Long-term data for endemic frog genera reveal potential conservation crisis in the Bale Mountains, Ethiopia

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Appendix I Species accounts

***Spinophrynoides osgoodi* (Loveridge, 1932)**
Bufo osgoodi Loveridge, 1932: Loveridge (1932: 47)
Nectophrynoides osgoodi (Loveridge, 1932): Grandison (1978)
Spinophrynoides osgoodi (Loveridge, 1932): Dubois (1987: 26)
Altiphrynoides osgoodi (Loveridge, 1932): Frost et al. (2006: 363)

Spinophrynoides osgoodi was described originally by Loveridge (1932) as a new species of the widespread genus *Bufo*, based on material collected by W.H. Osgood in 1926–27. Tandy and Keith (1972: 156) considered *Bufo osgoodi* to be a member of the *Bufo taitanus* (= *Mertensophryne taitana* of Frost et al., 2006) complex. Grandison (1978) included *osgoodi* in an expanded concept of the East African toad genus *Nectophrynoides*, currently comprising 13 nominal species, all endemic to Tanzania (e.g. Frost, 2011). Dubois (1987) erected the monotypic genus *Spinophrynoides* for *osgoodi* based on it having a different breeding biology to *Nectophrynoides*. Most recently, Frost et al. (2006) transferred *osgoodi* to *Altiphrynoides* (see also below), but this was not based on any new data, and here we follow Largen's (2001) taxonomy. The presence of this Ethiopian endemic genus in the Bale Mountains has been overlooked by non-herpetologists and conservation managers because *S. osgoodi* was not classified in *Spinophrynoides* until 1987 (e.g. WCMC, 1993; Miehe & Miehe, 1994).

The original description of *S. osgoodi* was based on two specimens collected in 1926–27 from an imprecise locality ('Gedeb Mountains', Loveridge, 1932), but it has subsequently been recorded from beyond the Bale Mountains, even including a specimen from the Gughe Mountains on the western side of the Rift Valley (Largen, 2001: map 7). In the Bale Mountains, where the vast majority of specimens have been recorded, *S. osgoodi* has been reported from both north and south of the Sanetti Plateau, typically in montane forest but extending also into open moorland at 1,950–3,520 m (Largen, 2001). It is a small to medium (snout–vent length, SVL, to 62 mm) species whose large clutches of eggs in strings have been found laid in small pools in an open glade within *Hypericum* woodland at 3,200 m, these eggs developing into free-swimming aquatic tadpoles that metamorphose into froglets (Grandison, 1978; Largen, 2001).

In the 2004 and 2006 Global Amphibian Assessments (Stuart et al., 2008) and current Red List (IUCN, 2010) *S. osgoodi* was assessed as Vulnerable because its 'Extent of Occurrence is less than 20,000 km² and its Area of Occupancy is less than 200 km², its distribution is severely fragmented, and there is continuing decline in the extent and quality of its forest habitat in the Ethiopian Mountains'. The population trend was stated to be decreasing although to the best of our knowledge there have been no quantitative assessments of population size or density. Major threats to the species were considered to be 'environmental degradation resulting from human settlement and expansion'. With respect to necessary conservation measures, the Global Amphibian Assessments stated 'the main priority is prevention of further loss of prime montane forest habitat. The species is relatively common in the Bale Mountains National Park, but there is a need to identify further sites suitable for conservation'.

S. osgoodi is listed in CITES Appendix I because the species was formerly included within the genus *Nectophrynoides,* all species of which are listed under Appendix I of CITES. However, there is 'no known utilization' of *S. osgoodi* (IUCN, 2004).

