Roberts, David L. and Jari, Ivan (2016) *Inferring extinction in North American and Hawaiian birds in the presence of sighting uncertainty*. PeerJ, 4 . ISSN 2167-8359.

**Downloaded from**
https://kar.kent.ac.uk/57033/ The University of Kent's Academic Repository KAR

**The version of record is available from**
https://doi.org/10.7717/peerj.2426

**This document version**
Publisher pdf

**DOI for this version**

**Licence for this version**
CC BY (Attribution)

**Additional information**

**Versions of research works**

**Versions of Record**
If this version is the version of record, it is the same as the published version available on the publisher's web site. Cite as the published version.

**Author Accepted Manuscripts**
If this document is identified as the Author Accepted Manuscript it is the version after peer review but before type setting, copy editing or publisher branding. Cite as Surname, Initial. (Year) ‘Title of article’. To be published in *Title of Journal*, Volume and issue numbers [peer-reviewed accepted version]. Available at: DOI or URL (Accessed: date).

**Enquiries**
If you have questions about this document contact ResearchSupport@kent.ac.uk. Please include the URL of the record in KAR. If you believe that your, or a third party's rights have been compromised through this document please see our Take Down policy (available from https://www.kent.ac.ukguides/kar-the-kent-academic-repository#policies).
Inferring extinction in North American and Hawaiian birds in the presence of sighting uncertainty

David L. Roberts¹ and Ivan Jarić²,³

¹ Durrell Institute of Conservation and Ecology, School of Anthropology & Conservation, University of Kent, Canterbury, Kent, United Kingdom
² Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Berlin, Germany
³ Institute for Multidisciplinary Research, University of Belgrade, Belgrade, Serbia

ABSTRACT

For most species the timing of extinction events is uncertain, occurring sometime after the last sighting. However, the sightings themselves may also be uncertain. Recently a number of methods have been developed that incorporate sighting uncertainty in the inference of extinction based on a series of sightings. Here we estimate the timing of extinction for 41 of 52 North American and Hawaiian bird taxa and populations, the results of which suggest all became extinct before 2009. By acknowledging sighting uncertainty it results in two opposite effects, one pushing the timing of extinction away from the last sighting and the other drawing the timing of extinction nearer to it. However, for 14 assessed taxa and populations the upper 95% bounds lie beyond the end of the observation period and therefore suggest the possibility of continued persistence. This has important implications for conservation decision-makers and potentially reduces the likelihood of Romeo’s Error.

INTRODUCTION

For many species our knowledge of their persistence is based on sightings that vary in quality and therefore the level of reliability (Roberts, Elphick & Reed, 2010). For species that are approaching extinction or that may already be extinct acknowledging this uncertainty can have profound effects on conservation decision-making, as erroneous evidence based on uncertain sightings can result in wasted resources (McKelvey et al., 2008). For example in 2005, based on a brief sighting and a pixelated image, the ivory-billed woodpecker was declared to have been rediscovered (Fitzpatrick et al., 2005), resulting in the mobilisation of resources for management strategies and recovery plans (Gotelli et al., 2012). However, based on the evidence its rediscovery was brought into question (Sibley et al., 2006), and subsequent extensive searches have failed to result in further sightings (Gotelli et al., 2012).

Several methods have been developed for the inference of extinction based on sighting data (see Solow, 2005 for a review), however until recently, these methods treated all sightings as certain.
methods have been developed that incorporate uncertainty (e.g., Solow et al., 2012; Jarić & Roberts, 2014; Lee et al., 2014).

Elphick, Roberts & Reed (2010) estimated the time of extinction for 38 of 52 North American and Hawaiian bird taxa and populations that are thought to be potentially extinct, along with the likelihood of extinction by 2009. In the study they based their analysis on sightings that are assumed to have the highest level of reliability (e.g., museum specimens), and then repeated the analysis by including additional sightings for which sufficient documentation exists to satisfy experts. In this way Elphick, Roberts & Reed (2010) attempted to acknowledge the issue of sighting uncertainty and incorporate it into their analysis on an ad hoc based criteria. Their analysis, however, excluded a number of controversial sightings that experts disagreed as to whether they should be accepted. In this paper we revisit this study, using a method that explicitly incorporates sighting uncertainty (Jarić & Roberts, 2014), to investigate the impact of accounting for sighting uncertainty when inferring extinction.

