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Synthesis

A roadmap to meaningful dingo conservation

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Abstract

Many top-predators are declining and/or threatened. For these reasons, conservation efforts are a management priority for many species, and structured management processes are developed to facilitate their conservation. However, this is not presently the case for the dingo, which is threatened by introgression of genetic material from other and more modern dog breeds. There is strong support for dingo conservation from some sectors, but this support lacks the direction of a formal threat abatement plan. Dingo conservation is actively opposed by other sectors. Here, we evaluate the conservation status of Australian dingoes in accordance with the Australian Government's Threatened Species Scientific Committee Guidelines for assessing the conservation status of native species according to the *Environment Protection and Biodiversity Conservation Act 1999*, and also the *Environment Protection and Biodiversity Conservation Regulations 2000*. We also use the International Union for the Conservation of Nature (IUCN) species translocation guidelines to assess the utility of translocation or reintroduction as a suitable conservation action for dingoes. We further describe five socio-ecological facts about dingoes influencing their conservation status and management. We show that dingoes do not meet the criteria for listing under current threatened species legislation in any Australian jurisdiction. We also show that translocation or reintroduction is not a suitable or appropriate conservation action for dingoes on the Australian mainland at this time, nor will ever be, so long as interbreeding between modern and ancient dogs continues and dingoes continue to naturally recolonise areas where they are currently rare or absent. The most important barriers to dingo conservation are (1) continued and inevitable intermixing of modern and dingo genes, (2) futile efforts from some sectors to have dingoes redefined as a distinct species, and (3) data indicating progressive numerical and range declines in pure dingoes. Despite these challenges, we show that internationally-agreed CITES regulations, livestock breed standards, and pet breed standards each already support existing principles to conserve genetic diversity of ancient breeds (such as dingoes) against the threat of hybridisation. In

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accordance with these international standards, we propose a set of criteria for categorising the free-roaming dogs of Australia into distinguishable groups, and we outline a roadmap to meaningful dingo conservation. We conclude that conservation of dingoes in Australia is warranted, possible and conceptually quick and easy to implement consistent with existing legislation and guidelines. However, this will require acceptance of dingoes as a uniquely Australian ancient dog breed largely free from modern dog breed genes, followed by implementation of strategies to mitigate the threat of continued interbreeding with modern dogs.

Introduction

Top predators are increasingly being recognised for their influential ecological roles at the same time that the populations of many are in decline (Estes et al. 2013, Ripple et al. 2014). In response, great efforts are underway to conserve and restore many top predator species from a variety of carnivore families. In many cases, these efforts have required broad changes in policy, practice, perceptions, attitudes and behaviours towards predators, as modern human societies learn to coexist with predators rather than trying to remove, exclude or eliminate them (Trouwborst 2010, Carter and Linnell 2016, Chapron and López-Bao 2016). Many regions or countries have legal instruments that serve to identify and protect threatened species, such as the European Union's *Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora* (or *Habitats Directive*), the *Endangered Species Act* in the United States, or the *Environmental Protection and Biodiversity Conservation Act* in Australia. The International Union for the Conservation of Nature (IUCN) also assists in this regard. Such instruments have formally identified or 'listed' many top predators as threatened species, facilitating their conservation and recovery. However, the prioritisation and implementation of predator conservation actions varies widely, and further direction is needed to achieve meaningful predator conservation in many cases (Linnell et al. 2008, Trouwborst 2014).

Subsequent to reported environmental gains following the reintroduction of grey wolves *Canis lupus* to Yellowstone National Park in 1995 (summarised by Ripple and Beschta 2012), ecologists around the world have also greatly increased advocacy for reintroduction or translocation as a means to achieve conservation of top predators and ecosystems (Ritchie et al. 2012, Newsome et al. 2015). Reintroduction of listed threatened species is now a common approach to threatened species recovery around the world, including top predators. However, predator reintroductions are often accompanied by controversy and conflict, which can jeopardise their recovery (Schoenecker and Shaw 1997, IUCN/SSC 2013). Arguments supporting predator reintroduction include: their rarity or absence from a given area, their important ecological roles, their intrinsic value, their unique taxonomic identity, or the 'unjustified', 'unethical' or 'inhumane' practice of (lethally or non-lethally) controlling predators (e.g. Wallach 2014, Newsome et al. 2015, Johnson and Wallach 2016, Carter 2017). Arguments against predator reintroduction primarily centre on the need to protect threatened fauna, livestock, and game, or in some cases, humans from predator attack or predation (Schoenecker and Shaw 1997, Wilson 2004, Mech 2017).

Social contention around predator conservation occurs in many places, including Australia, where the reintroduction of dingoes *Canis familiaris* continues to be both advocated and resisted for all the reasons described above. Dingoes are an iconic Australian animal, a valuable component of many Australian ecosystems, and worthy of conservation for many reasons (Corbett 2001b, Purcell 2010). Dingoes are threatened by hybridisation and are in decline, and calls for their conservation and reintroduction are common (discussed below). But Fleming et al. (2012a) asked: 'do dingoes even need to be reintroduced?' or 'is dingo reintroduction the right answer?' Given the general importance of conserving predators and the emphasis on reintroductions as a means to achieve their conservation, here we:

1. Define the different categories of free-roaming dogs present in Australia;
2. Assess the conservation status of dingoes under Australian law;
3. Assess the suitability of dingo reintroduction according to IUCN guidelines;
4. Describe five socio-ecological factors strongly influencing the conservation status and management of dingoes; and
5. Outline an achievable pathway towards meaningful dingo conservation consistent with these categories, laws, guidelines and factors.

Definitions used in this paper

Despite over 200 years of changing views about the taxonomy of the dingo (Jackson and Groves 2015), evidence from multiple sources now demonstrate that dingoes are an ancient breed of dog, *Canis familiaris* (reviewed in Jackson et al. 2017). That is, dingoes were derived from grey wolves. Though the phylogeny of the dingo (and canids in general) is becoming increasingly clearer on this point, the differing opinions on dingo nomenclature has generated ongoing confusion about their distribution, abundance and conservation status. Corbett (2001a, 2001b, 2004) reports that dingoes have an international distribution and that their numbers are declining, whereas Allen and West (2013) report that dingoes have an Australian distribution and that their numbers and distribution is increasing. The genetic study of Stephens et al. (2015) shows that dingoes of pure ancient lineage are present across only part of Australia, and that their numbers and distribution are declining, while the proportion and range of crossbreds between ancient dingoes and modern dogs is increasing (Figure 1). These discrepancies and differences of opinion arise because of the different taxonomic definitions for dingoes adopted in these studies. We refer to the dingo and all other dogs as *Canis familiaris* (Jackson et al. 2017) and, for clarity, adopt the following definitions in this paper (summarised in Figure 1):

International dog (I-dog): Dogs from all countries, including all ancient and modern breeds, derived by passive and/or active domestication from grey wolves or a common ancestor at one or more locations.

