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Original Article

Opportunistically Acquired Evidence is Unsuitable Data to Model Fox (*Vulpes vulpes*) Distribution in Tasmania

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ABSTRACT Despite the absence of direct observation of live foxes in the Tasmanian environment, a recent study concluded that foxes are now widespread on the island and proposed a habitat-specific model incorporating 9 cases of physical evidence presumed to confirm their unique presence. We briefly review the history of fox incursions into Tasmania and then assess the quality of putative physical evidence against a defined evidentiary standard. Overall, 14 of 17 incidents described since 1998 were associated with between 1 and 4 criteria indicative of unreliable data or were not associated with adequately documented physical evidence. Anonymous and anecdotal information was fully or partially relied upon in 10 of 17 cases and of these 5 were widely acknowledged to be hoaxes. We conclude that opportunistically acquired evidence is a poor substitute for data obtained by properly designed and independent wildlife surveys for confirming unique fox incursions and as the basis of ecological models predicting true habitat-specific fox distribution. Species rarity decreases the reliability of wildlife surveys and population models; thus validation of unique incursions in particular requires appropriate rigor in evidentiary standards and data quality. Precautionary management that may be considered in response to uncertain information, or opportunistically collected specimens of doubtful provenance, does not imply that such information should be treated as scientific data. We suggest that an eradication program is justified as a precautionary measure only after rigorous qualitative analysis reveals data capable of rejecting the null hypothesis that the species of interest is absent. © 2014 The Wildlife Society.

KEY WORDS data quality, eradication, fox distribution, invasive species, pest incursion, red fox, Tasmania, wildlife survey.

Island ecosystems are vulnerable to invasive species incursions (Hulme 2009) and those offshore from the Australian mainland are often of high biodiversity value that require addition vigilance and enhanced barrier surveillance (Howald et al. 2007, Raymond et al. 2011). Early detection of invasive species incursions (Kery et al. 2010) is key to the initiation of timely management action (Armstrong and Ball 2005, Darling and Blum 2007) and the overall feasibility of successful eradication (Myers et al. 2000). Worldwide, few biosecurity surveillance systems have been optimized for proactive detection of unique incursions into island ecosystems (Hulme 2009), with most commencing subsequent to an invasive species incursion being unequivocally confirmed (Jarrad et al. 2011). A diversity of surveillance methods are used in order to collect data that aim to define the distribution and abundance of invasive species and to monitor the success of the eradication program (Marsh and Trenham 2008). Rapid initiation of eradication programs immediately subsequent to the detection of alien species (Genovesi 2001) is consistent with the application of the "precautionary principle" (Applegate 2000), which requires a "knowledge condition," or level of proof that a threat exists (Manson 2002), as a trigger for the application of anticipatory measures (Petersen and van der Zwaan 2003). Despite this, comparatively little consideration has been given to what quality of evidence and formal qualitative analysis is required before an incursion can be reliably confirmed. Although assessing the "weight of evidence" to imply that an incursion has occurred is a common form of risk assessment, frequently there is no formal process of data integration, meaning that *ad hoc* "judgements" are made concerning the validity of key data (Weed 2005). Such an approach may lack transparency and have little capacity for the qualification of potential error and uncertainty (Linkov et al. 2009). Importantly, if the absence of an invasive species

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is considered as a null hypothesis, Type I (false positives) as well as Type II (false negatives) errors are 2 of the most significant inferential errors that may affect the quality of data used to affirm the presence or distribution of invasive species (Barrett et al. 2010) and the overall validity of decisions to initiate precautionary eradication attempts. Moreover, the generalizability of habitat-specific ecological models that use these data in an attempt to predict invasive species presence and distribution, as well as directing the allocation of resources for eradication efforts (Sarre et al. 2012), are highly dependent upon the quality of these data (Vaughan and Ormerod 2005).

The European red fox (*Vulpes vulpes*) was established on mainland Australia from multiple intentional introductions after 1845 (Abbott 2011) and currently threatens the conservation status of a range of Australian fauna (Bennett et al. 1989, Dickman 1996, Priddel and Wheeler 1997). In 1998 a single fox was reported to have escaped from a cargo vessel berthed at the Port of Burnie (Tasmania) that originated from the Port of Melbourne (Bryant 2001) that supports an extensive fox population (Marks and Bloomfield 1999). Plaster casts of fox prints and video footage confirmed the presence of this fox, yet because this single incursion occurred outside of the southern hemisphere fox breeding season (Ryan 1976, McIlroy et al. 2001), it did not imply a significant potential for establishment.