METHODS

We apply here the approach of Jarić & Roberts (2014) that represents a modification of the existing methods for inferring extinction based on sighting records, which allows for inclusion of specific sighting reliabilities of individual observations. In line with the original approach, we apply it to the standard Solow method (Solow, 1993), which was also used to infer extinction by Elphick, Roberts & Reed (2010). For details on Solow method modification, see Jarić & Roberts (2014) as well as Supplemental Information 1.

We revisited the 52 North American bird taxa and populations assessed by Elphick, Roberts & Reed (2010) that are presumed to be extinct, or whose persistence is a point of discussion. In their study and used here, Elphick, Roberts & Reed (2010—supplementary material) compiled sighting records for all taxa but divided the sightings into three categories that form a nest hierarchy:

1. Physical Evidence (PE)—e.g., museum specimens, but also uncontroversial photographs, video, and sound recordings.
2. Independent Expert Opinion (IEO)—evidence that experts deemed sufficiently documented to confirm the record.
3. Controversial sightings (CS)—sightings judged to lack firm evidence including any sighting for which there is published disagreement between experts.

Elphick, Roberts & Reed (2010) used the method of Solow (1993) for the inference of extinction (but also see Solow, 2005) and based their analysis on PE and PE + IEO, but excluded CS. Following Jarić & Roberts (2014), who applied the sighting reliability scoring system used by BirdLife International (Table 1 of Lee et al., 2014), we assign PE sightings (i.e., Lee et al.’s “Record described as being based on collected individual”) with a lower limit of reliability of 0.8, and upper limit of 0.9 and a mean of 0.85. This was repeated for IEO (i.e., Lee et al.’s “Record based on observation described in the literature as ‘confirmed’ or considered fairly convincing”) and CS (i.e., Lee et al.’s “Record described in the literature as (or judged to be) unconfirmed or questionable”), 0.6, 0.8, 0.7 and 0.1, 0.4, 0.25 respectively.
First sightings in each sighting record dataset were used to establish the beginning of the sighting period, and excluded from the analysis (Solow, 2005). Minimum number of sightings in a sighting record \((n \geq 5\), i.e., 4 following the exclusion of the first sighting) was defined in line with Solow (2005) and Elphick, Roberts & Reed (2010). Consequently, analyses were conducted only for sighting records and reliability score setups with the most likely number of observations \((r\) value, see Jarić & Roberts, 2014) of at least 3.5 (i.e., excluding the reliability score for the first sighting). The approach was used to estimate the \(p\) value for each species (with \(T = 2009\) in line with Elphick, Roberts & Reed, 2010), probable extinction time \((T_E)\) and the upper bound \((T_{CI})\) of a \(1-\alpha\) confidence interval \((\alpha = 0.05)\).

