Conservation Biology

Contributed Paper

Identifying Anomalous Reports of Putatively Extinct Species and Why It Matters

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Abstract: *As species become very rare and approach extinction, purported sightings can stir controversy, especially when scarce management resources are at stake. We used quantitative methods to identify reports that do not fit prior sighting patterns. We also examined the effects of including records that meet different evidentiary standards on quantitative extinction assessments for four charismatic bird species that might be extinct: Eskimo Curlew (*Numenius borealis*), Ivory-billed Woodpecker (*Campephilus principalis*), Nukupu`u (*Hemignathus lucidus*), and O`ahu `Alauahio (*Paroreomyza maculata*). For all four species the probability of there being a valid sighting today, given the past pattern of verified sightings, was estimated to be very low. The estimates of extinction dates and the chance of new sightings, however, differed considerably depending on the criteria used for data inclusion. When a historical sighting record lacked long periods without sightings, the likelihood of new sightings declined quickly with time since the last confirmed sighting. For species with this type of historical record, therefore, new reports should meet an especially high burden of proof to be acceptable. Such quantitative models could be incorporated into the International Union for Conservation of Nature's Red List criteria to set evidentiary standards required for unconfirmed sightings of "possibly extinct" species and to standardize extinction assessments across species.*

Keywords: critically endangered, data quality, extinction, IUCN Red List, museum specimens, species persistence, sighting record

Identificación de Reportes Anómalos de Especies Putativamente Extintas y Porqué es Importante

Resumen: *A medida que una especie se vuelve rara y se acerca a la extinción, los posibles avistamientos pueden causar controversia, especialmente cuando están en juego escasos recursos para manejo. Utilizamos métodos cuantitativos existentes para identificar reportes que no concuerdan con anteriores patrones de avistamiento. También examinamos los efectos de la inclusión de registros que cumplen con estándares probatorios diferentes de las evaluaciones cuantitativas de extinción para cuatro especies carismáticas de aves que podrían extinguirse:* Numenius borealis, Campephilus principalis, Hemignathus lucidus *y* Paroreomyza maculata*. Para las cuatro especies, la probabilidad de que hubiera un avistamiento válido hoy, dado el patrón de avistamientos verificados en el pasado, fue muy baja. Sin embargo, las estimaciones de las fechas de extinción y la posibilidad de nuevos avistamientos difirió considerablemente dependiendo del criterio utilizado para la inclusión de datos. Cuando un registro histórico de avistamientos careció de largos períodos sin avistamientos, la probabilidad de nuevos avistamientos declinó rápidamente desde el último avistamiento confirmado. Por lo tanto, los reportes nuevos para especies con este tipo de registro histórico deben cumplir con una fuerte carga de pruebas para ser aceptados. Tales modelos cuantitativos podrían ser incorporados en los criterios de la Lista Roja de la Unión Internacional para la Conservación de la Naturaleza para fijar*

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Paper submitted January 7, 2009; revised manuscript accepted April 1, 2009.

Conservation Biology, Volume **, No. *, ***–***

DOI: 10.1111/j.1523-1739.2009.01292.x

estándares probatorios requeridos por avistamientos no confirmados de especies "posiblemente extintas" y para estandarizar la evaluación de extinciones de especies.

Palabras Clave: avistamiento, calidad de datos, críticamente en peligro, especímenes de museo, extinción, Lista Roja UICN, persistencia de especies

Introduction

Reliable sightings of species in time and space are required to infer changes in their geographic ranges, population trends, and likelihood of extinction. Anecdotal and inconclusive physical occurrence data can lead to serious errors in conservation practice and waste limited resources (McKelvey et al. 2008). Careful assessments of purported "sightings" are particularly important for charismatic rare species that are observed only sporadically because each sighting is a rare event and can greatly affect how conservation measures are applied. Following earlier literature, we use *sightings* in a broad sense to refer to any record of occurrence, including specimens, photographs, audio recordings, and so forth, and we considered a series of "sightings" for a taxon a "sighting record."

Erroneous or controversial statements of persistence arise for various reasons, ranging from simple misidentification and data entry errors to outright fraud (e.g., Rasmussen & Prŷs-Jones 2003; Table 1). In some cases the problem can be taken to an extreme, as with the supposed sightings of the Loch Ness monster, which resulted in a mythical species being given a scientific name (*Nessiteras rhombopteryx*), thus qualifying it for legal protection in the United Kingdom (Scott & Rines 1975). Because of limited funds for conservation and the economic ramifications of legal decisions concerning rare species protection, the development of an objective framework for evaluating sightings is important (McKelvey et al. 2008).

Assessing the validity of alleged sightings is particularly important for species that are critically endangered or thought to be extinct because of the potential for committing what has been referred to as a Romeo error—giving up on a species too soon and thereby contributing to its demise (Collar 1998). The transition between critically endangered and presumed extinct categories has important implications for conservation prioritization. For this reason it has been suggested that the red list system of the International Union for Conservation of Nature (IUCN 2001) should include a separate category for "possibly extinct" species (Butchart et al. 2006; Roberts 2006).