In 2001 the Tasmanian National Parks and Wildlife Service reported that 11–19 foxes had been deliberately released into the Tasmanian environment (Dennis 2002, Saunders et al. 2006, Sarre et al. 2007, Marshall 2011). A subsequent Tasmanian Police investigation determined this claim to be entirely anecdotal without supportive physical evidence being produced (Tasmanian Police documents 2002, Supplementary Appendix 1, available online). However, later assessments concluded that sufficient evidence indicated that multiple foxes were present (Emms et al. 2005, Wilkinson 2009) based upon a large number of uncorroborated anecdotal fox sightings together with a series of opportunistically recovered fox carcasses, some of which were quickly determined or suspected to be hoaxes (Saunders et al. 2006). In contrast with the single fox incursion in 1998, only one other instance of putative fox footprints have been located in Tasmania in over a decade and no known video or photographic images exists despite >3,000 anecdotal sightings from members of the public (Anonymous 2012). Furthermore, no foxes have been directly confirmed using common survey techniques such as trapping (Bubela et al. 1998); shot samples (Coman 1988); spotlight surveys (Reynolds and Short 2003, Vine et al. 2009); trail cameras (Kays et al. 2009, Vine et al. 2009); or shown to have taken, or been killed by, a poison fox bait (Marks et al. 2009) or any other control method (Parkes and Anderson 2009).

The targeting of the current fox eradication program (FEP) that began in Tasmania in 2002 (Saunders et al. 2006) using widespread 1080 (fluoroacetic acid) baiting (Parkes and Anderson 2009) was guided by ecological models of fox distribution proposed by Sarre et al. (2012). The model is based upon 2 forms of indirect fox survey data accumulated over more than a decade; 56 mitochondrial DNA (mtDNA) putative fox-positive scats from a pool of 9,940 predator scats collected overall (Berry et al. 2007; Sarre et al. 2007, 2012) and 9 cases of *post mortem* biological specimens and other physical evidence (Sarre et al. 2012). Ecological models that predict the presence or absence of species in various habitats should be aware that data collected must be suited to defining "habitat" used by the species rather than much broader classifications of landscape and vegetation types (Hall et al. 1997). Models should ideally be assessed for their predictive accuracy (Fielding and Bell 1997) by corroborative observations and data independent of the model (Verbyla and Litvaitis 1989). The collection of independent data to test the predictive capacity of a model is the best way to test the model's generalizability (Vaughan and Ormerod 2005) and when such testing has not been achieved, qualitative assessments of the data used in a habitat-specific model appears essential. Accordingly, separate papers are devoted to the existence of Type I error in molecular data used to describe fox distribution in Tasmania based upon the anomalous spatial and temporal distribution and detection patterns of fox mtDNA assigned scats (Marks et al. 2014) and the replication of a species-specific polymerase chain reaction assay found to be associated with false positives (Gonçalves et al. 2014). In this paper, we briefly review the history of fox incursions into Tasmania from the 1840s until the single fox incursion in 1998, and then examine the evidentiary quality of the cases believed to confirm unique fox presence thereafter.

STUDY AREA

The island state of Tasmania (68,401 km^2) is approximately 200 km south of the Australian continental landmass and has been geographically isolated from natural mainland terrestrial fauna for approximately 12,000 years (Gollan 1985) owing to the formation of the geologically recent Bass Strait sea barrier (Davies 1965; Fig. 1). Tasmania remains the largest island refuge for many species threatened by foxes on mainland Australia (Bryant 2001, Saunders et al. 2006). The island has a mountainous center and supports extensive agriculture in the relatively flat grasslands and cleared areas of the Southeast and Midlands. It is extensively forested and dominated by native eucalypt forests (Williams and Potts 1996) and a diverse range of other vegetation communities such as tall and alpine heathlands, large areas of cool temperate rainforests, low-lying lakes, and extensive riparian communities (Jeans 1977).

METHODS

History of Fox Introductions to Tasmanian 1843–1997

We sought references pertaining to the import or sighting of foxes from the 19th century until the year prior to the introduction of a single fox to the Burnie Port in 1998. We then searched scientific, historical, and Australian newspaper databases (Trove: National Library of Australia, Canberra) and microfiche records of the Tasmanian Archives and