**RESULTS**

Of the 52 taxa and populations, there were sufficient sightings to conduct analyses for 41, compared with 38 taxa and populations analyzed by Elphick, Roberts & Reed (2010). Estimated extinction dates \((T_E)\) ranged from 1855 to 2008, with the upper 95% bounds \((T_{CI})\) on these estimates ranging from 1863 to 2113 (Table 1). Based on these analyses, there is no indication that any taxa and populations are likely to persist, including the ‘Alalā (Hawaiian crow, *Corvus hawaiiensis*) which was the only taxa in Elphick, Roberts & Reed’s (2010) study for which there was any indication of likely persistence. Taxa and populations for which the 95% confidence intervals around the predicted extinction date includes dates after 2008 were Eskimo Curlew (*Numenius borealis*), Ivory-billed woodpecker (*Campephilus principalis*), ‘Alalā (Hawaiian crow), Kaua‘i ‘ō‘o (*Moho braccatus*), O‘ahu ‘ō‘o (*M. apicalis*), Kama‘o (*Myadestes myadestinus*), Oloma‘o (Moloka‘i) (*M. lanaiensis rutha*), ‘Ō‘u (Kaua‘i) (*Psittirostra psittacea*), Nukupu‘u (Kaua‘i) (*Hemignathus lucidus hanapepe*), Nukupu‘u (Maui) (*H. l. affinis*), O‘ahu ‘alauahio (*Paroreomyza maculata*), Maui ‘akepa (*Loxops coccineus ochraceus*), Oahu ‘akepa (*L. c. rufus*) and the Po‘o-uli (*Melamprosops phaeosoma*) (indicated in bold in Table 1). In comparison, Elphick, Roberts & Reed’s (2010) analysis only observed such confidence intervals for the ‘Alalā (Hawaiian crow), as well as partly for Kama‘o, O‘ahu ‘alauahio and the Po‘o-uli (i.e., they had \(T_{CI} > 2009\) only when using PE, while for PE + IEO combination it was \(T_{CI} < 2009\). Elphick, Roberts & Reed (2010) only provided sighting data to 2009, and therefore other, most likely controversial, sightings may have occurred during the following years, assuming no further sightings have actually occurred since 2009. Taxa and populations for which the 95% confidence intervals around the predicted extinction dates include dates after 2016 were ‘Alalā (Hawaiian crow), Oloma‘o (Moloka‘i), Nukupu‘u (Kaua‘i), Nukupu‘u (Maui), O‘ahu ‘alauahio, Maui ‘akepa and the Oahu ‘akepa (Table 1).

**DISCUSSION**

Incorporating uncertainty in the inference of extinction of a species has two effects that run counter to each other, one potentially pushing forward the date of extinction and the other drawing it to an earlier year. Firstly, by reducing the reliability from 1.0 it increases uncertainty in the date of extinction and therefore results in the inferred persistence of the taxa being potentially pushed beyond those inferred through methods that do
Table 1  Evaluated North American and Hawaiian bird taxa potentially considered extinct. IUCN Red List category (http://www.birdlife.org/datazone/species accessed July 2016; CR(PE), Critically Endangered (Possibly Extinct); EW, Extinct in the Wild; EX, Extinct), year of last reported sighting including controversial sightings reported up to 2009 (Elphick, Roberts & Reed, 2010—supplementary material), number of years with confirmed records (n). Sighting reliability estimates give the upper, mean and lower sighting reliabilities as described in the methods. \( p \) is the probability of a sighting record in 2009, \( T_E \) estimated year of extinction, and \( T_{CI} \) the upper 95% bound on that estimate of \( T_E \). Years highlighted in bold represent results that do not support extinction.