Butchart et al. (2006) proposed a qualitative framework for categorizing the level of confidence that a species is actually extinct. The framework considers evidence for and against extinction and time since the species was last "reliably" reported. Five main types of evidence suggesting extinction and four types of evidence against concluding that a species is extinct are included. Of these types of evidence, two from each category are relevant to the issue of sighting quality because they relate to species observations. Evidence that suggests extinction includes situations when, for species with recent last sightings, the decline is well documented and when recent surveys appear to have been adequate to detect the species but have failed to do so. Evidence against extinction includes situations when the species is known to be difficult to detect and when there have been reasonably convincing local reports or recent unconfirmed sightings.

Butchart et al. (2006) used their criteria to create a visual framework for categorizing the likelihood of extinction that depends on valid sighting records. No recommendation was given on how to treat the quality of sightings, however; yet, this is a major dilemma that conservationists face when considering records of possibly extinct species. Although the IUCN Red List assessments have changed from their qualitative origins to a more quantitative form, each sighting that goes into determining whether the species is possibly extinct is still judged in a largely ad hoc fashion.

Here we illustrate how different evidentiary standards can affect the conclusions drawn about the likely persistence of species. Moreover, we show how existing quantitative methods for assessing sighting records can be used to augment the existing framework of Butchart et al. (2006), thereby adding more information that can be used when assessing the status of the very rarest species.

Methods

An inherent problem with much of the literature on species that may be extinct is that intense focus is directed toward suspected sightings but far less attention is paid to the absence of sightings. Statistical methods developed to estimate the probability of extinction from sighting records can be used to evaluate new sightings based on the prior pattern of both confirmed sightings and occasions during which there were no documented sightings (e.g., Solow 2005; Solow et al. 2006). When a recent sighting is irrefutable (e.g., multiple witnesses of a specimen being collected), such an analysis is trivial. But when there is uncertainty about a sighting, the pattern of confirmed sightings and lack of sightings provides an additional way to evaluate the controversial sighting. If

Table 1. Types of errors in sighting records that can occur even with "verifiable" physical evidence.

Type of error	*Examples and comments*
Interpretation errors of labels	difference in British vs. American dating whereby 11 March 2007, could be recorded as either 11/3/07 or 3/11/07; abbreviation of the year to the last two digits
Interpretation errors of specimens	recent rediscovery of the polecat (*Mustela putorius*) in Scotland resulted from surreptitious translocation rather than a persisting population (Solow et al. 2006)
Labeling or location errors	spatial and temporal imprecision
	transcriptional errors
	insufficient knowledge by the end users of location names used by collector; changes in geographical names
	gradual loss of data and accumulated errors of the type mentioned above with increasing age of specimen as they pass through many hands
	labeling with the center where the specimens were accumulated or shipped rather than the collection locality; assumed origin of the specimen by curators
	curators substituting original labels for their own, making it impossible to verify spelling, handwriting, or original data
Specimen misidentification once in a collection	known as Elvis taxa (Erwin & Droser 1993)
Deliberate fraud through	
planting of specimens in the field	most notably, Prof. J. W. Heslop Harrison in an attempt to increase evidence for his theory that the island of Rum was a refugium (Pearman & Walker 2004)
theft and relabeling	most notorious example, Richard Meinertzhagen (Rasmussen & Prŷs-Jones 2003)
misrepresentation for commercial purposes	Victorian orchid collectors who, on occasion, gave erroneous geographic origins to protect their sources

the sighting record implies that a species is extinct, then any new reports warrant extremely careful scrutiny.

We used this approach to examine the effect of accepting sightings that meet different evidentiary standards on the inferences one would make about the extinction of four charismatic bird species that might be extinct and that have received much attention from academic and amateur ornithologists: the Eskimo Curlew (*Numenius borealis*), Ivory-billed Woodpecker (*Campephilus principalis*), Nukupu`u (*Hemignathus lucidus*), and O`ahu `Alauahio (*Paroreomyza maculata*) (Table 2). The same analyses also may be used to ask the question: Given what the pattern in the sightings we are certain of says about a species' chance of persisting, are controversial reports anomalous and thus deserving of greater scrutiny?

We used a statistical model to calculate the predicted year of extinction for each target species, given past sighting patterns, and then used this information to evaluate whether controversial sightings are likely to be valid. This model estimates the chance that a species is extinct in a given year, subsequent to the last accepted sighting. If this chance is low, then a report would be unexceptional, lessening the need for extreme scrutiny because the consequences of an error would not be great. In contrast, if the estimated chance that a species is extinct is very high, then much more careful scrutiny of the report would be warranted. The mathematical analysis alone cannot be used to determine the record's validity, but akin to an outlier analysis in regression, it allows one to identify sightings that are unexpected (because the species is predicted to be extinct) and thus require especially high evidentiary standards before acceptance. In some respects, our analysis superficially resembles one used by Solow et al. (2006). In their study, however, sightings about which there was no doubt were used to answer questions about changes in the underlying sighting process. We reversed the situation and used the underlying sighting process to make inferences about controversial reports that have not been confirmed.