Australian dog (A-dog): A geographic subset of I-dogs occurring in Australia only, including all ancient breeds (i.e. Australian dingoes, below) and modern breeds.

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Wild-living or free-roaming dogs (WL-dog): The wild-living or free-roaming portion of A-dogs, including all ancient breeds, modern breeds and crossbreds between them (often referred to locally as 'hybrids' or 'wild dogs').

Australian dingo (A-dingo): One ancient breed of I-dog, geographically isolated and restricted to Australia for about 5,000 years; does not contain genetic material from modern dog breeds.

International dingo (I-dingo): Dingo-like breeds of I-dog derived anciently from grey wolves by domestication, and may presently be found in south-east Asia, Indonesia or New Guinea; does not contain genetic material from modern dog breeds.

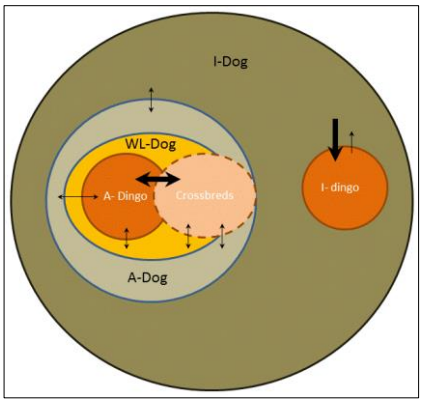

Figure 1. A Venn diagram displaying the conceptual relationships between each group of *Canis familiaris* as defined in the text. Arrows represent the relative strength and direction of gene transmission affecting hybridisation or interbreeding between groups.

Some have also suggested that the definition of Australian dingoes be even further refined or split to distinguish between different geographic populations (i.e. alpine dingoes, desert dingoes, tropical dingoes, forest dingoes etc.; see Corbett 2001b). Besides a general pattern suggesting the presence of at least two types of dingoes in Australia (Cairns and Wilton 2016), there is presently no taxonomic basis for further fine-scale geographic definitions (Jackson and Groves 2015, Jackson et al. 2017). Thus, here, we do not consider or assess sub-populations below the Australian dingo level.

Australian policy and legislative instruments for conserving fauna

Australia has developed robust policy for assessing the conservation status and threats to native fauna, which is contained in the *Environment Protection and Biodiversity Conservation Act 1999* (hereafter 'EPBC Act'). To guide the process for listing a threatened taxa, the Australian Government has prepared the 'Threatened Species Scientific Committee Guidelines for assessing the conservation status of native species according to the *Environment Protection and Biodiversity Conservation Act 1999* and *Environment Protection and Biodiversity Conservation Regulations 2000*', which forms part of the EPBC Act. These guidelines comprise of Parts A–G, which include guidance on things like commercial fish harvest or identifying species extinct in the wild etc., which have no relevance to Australian dingoes. However, three parts are relevant to Australian dingoes (Part A, Part B, and Part D).

Part A of these guidelines provide the criteria for listing species in the Critically Endangered, Endangered, or Vulnerable categories under the EPBC Act, which primarily consider a species' distribution, abundance and population trends (Table 1). Using Part A of these guidelines, a species' conservation status is categorised with subjective terms such as 'severe reduction in numbers', 'very low abundance', or 'restricted distribution', for example. To inform this categorisation process, Part B of the guidelines provide clear guidance thresholds – informed by and adapted from the IUCN Red List Categories and Criteria – that may be used to judge the subjective terms used in the criteria identified in Part A. For example, a species must have undergone at least an 80% reduction in numbers over a ten year period to qualify for a 'very severe reduction in numbers' (Critically Endangered) or at least a 30% reduction in numbers over three generations to qualify for a 'substantial reduction' (Vulnerable). Regarding geographic distribution, the extent of occurrence of a species must be <20,000km^2 to qualify as 'limited' (Vulnerable) or <100km^2 to qualify as 'very restricted' (Critically Endangered). Regarding population size, the estimated number of mature individuals needs to be <10,000 (and declining) before a species can be considered 'limited' (Vulnerable), or <250 (and declining) for a species to be considered 'very low' (Critically Endangered). Regarding their probability of extinction, quantitative analyses would need to show a ≥10% chance of a species becoming extinct in the wild in the next 100 years to be considered Vulnerable, or a ≥50% chance of becoming extinct in the next ten years to be considered Critically Endangered. Part D provides definitions and instructions for calculating the extent of occurrence (EOO) and area of occupancy (AOO) of a species. Within Part D, EOO "is defined as the area contained within the shortest continuous imaginary boundary which can be drawn to encompass all the known, inferred or projected sites of present occurrence of a taxon, excluding cases of vagrancy" and AOO "is defined as the area within its 'extent of occurrence' which is occupied by a taxon, excluding cases of vagrancy". To be eligible for consideration and then formally listed as threatened under the EPBC Act, an organism needs to (1) be native to Australia, (2) be an unequivocally defined species or sub-species, and (3) meet at least one of the criteria for listing.