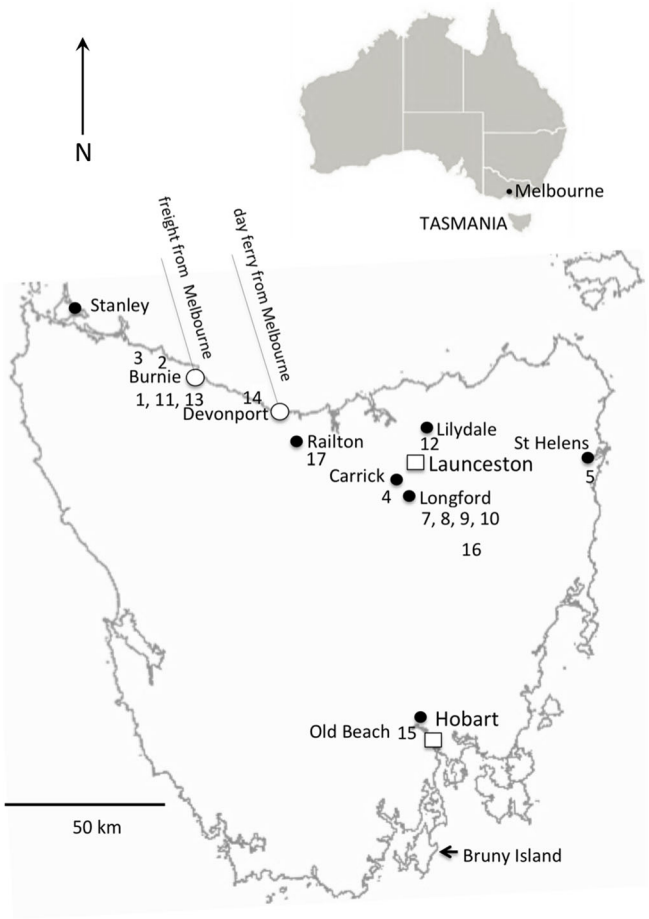

Figure 1. The 68,500-km^2 island state of Tasmania and approximate location of the main fox-associated incidents from 1998 to 2009 (1–17) corresponding to the information in Table 3.

Heritage Office (State Library: Hobart), which included newspaper reports of red fox sightings and claims of physical evidence in the archives of Tasmanian newspaper articles (The Mercury, The Advocate, The Examiner, The Courier, The Colonial Times and The Tasmanian Story).

Quality of Physical Data Indicative of Unique Fox Presence in Tasmania After 1997

We found 17 total reported incidents referred to by the Tasmanian government and Tasmanian Police records between 1998 and 2009 regarding putative evidence of fox incursions and physical evidence believed to be associated with foxes in the Tasmanian landscape since the confirmed incursion of a single fox at the Port of Burnie in 1998. We re-examined each case and assessed their suitability to be considered as valid data confirming unique fox presence against a defined evidentiary standard that rated each instance for credibility by fitting them into 1 of 4 categories and 9 disqualifying criteria (Table 1).

RESULTS

Historical Records of Foxes and Their Introduction to Tasmania 1843–1997

We found 17 fox-associated reports, including 5 reported fox introductions, recorded in Tasmania between 1843 and 1972. In 1846 a reference to the hunting of a fox sourced from Victoria was found along with reports in 1860, 1862, and 1871 of fox importation from the United Kingdom and another report of foxes being released at Stanley in Northwest Tasmania in 1854. In 1882 and 1911 it was reported that a fox was held at Hobart Zoo and in 1912 that one was held in a cage at a Launceston Park. Some claims of large-scale releases of foxes in Tasmania in 1933 were determined to be fallacious and similar claims were repeated in 1949. We found 4 anecdotal reports of one or more putative fox bodies being seen or recovered by shooting or trapping in Tasmania, including the capture and necropsy of a presumed pet fox in Launceston in 1972. Anecdotal accounts of sightings of live or dead foxes by members of the public in the 1980s (Statham and Mooney 1991) had been investigated in the field by Tasmanian government and contract biologists (J. Robinson, Department of Conservation and Environment, personal communication), yet none were corroborated with physical evidence (Table 2).

Table 1. Criteria used to define the credibility rating of physical evidence and fox associated incidents and disqualifying criteria for 17 fox associated incidents recorded between 1998 to 2009 listed in Table 3.

Rating	Evidentiary standard
Credibility rating	
High	At least 2 pieces of corroborating physical evidence from independent sources documented for the same incident with no known prior human interference with the specimen
Medium	A single piece of physical evidence with no known prior human interference with the specimen
Low	A single piece of physical evidence found in circumstances where prior human interference could not be clearly discounted
Unfounded	Physical evidence was found in circumstances where prior human interference was known and/or was associated with one or more disqualifying criteria (a–i).
Disqualifying criteria	
a	Retrospective disclosures that fox-associated activity were, or were highly likely to be, hoaxes
b	Information was provided anonymously and was not independently verifiable
c	Physical evidence that was key to claims had been destroyed, lost, or not documented in a way that permitted independent analysis
d	The informant who presented wildlife exhibits or made claims had been prosecuted for prior wildlife offences
e	Claims were based upon accounts that required unknown or anonymous third party involvement in the movement of the specimen
f	Two or more inconsistent accounts existed for the same incident
g	Laboratory analysis was misreported
h	Estimated time of death in the necropsy report did not support witness claims
i	No physical evidence was presented

Table 2. Events associated with the potential release, sighting, or capture of red foxes in Tasmania from 1843 to 1980s as recorded by the Tasmanian press, historical documents, and other publications.