Each analysis was repeated using different acceptance criteria for sightings to examine sensitivity to different data standards. A number of models exist for these purposes, each differing in their assumptions about the underlying distribution of sightings (Solow 2005). Our prior work with goodness-of-fit tests demonstrates that data from North American and Hawaiian birds best fit the assumptions of a uniform (stationary Poisson) model (Vogel et al. 2009), which suggests that methods that assume other distributions are not appropriate (e.g., that used in Solow et al. 2006). Although the method we used does not explicitly model the separate effects of search effort (cf. Burgman et al. 1995; McCarthy 1998) or detectability, it does implicitly account for them because they both affect sighting probability. Because all factors influencing sighting rate were modeled collectively, the method assumes that there is no systematic trend in the likelihood of detection over time. Testing this assumption for our target species was not possible because of the lack of long-term data on annual search effort. Nevertheless, given the large increase in bird-watching activities in our study region over the past century, the especially great interest in finding rare species, the substantial

Table 2. Sighting records for four possibly extinct species based on three different levels of sighting quality.

Species (geographical population)	*Sighting quality*	*Sighting record (years)*
Eskimo Curlew[a] (*Numenius borealis*)	physical evidence	1900, 1901, 1902, 1903, 1904, 1905, 1906, 1908, 1911, 1912, 1913, 1914, 1918, 1932, 1962, 1963
	independent expert opinion (added to physical evidence)	1926, 1929, 1930, 1933, 1937, 1939, 1945, 1947, 1948, 1950, 1959, 1960, 1961
	controversial sightings	1956, 1964, 1968, 1970, 1972, 1973, 1974, 1976, 1977, 1980, 1981, 1982, 1983, 1985, 1987, 1990, 1992, 1996, 2002, 2006
Ivory-billed Woodpecker (U.S.)[b] (*Campephilus principalis*)	physical evidence	1897, 1898, 1899, 1900, 1901, 1902, 1904, 1905, 1906, 1907, 1908, 1909, 1910, 1913, 1914, 1917, 1924, 1925, 1932, 1935, 1938, 1939
	independent expert opinion added	1911, 1916, 1920, 1921, 1923, 1926, 1929, 1930, 1931, 1933, 1934, 1936, 1937, 1941, 1942, 1943, 1944
	controversial sightings	1946, 1948, 1949, 1950, 1951, 1952, 1955, 1958, 1959, 1962, 1966, 1967, 1968, 1969, 1971, 1972, 1973, 1974, 1976, 1981, 1982, 1985, 1986, 1987, 1988, 1999, 2004, 2005, 2006
Nukupu`u[c] (*Hemignathus lucidus*)	physical evidence	1837, 1838, 1888, 1891, 1892, 1893, 1894, 1895, 1896, 1897, 1899
	independent expert opinion added	1879
	controversial sightings	1960, 1961, 1965, 1967, 1968, 1973, 1974, 1975, 1976, 1978, 1979, 1981, 1983, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996
O`ahu `Alauahio[d] (*Paroreomyza maculata*)	physical evidence	1837[e], 1888, 1891, 1892, 1893, 1896, 1897, 1901, 1902, 1903, 1950, 1968
	independent expert opinion added	1936, 1937, 1939, 1940, 1946, 1947, 1948, 1949
	controversial sightings	1952, 1955, 1956, 1957, 1958, 1960, 1961, 1964, 1966, 1968, 1969, 1972, 1973, 1974, 1975, 1976, 1977[f], 1978, 1984, 1985, 1989, 1990, 1991, 1993, 1996, 1997, 2000, 2001, 2002

[a] *Data from Hahn (1963), Gollop et al. (1986), and Gollop (1988).*
[b] *Data from Tanner (1942), Hahn (1963), Jackson (2002, 2004), Fitzpatrick et al. (2005), Hill (2006), and Floyd (2007).*
[c] *Data from Banko (1979, 1984a), Pratt and Pyle (2000), Reynolds and Snetsinger (2001), and R. L. Pyle and P. Pyle (unpublished data). We follow Pratt and Pyle's (2000) conclusion that all reports since 1900 are unconfirmed.*
[d] *Data from Banko (1979, 1984b), Reynolds and Snetsinger (2001), USFWS (2006), Pyle and Pyle (2009), and R. L. Pyle and P. Pyle (unpublished data). We follow Shallenberger and Pratt (1978) and Pyle and Pyle (2009), who conclude that all reports since 1968 are unconfirmed.*
[e] *The 1937 reference is reported as 1936/1937; we used 1937 to be conservative in our estimates.*
[f] *The 1977 reference is reported as 1977/1978; we used 1977 because there is an additional report from 1978.*

decline in most natural habitat types, the improved ability to access previously isolated regions, and the substantial improvements in the availability of high-quality optical equipment, it seems unlikely that assumption violations would create the form of bias necessary to lead to the conclusion that a species is extinct when it is not.