Conservation status of Australian dingoes

Consideration of the EPBC Act guidelines (Table 1) show that dogs or dingoes of any kind do not meet the criteria for listing as a threatened species (Table 2), which is why Australian dingoes are not already listed as threatened. Despite their exotic origin, Australian dingoes are considered to be native under Australian law because they were present before European arrival (Fleming et al. 2012a, Woinarski et al. 2012). However, Australian dingoes are not an unequivocally defined species or sub-species, and cannot be considered such under current and internationally accepted guidelines for taxonomic classification of organisms (Jackson and Groves 2015, Jackson et al. 2017); this means Australian dingoes and wild-living dogs are ineligible for consideration for listing under the EPBC Act. Regardless, the number of mature individuals is presently greater than 10,000, their AOO is greater than 2,000km^2, their EOO is greater than 20,000km^2, and no quantitative analyses has shown a greater than 10% chance that they are likely to become extinct in the next 100 years. This means that Australian dingoes do not meet any of the EPBC Act criteria for listing. The only criteria Australian dingoes come close to meeting regards a reduction in population size, and to qualify for listing as even a Vulnerable species under this criteria, it must be shown that their numbers have declined by at least 30% over three generations (Table 1), which has not yet been done (Woinarski et al. 2012). The IUCN considers international dingoes to have already met this criteria, and therefore considers them to be Vulnerable at an international scale (Corbett 2008). However, Woinarski et al. (2012) consider international dingoes to be only 'approaching vulnerable', acknowledging their contested taxonomic description and its influence on eligibility requirements (compare Crowther et al. 2014, Dinets 2015, Jackson et al. 2017, for example). A regional IUCN assessment for Australian dingoes has not yet been undertaken.

Table 1. Criteria for listing threatened species under Australian law (from Part A of the 'Threatened Species Scientific Committee Guidelines for assessing the conservation status of native species according to the *Environment Protection and Biodiversity Conservation Act 1999* and *Environment Protection and Biodiversity Conservation Regulations 2000*).

#	Criterion	Critically endangered	Endangered	Vulnerable
1	It has undergone, is suspected to have undergone or is likely to undergo in the immediate future:	A very severe reduction in numbers	A severe reduction in numbers	A substantial reduction in numbers
2	Its geographic distribution is precarious for the survival of the species and is:	Very restricted	Restricted	Limited
3	The estimated total number of mature individuals is:	Very low	Low	Limited
	and either of (a) or (b) is true:			
	(a) evidence suggests that the number will continue to decline at:	A very high rate	A high rate	A substantial rate
	(b) the number is likely to continue to decline and its geographic distribution is:	Precarious for its survival	Precarious for its survival	Precarious for its survival
4	The estimated total number of mature individuals is:	Extremely low	Very low	Low
5	The probability of its extinction in the wild is at least:	50% in the immediate future	20% in the near future	10% in the medium-term future

Table 2. An assessment of the conservation status of I-dingoes, A-dingoes and WL-dogs (see text for definitions) according to the criteria for listing threatened species under Australian environmental law (see Table 1 for details), showing the influence of taxonomic definition on dingoes' conservation status.

#	Criterion	I-dingo	A-dingo	WL-dog
1	It has undergone, is suspected to have undergone or is likely to undergo in the immediate future:	A substantial reduction in numbers	A substantial reduction in numbers	An increase in numbers
2	Its geographic distribution is precarious for the survival of the species and is:	Declining	Declining	Increasing
3	The estimated total number of mature individuals is:	High	Limited	High
	and either of (a) or (b) is true:			
	(a) evidence suggests that the number will continue to decline at:	A substantial rate	A substantial rate	Increasing at a substantial rate
	(b) the number is likely to continue to decline and its geographic distribution is:	Precarious for its survival	Precarious for its survival	Sufficient for its survival
4	The estimated total number of mature individuals is:	High	Limited	High
5	The probability of its extinction in the wild is at least:	≥10% in the medium-term future	≥20% in the near future	<0%

Ignoring their ineligibility, adopting the Australian dingo definition does bring them closest towards their listing as Vulnerable at a national level (Table 2). Though Australian dingoes have had a ~60% ('severe') reduction in their distribution since Europeans arrived in Australia over 200 years ago (Corbett 2001b, Allen and West 2013, Stephens et al. 2015), prompting the listing of Australian dingoes as threatened at a State level in some jurisdictions (e.g. Clarke 2007, Anon 2013), no one has yet measured a 30% reduction of Australian dingoes over three generations. Woinarski et al. (2012) assumed a generation time of five years. Behrendorff and Allen (2016) demonstrated that the wild-living dogs on Fraser Island can live and breed

for up to 13 years. Baseline data on the distribution of Australian dingoes and wild-living dogs was provided by Stephens and colleagues (2015), so if a future reproduction of that study in the next 10–20 years shows that dingoes have declined by 20–30%, then Australian dingoes should qualify for listing as Vulnerable under criteria A2e, A3e or A4e at that time (provided they can first overcome their ineligibility under the EPBC Act). Such a future study may find that hybridisation moves slower than the rate required to list them under these criteria, and if this is the case, then we must wait until Australian dingoes meet some other criteria before they can be listed, which is likely to be several decades away.

Australian dingoes are still present across at least 2.3 million km^2 (Figure 2; see also (Stephens et al. 2015)), so they are still a long way from reaching the 20,000 km^2 threshold when their geographic distribution becomes categorised as 'limited' (Vulnerable). The abundance of Australian dingoes is probably now approaching the 10,000 threshold when they can become categorised as 'limited' (Vulnerable) under criteria C1, though this also requires showing a reduction of at least 10% in three generations (Table 1). National-level abundance data for Australian dingoes is not available, but if home range sizes are 1,000km^2 (Newsome et al. 2013) and there are four sexually mature individuals per pack across their extended range, then there is about 9,200 mature Australian dingoes in Australia. Home ranges are typically far less than half this size (reviewed in Fleming et al. 2012b) and more than four mature individuals can often be present in a pack (Thomson 1992, Allen 2010, Allen et al. 2015b), suggesting that the number of mature Australian dingoes is more than double this number. Though unclear, we estimate that there may be 10,000–20,000 mature Australian dingoes currently present across their 2.3 million km^2 distribution. Wild-living dogs (including animals with 'mostly dingo' genetics) do not meet or come close to any criteria for listing as a threatened species under the EPBC Act. They are currently distributed across ~6.5 million km^2 (85% of Australia, and this range is naturally increasing; (Allen and West 2013). Like Australian dingoes, abundance data for wild-living dogs is not available, but according to the same rationale used for Australian dingoes (above), we estimate that there may be 26,000–52,000 mature wild-living dogs present in Australia, and this number will increase as their range and intermixing continues to increase.