***Altiphrynoides malcolmi* (Grandison, 1978)**
Nectophrynoides malcolmi Grandison, 1978
Altiphrynoides malcolmi (Grandison, 1978): Dubois (1987: 27)

Altiphynoides malcolmi was originally described as a new species of the East African genus *Nectophrynoides* by Grandison (1978). Dubois (1987) erected the genus *Altiphrynoides* for Grandison's species on the basis that its reproduction differs to that of *Nectophrynoides* (and *Spinophrynoides*). We follow Largen (2001) in considering *Altiphynoides* to be a monotypic genus, despite Frost et al.'s (2006) inclusion of *Spinophrynoides osgoodi* in *Altiphrynoides* (see above). Because *A. malcolmi* has been classified in *Altiphrynoides* only since 1987 the presence of this endemic genus has been overlooked in some summaries of the fauna (e.g. WCMC, 1993; Miehe & Miehe, 1994).

  doi:10.1017/S0030605311001426

The type series of > 160 *A. malcolmi* was collected by M.J. Largen and colleagues in December 1971, April 1972, April 1974 and April 1975 at 3,200–4,000 m from localities on the northern and north-eastern (Dinsho/Dinshu and Goba) side of the Sanetti Plateau. An additional 20 specimens of *A. malcolmi* were collected in August 1986 from the Harenna escarpment during the original Harenna Forest Expedition (Largen, 2001). Overall, this species is thus reported from 3,200–4,000 m, spanning the transition from the upper limits of the *Schefflera–Hagenia–Hypericum* forest to open Afroalpine moorland (Largen, 2001).

This small species (SVL < 32 mm, Largen, 2001) was observed by Largen and colleagues forming large breeding aggregations in a forest glade in April 1975 (Grandison, 1978). Following internal fertilization, small clutches (< 32) of large eggs are laid communally in moist places at the base of herbaceous vegetation or under leaves/logs close to streams but not in water. Tadpoles hatch from the eggs, but these are non-feeding and remain on land until metamorphosis.

The Global Amphibian Assessments (IUCN, 2004, 2010; Stuart et al., 2008) categorized *A. malcolmi* as Endangered 'because its extent of occurrence is less than 5,000 km² and its area of occupancy is less than 500 km², all individuals are in fewer than five locations, and there is continuing decline in the extent and quality of its habitat in the Bale Mountains'. As with *S. osgoodi, A. malcolmi* is a CITES Appendix I species because it was formerly classified in *Nectophrynoides*, even though there is 'no known utilization of this species' (IUCN et al., 2006).

Ericabatrachus baleensis (Largen, 1991)

Ericabatrachus is a monotypic, possibly petropedetine/id (Largen, 2001) or phrynobatrachine/id (Dubois, 2005; Frost et al., 2006) frog endemic to the Bale Mountains. Dubois' (2005) and Frost et al.'s (2006) classifications are apparently based on Largen's (1991: 141) description of the holotype of *Ericabatrachus baleensis* as 'Habitus *Phrynobatrachus*-like', although Largen clearly did not view *E. baleensis* as a phrynobatrachine/id. Scott (2005) provided morphological evidence that *Ericabatrachus* is more closely related to the pyxicephalid *Cacosternum* but its relationships are obviously not yet well understood. *E. baleensis* was described from 23 specimens collected by M.J. Largen and D.W. Yalden in August during the 1986 Harenna Forest Expedition. Twenty-two of the types were collected from the margins of a stream in giant *Erica* forest in a single day (15 August) at the type locality for *Balebreviceps hillmani* (see below) at 3,200 m, with one immature paratype coming from a stream at Katcha, at 2,400 m in the Harenna Forest. The original type locality collection data are very precise: daytime, in damp grass at edge of swiftest parts of mountain torrent, into which they hopped when disturbed, surfacing to cling to the bank at the water level (Largen, 1991). This locality has the name Tulla Negesso.

The reproduction and life history of *E. baleensis* are unknown but Largen (1991) interpreted the presence of large ovarian eggs in some female paratypes of *E. baleensis* as indicative of terrestrial clutches, potentially with direct development. No larvae have been reported for *E. baleensis*. The presence of *E. baleensis* and its endemicity have been overlooked by at least some important works on the Bale Mountains (e.g., Miehe & Miehe, 1994).