For each species sightings were organized as a series of values, $t_1 < t_2 < \ldots < t_n$, where years are numbered starting with $t_1 = 0$ (i.e., 1971, 1974, 1976 would be numbered 0, 3, 5, respectively, for $n = 3$ sightings). Consequently, t_n is the number of years from the first to the last sightings. The expected years to extinction (T_E) from the start of the sighting record can be estimated as $\hat{T}_E = \frac{n+1}{n} t_n$. The expected year of extinction, then, is T_E plus the year of the first sighting in the sighting record. For example, if the first sighting in the record came from 1900, the last sighting came from 1950, and the estimated years to extinction (T_E) was 70, then the predicted year of extinction would be 1970. In a similar fashion, the number of years to the upper bound of this estimate (T_E^u) for a given confidence level (1 – α) can be calculated as $T_E^u = t_n/\alpha^{1/(n-1)}$ (Solow 2005), from which one can calculate an upper confidence bound for the extinction year estimate. For each species we predicted the year of extinction, and the upper limit of the 95% confidence interval (CI) for physical evidence only (i.e., uncontroversial specimen and photographic records); independent expert opinion (i.e., evidence where there is adequate documentation to satisfy experts, including physical evidence); and when including controversial sightings (i.e., evidence for which there is substantial debate or verifying evidence is lacking). Solow (2005) states that, although the question of optimal sample size (number of sightings in a record) has not been formally explored, in his experience, there should be at least five sightings for an analysis to be valid and that increasing the number of records

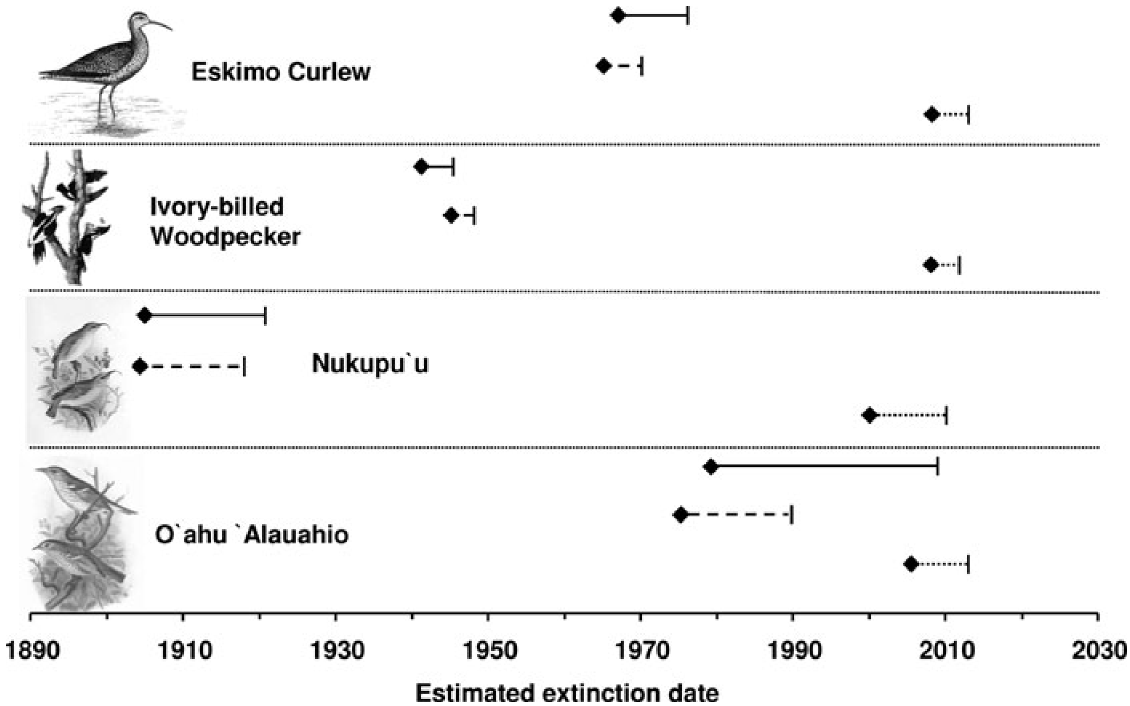

Figure 1. For each species bars demarcate the estimated year of extinction (◆) to the upper bound of the 95% CI: solid line (top for each species), estimates from the physical evidence data only; dashed line (middle), estimates from the independent expert opinion data (includes physical evidence); dotted line (bottom), estimates when including controversial sightings.

improves the estimates. Consequently, for the Eskimo Curlew and Ivory-billed Woodpecker, which have many sightings, we included records starting around 1900. For the two Hawaiian species, which have relatively fewer uncontroversial sightings, we included all of the documented records we could find.