One additional way of defining dingoes, not assessed here, is a definition based solely on phenotype. Corbett (2001b) reports that approximately 74% of dingoes in Australia are yellow, red or tan with four white socks and a white tail tip (Figure 3). Laypeople commonly define dingoes this way, and (wrongly) consider all other colour variants to be wild-living dogs of little conservation value (Elledge et al. 2006, Elledge et al. 2008). The proportions of different coat colours in the national dingo population may well be changing in corollary with hybridisation, but in the absence of adequate data, defining dingoes by phenotype in this way means that much more data on the frequency and variability of coat colours is required before such dingoes can be listed as a threatened species. However, one clear advantage of defining dingoes by their colour is that their management and conservation would become relatively straightforward to implement. 'Yellow dingoes with five white points' could be easily identified visually *in situ* and therefore conserved, and all other colour variants could be easily identified and removed from the population (Elledge et al. 2008); discussed also for wolf-dog hybrids, in (Linnell et al. 2008). The decision to 'kill or conserve' would be made easy in this way, but this approach is likely to present problems where a given individual thought to be worthy of conservation (because of its location or functional role) does not 'look like a dingo'. This is the case for most wild-living dogs in south-eastern Australia (Jones 2009, Radford et al. 2012), which would all require removal if dingoes were defined by their colour in some conservation strategy. Other phenotypes might also be considered valuable, but defining dingoes by multiple phenotypes only negates phenotype as a defining characteristic and suggests that adopting a wild-living dog definition is more appropriate. Furthermore, if dingoes were given a broader definition inclusive of all dogs, then they would be more widely distributed than humans (Gompper 2014) and likely to never be of conservation concern or meet any criteria for listing as a threatened species.

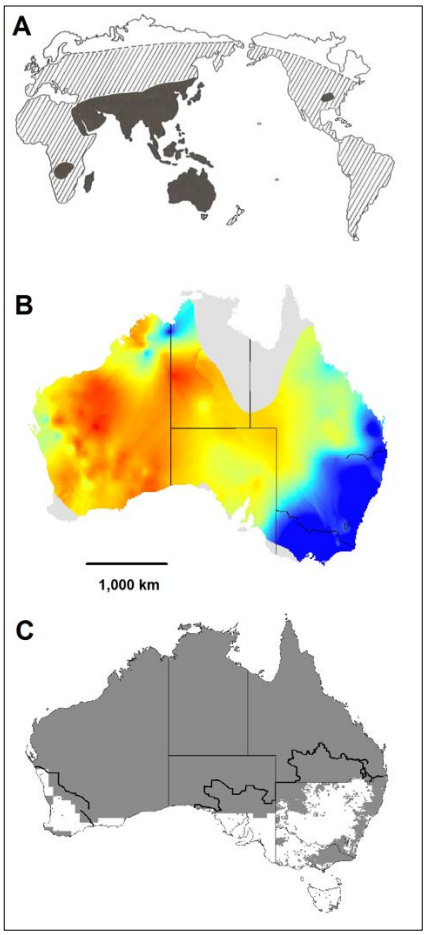

Figure 2. The distributions of dingoes, as reported by: (A) Corbett (2001b), where shaded areas = current distribution of I-dingoes and hatched areas = former distribution of I-dingoes; (B) Stephens et al. (2015), where modelled purity grades from red areas that are occupied by dingoes with higher proportions of genetically purity (i.e. A-dingoes) to blue areas that are occupied by dingoes with low proportions of genetic purity (i.e. WL-dogs); and (C) Allen and West (2013), where shaded areas are known to be presently occupied by WL-dogs.

Figure 3. A 'yellow' or 'tan' coloured dingo with five 'white points', often considered by laypeople to represent a pure dingo (or A-dingo), with other colour variants wrongly considered to be WL-dogs or crossbreds (Photo credit: Lee Allen).

In summary, Australian dingoes are considered to be native, but international dingoes, Australian dingoes and wild-living dogs are ineligible for consideration as a threatened species in Australia because they are derived from a domesticate and are not a distinct taxon. Even if they did become eligible, each presently fail to meet any EPBC Act criteria for listing anyway. Australian dingoes may become equivalent to Vulnerable if empirical work can show that their numbers are declining at a rate of at least 30% over three generations. International dogs, and Australian dogs, with or without Australian dingo genes, also do not meet the criteria for listing and are unlikely to ever do so.

The case for reintroduction or translocation of dingoes

Dingoes have been nominated for listing under the EPBC Act at least three times in recent years, but have been rejected each time because of insufficient population data (Kennedy 2016). This may be due to confusion and/or disagreement about their taxonomic definition (which determines their eligibility for consideration) and the subsequent misrepresentations and uncertainty about their distribution, abundance and population trends. Should they someday be listed as a threatened species in Australia, the taxonomic definition applied will have major implications for the subsequent management actions required to ensure their recovery, including reintroduction, which has been proposed (Wallach 2014, Newsome et al. 2015). But whether or not dingoes even need to be or should be reintroduced has not been assessed. Discourses around proposed predator reintroductions tend to highlight the potential positive outcomes and downplay the negatives (Arts et al. 2012, Allen and West 2015). Not all predator reintroductions are successful, and they often yield unexpected and negative consequences (Hayward et al. 2007, IUCN SSC 2013). Reintroductions need to be considered very carefully.

The IUCN principles and guidelines for assessing the suitability of reintroductions as a conservation action (IUCN SSC 2013) are as follows:

1. A conservation translocation has intended conservation benefit, but it also carries risks to ecological, social and economic interests;

2. There should generally be strong evidence that the threat(s) that caused any previous extinction have been correctly identified and removed or sufficiently reduced;

3. Assessment of any translocation proposal should include identification of potential benefits and potential negative impacts, covering ecological, social and economic aspects. This will be simpler for a reinforcement or reintroduction within indigenous range compared to any translocation outside indigenous range;

4. Global evidence shows that introductions of species outside their indigenous range can frequently cause extreme, negative impacts that can be ecological, social or economic, are often difficult to foresee, and can become evident only long after the introduction;

5. Conservation translocations outside indigenous range may, therefore, bring potentially high risks that are often difficult or impossible to predict with accuracy;

6. Hence, although risk analysis around a translocation should be proportional to the presumed risks, justifying a conservation introduction requires an especially high level of confidence over the organisms' performance after release, including over the long-term, with reassurance on its acceptability from the perspective of the release area's ecology, and the social and economic interests of its human communities;

7. In any decision on whether to translocate or not, the absolute level of risk must be balanced against the scale of expected benefits; and

8. Where a high degree of uncertainty remains or it is not possible to assess reliably that a conservation introduction presents low risks, it should not proceed, and alternative conservation solutions should be sought.

