available at www.sciencedirect.com

SCIENCE DIRECT®

journal homepage: www.elsevier.com/locate/biocon

Short communication

Inferring extinction from biological records: Were we too quick to write off Miss Waldron's Red Colobus Monkey (*Piliocolobus badius waldronae*)?

David L. Roberts[a,*], *Andrew C. Kitchener*[b,c]

[a]*Royal Botanic Gardens, Kew, Richmond, Surrey, TW9 3AB, UK*
[b]*Department of Natural Sciences, National Museums of Scotland, Chambers Street, Edinburgh, EH1 1JF, UK*
[c]*Institute of Geography, School of Geosciences, University of Edinburgh, Drummond Street, Edinburgh EH8 9XP, UK*

ARTICLE INFO

Article history:
Received 22 April 2005
Received in revised form
22 August 2005
Accepted 16 September 2005
Available online 14 November 2005

Keywords:
Decline
Extinction
Miss Waldron's Red Colobus
Piliocolobus badius waldronae
Rediscovery

ABSTRACT

We are now entering a time of immense environmental upheaval where experts are increasingly required to provide conservation assessments. Quantitative assessment of trends in species' range and abundance is costly, requiring extensive field studies over a long period of time. For many species in dense habitats, it may be very difficult to establish reliable and sensitive survey and monitoring techniques, which are able to warn of potentially catastrophic population declines. Unfortunately many other species are only known through a few 'chance' sightings or a handful of museum specimens and therefore extinction may be even harder to ascertain. In 2000 Miss Waldron's Red Colobus, Piliocolobus badius waldronae, was reported as extinct, but since then (in 2001) a single specimen has been collected. Four probabilistic methods were used to infer extinction based on a record of sightings of the subspecies. Based on the date when the extinction statement of Miss Waldron's Red Colobus was made, all four methods returned probability values >0.05, suggesting that the subspecies is extant, but is extremely rare. If we cannot successfully monitor populations of critically endangered taxa, it becomes almost impossible to predict their extinction with any certainty and we can expect increasing numbers of false alarms in future years, which may undermine the potential for conservation action and, more worryingly, public support for conservation.

1. Introduction

In 2000 Oates et al. (2000) brought to the world's attention the possible extinction of Miss Waldron's Red Colobus Monkey (*Piliocolobus badius waldronae*) and stated that many more primate species would follow its fate. McGraw (1998) had discussed its possible extinction earlier and this seemed to be confirmed by subsequent surveys of other likely areas (McGraw, 2001). However, only two years later, McGraw and Oates (2002) presented evidence for its continued survival. A hunter had given a skin to McGraw and Oates in January 2002, which had come from an animal that had been killed in the previous three months. This example of extinction and rediscovery raises concerns about how we know when

* *Corresponding author*: Tel.: +44 2083325291; fax: +44 2083325278.
E-mail address: d.roberts@rbgkew.org.uk (D.L. Roberts).
0006-3207/$ - see front matter
doi:10.1016/j.biocon.2005.09.033

a species or subspecies is extinct (Keith and Burgman, 2004), given the difficulty of effectively surveying and monitoring critically endangered species, particularly in dense habitats such as rainforests. Making false alarms could undermine potential last-minute conservation action and wider public support caused by conservationists "crying wolf" too frequently.

Until recently, a species or subspecies was regarded as extinct if it had not been observed for 50 years (Reed, 1996). However, the usefulness of this criterion is dependent on the life-history characteristics of the species in question. A revision of the IUCN Red List categories resulted in a species being classified as 'extinct' only when exhaustive surveys failed to produce any observations over a time period appropriate to the species' life history and throughout its known historical range (IUCN, 2001). McInerny et al. (submitted) stated that, "extinctions are most frequently asserted after subsequent investigation and so uncertainty often surrounds the classification of a species as extinct. This necessitates acknowledgement of the probabilistic nature of any extinction statement." Many species and subspecies are only known from through a few 'chance' sightings or a handful of museum specimens and therefore extinction may be even harder to ascertain. Several methods have been presented which provide the basis for an extinction hypothesis (see Solow, 1993a,b, 2005; Burgman et al., 1995; McCarthy, 1998; Solow and Roberts, 2003). These methods calculate the probability that another sighting will be made given the characteristics of a sighting record.

In this paper we examine the statement that Miss Waldron's Red Colobus Monkey is extinct, using four probabilistic methods for inferring extinction.

2. Methods

A chronological record of sightings of *P. b. waldronae* was constructed based on Oates et al. (2000) and specimens held in British museums (Napier, 1985) (Table 1). A single specimen from Ghana in the Natural History Museum, London, (BMNH.ZD.1976.1792) was excluded owing to its questionable identity (Napier, 1985). This specimen exhibits the characteristic black coloration on the limbs and black tail with some red hairs of *P. b. badius* (P. H. Napier unpublished record; D. L. Roberts pers. obs. 2004).