For the stationary Poisson model we used here one can determine whether a species is likely to be extinct and thus gauge whether a controversial new record is particularly surprising. The probability that a species persists to a target year, given the prior sighting record, can be calculated using $p = (t_n/T)^{n-1}$ (after Solow 1993). Here the time interval T starts in the year of the first sighting and ends in the target year of interest. We calculated p for each species for each year after the last accepted sighting through 2008. That is, for a species for which the last accepted sighting was in 1963, we calculated p for 1964, 1965, ... , 2008. We made these calculations first with the physical evidence only and then after adding the sightings supported by independent expert opinion. See Solow (2005) for a discussion of model development and assumptions.

Results

The analysis of the physical evidence and independent expert opinion records suggested that the Eskimo Curlew, Ivory-billed Woodpecker, and the Nukupu`u are probably extinct (Figs. 1 & 2). For the O`ahu `Alauahio, when only the physical evidence was used, the estimated year of extinction was 1980; 2009 was the upper bound for the 95% CI. The larger CI for O`ahu `Alauahio compared with the other species was because of the long (47- and 18-year) time gaps between the last three sightings of this species (Table 2), which then required a long series of years after the last sighting before extinction could be assumed. If all independent expert opinion sightings were included, however, the gaps in the sighting record were reduced and the expected year of O`ahu `Alauahio extinction and upper bound were estimated as 1975 and 1989, respectively. This pattern, whereby the estimates from the physical evidence data resulted in a later date of extinction than did those from the independent expert opinion data, was repeated for the Eskimo Curlew and the Ivory-billed Woodpecker. The inferred extinction date was therefore affected by the type of evidence accepted, with the greatest difference seen for the Nukupu`u. For this species the estimated times to extinction differed by as much as 96 years depending on which data standard was used (Fig. 1). The time since the most recent controversial sighting and the most recent sightings with physical evidence was 97 years (Table 2). Even for the more conservative comparison between the physical evidence and independent expert opinion data sets, the difference for all species between the inferred

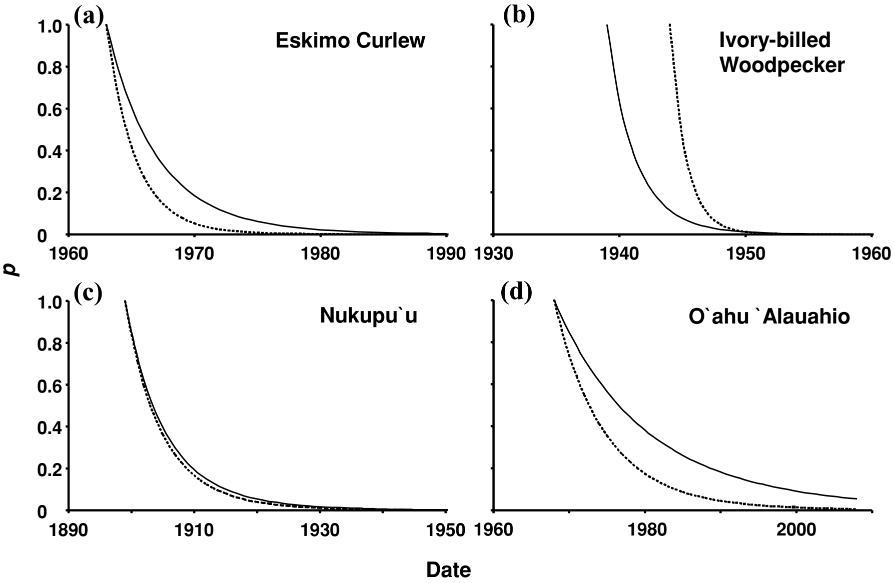

Figure 2. Estimated probability (p) that a species is extinct, given the sighting records shown in Table 2, for the (a) Eskimo Curlew, (b) Ivory-billed Woodpecker, (c) Nukupu`u, and (d) O`ahu `Alauahio. Estimates based on two different types of sighting records (physical evidence, solid line; independent expert opinion, dashed line). As p *approaches zero the burden of proof for a new sighting should increase.*

extinction dates ranged from −6 to 4 years across species (Fig. 1).