Proposed reintroductions of dingoes do have intended conservation benefit, but they also carry acknowledged ecological, social and economic risks (Newsome et al. 2015). These primarily relate to dingo predation of threatened fauna (Allen and Fleming 2012), livestock (particularly sheep *Ovis aries* and goats *Capra hircus*; (Allen and West 2013, 2015), and the social discord resulting from community management of dingo problems (Thompson et al. 2013). If dingoes were defined as Australian dingoes, then about 60% of Australia could theoretically receive them. But the threatening process causing international dingo and Australian dingo decline within this area is hybridisation with wild-living dogs and Australian dogs, which has not abated nor diminished and has arguably increased given the continued introgression of Australian dog genetics and expansion of wild-living dogs across the continent (e.g. Corbett 2001a; Clarke 2007; Stephens *et al.* 2015). If dingoes were defined as wild-living dogs, then about 15% of Australia could theoretically receive them, but wild-living dogs are not of conservation concern (Table 2), and no threats to wild-living dog conservation have been identified (see below).

A triple bottom-line assessment of potential benefits and negative impacts of reintroduction proposals have not been undertaken for either international dingoes, Australian dingoes or wild-living dogs, but their predation risks to extant threatened fauna have been formally assessed (dingoes represent a very high risk to extant threatened fauna; (Coutts-Smith et al. 2007, Allen and Fleming 2012, Doherty et al. 2017)). The expected performance of reintroduced dingoes in the areas where they might be reintroduced is also unclear (Fleming et al. 2012a, Ritchie et al. 2012, Baker et al. 2017). Though their impacts might be ecologically acceptable in isolated areas (e.g. some small national parks or reserves), dingoes (of any sort) are unlikely to be socially and economically acceptable in these areas (Thompson et al. 2013), or ecologically acceptable or suitable outside of reserves. Dingo reintroduction will produce little (if any) benefit for the conservation status of Australian dingoes, so the predicted benefits have been articulated to revolve around indirect benefits to other species (Letnic 2014, Wallach 2014, Newsome et al. 2015). These putative benefits must be balanced against the certain and large negative economic and social impacts to rural communities (IUCN SSC 2013, Thompson et al. 2013, Wicks et al. 2014).

Given that a high degree of uncertainty remains about the need for or utility of Australian dingo reintroduction, and the likelihood that such a conservation introduction does not present low risks, the IUCN guidelines for deciding when translocation is an acceptable option indicate that proposed Australian dingo reintroductions 'should not proceed, and alternative conservation solutions should be sought', regardless of whether dingoes are defined as international dingoes, Australian dingoes or wild-living dogs.

Socio-ecological facts influencing dingo conservation status and management

The challenges faced by proposed conservation actions for dingoes are largely a result of misunderstandings and confusion about some fundamental socio-ecological facts about their ecology and management. These facts need to be understood before sensible consideration of dingo conservation proposals can be achieved, and include:

1. Wild-living dogs occupy approximately 85% of the former range of Australian dingoes, and are already increasing and expanding without assistance in the remaining 15% despite attempts to keep them out (Allen and West 2013, Fleming et al. 2014);

2. Dingo reintroduction is presently illegal in the places of Australia where Australian dingoes are absent and also most places where they are present (e.g. DEEDI 2011, DEPI 2013);

3. Dingo reintroduction is opposed by many people who live in the places where Australian dingoes and wild-living dogs are rare or absent (e.g. small livestock producers and their communities);

4. Australian dingo and wild-living dog populations persist and usually still maintain carrying capacity under contemporary lethal control efforts (e.g. Allen et al. 2014, Allen et al. 2015b); and

5. There is no consensus on the ecological roles of dingoes (of any description) or the ecological consequences of lethal dingo control, and evidence for both is equivocal and/or debated (e.g. Allen 2011, Hayward and Marlow 2014, Newsome et al. 2015).

Understanding these facts is important for several reasons. For example, the presence of wild-living dogs with varied frequencies of dingo genes across 85% of mainland Australia means that *in situ* Australian dingo reintroductions into this area are destined to fail quickly given the continued presence of the threatening process of genetic introgression (compromising IUCN Guideline 2, above). Translocating Australian dingoes into an area occupied or becoming occupied by wild-living dogs and will only result in conversion of Australian dingoes into wild-living dogs. Some believe that the presence of stable packs of Australian dingoes would repel introgression from wild-living dogs (Wallach et al. 2009), but this cannot be achieved and has never been observed in the great many places of central and western Australia where populations of Australian dingoes (unaffected by Europeans) continue to be converted into Australian dogs (Corbett 2008, Stephens et al. 2015). It would also be folly to propose that wild-living dogs be reintroduced to places where they already exist, or places where they are already recovering without human intervention. Knowledge of Fact 1 alone implies that there is simply no case whatsoever for dingo reintroduction at present, regardless of the taxonomic definition adopted. This is not to say that Australian dingoes or wild-living dogs are not worth conserving or that attitudes towards them need not be improved, but rather that reintroduction or translocation is not needed to advance dingo conservation aspirations. Moreover, when seeking to strike a balance between conservation and control objectives, allowing tens of thousands of individuals to persist in 85% of their former range while resisting their establishment in only the remaining 15% of their range (where sheep and goats are produced) could be considered an outstanding conservation outcome in light of recovery goals for similar species (e.g. Bangs and Smith 2008). Ecological changes associated with grey wolf reintroduction into Yellowstone National Park in North America have prompted calls to reintroduce dingoes into national parks within the area already occupied by wild-living dogs in Australia (Newsome et al. 2015). But the Australian dingo situation is vastly different from the North American grey wolf situation (Allen 2012, Morgan et al. 2017); there are about 5,500 wolves occupying 15% of their former range (Mech 2017, Vucetich et al. 2017), yet there are tens of thousands of dingoes occupying at least 85% of their former range (Fact 1).