In the Global Amphibian Assessments (IUCN et al., 2004, 2006; Stuart et al., 2008), *E. baleensis* was categorized as Endangered on the basis of an extent of occurrence of < 5,000 km² and 'continuing decline in the extent and quality of its habitat'. Accompanying notes state that a Critically Endangered assessment was narrowly avoided because the species 'almost certainly occurs more widely'. *Ericabatrachus* is not a CITES listed taxon. We know of no published records beyond the type series.

Balebreviceps hillmani (Largen & Drewes, 1989)

The monotypic *Balebreviceps* is a member of the Brevicipitinae/dae, a group of frogs endemic to sub-Saharan Africa. Its precise relationships to other brevicipitines/ds, most species of which occur in the Eastern Arc Mountains of Kenya and Tanzania, remain unclear (e.g. Largen & Drewes, 1989; Loader et al., 2004). *Balebreviceps hillmani* was described originally from 16 individuals, all collected by M.J. Largen and colleagues from a single locality during one day (15 August) of the Harenna Forest Expedition of 1986. To the best of our knowledge no subsequent collections had been made, nor any reports published of this species being encountered at the type or any other locality (e.g. Largen & Spawls, 2010). All of the type specimens were collected by day from beneath logs and boulders within giant *Erica* forest 50 m below the timber line on the Harenna escarpment (Largen & Drewes, 1989). The precise locality is immediately east of the road (between the Sanetti Plateau and Rira), at Tulla Negesso, particularly on the floor of the giant *Erica* forest between the road and the part of the stream that is the type locality of *E. baleensis*. The presence of *B. hillmani* and its endemicity were overlooked by at least some important works on the Bale Mountains (e.g., Miehe & Miehe, 1994).

The breeding biology and life history of *B. hillmani* are unknown but, based on close relatives, is predicted to have terrestrial eggs with direct-development into froglets (Largen & Drewes, 1989; Müller et al., 2007). *B. hillmani* is categorized as Endangered, narrowly missing Critically Endangered, for the same reasons noted above for *Ericabatrachus* (IUCN et al., 2004, 2006; Stuart et al., 2008). *Balebreviceps* is not a CITES listed taxon. We know of no published records beyond the type series.

Appendix 2 Details of the fieldwork undertaken to locate amphibians in the Bale Mountains

For each record, the data are given in the following format: Date (as day/month/year): Locality: Length and timing of search: (frogs found). Where one non-herpetologist found frogs by day while looking for other organisms, this is arbitrarily recorded here as c. two person hours. Expeditions 10–14 also involved local assistants from Harenna (Issa, Hussein, Hussein and Mohammed).

Abbreviations: AAU, Addis Ababa University; BMNP, Bale Mountains National Park; CI, Conservation International; EWCA, Ethiopian Wildlife Conservation Authority; FZS, Frankfurt Zoological Society; MCZ, Museum of Comparative Zoology, Harvard University; NHM, The Natural History Museum, London; PH, person hours; TM, Trento Museum; UB, University of Basel; UR, University of Richmond, Virginia; WWF, near the WWF hut, below Rira; *Aa, Amieta angolensis; Am, Altiphrynoides malcomi; Ax, Afrixalus* sp.; *Bs, Bufo* sp.; *Bh, Balebreviceps hillmani; Eb, Ericabatrachus baleensis; Hs, Hyperolius* sp.; *Lg, Leptopelis gramineus; Lr, L. ragazzii* and/or *L.* cf. *ragazzii; Ls, Leptopelis* sp.; *Lss, Leptopelis* spp.; Ofs-X, other (not the four species of particular interest) unspecified frog species (where X is number of species); *Pe, Ptychadena erlangeri; Phs, Phrynobatrachus* sp.; *Pk, Paracassina kounhiensis; Pn, Pychadena neumanni* and *P.* cf. *neumanni; Ps, Ptychadena* sp.; *Pss, Ptychadena* spp.; *So, Spinophrynoides osgoodi*; UE, unidentified eggs; *Xp, Xenopus* sp.