| Species                        | IUCN Red List | Last sighting | n | Sighting reliability | \( p \)   | \( T_E \) | \( T_{CI} \) |
|-------------------------------|---------------|---------------|---|----------------------|---------|---------|---------|
| Labrador duck                 | EX            | 1878          | 13| Upper                | 3E−7    | 1880    | 1889    |
| (Camptorhynchus labradorius)  |               |               |   | Mean                 | 7E−7    | 1879    | 1889    |
|                               |               |               |   | Lower                | 2E−6    | 1879    | 1890    |
| Heath hen                     | EX            | 1932          | 39| Upper                | 4E−15   | 1933    | 1936    |
| (Tympanuchus c. cupido)       |               |               |   | Mean                 | 7E−14   | 1933    | 1936    |
|                               |               |               |   | Lower                | 1E−12   | 1933    | 1936    |
| Laysan rail                   | EX            | 1945          | 29| Mean                 | 3E−8    | 1946    | 1952    |
| (Zapornia palmeri)            |               |               |   | Lower                | 1E−7    | 1946    | 1952    |
| Hawaiian rail                 | EX            | 1893          | 9 | Upper                | 0.010   | 1905    | 1956    |
| (Zapornia sandwichensis)      |               |               |   | Mean                 | 0.014   | 1903    | 1961    |
| Eskimo curlew                 | CR(PE)        | 2006          | 49| Upper                | 0.062   | 2003    | 2010    |
| (Numenius borealis)           |               |               |   | Mean                 | 0.028   | 1999    | 2007    |
|                               |               |               |   | Lower                | 0.004   | 1989    | 1997    |
| Great auk                     | EX            | 1888          | 24| Upper                | 8E−10   | 1872    | 1879    |
| (Pinguinus impennis)          |               |               |   | Mean                 | 1E−9    | 1865    | 1872    |
|                               |               |               |   | Lower                | 1E−9    | 1855    | 1863    |
| Passenger pigeon              | EX            | 1907          | 26| Upper                | 3E−15   | 1906    | 1909    |
| (Ectopistes migratorius)      |               |               |   | Mean                 | 2E−14   | 1905    | 1908    |
|                               |               |               |   | Lower                | 8E−14   | 1904    | 1907    |
| Carolina parakeet             | EX            | 1950          | 50| Upper                | 1E−10   | 1946    | 1950    |
| (Conuropsis carolinensis)     |               |               |   | Mean                 | 4E−10   | 1942    | 1947    |
|                               |               |               |   | Lower                | 3E−10   | 1933    | 1938    |
| Ivory-billed woodpecker       | CR            | 2006          | 68| Upper                | 0.065   | 2005    | 2010    |
| (Campephilus principalis)     |               |               |   | Mean                 | 0.019   | 2000    | 2006    |
|                               |               |               |   | Lower                | 5E−4    | 1987    | 1993    |
| ‘Alalā (Hawaiian crow)        | EW            | 2003          | 68| Upper                | 0.220   | 2007    | 2015    |
| (Corvus hawaiiensis)          |               |               |   | Mean                 | 0.251   | 2007    | 2017    |
|                               |               |               |   | Lower                | 0.286   | 2008    | 2018    |
| Kaua‘i ‘ō‘ō                    | EX            | 2001          | 43| Upper                | 0.103   | 2002    | 2013    |
| (Moho braccatus)              |               |               |   | Mean                 | 0.080   | 2000    | 2012    |
|                               |               |               |   | Lower                | 0.055   | 1996    | 2010    |
| O‘ahu ‘ō‘ō                     | EX            | 1976          | 10| Upper                | 0.292   | 1994    | 2113    |
| (Moho apicalis)               |               |               |   | Mean                 | –       | –       | –       |
|                               |               |               |   | Lower                | –       | –       | –       |