Some States allow the keeping of dingoes as a pet (under permit), but State laws across most of Australia typically preclude the transport, sale or release of dingoes, under any definition (Fact 2; DEEDI 2011, DEPI 2013, Anon 2014), and conservationists have been prosecuted for the illegal sale and transportation of Australian dingoes before (DSEWPC 2013). Thus even if an agreed definition was reached and Australian dingoes were somehow listed as a threatened species, State laws would first need to be altered before their reintroduction could legally occur. Sufficient support for altering the law in this way is highly unlikely to occur given Fact 3 and the value of livestock agriculture to the rural economy. Community attitudes towards Australian dingo reintroduction have not been formally assessed, although public responses to reintroduction proposals are typically met with extreme opposition by those who will be required to live with them (e.g. https://natureoutwest.wordpress.com/2016/05/24/proposal-to-introduce-fingoes-into-eynesbury-forest/). Should attitudes towards Australian dingo reintroduction be formally assessed, we anticipate that the majority of those who will need to live with them (i.e. rural communities) will oppose it, whereas the majority of those who will not have to live with them (i.e. urban communities) will support it, as has been found for wolves (e.g. Wilson 2004, Smith et al. 2014, Dressel et al. 2015, Shi et al. 2015, Mech 2017). Before Australian dingo reintroduction is seriously considered, any such proposals will need to be socially and economically acceptable to the communities where they are proposed to be reintroduced (IUCN Guideline 6, above). Transient wild-living dogs already occasionally appear in places far from the edge of their extended range, and when this occurs, communities typically rally together to find and destroy the animal. Intentionally reintroducing Australian dingoes into such 'unacceptable' conditions will undoubtedly cause intense social conflict and risk the failure of the reintroduction exercise. If Australian dingoes are ever reintroduced, then we should want this reintroduction to have the best chance of success.

Beliefs that lethal control threatens the persistence of Australian dingoes and wild-living dogs continue (e.g. Kennedy 2016, Carter 2017) despite a large and increasing body of robust evidence that contemporary control practices do not threaten their persistence at all (Fact 4, and also Fact 1; Allen et al. 2014, Allen et al. 2015b). Wild-living dogs are abundant and subject to lethal control across about half of Australia (data available in Allen et al. 2015a), but there is no evidence that lethal control is inconsistent with wild-living dog conservation given their widespread distribution, high numbers, and continued expansion across the continent despite their control (Allen and West 2013). Woinarski et al. (2012) identify lethal control as a 'minor' threat to Australian dingoes because it is considered to be 'ineffective' at reducing their populations. Contemporary wild-living dog control is characterised by 'the spatiotemporally sporadic application of relative minor amounts of poison baits, supplemented with localised trapping and shooting' (*sensu* Allen et al. 2014). In almost all cases where this approach is used, wild-living dogs persist and their populations fluctuate independent of lethal control over extended timeframes (Eldridge et al. 2002, Allen et al. 2014). Lethal wild-living dog control may well be opposed on philosophical, moral, ethical or cultural grounds (e.g. Lewis et al. 2017), but contemporary control practices have little (if any) effect on wild-living dog population dynamics or status across broad spatial or temporal scales. Local eradication of wild-living dogs appears only to be possible where exclusion fences prevent recolonization following lethal control or removal, which is beginning to occur within some sheep grazing areas (Clark et al. *in press*). Should Australian dingoes be recognised as a threatened taxon, then the exclusion and/or control of non-dingo wild-living dogs and the containment of Australian dogs become essential management actions to conserve Australian dingoes (see also Linnell et al. 2008). Understanding Fact 4 is important because argument about the acceptability of lethal control often misdirects discussions of Australian dingo reintroduction unnecessarily. When it is understood that lethal control is consistent with Australian dingo conservation, both numerically and functionally, then Australian dingo conservation discussions can progress towards issues that are likely to have far greater effect on actual their conservation (i.e. taxonomic definitions, and evidence of population decline).

Despite a growing body of literature discussing dingoes' ecological roles, reliable evidence that dingoes have net benefits on ecosystems remains absent (Fact 5; Allen et al. 2013, Allen et al. 2017). Once defined, wild-living dogs or Australian dingoes may be worthy of conservation purely because of their intrinsic and genetic value; the conservation of top predators need not be contingent on them having beneficial functional roles. Like debates about lethal control, debates about dingoes' functional roles also divert attention from the real barriers to Australian dingo conservation. Not knowing what their roles are also means that we do not yet know what the outcome of dingo reintroduction will be. This fact means that there is a high degree of uncertainty about the proposed benefits (if any) of dingo reintroduction, reaffirming the view that dingoes should not be reintroduced at present (IUCN Guideline 8, above). In summary, there

is presently no case whatsoever for dingo reintroductions to be used as actions to conserve dingoes or ecosystems, besides potential scientific value or learnings that may arise from such an exercise. But there is a strong case for Australian dingo conservation for other reasons and through other actions.

The pathway towards meaningful Australian dingo conservation

Consideration of the EPBC Act guidelines for listing threatened species (Table 1) indicates that dingoes may only ever qualify for listing as a threatened species in Australia if (1) they are first recognised by the International Commission on Zoological Nomenclature (ICZN) as a separate species from *Canis familiaris* and (2) the population size of Australian dingoes, or perhaps international dingoes, is shown to have declined by at least 10% in three generations (Table 2, Figure 3). Consideration of the IUCN guidelines for species translocations (IUCN/SSC 2013) further indicates that reintroduction is not a suitable or appropriate conservation action at this time, nor will ever be, so long as the threat of continued hybridisation is present and dingoes continue to expand into areas where they are currently rare or absent. So what is the best approach to meaningful dingo conservation? The current approaches to their conservation include (1) lobbying to have them recognised as a distinct taxon (Crowther et al. 2014, AJP 2015, Kennedy 2016, Carter 2017) when they are not a distinct taxon (Jackson and Groves 2015, Jackson et al. 2017), (2) arguing that knowledge of their ecological roles should precipitate their conservation (Ritchie et al. 2012, Letnic 2014, Wallach 2014) when knowledge of their ecological roles is unclear (Allen et al. 2013, Allen et al. 2017) and has no influence on the listing process anyway, and (3) claiming that cessation of lethal control is necessary to preserve Australian dingoes (Wallach et al. 2009, Letnic 2014, Johnson and Wallach 2016) when lethal control does not threaten or inhibit their persistence at all (Woinarski et al. 2012, Allen et al. 2014). These attempts have been and continue to be unsuccessful (Kennedy 2016). An alternative approach is needed.