For all four species the estimated probability of persistence (given the previous time series of sightings and assumptions of the models) declined quickly with time since the last confirmed sighting (Fig. 2). This pattern existed whether we accepted only sightings with physical evidence or used the expanded time series that included independent expert opinion records. When considering only physical evidence the chance of an O`ahu `Alauahio persisting to 1999 was estimated to be $<$10%, with a continuing decline in probability thereafter (Fig. 2d), which suggests that sightings after this date require very careful scrutiny. The greatest disparity in the predictions from the physical evidence and independent expert opinion time series appeared for this species, where the former suggests a $>$10% chance of persistence until as recently as the late 1990s and the latter suggests a much lower probability ($p \leq 0.016$) (Fig. 2d). The use of the second (more liberal) data set, therefore, would paradoxically lead one to conclude that a much higher burden of proof is needed before a new report is acceptable. For the Ivory-billed Woodpecker the prior sighting record suggests that even by the time of the first controversial sighting, the species was relatively unlikely to remain extant ($\sim$21% chance), regardless of the level of evidence (physical or independent expert opinion) used (Fig. 2b). In contrast, the first controversial sighting of Eskimo Curlew was plausible because there was a high chance that the species was extant at that time ($>$77% chance; Fig. 2a).

Discussion

In 1988 all four of the species we evaluated were categorized as threatened by the IUCN. Since 1994 three of the four species have been reclassified as critically endangered, the exception being the Ivory-billed Woodpecker, which was designated extinct until 2000 and reclassified as critically endangered thereafter (http://www.redlist.org). According to the IUCN Red List criteria, a species is extinct "when there is no reasonable doubt that the last individual has died" (IUCN 2001). In these guidelines the IUCN goes on to say, "a taxon is presumed Extinct when exhaustive surveys in known and/or expected habitat... throughout its historic range have failed to record an individual." Even for species that attract considerable attention, such as those described in our analyses, this level of certainty is difficult to achieve because any statement of extinction is probabilistic and because extremely intensive survey efforts are required for a high confidence of extinction from an area (Scott et al. 2008). Without explicit criteria to define "reasonable doubt," the IUCN guidelines necessarily rely on ad hoc assessments to determine whether species should be listed as critically endangered, possibly extinct, or extinct. Based on the statistical methods we used, both the physical evidence and the independent expert opinion sighting records support the conclusion that all four of the species are very likely extinct.

As the time since the last verified sighting increases, the probability that a species persists, and thus the chance of another valid sighting, decreases. Adding other independent expert opinion sightings to those in the physical evidence series can affect a sighting record either by filling in gaps between the sightings with physical evidence or by pushing forward the date of the last sighting. Filling in sighting gaps has the—perhaps surprising—effect of moving the expected date of extinction to an earlier year, as was observed for Eskimo Curlew and O`ahu `Alauahio. A more recent last sighting, in contrast, moves the expected date of extinction to a later year, as shown for the

Ivory-billed Woodpecker. When both changes happen in a sighting record, as was the case for the Eskimo Curlew and Ivory-billed Woodpecker, the effect on the predicted extinction date will depend on the details of the sighting record. Including controversial sightings will, by definition, move expected extinction dates forward in time, and for all four species evaluated here, the estimated date of extinction for the most liberal sighting series was 2000 or later, with the upper bounds of the 95% CI extending to at least 2010 (Fig. 1). Consequently, what is accepted as a valid sighting can have a substantial effect on any assessment of whether extinction has happened, with concomitant implications for the assessment of subsequent sightings. Therefore, an ever-increasing burden of proof should be required with increasing time since the last verified sighting. The burden of proof also should be greater when there is a pattern of frequent sightings prior to the last accepted record and lower when long periods between sightings are common in the historical record. The methods we used provide an objective way to determine which reports are especially influential and thus require the greatest scrutiny. Importantly, this approach can be used to standardize assessments across species.

Broader Issues and Future Considerations

Consistent with our findings, Butchart et al. (2006) concluded that the Eskimo Curlew, Nukupu`u, and O`ahu `Alauahio are probably extinct. (Butchart et al. did not evaluate the Ivory-billed Woodpecker.) Even for these species, which have received considerable attention, there remains debate over the last acceptable sighting. BirdLife International—the body that conducts the red-list assessments for all bird species—reports that the last Eskimo Curlew "recorded with certainty" was in the early 1980s (BirdLife International 2009), Butchart et al. (2006) cites 1981, and we used 1963, the year of the last uncontroversial physical record (Table 2). As far as we are aware no standard method has been used to evaluate all Eskimo Curlew sightings systematically since the last physical record, so we treated all subsequent records as controversial.

For the Nukupu`u, BirdLife International (2009) states that the "last confirmed sightings" were in 1995–1996, compared with 1899 in our assessment. The reason for this discrepancy is that BirdLife does not address Pratt and Pyle's (2000) conclusion that all sightings of this species since 1900 are unconfirmed. There is also a discrepancy for O`ahu `Alauahio; BirdLife International (2009) lists 1985 as the last "well documented observation," whereas Pyle and Pyle (2009) give 1968, when the last specimen was taken. The earlier date is based on the assessments of Shallenberger and Pratt (1978) and Shallenberger and Vaughn (1978) that only three records since 1950 for this species are valid. (One record is the specimen from 1968; unfortunately, the authors do not state what the other two records are, although both are from before 1976 [D. Pratt, personal communication].) These examples demonstrate the controversies over many sighting records and our categorization of sighting dates in Table 2 reflects this problem.