(continued on next page)
| Species | IUCN Red List | Last sighting | n | Sighting reliability | p   | TE | TCI |
|---------|---------------|---------------|---|----------------------|-----|----|----|
| Bishop’s ‘ō‘ō (Moloka‘i) (Moho bishopi) | EX | 1904 | 5 | Upper | 3E–4 | 1907 | 1919 |
|         |               |              |   | Mean                | –   | –  |    |
|         |               |              |   | Lower               | –   | –  |    |
| Hawai‘i ‘ō‘ō (Moho nobilis) | EX | 1976 | 24 | Upper | 0.008 | 1974 | 1991 |
|         |               |              |   | Mean                | 0.006 | 1967 | 1985 |
|         |               |              |   | Lower               | 0.001 | 1944 | 1963 |
| San Clemente [Bewick’s] wren (Thryomanes bewickii leucophrys) | – | 1941 | 20 | Upper | 7E–7 | 1944 | 1951 |
|         |               |              |   | Mean                | 1E–6 | 1944 | 1951 |
|         |               |              |   | Lower               | 3E–6 | 1944 | 1952 |
| Laysan millerbird (Acrocephalus f. familiaris) | EX | 1916 | 12 | Upper | 2E–6 | 1919 | 1927 |
|         |               |              |   | Mean                | 4E–6 | 1919 | 1928 |
|         |               |              |   | Lower               | 9E–6 | 1919 | 1929 |
| Kama‘o (Myadestes myadestinus) | EX | 1999 | 50 | Upper | 0.069 | 2001 | 2011 |
|         |               |              |   | Mean                | 0.067 | 2000 | 2011 |
|         |               |              |   | Lower               | 0.050 | 1997 | 2009 |
| Oloma‘o (Moloka‘i) (Myadestes lanaiensis rutha) | CR(PE) | 2005 | 16 | Upper | 0.188 | 2001 | 2025 |
|         |               |              |   | Mean                | 0.154 | 1998 | 2024 |
|         |               |              |   | Lower               | 0.129 | 1993 | 2024 |
| Oloma‘o (Lāna‘i) (Myadestes l. lanaiensis) | CR(PE) | 1934 | 9 | Upper | 0.001 | 1941 | 1960 |
|         |               |              |   | Mean                | 0.003 | 1941 | 1963 |
|         |               |              |   | Lower               | 0.005 | 1942 | 1967 |
| Bachman’s warbler (Vermivora bachmanii) | CR(PE) | 2001 | 61 | Upper | 0.004 | 1997 | 2002 |
|         |               |              |   | Mean                | 0.001 | 1993 | 1998 |
|         |               |              |   | Lower               | 4E–5 | 1981 | 1987 |
| Dusky seaside sparrow (Ammodramus maritimus nigrescens) | EX | 1980 | 48 | Upper | 6E–5 | 1983 | 1988 |
|         |               |              |   | Mean                | 1E–4 | 1983 | 1989 |
|         |               |              |   | Lower               | 2E–4 | 1983 | 1989 |
| ‘Ō‘ū (Kaua‘i) (Psittirostra psittacea) | CR(PE) | 1997 | 33 | Upper | 0.057 | 2000 | 2010 |
|         |               |              |   | Mean                | 0.060 | 1999 | 2010 |
|         |               |              |   | Lower               | 0.055 | 1996 | 2010 |
| ‘Ō‘ū (Hawai‘i) (Psittirostra psittacea) | CR(PE) | 1987 | 42 | Upper | 0.004 | 1990 | 1998 |
|         |               |              |   | Mean                | 0.007 | 1991 | 2000 |
|         |               |              |   | Lower               | 0.013 | 1991 | 2001 |
| ‘Ō‘ū (Moloka‘i) (Psittirostra psittacea) | CR(PE) | 1965 | 6 | Upper | 0.015 | 1940 | 1978 |
|         |               |              |   | Mean                | 0.010 | 1929 | 1964 |
|         |               |              |   | Lower               | –     | –   |    |
| ‘Ō‘ū (Lāna‘i) (Psittirostra psittacea) | CR(PE) | 1927 | 8 | Upper | 9E–4 | 1933 | 1951 |
|         |               |              |   | Mean                | 0.001 | 1933 | 1953 |
|         |               |              |   | Lower               | 0.002 | 1933 | 1955 |
| ‘Ō‘ū (Maui) (Psittirostra psittacea) | CR(PE) | 1945 | 7 | Upper | 0.004 | 1927 | 1954 |
|         |               |              |   | Mean                | 0.004 | 1919 | 1947 |
|         |               |              |   | Lower               | 0.003 | 1911 | 1938 |
| Species                                      | IUCN Red List | Last sighting | $n$ | Sighting reliability | $p$  | $T_E$  | $T_CI$  |
|----------------------------------------------|---------------|---------------|-----|----------------------|------|--------|---------|
| Greater koa-finch (Rhodacanthis palmeri)    | EX            | 1967          | 8   | Upper                | 0.007| 1943   | 1970    |
|                                              |               |               |     | Mean                 | 0.003| 1928   | 1952    |
|                                              |               |               |     | Lower                | 7E−4 | 1911   | 1927    |
| Greater ‘amakihi (Hemignathus sagittirostris)| EX            | 1901          | 5   | Upper                | 9E−5 | 1903   | 1912    |
|                                              |               |               |     | Mean                 | –    | –      | –       |