There is widespread agreement from almost all stakeholders that Australian dingoes represent a highly valued genotype, and therefore warrant conservation for retention of genetic diversity regardless of any other benefits or costs of their presence in ecosystems or the conflicting management perspectives of different stakeholder groups. Harnessing this consensus could be used to create clear conservation guidance governing the conservation of Australian dingoes. In this regard, the Convention on International Trade in Endangered Species (CITES) resolutions, international livestock breed standards, and international pet breed standards each already support existing principles to conserve genetic diversity of species or ancient breeds (such as Australian dingoes). These widely endorsed and applied standards provide a useful template for distinguishing between 'pure' animals worthy of conservation and the 'hybrid' animals that threaten them.

Referring to the conservation of wolves and the issue of wolf-dog hybrids in Europe, Trouwborst (2014; pg. 121) asks which 'wolves with dog blood' count as 'hybrids' and should therefore be removed from the wild population, and concludes that "it would probably be most appropriate, in line with evolving scientific insights, to adopt an *ad hoc* definition of hybrids incorporating genetics and morphology, whereby any wolf-like animal that can be proven (genetically) to have certain dog genes and/or (morphologically) to have certain physical dog characteristics, is considered a 'wolf-dog hybrid'" worthy of removal. CITES resolutions identify 'four generations' as the cut-off point for defining a hybrid (CITES 2007). This definition has been adopted in the European Union's Habitats Directive and Bern Convention, the purpose of which "is to protect wolves, not to protect wolf-dog hybrids" (Trouwborst 2014; pg. 115). Various livestock breed societies have similar regulations pertaining to which animals can be registered as 'pure' genotypes. For example, the Angus breed of beef cattle *Bos taurus* are considered for registration as base animals when upgraded to 87.5% pure (Angus Australia 2017). The Charolais Society is more stringent, stipulating that base animals must be 96.8% Charolais lineage to be considered pure (Lasley 1978), and only animals with full French blood (i.e. pure French dam and sire) can be labelled so (Charolais Society of Australia Ltd 2014). The Limousin breed has similar requirements for French purity (Australian Limousin Breeders' Society Ltd 2014). During the period when Angora goats were being multiplied to re-establish the Australian goat industry after the 1960s, Mohair Australia Ltd had a requirement of five generations of backcrossing with pure Angora goat genetics (i.e. 96.8% pure) before an animal could be considered pure, but only the progeny of registered pure animals are now allowed to be registered (Mohair Australia Ltd 2007). Similar standards are also used to define pet animals. For example, The International Cat Association (TICA) supports the creation of 'designer cats' which are the hybrid offspring of 'pure' species and domestic cats (e.g. hybrids of *Leptailurus serval* (serval) and *Felis catus* (domestic cat), known as savannah cats). TICA also uses four generations to distinguish between pure and hybrid specimens – a definition now adopted in regulations governing import or trade of such pets (Markula et al. 2016). Far from being worthy of conservation, such hybrids have been identified as key threats to native species of conservation concern (Allen and Fleming 2012, Markula et al. 2016).

In an almost perfect analogy to the dingo-dog situation in Australia, the express removal of hybrids and feral dogs is not only sanctioned but encouraged in several European countries to protect wolves from hybridisation (Linnell et al. 2008). The reformation of laws is also encouraged, where needed, to achieve it (Trouwborst 2014). Furthermore, action to address hybridisation is not only called for in places where purebreds are specifically protected, but also in places where they are not specifically protected. Where hybridisation is a key threat to the conservation of a species, as is the case for both wolves and Australian dingoes, the European Commission *Guidelines for population level management plans for large carnivores* (Linnell et al. 2008) states:

> *Everything possible should be done to minimise the risk of hybridisation between wolves and dogs. This requires that the keeping of wolves and wolf-dog hybrids as pets be prohibited, discouraged, or at least carefully regulated, and that strong actions be taken to minimise the numbers of feral and stray dogs.*
>
> *Everything practically possible should be done to remove obvious hybrids from the wild should such an event occur and be detected. In reality this will be most effectively achieved through lethal control, as the chances of selectively live capturing all the specific members of a hybrid pack are minimal.*

Trouwborst (2014; pg. 112) affirms that recommendations for addressing this challenge include both preventive and mitigation measures. Preventive measures mainly concern, first, actions to reduce numbers of feral and stray (free-ranging) dogs (or wild-living dogs) to a minimum and, second, the prohibition or restriction of the keeping of wolves and wolf-dog hybrids (or Australian dingoes) as pets. Mitigation involves the detection of hybrid specimens and their removal from the wild wolf (or Australian dingo) population. Such preventative and mitigation measures are already embodied in the National Wild Dog Action Plan (Anon 2014) and other State-based conservation Action Statements (Major 2009, Anon 2013) in Australia. These contain some provision for Australian dingo conservation, but acknowledge the difficulty of distinguishing between the various categories of free-ranging *Canis* present across the continent (Figure 1).

In summary, the best pathway towards meaningful dingo conservation is first recognising Australian dingoes as an ancient breed of dog and threatened genetic resource, and then defining them according to established international frameworks for conserving wildlife, livestock and pet breeds. Criteria for choosing genes and strains to be preserved fall into those that address genetically viable population size (termed 'effective population size, N_e'), biological value, genetic status (i.e. purity), and ecological, cultural and social value (Maijala 1990). In most instances, Australian dingoes could be justifiably conserved based on one or more of these categories, particularly genetic status and the value set.