M.J. Largen, D.W. Yalden, P.A. Morris and others

1. (December 1971)
17/12/1971: Dinsho area: 6 PH day: (1 *Lg,* 1 *Lr,* 2 *Am,* 6 Ofs-3). 18/12/1971: Dinsho and Mt Gaysay: 9 PH day: (1 *So,* 18 Ofs-3). 19/12/1971: Dinsho: 1 PH day: (1 *So,* 1 *Lg,* 2 Ofs-2). 21/12/1971: Urgana Valley and Little Batu (Sanetti Plateau): 2 PH day: (1 *Am,* 2 Ofs-1). 23/12/1971: Garba Guracha (Sanetti Plateau) and E of Dinsho: 2 PH day: (2 *Am,* 2 Ofs-1). 24/12/1971: Little Batu (Sanetti Plateau): 2 PH (1 *Lg*).

2. (April 1972)
29/4/1972: Near Dinsho: 3 PH day (17 *Lg,* 1 *Lr,* 3 *Am,* 2 Ofs-1).

3. (April 1974)
28/4/1974: S of Goba: 5 PH day (115 *Am*; 49 *So*, 1 *Lr*)

4. (April 1975)
16/4/1975: Dinsho and S of Goba: 6 PH day (8 *Lg,* 4 Ofs-2). 17/4/1975: S of Goba:
8 PH day (75 *Am,* 1 *Lg,* 2 Ofs-1). 19/4/1975: S of Goba: 6 PH day and night (32 *So*).

5. Harenna expedition (August 1986)
3/8/86: Katcha: 6 PH day and night (3 *So,* 2 *Lg,* 4 *Lr,* 9 Ofs-2). 4/8/1986: Katcha: 4 PH night (19 *So,* 3 *Lr,* 1 *Lg,* 1 *Eb,* 20 *Ax,* 4 Ofs-2). 7/8/1986: Katcha: 3 PH night (15 *Lr,* 9 Ofs-4). 3/8/1986: Magano: 3 PH day (24 *Lg,* 5 Ofs-1). 8/8/1986: S of Katcha: 6 PH (3 *So,* 6 *Lr,* 1 Ofs-1). 9/8/1986: Shawe bridge and Magano: 4 PH day (1 *So,* 11 Ofs-4). 15/8/1986: Tulla Negesso: 30 PH day (30 *Am,* 10 *So,* 18 *Bh,* 23 *Eb,* 1 *Lr,* 3 Ofs-2). 19/8/1986: Magano: 9 PH day (16 *Xp,* 17 Ofs-3).

Steve Spawls (SS) and others

6. SS, Jonathan and Tim Spawls (Dec 1994 to Jan 1995)
30/12/1994: Saneti Plateau: 6 PH day. 31/12/1994: Dinsho: 6 PH day. 1/1/1995: Harenna escarpment, close to road: 6 PH day (40 *Am,* 1 *Bh,* 6 or 7 *So*?, some *Pk, Pn, Lg*).

7. SS, Colin Tilbury (Sept 1996)
21/9/1996: NE edge of Sanetti Plateau: 2 PH early morning (3 *Am*). 21/9/1996: Harenna escarpment: 20 PH daytime to early evening (20 + *Am,* 1 *Bh*; some *Lg*). 22/9/1996: Dinsho: 6 PH (*Bs*).

8. SS, Jonathan and Tim Spawls (Dec 1996)
29/12/1996: Sanetti Plateau: 6 PH day. 30/12/1996: Dinsho: 6 PH day. 31/12/1996: Harenna escarpment: 6 PH day (18 + *Am,* 1 *Bh*).

9. SS, Jonathan and Tim Spawls, Chris Smith (Oct 1999)
26/10/1999: Sanetti Plateau: 8 PH day. 27/10/1999: Dinsho: 8 PH day. 28/10/1999: near Rira: 8 PH day (*Ps*).