Inconsistencies among authors highlight the consequences of ad hoc assessments of sighting records for the conclusions drawn about species extinction. Such inconsistency also reinforces the need for a commonly accepted set of data standards to better ensure consistency in conservation assessments and the resulting management decisions. A formal method of weighing different types of sighting evidence could be developed and incorporated into the IUCN guidelines to extend the consistency of species conservation assessments. Consideration also should be given to the question of whether it is better to have a one-model-fits-all approach to sighting assessments or whether a more flexible approach, whereby the evidentiary burden of proof depends on the biology of the taxon, is more appropriate (McKelvey et al. 2008).

Because they can be used to generate a quantitative metric, we believe the use of sighting record models—such as the one we used here to illustrate the effects of different evidentiary standards—also would be a helpful supplement to the types of information currently used when evaluating extinction status. Like population viability analysis, such methods are not a panacea because their value depends on the specific model assumptions and quality of data used (cf. Reed et al. 2002). Consequently, there are species for which the available information is clearly inadequate for the use of these models to be appropriate (e.g., Beck's Petrel [*Pseudobulweria becki*], Kona Grosbeak [*Chloridops kona*], and many others that are data deficient). Nonetheless, these methods can provide another piece of information that would help conservation biologists move toward a more rigorous, explicit, and repeatable system for assessing and comparing the status of different species.

Although there is clearly a need to develop a formal framework to determine which sightings should be used in extinction assessments, this approach is useful only if there is also effective dissemination of the guidelines so that stakeholders know what type of information should be collected. Ultimately, conservation biologists need to consider when, and whether, it is better to conclude that a sighting is valid when in fact it is a misidentification or to run the risk of concluding a species is extinct when it is not. Conservation biologists tend to be much more willing to make the former type of error, but the costs of the latter error are not inconsequential, given constraints on conservation funding and, when competing interests are involved, the credibility of conservation practitioners. Creating a rigorous, repeatable approach for identifying suspect reports (e.g., using Solow's (2005) methods) and then evaluating sightings (cf. McKelvey et al. 2008) would likely reduce the risks of both types of errors, while making explicit the decisions that are being made.

Acknowledgments

We thank P. Pyle and R. Pyle for updated data on Hawaiian bird sightings, L. Bevier and D. Sibley for many long discussions about these issues, and P. Pyle, M. Burgman, and two anonymous reviewers for comments on earlier drafts. D.L.R. was funded by the Sarah and Daniel Hrdy Fellowship in Conservation Biology from Harvard University.

Literature Cited

Banko, W. E. 1979. History of endemic Hawaiian birds. Museum collections. Avian history report 2. Cooperative National Park Resources Study Unit, University of Hawaii at Manoa, Honolulu, Hawaii.

Banko, W. E. 1984*a*. History of endemic Hawaiian birds. Part I. Population histories—species accounts forest birds: `Akialoa, Nukupu`u and `Akiapōlā`au. Avian history report 9. Cooperative National Park Resources Study Unit, University of Hawaii at Manoa, Honolulu, Hawaii.

Banko, W. E. 1984*b*. History of endemic Hawaiian birds. Part I. Population histories—species accounts forest birds: `Amakihi, Creeper, `Akepa and Po`o Uli. Avian history report 8A & 8B. Cooperative National Park Resources Study Unit, University of Hawaii at Manoa, Honolulu, Hawaii.

BirdLife International. 2009. World bird database. BirdLife International, Cambridge, United Kingdom. Available from http://www.birdlife.org/datazone/index.html (accessed March 2009).

Burgman, M. A., R. C. Grimson, and S. Ferson. 1995. Inferring threat from scientific collections. Conservation Biology **9:**923–928.

Butchart, S. H. M., A. J. Stattersfield, and T. M. Brooks. 2006. Going or gone: defining 'Possibly Extinct' species to give a truer picture of recent extinctions. Bulletin of the British Ornithologists' Club **126A:**7–24.

Collar, N. J. 1998. Extinction by assumption: or, the Romeo error on Cebu. Oryx **32:**239–244.

Erwin, D. H., and M. L. Droser. 1993. Elvis taxa. Palaios **8:**623–624.

Fitzpatrick, J. W., et al. 2005. Ivory-billed Woodpecker (*Campephilus principalis*) persists in continental North America. Science **308:**1460–1462.

Floyd, T. 2007. The Ivory-billed Woodpecker. Birding **39:**26.

Gollop, J. B. 1988. The Eskimo Curlew. Pages 583-595 in W. J. Chandler, editor. Audubon wildlife report. 1988/1989. Academic Press, New York.

Gollop, J. B., T. W. Barry, and E. H. Iversen. 1986. Eskimo Curlew a vanishing species? Special publication 17. Saskatchewan Natural History Society, Regina, Canada. Available from www.npwrc.usgs.gov/resource/birds/curlew/ (accessed February 2009).