Conclusions and recommendations

Deciding to define dingoes as Australian dingoes and then recognising them as a threatened domesticate may seem like (and is) a relatively straightforward exercise, however, this will not satisfy all community expectations about dingo conservation (Figure 3). Some advocacy groups and scientists promote defining Australian dingoes as a separate species and then listing them as a threatened species under the EPBC Act. But should this occur, the subsequent Australian dingo recovery plan (which is required by the EPBC Act to be developed following the listing of a threatened species) would identify hybridisation with non-dingo wild-living dogs and Australian dogs as the key threatening process, which would necessarily trigger control of non-dingo wild-living dogs and containment of Australian dogs as primary recovery actions (e.g. Linnell et al. 2008). Such measures are already being implemented across much of Australia (Anon 2014). However, lethal control of wild-living dogs is vehemently opposed by advocacy groups and some scientists, who argue for a broader morphological or non-genetic definition of wild-living dogs to be accepted (e.g. Purcell 2010, Crowther et al. 2014). This definition may be fine, but wild-living dogs then do not meet the criteria for listing as a threatened species, voiding any need for formal conservation action or recovery planning, and eroding any concern that lethal control threatens their persistence (Table 2). Defined this way, wild-living dogs become an invasive species, overabundant in some areas, and subject to coordinated control campaigns. This, in turn, fuels concern from advocacy groups, who claim that Australian dingoes are threatened and require conservation (e.g. AJP 2015, Kennedy 2016, Carter 2017), and the cycle of confusion is repeated again and again (Figure 4).

Figure 4. The cycle of confusion underpinning debate about the conservation status of dingoes and the acceptability of key actions to conserve them under current Australian Government legislative instruments (A = general taxonomic description, B = current distribution or extent of occurrence, C = current abundance, D = population trend; see text for further description of the definitions).

Even though cessation or reversal of hybridisation is likely to be impossible across most (or all) of mainland Australia, and Australian dingoes and wild-living dogs are ineligible for listing under the EPBC Act, this reality should not preclude Australian dingo identification and conservation as a threatened genotype. The decision to list or delist an animal should not be contingent on our ability to achieve their recovery (Vucetich et al. 2017). If Australian dingoes are deemed to be threatened, then they should be recognised as threatened, even if we cannot do anything about it. The continued introgression of non-dingo wild-living dog and Australian dog genetics into the Australian dingo population means that Australian dingoes will likely become effectively extinct on mainland Australia within 50–100 years regardless of any management actions to prevent or reverse hybridisation (Corbett 2001b). Thus, other dingo conservation actions may also be required, such as reserving offshore islands for only Australian dingoes, or fencing large tracts of land as 'mainland islands' and stocking them only with Australian dingoes (Woinarski et al. 2012). The size of the island reserves must be large enough to carry an effective population size of about 100 animals or more to maintain genetic integrity and prevent loss of heterozygosity (Maijala 1990). Offshore islands currently occupied by Australian dingoes and wild-living dogs, such as Fraser Island in Queensland or the many islands off the coast of northern Australia, may be the most logical places to begin conserving Australian dingoes in this way. In all cases though, this will require the removal or neutering of non-pure dingoes, or wild-living dogs, which is likely to be controversial. Widespread lethal and non-lethal removal of hybrids from the wild is also warranted (Linnell et al. 2008). If society is serious about Australian dingo conservation, then these actions may be the only means of their conservation in the wild.

To progress meaningful Australian dingo conservation, we recommend that immediate action be taken to reach consensus on the categorisation of Australian free-ranging *Canis*. We suggest that 93% purity be used as the minimum standard for categorising an animal as Australian dingo because it is:

1. Approximately the same as a fourth generation backcross;
2. Genetically detectable given current genetic testing methods;
3. Similar to the accepted standards of international wildlife trade, domestic livestock breed societies, and domestic pet breed societies;
4. An approach with strong and analogous precedents used for conserving wolves, the most closely related species to dingoes; and
5. Consistent with the intent of existing guidance on managing wild-living dogs in Australia.

Depending on societal and political preferences for this or other definitions, sufficient data may already be available to reach this consensus. If, however, consensus is not easily achieved, targeted genetic and taxonomic research to distinguish between the proposed types or definitions (above) may need to be first completed. We further recommend that actions be implemented now to enable repeating the work of Stephens et al. (2015) in future years – genetic samples of wild-living dogs across Australia should be collected, collated and preserved for future analyses. Likewise, a study of the genetics of international dingoes is essential for deciding which populations warrant representation in conservation zones. We also recommend that common arguments about the potential ecological roles of dingoes, or the ethics or outcomes of dingo control be excluded from discussions and debates about dingo nomenclature or conservation status. As important as these subjects may be for other reasons, they have little (if any) influence on the process used to identify threatened taxa and only hinder constructive discussion on dingo conservation. Continued indecision is not an option: it is actually a passive decision to allow Australian dingoes to decline. We conclude that meaningful progress towards conservation of Australian dingoes is possible and conceptually easy to achieve in the very near future, at least on islands, but it will require compromise from stakeholders with divergent views about the definition and management of dingoes.

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Biographical sketch

Benjamin Allen has been employed in the private and public sectors primarily as a dingo ecologist, conservationist and manager for over 12 years. He is a Vice-chancellors Research Fellow at the University of Southern Queensland (USQ) and the Vice-President of the Australasian Wildlife Management Society (AWMS). He develops practical solutions to human-wildlife conflicts in Australia and internationally, often in livestock grazing systems and peri-urban areas.

Lee Allen is a senior zoologist Queensland Department of Agriculture and Fisheries, where he has been researching dingo ecology and management for 37 years. He has undertaken a wide variety of dingo management extension and training activities, and developed dingo population monitoring techniques now widely adopted across Australia and internationally. Dr Allen has spent most time investigating the impacts of dingoes and dingo control on livestock.

Guy Ballard is an ecologist with the Vertebrate Pest Research Unit of the New South Wales Department of Primary Industries and an Adjunct Senior Lecturer with the University of New England. He has extensive experience with large-scale predator research projects, regularly working with private landholders and Government agency staff to improve the management of invasive and threatened species.

Stephen Jackson is a zoologist at the New South Wales Department of Primary Industries, and has studied the behavioural and environmental ecology, taxonomy and captive husbandry of mammals and other animals over the last 25 years. He has worked in a number of different roles including field ecologist, zookeeper, curator, government regulator, part time lecturer and wildlife consultant. He is an adjunct Senior Lecturer at the University of New South Wales, Associate of the National Museum of Natural History (Smithsonian Institution, Washington DC), and a Fellow of the Linnean Society.

Peter Fleming is Research Leader in Predator and Prey Management with the New South Wales Department of Primary Industries, where he has worked for over 34 years. He is adjunct in the Faculty of Ecosystem Management at the University of New England (UNE) where he is currently investigating the trophic interactions of eutherian and marsupial predators, their prey and vegetation, and the impacts of those on people.