature*, 426, 245.
- ROBSON, C., EAMES, J.C., WOLSTENCROFT, J.A., NGUYEN, C. & TRUONG, V.L. (1989) Recent records of birds from Vietnam. *Forktail*, 5, 71–97.
- SECRETARIAT OF THE CONVENTION ON BIOLOGICAL DIVERSITY (2010) *Decision Adopted by the Conference of the Parties to the Convention on Biological Diversity at its Tenth Meeting: X/2. The Strategic Plan For Biodiversity 2011–2020 and the Aichi Biodiversity Targets*. <https://www.cbd.int/doc/decisions/cop-10/cop-10-dec-02-en.pdf> [accessed 10 March 2016].
- SMITH, C.S., HOWES, A.L., PRICE, B. & McALPINE, C.A. (2007) Using a Bayesian belief network to predict suitable habitat of an endangered mammal—the Julia Creek dunnart (*Sminthopsis douglasi*). *Biological Conservation*, 139, 333–347.
- SOLOW, A.R. (2005) Inferring extinction from a sighting record. *Mathematical Biosciences*, 195, 47–55.
- STRAUSS, D. & SADLER, P.M. (1989) Classical confidence intervals and Bayesian probability estimates for ends of local taxon ranges. *Mathematical Geology*, 21, 411–427.
- SUWANRAT, S., NGOPRASERT, D., SUTHERLAND, C., SUWANWAREE, P. & SAVINI, T. (2015) Estimating density of secretive terrestrial birds (Siamese fireback) in pristine and degraded forest using camera traps and distance sampling. *Global Ecology and Conservation*, 3, 596–606.
- TANTIPISANUH, N., GALE, G.A. & POLLINO, C. (2014) Bayesian networks for habitat suitability modeling: a potential tool for conservation planning with scarce resources. *Ecological Applications*, 24, 1705–1718.
- UN SUSTAINABLE DEVELOPMENT KNOWLEDGE PLATFORM (2016) Sustainable Development Goals. <https://sustainabledevelopment.un.org/?menu=1300> [accessed 16 November 2016].
- VAN PROOSDIJ, A.S.J., SOSEF, M.S.M., WIERINGA, J.J. & RAES, N. (2016) Minimum required number of specimen records to develop accurate species distribution models. *Ecography*, 39, 542–552.
- WIJESINGHE, M.R. & BROOKE, M. DE L. (2005) Impact of habitat disturbance on the distribution of endemic species of small mammals and birds in a tropical rain forest in Sri Lanka. *Journal of Tropical Ecology*, 21, 661–668.
- WILLCOX, D. (2015) The conservation status of small carnivores in the Ke-Go-Khe Net Lowlands, Central Vietnam. *Small Carnivore Conservation*, 52, 56–73.
- WILLIAMS, S.E. & PEARSON, R.G. (1997) Historical rainforest contractions, localized extinctions and patterns of vertebrate endemism in the rainforests of Australia's wet tropics. *Proceedings of the Royal Society B*, 264, 709–716.
- WISZ, M.S., HIJMANS, R.J., LI, J., PETERSON, A.T., GRAHAM, C.H., GUISAN, A. & NCEAS PREDICTING SPECIES DISTRIBUTIONS WORKING GROUP (2008) Effects of sample size on the performance of species distribution models. *Diversity & Distributions*, 14, 763–773.
- WORLDCLIM (2016) WorldClim climatic dataset Version 1.4. <http://www.worldclim.org/>.

Biographical sketches

MATT GRAINGER is interested in developing pragmatic solutions to complex conservation and sustainability problems. DUSIT NGOPRASERT is focused on the conservation and population ecology of mammalian carnivores and birds. PHILIP MCGOWAN seeks to understand how species conservation can be achieved efficiently and effectively and TOMMASO SAVINI is interested in behavioural ecology and landscape use of mammals and birds.