10. MCZ (July 2006). Breda Zimkus and Ryan Kerney (MCZ); Daniel Pawlos (EWCA)

1/7/2006: 3,055 m, Gaysay, 2 km west of Dinsho, and near BMNP lodge: 3 PH day pm (*Pc,* UE, T). 2/7/2006: 2801 m, South of Rira: 2 PH day pm (*Pn*): 2 PH night. 3/7/2006: 2,816 m, Kolala Lake, nr. Rira: 2 PH day am (*Lr, Ls, Ps,* T): 2,378 m, Katcha Camp:
4 PH day pm (*Pn,* T). 4/7/2006: 3,400–4,000 m Harenna Escarpment and S side of Sanetti Plateau: 4 PH day am: Tulla Negesso: 4 PH am/pm: 2,810 m, Telila Stream, nr. Rira: 2 PH pm (*Lr,* T). 5/7/2006: 3,800–4,100 + m, Sanetti Plateau: 3 PH day am (*Ls,* T). 13/7/2006: 1,750 m, 18 km south of Katcha Camp: 4 PH day am (*Pe*). 14/7/2006: 2,300–2,400 m, north of Katcha:
5 PH am/pm (*Pe, Pn, Lg, Lr*, T). 15/7/2006: 2,700–2,800 m, Gussa River, nr. Rira: 3 PH day am (*Ls*).

11. NHM (September 2006). David Gower and Simon Loader (NHM), Roman Aberra (EWCA), Daniel Tilaye (BMNP)

15/9/2006: Dinsho: 3 PH day pm: 3 PH night (*Lg,* T). 16–19/9/2006: Dinsho: locals and park staff casual daytime searching (*Pss, Lg*). 16/9/2006: 3,900 m on N side of Sanetti Plateau: 6 PH day am (1 *Am*): 4,000 + m, Sanetti Plateau: 1.5 PH day am: Tulla Negesso: 6 PH

day pm: (*Lr*): Katcha: 3 PH night (*Lr, Ls*). 17/9/2006: Katcha: 1 PH day am (*Ps*): 2,400–2,500 m, above Katcha: 5 PH day am: 2900–3200 m, W of Rira: 10 PH day pm: 2,750 m, West of Rira: 5 PH day pm: 2,815 m, nr. Rira: locals day (3 *Bh*, 3 *Am*). 18/9/2006: 1,900 m, Harenna Forest: 1 PH : Tulla Negesso: 6 PH day pm: 1,900 m, Shawe River: locals day pm (*Ls*): 2,800 m, nr. Rira: locals day pm (*Ps. Ls*): Tulla Negesso: overnight four terrestrial funnel traps on ground: Tulla Negesso: 3 PH night (1 *Bh*). 19/9/2006: Tulla Negesso: 1.5 PH day am: 3,060 m, Gaysay: 3.5 PH (*Ps*).

12. UB, EWCA and AAU (July–August 2008). Simon Loader, Abebe Mengistu, Silvia Schwaller, Michael Geiser (UB), Roman Aberra (AAU, EWCA), Samy Saber, Fikirte Gebresenbet (AAU)