Hahn, P. 1963. Where is that vanished bird? An index to the known specimens of the extinct and near extinct North American species. Royal Ontario Museum, University of Toronto, Ontario, Canada.

Hill, G. E., D. J. Mennill, B. W. Rolek, T. L. Hicks, and K. A. Swiston. 2006. Evidence suggesting that Ivory-billed Woodpeckers (*Campephilus principalis*) exist in Florida. Avian Conservation and Ecology **1:** http://www.ace-eco.org/vol1/iss3/art2/.

IUCN (International Union for Conservation of Nature). 2001. Red List categories and criteria. Version 3.1. IUCN Species Survival Commission, Gland, Switzerland, and Cambridge, United Kingdom.

Jackson, J. A. 2002. Ivory-billed Woodpecker (*Campephilus principalis*). Page 711 in A. Poole, editor. The birds of North America online. Cornell Laboratory of Ornithology, Ithaca, New York. Available from http://bna.birds.cornell.edu/BNA/account/Ivory-billed_Woodpecker/ (accessed February 2009).

Jackson, J. A. 2004. In search of the Ivory-billed Woodpecker. Smithsonian Institution Press, Washington, D.C.

McCarthy, M. A. 1998. Identifying declining and threatened species with museum data. Biology Conservation **83:**9–17.

McKelvey, K. S., K. B. Aubry, and M. K. Schwartz. 2008. Using anecdotal occurrence data for rare of elusive species: the illusion of reality and a call for evidentiary standards. BioScience **58:**549–555.

Pearman, D. A., and K. J. Walker. 2004. An examination of J. W. Heslop Harrison's unconfirmed plant records from Rum. Watsonia **25:**45–63.

Pratt, T. K., and R. L. Pyle. 2000. Nukupu`u in the twentieth century: endangered species or phantom presence? `Elepaio **60:**35–41.

Pyle, R. L., and P. Pyle. 2009. The birds of the Hawaiian Islands: occurrence, history, distribution, and status. Bishop Museum Press, Honolulu, Hawaii. Available from http://hbs.bishopmuseum.org/birds/rlp-monograph (accessed June 2009).

Rasmussen, P. C., and R. P. Prŷs-Jones. 2003. History vs mystery: The reliability of museum specimen data. Bulletin of the British Ornithologists' Club **123A:**66–94.

Reed, J. M., L. S. Mills, J. B. Dunning Jr., E. S. Menges, K. S. McKelvey, R. Frye, S. Beissinger, M.-C. Anstett, and P. Miller. 2002. Emerging issues in population viability analysis. Conservation Biology **16:**7–19.

Reynolds, M., and T. J. Snetsinger. 2001. The Hawaii rare bird search 1994–1996. Pages 133–142 in J. M. Scott, S. Conant, and C. Van Riper III, editors. Evolution, ecology, conservation, and management of Hawaiian birds: a vanishing avifauna. Studies in avian biology no. 22. Cooper Ornithological Society, Camarillo, California.

Roberts, D. L. 2006. Extinct or possibly extinct? Science **312:**997–998.

Scott, P., and R. Rines. 1975. Naming the Loch Ness monster. Nature **258:**466–468.

Scott, J. M., F. L. Ramsey, M. Lammertink, K. Rosenberg, R. Rohrbauch, J. A. Wiens, and J. M. Reed. 2008. In search of "extinct" species: effort required to conclude absence of endangered birds. Avian Conservation and Ecology **3:**http://www.ace-eco.org/vol3/iss2/art3/.

Shallenberger, R. J., and H. D. Pratt. 1978. Recent observations and field identification of the Oahu Creeper (*Loxops maculate maculate*). `Elepaio **38:**135–140.

Shallenberger, R. J., and G. K. Vaughn. 1978. Avifaunal survey in the central Ko`olau Range, Oahu. Ahuimanu Productions, Kailua, Hawaii.

Solow, A. R. 1993. Inferring extinction from sighting data. Ecology **74:**962–964.

Solow, A. R. 2005. Inferring extinction from a sighting record. Mathematical Biosciences **195:**47–55.

Solow, A. R., A. C. Kitchener, D. L. Roberts, and J. D. S. Birks. 2006. Rediscovery of the Scottish polecat, *Mustela putorius*: Survival or reintroduction? Biological Conservation **128:**574–575.

Tanner, J. T. 1942. The Ivory-billed Woodpecker. Research report no. 1. National Audubon Society, New York.

USFWS (U.S. Fish and Wildlife Service). 2006. Revised recovery plan for Hawaiian forest birds. USFWS, Region 1, Portland, Oregon.

Vogel, R. M., J. R. M. Hosking, C. S. Elphick, D. L. Roberts, and J. M. Reed. 2009. Goodness of fit of probability distributions for sightings as species approach extinction. Bulletin of Mathematical Biology **71:**701–719.