Year	Location	Summary	Authority
1843	Unknown	A "full grown fox was shot while quail shooting by Mr. McConnell and brought to Hobart Town".	Colonial Times, 2 Jun
1846	Lake Dulverton	Cornwall hounds at Oatlands ran down a "bagged Port Phillipian fox" that was taken in Lake Dulverton.	The Courier, 18 Jul
1854	Stanley	Foxes allegedly released.	Lloyd Robson (1989)
1860	Hobart	One fox brought to Hobart.	The Argus 1860 (Abbott 2011)
1862	Hobart	Two foxes dispatched from Britain.	The Argus 1862 (Abbott 2011)
1864	Oatlands	One fox allegedly released.	Anonymous (2012)
1871	Unknown	John Woodcock Graves (Jnr) is involved with Captain Harmsworth of the "Ethel" in importing "4 fine foxes from England" for hunting.	The Mercury, 23, 26, & 28 Sep
1882	Hobart	One fox held at Hobart Zoo.	Anonymous (2012)
1890	Hobart	Two foxes allegedly released near Hobart.	Anonymous (2012)
1911	Scottsdale	"A fox supposed to have been captured" in a group of 3 young foxes, and 1 successfully transferred to Beaumaris zoo (Hobart); "two others were burnt in a hedge" at Scottsdale.	The Mercury, 6 & 20 Mar
1912	Launceston	A fox imported from Victoria was displayed in a cage at City Park after being brought as cargo on the "Woollami" at Launceston wharf where it escaped and got ashore but was soon re-captured.	Lloyd Robson (1989)
1930	Unknown	The Fauna Board investigated how "two young foxes having been brought to Tasmania … by a showman from New South Wales … (and) had been killed."	The Mercury, 12 Feb 1930
1933	Unknown	The Fauna Board and Tasmanian Police investigated a letter claiming that 3 young foxes had been brought from Victoria, under the guise of sheep-dog pups and released in Tasmania. The article reported that "a prominent pastoralist" had since shot a fox. The Board's investigations claimed the story was "entirely untrue."	The Mercury, 19 Jul
1949	Hobart	Media claim that "many years ago…a pair of foxes were illegally introduced into Tasmania."	The Mercury, 27 Aug & 10 Sep
1970	Interlaken	Fox sighting reported from the Interlaken area by shooter.	The Mercury, 3 Aug
1973	Northern Midlands	Anecdotal claim of 3 dead foxes found in the back of a Land Rover.	The Advocate, 22 Aug
1972	Launceston	Fox reported to be captured in a rabbit trap on a dairy property at Riverside; identified by Department of Agriculture, King Meadows (Launceston: Tasmania).	The Examiner, 29 Jul (Statham and Mooney 1991)
1980s	Tasmania	Approx. one unsubstantiated report of a fox sighted in Tasmania each year.	Statham and Mooney (1991)
1990	Tasmania	Unsubstantiated reports of fox sighted in Tasmania.	Bryant (2001)

Table 3. Summary of the main fox-associated incidents in Tasmania from 1998 to 2009 with rating of credibility (C) based on the criteria in Table 1.

					Disqualifying criteria[b]								
No.	Location	Year	Evidence claimed	C[a]	a	b	c	d	e	f	g	h	i
1	Burnie Port area	1998	Escaped live fox from ship	H[c]									
2	Cooee Saleyards	1999	Fresh fox skin with head attached	U	●	●							
3	Wynyard	2001	Photograph of fox	U	●	●							
4	Carrick	2001	Escaped live fox from shipping container	U									●
5	St Helens	2001	Fox shot	U	●	●							
6	Unknown	2001	Multiple fox imports	U		●			●	●			●
7	Longford	2001	Fox shot	U	●	●				●	●		
8	Longford	2001	Cast of fox foot print	L									
9	Symmons Plains	2001	Fox shot	U			●	●		●			
10	Longford–Symmons	2001	DNA genotype match of fox siblings	U							●		
11	Burnie	2002	Fox scat recovery	M									
12	Lilydale	2002	Dead fox recovered	U	●	●							
13	Burnie CBD	2003	Dead fox recovered	U			●					●	
14	Lillico	2006	Dead juv fox recovered	U		●			●				
15	Old Beach	2006	Fox DNA at chicken kill site	U						●			
16	Glen Esk	2006	Dead fox recovered	U		●			●			●	
17	Railton	2009	Fox skull found stored in shed	U		●			●				

[a] H, high; M, medium; L, low; incidents that were unfounded (U) contained one or more disqualifying criteria.