Table 1 – Chronological record of sightings, specimens and/or status of Miss Waldron's Red Colobus Monkey

Year	Record
1912	2 specimens
1933	5 specimens
1934	2 specimens
1952	9 specimens
1953	1 specimen
1954	1 specimen collected by Booth. Booth (1954) reported seen in mixed groups of *Piliocolobus b. badius* and *P. b. waldronae* in Côte d'Ivoire. In the same year Collins (1956) record the species as "still relatively abundant".
1956	Booth (1956) reported that in Ghana its extinction was a probability.
1975	Asibey (1978)
1978	Olson (1986)
2000	Considered "possibly extinct" (Oates et al., 2000)
2001	Single skin provided by hunter (McGraw and Oates, 2002). Never seen a living specimen in over 10 years of research (McGraw, pers. com., 2004)

Four probabilistic methods were used to infer extinction based on the sighting and specimen records described in Table 1 (Solow, 1993a,b, 2005; Solow and Roberts, 2003), with the records arranged as a binary series within the period, T, at ordered times, $t_1 < t_2 < \ldots < t_n$.

Using the time of the last sighting (t_n) the Solow equation gives the probability that n observations occurred within the period $0 < t < t_n$, given that sightings are equally likely to occur within the period T (Solow, 1993a).

$$p = \left(\frac{t_n}{T}\right)^n. \quad (1)$$

The Solow equation (1993a) is suitable for small populations that are predisposed to rapid extinction, as the sightings are assumed to follow a stationary Poisson process (Solow, 1993b). However, in a declining population, sightings are less likely to occur towards the end of the period because sightings will reduce as the population declines. Assuming that the sightings follow a Poisson process with decreasing rate function, Solow developed the following equation (Solow, 1993b).

$$p = Fs(t_n)/Fs(T), \quad (2)$$

where

$$s = \sum_{i=1}^{n} ti \quad (3)$$

and the function $Fs(t)$ is given by

$$F_s(t) = 1 - \sum_{i=1}^{[s/t]} (-1)^{i-1} \binom{n}{i} (1 - (it/s))^{n-1}. \quad (4)$$

The Solow/Roberts non-parametric equation (Solow and Roberts, 2003) does not require a complete sighting record, as the number of sightings (n) is not required for its calculation (Solow and Roberts, 2003). Using t_n, T and t_{n-1} the equation generates the probability that another sighting will occur.

$$p = \left(\frac{t_n - t_{n-1}}{T - t_{n-1}}\right). \quad (5)$$

More recently, Solow (2005) used an estimate of the shape parameter of the Weibull extreme value distribution, $\hat{v}$,

$$\hat{v} = \frac{1}{k-1} \sum_{i=1}^{k-2} \log \frac{T_1 - T_k}{T_1 - T_{i+1}} \quad (6)$$

to produce an approximate p value for testing for extinction.

$$p = \exp\left(-k\left(\frac{T - t_n}{T - t_{n-k+1}}\right)^{1/\hat{v}}\right). \quad (7)$$

This method had been used previously to estimate the extinction data of the Dodo (*Raphus cucullatus*) (Roberts and Solow, 2003).

3. Results

All four methods suggest that based on the records (Table 1), *P. b. waldronae* should still have existed when the Oates et al. (2000) paper was published ($p = 0.075$, Solow, 1993a; $p = 0.136$, Solow, 1993b; $p = 0.117$, Solow and Roberts, 2003; $p = 0.078$, Solow, 2005). However, all four have very small p values suggesting that the subspecies is extremely rare and close to extinction (McCarthy, 1998).

4. Discussion

This study illustrates the uncertainty in determining whether a taxon is extinct or not. When species or subspecies decline they may go through multiple stable states; that is to say that prior to their decline the population would have been stable, but once the species has gone through a major decline, it may persist in small numbers until it is either rescued from extinction or stochastic events take hold, e.g. the decline of the Black Rhinoceros, *Diceros bicornis*. For some species their numbers are below our sighting threshold, and hence would be beyond any effective means of survey and monitoring. Therefore, this may result in the taxa being prematurely described as extinct, although some may consider these as irrecoverable. Although humans may cause a massive decline in a species, it is likely that stochastic events "push them over the edge". If introduced feral pigs, *Sus domestica*, buffaloes, *Bubalus bubalis*, and donkeys, *Equus asinus*, cannot be eradicated from Australia using modern methods such as helicopters and semiautomatic weapons (Bowman, 2001), it is unlikely that inadvertent extinctions are caused directly through human activities, such as by hunting, but that these only precipitate their extinction. This is because the required effort increases dramatically once the population of a species falls to very low densities (Bowman, 2001) i.e. below the sighting threshold. In the case of Miss Waldron's Red Colobus Monkey, it has been in decline since Booth's (1956) statement that extinction was inevitable. However, although the subspecies has been in decline for nearly 60 years and has not been seen alive for 26 years, it still seems to have managed to hang on, but for how much longer?