|                                              |               |               |     | Lower                | –    | –      | –       |
| Lesser ‘akialoa (Hemignathus obscurus)      | EX            | 1940          | 19  | Upper                | 5E−6 | 1923   | 1934    |
|                                              |               |               |     | Mean                 | 4E−6 | 1917   | 1928    |
|                                              |               |               |     | Lower                | 3E−6 | 1911   | 1923    |
| Greater ‘akialoa (Kaua‘i) (Hemignathus ellisiomas stejnegeri) | EX | 1995 | 21 | Upper                | 0.027| 1991   | 2004    |
|                                              |               |               |     | Mean                 | 0.016| 1985   | 2000    |
|                                              |               |               |     | Lower                | 0.009| 1978   | 1994    |
| Nukupu‘u (Kaua‘i) (Hemignathus lucidas hanapepe) | CR(PE)       | 1996          | 24  | Upper                | 0.179| 2002   | 2022    |
|                                              |               |               |     | Mean                 | 0.198| 2001   | 2028    |
|                                              |               |               |     | Lower                | 0.083| 1983   | 2019    |
| Nukupu‘u (Maui) (Hemignathus lucidas affinis) | CR(PE)       | 1996          | 24  | Upper                | 0.256| 2004   | 2029    |
|                                              |               |               |     | Mean                 | 0.346| 2007   | 2047    |
|                                              |               |               |     | Lower                | 0.322| 2001   | 2086    |
| O‘ahu ‘alauahio (Paroreomyza maculata)       | CR(PE)       | 2002          | 46  | Upper                | 0.218| 2006   | 2019    |
|                                              |               |               |     | Mean                 | 0.191| 2004   | 2020    |
|                                              |               |               |     | Lower                | 0.099| 1995   | 2016    |
| Maui ‘alauahio (Lāna‘i) (Paroreomyza montana) | EX            | 1937          | 10  | Upper                | 7E−4 | 1942   | 1958    |
|                                              |               |               |     | Mean                 | 0.001| 1942   | 1960    |
|                                              |               |               |     | Lower                | 0.002| 1942   | 1961    |
| Kākāwahie (Paroreomyza flammea)              | EX            | 1963          | 16  | Upper                | 0.006| 1970   | 1987    |
|                                              |               |               |     | Mean                 | 0.008| 1969   | 1988    |
|                                              |               |               |     | Lower                | 0.009| 1968   | 1989    |
| Maui ‘akepa (Loxops coccineus ochraceus)     | EX            | 1995          | 21  | Upper                | 0.147| 2001   | 2019    |
|                                              |               |               |     | Mean                 | 0.144| 1999   | 2021    |
|                                              |               |               |     | Lower                | 0.122| 1995   | 2021    |
| Oahu ‘akepa (Loxops coccineus rufus)         | EX            | 1976          | 7   | Upper                | 0.125| 1965   | 2053    |
|                                              |               |               |     | Mean                 | 0.097| 1950   | 2044    |
|                                              |               |               |     | Lower                | –    | –      | –       |
| Hawai‘i mamo (Drepanis pacifica)             | EX            | 1960          | 12  | Upper                | 0.033| 1943   | 1996    |
|                                              |               |               |     | Mean                 | 0.035| 1935   | 1996    |
|                                              |               |               |     | Lower                | 0.041| 1926   | 2000    |
| Black mamo (Drepanis funerea)                | EX            | 1955          | 6   | Upper                | 0.024| 1944   | 1987    |
|                                              |               |               |     | Mean                 | –    | –      | –       |
|                                              |               |               |     | Lower                | –    | –      | –       |
not incorporate uncertainty. Secondly, however, by allowing for the incorporation of uncertainty it is possible to incorporate controversial sightings (i.e., Elphick, Roberts & Reed, 2010 only incorporate PE and IEO). This results in more sightings within a record and therefore fewer gaps between years in the sighting record, thus potentially drawing the extinction date closer to the time of the last sighting, although the date of the last sighting is by definition uncertain (see Jarić & Roberts, 2014).