[b] Disqualifying criteria based on (a) Retrospective disclosures that fox-associated activity were, or were highly likely to be, hoaxes; (b) Information was provided anonymously and were not independently verifiable; (c) Physical evidence that was key to claims had been destroyed, lost, or not documented in a way that permitted independent analysis; (d) The informant who presented wildlife exhibits or made claims had been prosecuted for prior wildlife offences; (e) Claims were based upon accounts that required unknown or anonymous third party involvement in the movement of the specimen; (f) Two or more inconsistent accounts existed for the same incident; (g) Laboratory analysis was misreported and did not support the claim; (h) Estimated time of death in the necropsy report did not support witness claims concerning carcass recovery; (i) no physical evidence presented. (For more complete explanation, see Supplementary Appendix 2).

[c] The video footage was not released for examination but was confirmed to contain footage of a fox (M. Kitchell, Director Department of Primary Industries, Parks, Water and Environment, personal communication).

Strength of Physical Evidence to Determine Unique Fox Presence After 1997

Between 1998 and 2012, we found 17 incidents when putative physical evidence was reported; however, key exhibits had been destroyed, lost, or were unavailable for examination in 2 instances. Overall, 14 of 17 incidents were associated with $\geq$1 disqualifying criteria (range = 1–4 disqualifying criteria). Anonymously provided information was fully or partially relied upon in 10 cases; of these, 5 were widely suspected or acknowledged to be hoaxes by the FEP (Anonymous 2012) and a past review (Saunders et al. 2006; Table 3).

The report of a fox disembarking a ship at the Port of Burnie in 1998 had a high level of credibility because it was associated with the documentation of 3 separate fox plaster print casts (Queen Victoria Museum reference 2011:1:1) containing 5 prints in all (no. 1: Table 3). Another anecdotal report of an incursion involving a live fox reported to have escaped from a shipping container in 2001 was not associated with the presentation of any physical evidence and the original witness of this claimed event was not identified (no. 4: Table 3). Similarly, no physical evidence was documented to support the allegation of multiple fox releases at various sites in Tasmania in the late 1990s. Tasmanian Police documentation (Supplementary Appendix 1) attest to the entirely anecdotal nature of the claims and absence of any physical evidence presented or found (no. 6: Table 3). Two instances of fox-associated evidence deemed to have a medium level of credibility were related to the recovery of a single scat with verified fox hairs found at Burnie in 2002 (no. 11: Table 3) and a plaster cast of a fox print taken at Longford in 2001 (no. 8: Table 3). The latter case was contemporaneous with anonymously provided photographs of hunters with a dead fox taken at the same location (Fig. 2), together with the receipt of a fox skin posted anonymously to a government office. These last 2 incidents were regarded as hoaxes (no. 7: Table 3). Another partially decomposed fox carcass was presented in 2001 and the claimant originally recorded statements attesting to an unfamiliarity with shooting foxes on the Australian mainland. However, this claim was later revised to include an admission of involvement in mainland fox shooting together with a history of wildlife offences in Tasmania (Anonymous 2003, Dean 2011). Claims that the gut contents of this fox contained an endemic Tasmanian rodent could not be independently verified given that the putative exhibit had been discarded or lost and a subsequent independent analysis had detected in its gut only hair from the house mouse (*Mus musculus*) (Queen Victoria Museum F/N 7273 2008:1:8), a common and widespread exotic species in mainland Australia and Tasmania (Strahan 1991; no. 9: Table 3). Three putative road-killed foxes were opportunistically presented; these included the remains of a fox cub anonymously reported from a mainland location (Canberra: Australian Capital Territory) on 23 February 2006 that were originally claimed to have been seen as a road kill in Tasmania on 25 December 2005, resulting in fragments of a fox cub being recovered (Wilkinson 2009; no. 14: Table 3). The estimated time to death of another putative road-killed fox collected close to the Burnie container ferry depot was based upon histology and gross autolytic changes in organs that placed the time of death at 36–48 hours prior to its collection on the main city highway, which did not corroborate its provenance as a road kill at the busy highway location where it was found. Claims attesting to the occurrence of fresh blood at the road-side (Wilkinson 2009) were also inconsistent with necropsy reports that confirmed a much earlier time of death (Animal Health Laboratory, DPIWE, 03/2299; no. 13: Table 3). In the third putative road kill, the estimated time of death also did not accord with the anecdotally reported time of death provided by an anonymous report from a vehicle driver who claimed to have run over and killed the fox during daylight hours (0930 hr). Histological changes in major organs indicated that death could not have occurred that morning as reported, but occurred $\geq$18 hours prior. Pathological evidence also suggested that the body had been run over by a vehicle *post mortem* (Dr. T. Ross, Veterinary Pathologist, Frankston, unpublished report to Tasmanian Government). This specimen was associated with subsequent claims that it had been moved at least twice between distant roadside locations (Wilkinson 2009; no. 16: Table 3). Lastly, a cleaned fox skull recovered from storage in a building could not be linked with evidence of living foxes or a specific collection site in Tasmania's central highlands (no. 17: Table 3).