Miss Waldron's Red Colobus Monkey is not the first species or subspecies to have been considered extinct and then subsequently rediscovered. Other "Lazarus" taxa include the dibbler, *Parantechinus apicalis*, sandhill dunnart, *Sminthopsis psammophila*, Jerdon's courser, *Cursorius bitorquatus*, forest owlet, *Athene blewitti*, noisy scrubbird, *Atrichornis clamosus*, and four-colored flowerpecker, *Dicaeum quadricolor*, all of which were considered extinct, having not been seen for over 50 years, only to reappear recently (Strahan, 1995; Fuller, 2001). In the case of subspecies, it may even be harder to determine extinction because of intergradations with neighbouring subspecies, so that phenotypes of the "extinct" taxon may "survive" outside the subspecies' former range. An example of this was the photograph of the extinct Burchell's zebra, *Equus quagga burchellii*, which appeared in a Land Rover advert a few years ago and there have been apparently successful attempts to select for the extinct quagga phenotype (*E. q. quagga*) from Damara zebras, *E. q. antiquorum* (Barnaby, 1996; Higuchi et al., 1984).

Application of the statistical methods described here for inferring extinction from sighting records and museum specimens will aid our understanding of the probability of whether a taxon has become extinct and help maintain public confidence in conservation.

REFERENCES

Asibey, E.O.A., 1978. Primate conservation in Ghana. In: Chivers, D.J., Lane-Petter, W. (Eds.), Recent Advances in Primatology, vol. 2. Conservation Academic Press, London, pp. 55–74.

Barnaby, D., 1996. Quaggas and Other Zebras. Bassett Publications, Plymouth.

Booth, A.H., 1954. A note on the colobus monkeys of the Gold and Ivory Coasts. Annals and Magazine of Natural History 12th Series 7, 857–860.

Booth, A.H., 1956. The distribution of primate in the Gold Coast. Journal of the West African Science Association 2, 122–133.

Bowman, D.M.J.S., 2001. Future eating and country keeping: what role has environmental history in the management of biodiversity? Journal of Biogeography 28, 549–564.

Burgman, M.A., Grimson, R.C., Ferson, S., 1995. Inferring threat from Scientific Collections. Conservation Biology 9, 923–928.

Keith, D.A., Burgman, M.A, 2004. The Lazarus effect: can the dynamics of extinct species lists tell us anything about the status of biodiversity? Biological Conservation 117, 41–48.

Collins, W.B., 1956. The tropical forest: an animal and plant association. The Nigerian Field 21, 4–27.

Fuller, E., 2001. Extinct Birds. Cornell University Press, Ithaca.

Higuchi, R., Brown, B., Freiberger, M., Ryder, O.A., Wilson, A.C., 1984. DNA sequences from the quagga, an extinct member of the horse family. Nature 312, 282–284.

IUCN, 2001. IUCN Red List Categories and Criteria: Version 3.1. IUCN Species Survival Commission. IUCN, Gland, Switzerland and Cambridge, UK.

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

McGraw, W.S., 1998. Three monkeys nearing extinction in the forest reserves of Côte d'Ivoire. Oryx 32, 233–236.

McGraw, W.S., 2001. A survey of forest primates near the Ivory Coast's Ehi Lagoon: Further evidence for the extinction of *Colobus badius waldroni*. American Journal of Physical Anthropology, AAPA Abstract Issue S32 (114), 106–107.

McGraw, W.S., Oates, J.F., 2002. Evidence for a surviving population of Miss Waldron's red colobus. Oryx 36, 223.

Oates, J.F., Abedi-Lartey, M., McGraw, W.S., Struhsaker, T.T., Whitesides, G.H., 2000. Extinction of a West African red colobus monkey. Conservation Biology 14, 1526–1532.

Olson, D.K., 1986. Determining range size for arboreal monkeys: methods, assumptions and accuracy. In: Taub, D.M., King, F.A. (Eds.), Current Perspectives in Primate Social Dynamics. Van Nostrand Reinhold, New York, pp. 212–227.

Reed, J.M., 1996. Using statistical probability to increase confidence of inferring species extinction. Conservation Biology 10, 1283–1285.

Napier, P.H., 1985. Catalogue of Primates in the British Museum (Natural History) and elsewhere in the British Isles. Part III: Family Cercopithecidae, Subfamily Colobinae. British Museum (Natural History), London.

Roberts, D.L., Solow, A.R., 2003. When did the dodo become extinct? Nature 426, 245.

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

Solow, A.R., 1993b. Inferring extinction in a declining population. Journal of Mathematical Biology 32, 79–82.

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

Solow, A.R., Roberts, D.L., 2003. A nonparametric test for extinction based on a sighting record. Ecology 84, 1329–1332.

Strahan, R., 1995. The Mammals of Australia. Chatswood, Reed.