14/7/2008: Dinsho: 2 PH daytime (1 *Lg*). 15/7/2008: Tulla Negesso: 4 PH daytime (1 *Am*): WWF: 4PH night (1 *Lg*, 1 *Lr*, T). 16/7/2008: Tulla Negesso: 6PH daytime: WWF: 9PH daytime (6 *Lr*, 5 *Lg*, T). 18/7/2008: 3,200 m, Fute: 3 PH daytime: 3,145 m, nr. Fute: 5 PH daytime (1 *Bh*). 19/7/2008: 3,255 m, Kotinsa: 1.5 PH daytime: 3,200 m nr. Kotinsa: 0.5 PH daytime. 20/7/2008: 3,200 m Kotinsa: 3 PH dayime (UE). 21/7/2008: 3,200 m, nr. Fute: 3 PH daytime (3 *Am*). 22/7/2008: 3,950 m, Sanetti Plateau: 1 PH daytime. 23/7/2008: 3,950 m, Sanetti Plateau: 2 PH daytime. 26/7/2008: 3,200 m, Kotinsa: 4 PH night. 27/7/2008: 3,200 m, Degebato: 3 PH day + 1 PH night. 28/7/2008: 3,200 m, Degebato: 3PH day. 29/7/2008: Rira: locals, day (1 *Lg*). 30/7/2008: 2,370 m, Katcha: 8PH day (3 *Lg*, 1 *Lr*, T): 2,800 m, nr. WWF: night (2 *Lr*, T). 31/7/2008: 3,300 m, Galema: 1 PH night: Rira: locals day (*Ps*). 1/8/2008: 3,301 m, Galema: 3 PH day (1 *Lg*, 1 *Ps*). 2/8/2008: 3,200 m, Tulla Negesso: 3 PH day: 3,200 m, nr. Fute: 2 PH day (1 *Bh*, 1 *Eb*): Rira: locals day (1 *Lg*, 1 *Ps*). 4/8/2008: 3,200 m, Kotinsa: 3PH day: Rira: locals day (5 *Ps*, 1 *Lg*). 5/8/2008: 3,200 m Kotinsa: 6.5 PH day: 3,200 m, Fute: 3.5 PH day (1 *Am*): Fute: 4 PH day (1 *Bh*). 29/7–5/8/2008: Rira: locals day (4 *Bh*, 8 *Lr*, 1 *Lg*). 7/8/2008: 3,160 m, Dinsho: park staff day (2 *Phs*). 27–28/8/2008: Weyib Valley, Sanetti Plateau: 6PH day.

13. AAU and EWCA (February–March 2009). Roman Aberra (AAU, EWCA)

22/2/2009: 2,780 m, WWF: 1.5 PH day (10 *Ps*, 1 *Lg*): 2,850 m, nr. WWF: 1.5 PH day (2 *Ps*). 23/2/2009: Tulla Negesso: 3 PH day (1 *Am*, 1 *Bh*): 2,790 m, nr. WWF: 1.5 PH pm (1 *Ps*, 1 *Lg*). 24/2/2009: 3,200 m, Fute: 1.5 PH day: 2,800 m, nr. WWF: locals (*Ps*): nr. Rira: 0.5 PH day (5 *Ps*, T): 2,900 m, nr. Rira: 1.5 PH night (4 *Ps*, 1 *Ls*). 25/2/2009: 3,150 m, Fute: 3 PH, day (5 *Am*). 26/2/2009: 3,250 m, Kotinsa: 6 PH day (1 *Bh*). 27/2/2009: 3,300 m, Galema: 3 PH day (2 *Bh*, 5 *Lg*, T). 28/2/2009: Tulla Negesso: 1.5 PH day (2 *Am*): 2,900 m, nr. Rira: 2 PH day (10 s *Lg*, 4 *Ps*). 1/3/2009: 2.800 m, nr. WWF: locals day (7 *Lg*, 4 *Ps*). 2/3/2009: 3,300 m, Degebato: 6 PH day. 3/3/2009: 2,350 m, Katcha: 5 PH day (10 *Lr*, 9 *Ps*, 2 *Lg*). 4/3/2009: 2,900 m, nr. Rira: 1.5 PH day: 2,800 m, nr. Rira: 0.5 PH day (50 T): 2,800 m, nr. Rira: 1 PH day (1 *Bh*).

14. UB, AAU, TM, UR and NHM (June 2009). Simon Loader, Abebe Mengistu (UB), Michele Menegon (TM), Rafael de Sá (UR), David Gower (NHM), Bruhtesfa Yimer (EWCA)