Figure 2. One of the 2 photographs anonymously posted to newspapers in 2001 of 2 unidentified hunters, with their faces obscured by scarves, holding a dead fox beneath a Tasmanian road sign. This event (no. 7: Table 3) was one of a series of hoaxes that received substantial media coverage as evidence of the presence of a fox population in Tasmania. The photograph was taken at the edge of Woodstock Lagoon, the location of the only case of fox footprints documented in Tasmania (no. 8: Table 3) since the 1998 fox incursion at the Port of Burnie (no. 1: Table 3).

DISCUSSION

Historical Records 1843–1997

Although there is a significant body of historical literature describing foxes being released in Tasmania since the mid-1840s, caution is warranted in its interpretation. The term "fox" was used generally in 19th century English (Haber 1962) and a "fox" used by hunting clubs was sometimes a species other than the red fox (Longrigg 1975, Carr 1976). In some accounts during the mid-1800s, dingoes (*Canis lupus dingo*) were referred to as the "Reynard" and hunted for sport (Roland 1970, Rolls 1984) although the extent of this practice is unclear (Abbott 2011). "Fox" is also a name given to a wide range of mammals that are not necessarily members of the Canidae, such as the "flying fox" (Pteropodidae; Strahan 1981, 1991) and fox squirrel (*Sciurus niger;* Moore 1957). Implicit in the Latin species name of the Tasmanian endemic brush-tail possum (*Trichosurus vulpecula*) is the meaning "little fox," given morphological similarities (Strahan 1981). Consequently, it cannot be reliably known if all historical accounts referring to a "fox" being recovered or seen refer to *V. vulpes* or to another species that may have been provided with a European local name, as was the case with other Tasmanian mammals (such as the common wombat [*Vombatus ursinus*], which was once commonly called a "badger" in Tasmania (Green 1974)). However, the group of foxes reported to be shipped from England to Tasmania in 1860, 1862, and 1871 and the "Port Phillipian fox" (a likely reference to Port Phillip Bay in Victoria) in 1846 correspond with the first records of single red fox releases by sporting shooters on mainland Australia in the mid-1840s (Abbott 2011) that were sourced from the United Kingdom (Rolls 1984) as was a common practice for many British colonies (Abbott 2011).

Overall, the validity of anecdotal red fox sightings and the identification of red fox carcasses cannot be reliably established as they depend upon accurate identification and discrimination from other species that cannot be retrospectively tested. One exception is a fox claimed to have been captured in a rabbit trap in Launceston in 1972 because it was examined by a government laboratory (Bryant 2001, Phillips 2008), where a necropsy revealed pet food in its stomach, leading to the conclusion that it was probably an escaped pet (Statham and Mooney 1991). However, the original provenance of the specimen and the credibility of the initial claim that it was captured in Tasmania remain speculative given that the report concerning its capture was not verified (J. Robinson, personal communication).

Do Archival Records Show That a Fox Population Established in Tasmania Prior to 1998?

Before 1998 no fauna surveys or texts on Tasmanian mammals list the red fox as an exotic species in Tasmania (Rounsevell et al. 1991, Strahan 1991, Wilson et al. 1992, Watts and Hird 1994). Prior to the incursion of a fox in 1998, surveys initiated after putative red fox sightings by members of the public in the 1980s failed to detect physical evidence of foxes (Statham and Mooney 1991). Frequently, the Tasmanian devil (*Sarcophilus harrisii*) was believed to be instrumental in preventing fox establishment, or assisted in maintaining a low abundance of fox populations (Wright 2010) through competition and predation on juvenile foxes (Anonymous 2013). The decline of Tasmanian devil populations due to devil facial tumor disease was thus associated with the high potential for the establishment of the fox in Tasmania (McCallum and Jones 2006, Jones et al. 2007). However, given the complex array of factors that may determine the success of biological invasions (Heger and Trepl 2003), in the absence of supportive empirical data or observation this hypothesis remains speculative.