In this study, by incorporating sighting uncertainty into the inference of extinction it allowed us to assess an additional 3 taxa and populations beyond Elphick, Roberts & Reed’s (2010) 38, due to the additional data this brings from the controversial sightings. Furthermore, the number of taxa and populations for which the 95% confidence interval around the predicted extinction date includes dates after 2008 increased from 6 to 14. This has potentially important implications in terms of conservation management and the distribution of resources for the additional 8 taxa and populations. Further, improper classification of these taxa could have resulted in Romeo’s Error (Collar, 1998), where the taxon is assumed to be extinct, which results in a lack of appropriate and timely conservation efforts, and consequently precipitates its true extinction.

Sighting observations of species or individuals are likely to have some level of uncertainty as to whether a correct identification has been made. Few have, however, attempted to quantify the level of uncertainty (e.g., Lee et al., 2015), test for the level of accuracy experimentally (e.g., Gibbon, Bindemann & Roberts, 2015) or incorporated this into their analyses (e.g., Jarić & Roberts, 2014; Lee et al., 2014). As we have shown here, acknowledging such uncertainties can have a profound impact on decision-making; in the case of a critically endangered species, it may influence whether it is considered extinct or extant and therefore whether conservation efforts and resources should be allocated. For some species, extinction may occur within years of being described as a new taxon to science. As an example, a cryptically coloured treehunter from Brazil, Cichlocolaptes mazarbarnetii, described in 2014, was last seen in 2007, but had lain misidentified in the National Museum of Brazil for over 20 years having been collected in 1986 (Lees & Pimm, 2015).

Finally, while we incorporated sighting uncertainty into a time-based extinction model, such sightings with spatial data are frequently used in occupancy modelling with apparently little consideration to the underlying uncertainty of the identification (but see Romero et al., 2014). This is likely to be particularly an issue when using historic sightings, whose location data may also be imprecise. Much of this data is becoming increasingly available.
online and can be accessed rapidly. However, consideration should be given to the quality of the data, including spatial and temporal inaccuracies (Yesson et al., 2007), particularly identification uncertainties.

### ADDITIONAL INFORMATION AND DECLARATIONS

#### Funding
IJ was supported through a sponsorship provided by the Alexander von Humboldt Foundation and the Federal German Ministry for Education and Research, as well as support by the Project No. 173045, funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

#### Grant Disclosures
The following grant information was disclosed by the authors:
Alexander von Humboldt Foundation and the Federal German Ministry for Education and Research.
Ministry of Education, Science and Technological Development of the Republic of Serbia: Project No. 173045.

#### Competing Interests
David L. Roberts is an Academic Editor for PeerJ.

#### Author Contributions
- David L. Roberts conceived and designed the experiments, performed the experiments, analyzed the data, wrote the paper, prepared figures and/or tables.
- Ivan Jarić performed the experiments, analyzed the data, wrote the paper, reviewed drafts of the paper.

#### Data Availability
The following information was supplied regarding data availability:
The data was previously published in Elphick CS, Roberts DL, Reed JM. 2010. Estimated dates of recent extinctions for North American and Hawaiian birds. Biological Conservation 143(3): 617–624.

#### Supplemental Information
Supplemental information for this article can be found online at http://dx.doi.org/10.7717/peerj.2426#supplemental-information.

### REFERENCES

Collar NJ. 1998. Extinction by assumption; or, the Romeo Error on Cebu. *Oryx* 32(4):239–244 DOI 10.1046/j.1365-3008.1998.0051.x.