18/6/2009: 2,750 m, nr. WWF: 3.75 PH night (10 s *Lr*, 10 s T). 19/6/2009: c. 4,000 m, Sanetti Plateau: 3 PH day: Tulla Negesso: 5.5 PH day: (1 *Bh*): 2,380 m, Katcha: 8 PH dusk/night (*Ps, Lr, Ax*, 100s T). 20/6/2009: 3,100 m, nr. Fute: 10 PH day (10 *Bh*, 2 *Eb*): 3,000–2,750 m, Fute to Rira: 5 PH day (1 *Am*): nr. WWF: 1.25 PH (T): 1,890 m, Shawe river: 4 PH night (*Lr, Ps, Xp*, 10s T). 21/6/2009: 3,100 m, Fute: 9 PH day (4 *Bh*, 5 *Am*): 3,100 m, Fute: 5 PH night: c. 1,600 m, Dola Mena to Rira: 3 PH day: 1,900 m, Magano: 1.5 PH day (*Ps, Xp, Pk*): 1,900 m, Magano: 3 PH night (*Xp, Pk, Ps*). 22/6/2009: 3,100 m, Fute: 1 PH day: 1,890 m, Shawe river: 1 PH day: 1,900 m, Magano: 4 PH day (*Xp, Ps, Phs*): 1,900 m, Magano: 2.5 PH night (*Xp, Ps, Pk, Hs*). 25–26/6/2009: c. 4,000 m, nr. Garba Guracha: 10 PH: 26/6/2009: c. 4,000 m, Sanetti Plateau: 2 PH (*Lg* T).

15. CI and FZS (September 2009) Robin Moore (CI), Thadaigh Bagallay (FZS)

6/9/2009: Tella Negesso: 6PH day (1 *Am*): 2,380 Katcha: 6PH dusk (*Phs, Ls*). 7/9/2009: 3,100, nr. Rira: 8PH night: Fute: 7 PH dusk (1 *Am*). 8/9/2009: nr. Dola Mena: 3PH day (*Phs, Aa*).

Appendix 3 Statistical analysis

The approach used to infer time of extinction is based on the Weibull distribution, a two-parameter model. Its origin is in weakest link analysis (Crawley, 2007); its use has traditionally been in engineering industrial risk analysis (for example, the failure of a component). The attraction for an analysis aimed at inferring extinction comes from the result that, provided the sample of sightings data are large enough, it is reasonable to assume that the k most recent sightings come from the same Weibull extreme value distribution, regardless of the parent distribution (Solow, 2005; see also Collen et al., 2010). We implemented the following from Solow (2005). The optimal linear estimate of time of extinction, $\hat{T}_E$ based on the k most recent sightings has the form

$$\hat{T}_E = \sum_{i=1}^{k} w_i t_{n-i+1} \quad (1)$$

The weight vector $w = (w_1, w_2, \ldots, w_k)'$ is given by

$$w = (e'\Lambda^{-1}e)^{-1}\Lambda^{-1}e \quad (2)$$

where e is a vector of k 1s and Λ is the symmetric k-by-k matrix with typical element

$$\Lambda_{ij} = \frac{\Gamma(2\hat{\nu} + i)\Gamma(\hat{\nu} + j)}{\Gamma(\hat{\nu} + i)\Gamma(j)} j \leq i \quad (3)$$

where Γ is the gamma function and

$$\hat{\nu} = \frac{1}{k-1} \sum_{i=1}^{k-2} \log \frac{t_n - t_{n-k+1}}{t_n - t_{i+1}} \quad (4)$$

is an estimate of the shape parameter of the Weibull extreme value distribution, where t_n is the n times a species is sighted during an observation period t.

Last, under the assumption that the species is extinct, the upper bound of an approximate $1 - \alpha$ confidence interval for $\hat{T}_E$ is

$$T_E^u = \frac{t_n - c(\alpha) t_{n-k+1}}{1 - c(\alpha)} \quad (5)$$

where

$$c(\alpha) = \left(\frac{k}{-\log \alpha} \right)^{-\hat{\nu}} \quad (6)$$

We looked at two levels of certainty: 95 and 80%. Variations in the sighting rate reflect variations in both 'sightability', which may be connected to abundance, and sighting effort. The main assumption of the technique is that although sighting effort may vary, it never falls to zero over an annual time step, particularly around the time of extinction (Solow, 2005).