Although many biological invasions are not adequately documented (Rodriguez-Cabal et al. 2012), it appears the majority fail to establish (Williamson 1997); and it has been suggested that only approximately 10% succeed (Williamson et al. 1986, Williamson and Fitter 1996). On mainland Australia from the 1840s onwards, $\geq$9 releases of foxes for hunting (Abbott 2011) did not appear to establish a population prior to large-scale releases in the 1870s (one close to Melbourne and another near Ballarat (Rolls 1984), the latter of which may not have persisted (Abbott 2011)). Translocated foxes have higher rates of mortality compared with those from a wild population (Andrews et al. 1973), as do other translocated carnivores; this is sometimes due to inadequate husbandry and stress (Jule et al. 2008). Notably, many of the putative fox releases in Tasmania prior to 1997 appear to have been undertaken for the purpose of hunting, most likely after releases of single animals that were pursued by hunters and dog packs (Longrigg 1975, Carr 1976, Rolls 1984), which frequently resulted in the death of the fox (Abbott 2011). Overall, historical records of red fox releases cannot be used to imply or conclude that the establishment of a fox population in Tasmania was inevitable.

Quality of Physical Data After 1997

Although Sarre et al. (2012) did not specify the 9 incidences of physical evidence used in their model, we found 17 total incidents overall between 1998 and 2012 regarding putative evidence of unique fox presence in the Tasmanian environment. Only the 1998 fox incursion was rated as highly credible given the existence of documented physical evidence (prints and video footage). Two other incidents were rated as having either a low or medium level of credibility, but overall, 14 of 17 incidents were associated with at least one criteria indicative of poor data quality or were not associated with the presentation of physical evidence. Some evidence was entirely anecdotal and the source of the claims could not be verified, such as the report of a fox escaping from a shipping container near Carrick and the claim of an intentional large-scale introduction of foxes. Significantly, the Tasmanian FEP relied heavily upon opportunistically acquired evidence presented or reported by members of the public, and none of the cases after 1998 were documented as a result of formal wildlife surveys independent of information or specimens provided by members of the public.

Because species rarity decreases the reliability of any population estimates, greater rigor is required in estimates of small or equivocal populations (McKelvey et al. 2008); requiring high-quality data with a low potential for Type I error. This is especially important when there is a need to define unique incursions or when the presence of a new invasive species remains equivocal over a prolonged period. Wildlife surveys that use "convenience sampling" and *post mortem* specimens taken opportunistically from roads or from third parties are inferior to rigorous probabilistic field surveys because there may be no valid basis for inferences drawn from the distribution of sampled animals and that of the population (Anderson 2001). Empirical survey data of known quality (Engeman 2003) will best provide confidence of fox detection (Kery et al. 2010), as well as permitting rapid and cost-effective eradication efforts (Armstrong and Ball 2005, Darling and Blum 2007). When equivocal physical data or unverifiable anecdotal reports of wildlife species or their sign are used to assess species presence, false positives and the misdirection of conservation resources has previously been documented (McKelvey et al. 2008). False positives were a recognized component of public surveillance data used to define the presence–absence of grey wolves (*Canis lupus*), and misclassifications were expected within such data sets (Miller et al. 2013).