Elphick CS, Roberts DL, Reed JM. 2010. Estimated dates of recent extinctions for North American and Hawaiian birds. *Biological Conservation* 143(3):617–624 DOI 10.1016/j.biocon.2009.11.026.
Fitzpatrick JW, Lammertink M, Luneau MD, Gallagher TW, Harrison BR, Sparling GM, Rosenberg KV, Rohrbaugh RW, Swarthout ECH, Wrege PH, Swarthout SB, Dantzker MS, Charif RA, Barksdale TR, Remsen Jr JV, Simon SD, Zollner D. 2005. Ivory-billed Woodpecker (*Campephilus principalis*) persists in continental North America. *Science* 308(5727):1460–1462 DOI 10.1126/science.1114103.

Gibbon GE, Bindemann M, Roberts DL. 2015. Factors affecting the identification of individual mountain bongo antelope. *PeerJ* 3:e1303 DOI 10.7717/peerj.1303.

Gotelli NJ, Chao A, Colwell RK, Hwang WH, Graves GR. 2012. Specimen-based modeling, stopping rules, and the extinction of the ivory-billed woodpecker. *Conservation Biology* 26(1):47–56 DOI 10.1111/j.1523-1739.2011.01715.x.

Jarić I, Roberts DL. 2014. Accounting for observation reliability when inferring extinction based on sighting records. *Biodiversity and Conservation* 23(11):2801–2815 DOI 10.1007/s10531-014-0749-8.

Lee TE, Black SA, Fellous A, Yamaguchi N, Angelici FM, Al Hikmani H, Reed JM, Elphick CS, Roberts DL. 2015. Assessing uncertainty in sighting records: an example of the Barbary lion. *PeerJ* 3:e1224 DOI 10.7717/peerj.1224.

Lee TE, McCarthy MA, Wintle BA, Bode M, Roberts DL, Burgman MA. 2014. Inferring extinctions from sighting records of variable reliability. *Journal of Applied Ecology* 51(1):251–258 DOI 10.1111/1365-2664.12144.

Lees AC, Pimm SL. 2015. Species, extinct before we know them? *Current Biology* 25(5):R177–R180 DOI 10.1016/j.cub.2014.12.017.

McKelvey KS, Aubry KB, Schwartz MK. 2008. Using anecdotal occurrence data for rare or elusive species: the illusion of reality and a call for evidentiary standards. *BioScience* 58(6):549–555 DOI 10.1641/B580611.

Roberts DL, Elphick CS, Reed JM. 2010. Identifying anomalous reports of putatively extinct species and why it matters. *Conservation Biology* 24(1):189–196 DOI 10.1111/j.1523-1739.2009.01292.x.

Romero D, Olivero J, Márquez AL, Báez JC, Real R. 2014. Uncertainty in distribution forecasts caused by taxonomic ambiguity under climate change scenarios: a case study with two newt species in mainland Spain. *Journal of Biogeography* 41(1):111–121 DOI 10.1111/jbi.12189.

Sibley DA, Bevier LR, Patten MA, Elphick CS. 2006. Comment on “Ivory-billed woodpecker (*Campephilus principalis*) persists in continental North America”. *Science* 311:1555a DOI 10.1126/science.1122778.

Solow AR. 1993. Inferring extinction from sighting data. *Ecology* 74(3):962–964 DOI 10.2307/1940821.

Solow AR. 2005. Inferring extinction from a sighting record. *Mathematical Biosciences* 195(1):47–55 DOI 10.1016/j.mbs.2005.02.001.

Solow AR, Smith W, Burgman M, Rout T, Wintle B, Roberts D. 2012. Uncertain sightings and the extinction of the ivory-billed Woodpecker. *Conservation Biology* 26(1):180–184 DOI 10.1111/j.1523-1739.2011.01743.x.

Yesson C, Brewer PW, Sutton T, Caithness N, Pahwa JS, Burgess M, Gray WA, White RJ, Jones AC, Bisby FA, Culham A. 2007. How global is the global biodiversity information facility? *PLoS ONE* 2(11):e1124 DOI 10.1371/journal.pone.0001124.