The recovery of the carcass of a recently dead cryptic or rare species of restricted range can nonetheless be a credible indicator that an extant population may exist in some environments (McKelvey et al. 2008); however, the context of such evidence is important. Hoaxing and deception is common in the investigation of speculative cryptic and rare wildlife species (Thomson 1991, Radford 2002, Daegling 2004, Halls et al. 2006, Paxton 2009), and an uncritical precautionary approach that accepts all materials irrespective of their provenance will be incapable of rejecting unreliable data. Importantly, abundant and well-distributed species such as the red fox are frequently harvested and kept as trophies by sporting shooters in much of the Australian mainland (Franklin 1996). Foxes are extremely common in most of Australia and in the mainland state closest to Tasmania (Victoria). For example, 150,822 fox scalps were returned as part of the 2003 Victorian fox bounty trial over a 52-week period by members of the public (Fairbridge and Marks 2005). Archival hunting trophies that have been translocated from locations where they were collected have been reported to confuse biodiversity assessments because of their uncertain origin (Helgen 2007). Hoaxing associated with the attempted eradication of red foxes on the Isle of Man in the United Kingdom also confused efforts to determine their presence and abundance given the translocation of foxes from the mainland some 55 km away (Macdonald and Halliwell 1994, Reynolds and Short 2003), where foxes were also common (Heydon et al. 2000, Webbon et al. 2004); and ongoing hoaxing has been documented recently (J. Reynolds, Game and Wildlife Conservation Trust United Kingdom, personal communication). The existence of transport infrastructure such as car ferries on the Isle of Man (Greig and McQuaid 2005) would conceivably facilitate such practices, as would the ferry services that link Melbourne with Tasmania (Fig. 1). Fox carcasses can be readily translocated from mainland Australia because of the large scale and socially acceptable nature of fox hunting in Australia (Franklin 1996); a former lack of legal and practical impediments for the movement of fox carcasses between Victoria and Tasmania (Saunders et al. 2006); the existence of a daily car ferry from Melbourne (Plowman 2004); and the presence of a large fox population in the urban (Marks and Bloomfield 1999) and rural areas surrounding Melbourne (Marks et al. 2009). At least 5 hoaxes perpetrated in Tasmania using *post mortem* fox specimens strongly suggest that such actions have a clear precedent. Accordingly, the presentation of *post mortem* fox carcasses or other biological materials that are readily accessible from the Australian mainland cannot alone be viewed as evidence of an extant fox population in Tasmania (Sarre et al. 2007, 2012; Parkes and Anderson 2009, 2011) unless the authenticity and provenance of each carcass has been established. This would require a clear corroboration of the claimed time and manner of death with the time and cause of death established via necropsy using pathological and histological assessments (Wobeser 1996).

Although Saunders et al. (2006) contended that the person(s) involved in releasing foxes would have had ample time to destroy physical evidence subsequently, it appears impossible to speculate usefully on what evidence might have once existed. Notably, these authors took what they referred to as a "precautionary" approach concerning anecdotal claims and other equivocal physical evidence because they were pessimistic about their ability to expose "well-planned" hoaxes. Later reviews of the Tasmanian FEP (Parkes and Anderson 2009, Parkes and Anderson 2011) were unequivocal in their conclusions that the same physical evidence supported the presence of a fox population in Tasmania despite the documentation of hoaxing. However, accepting a lower standard of evidence because of precaution pre-empts more rigorous assessments and appropriate standards of wildlife survey data necessary to clarify unique species incursions and distribution that require data of known quality and provenance (Mooney et al. 2005). The use of low-quality data in scientific analysis as part of a precautionary approach contrasts with the normal parsimonious standards of science (Sober 1981, Simon 2001). Precautionary management actions that may be considered in response to opportunistically acquired evidence of uncertain quality should not automatically imply that the same materials or observations are scientific data. The equivocal nature of physical evidence collected in Tasmania after 1998 suggests that such evidence is inappropriate as data used to describe habitat-specific fox distribution, especially because the habitat-specific distribution model that used such cases (Sarre et al. 2012) has yet to be validated by the detection of live foxes.

MANAGEMENT IMPLICATIONS

Management practices and policy decisions concerning invasive species incursions must adopt formal techniques

that account for evidentiary rigor and evidence-based conclusions. *Ad hoc* judgments of evidentiary quality should be replaced by a clear *a priori* evidentiary standard that ensures that putative evidence and data are capable of rejecting the null hypothesis (that an extant species of interest is absent). This principle is especially important if a population has not been unequivocally confirmed by the detection of living specimens and when prior hoaxing and the translocation of *post mortem* specimens from a nearby population where the species of interest is abundant are known to have occurred. Because opportunistically acquired physical evidence alone is inadequate to confirm an invasive species incursion, subsequent field investigations should be based upon properly designed and independent wildlife survey methods seeking empirical data of adequate quality. An eradication program is justified as a precautionary measure only after rigorous qualitative analysis reveals data capable of rejecting the null hypothesis.

Quantitative listings of opportunistically acquired physical specimens should be avoided as a "weight of evidence" approach to risk analysis, given that no single example might be reliably associated with the landscape or even be presumed to be the true habitat of the animal in which they were presented. The quality of such evidence cannot be tested using uncorroborated, anonymous, or anecdotal testimony. Before the inclusion of such records in habitat-specific models is considered, they must be corroborated with empirical data and/or the predictive value and generalizability of the model should be demonstrated independently. When this has not been achieved, the value of quantitative habitat models should be reassessed because they may overstate risk, misdirect resources, and provide a misleading indication of the presence and distribution of an invasive species.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article at the publisher's web-site.

APPENDIX 1. Tasmanian Police documents concerning the investigation of the alleged conspiracy to import foxes to Tasmania in 2001.

APPENDIX 2. Significant fox-associated incidents in Tasmania since May 1998 involving claimed recovery of physical exhibits with a credibility rating (HIGH, MEDIUM, LOW and UNFOUNDED).

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