Review of species identified for reintroduction to western Sydney

Report

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Executive Summary

This report reviews an indicative list of species that have been identified as potential candidates for reintroduction into sites in western Sydney. It also suggests additional species that had their historic ranges in these sites but which no longer persist there. For the indicative list of species, estimates of the population size that could be supported in each of four potential reintroduction sites have been identified, as well as measures that could be taken to increase their population sizes if reintroductions were to take place. The following species were considered likely, on the basis of specimen records, sightings, distribution modelling, reports or other accounts and knowledge of their habitat requirements, to have included the designated potential reintroduction sites within their historic ranges:

- Brown Antechinus *Antechinus stuartii* and Yellow-footed Antechinus *Antechinus flavipes*
- Eastern Quoll *Dasyurus viverrinus*
- Brush-tailed Phascogale *Phascogale tapoatafa*
- Common Dunnart *Sminthopsis murina*
- Southern Long-nosed Bandicoot *Perameles nasuta*
- Eastern Bettong *Bettongia gaimardi gaimardi*
- Koala *Phascolarctos cinereus*
- Bush Rat *Rattus fuscipes*
- New Holland Mouse *Pseudomys novaehollandiae*
- Bush Stone-curlew *Burhinus grallarius*
- Emu *Dromaius novaehollandiae*
- Green and Golden Bell Frog *Litoria aurea*

Two species were considered unlikely to have included the designated reintroduction sites within their historic ranges:

- Southern Brown Bandicoot *Isoodon obesulus obesulus*
- Brush-tailed Bettong *Bettongia penicillata*

The Spotted-tailed Quoll *Dasyurus maculatus maculatus,* Squirrel Glider *Petaurus norfolcensis*, Yellow-bellied Glider *Petaurus australis*, and Australian Bustard *Ardeotis australis* were considered to have occurred in or near the designated reintroduction sites in western Sydney, with records for the two glider species being stronger, more numerous and better provenanced than for the quoll or bustard.

Population estimates for each of the species on the indicative list were made using population density estimates for these species in other areas, using data from similar habitats to those in the Cumberland Plain woodland / Castlereagh forest where available. The resulting estimates show considerable variation between species and are subject to numerous caveats, including the extent of management that might be available to augment habitat quality if reintroductions were to proceed.

Background

The National Parks and Wildlife Service (NPWS) is developing plans to establish a feral predator free area at a site in western Sydney. The project will seek to reintroduce threatened and declining animal species and restore ecosystem function and processes in the designated area.

As specified in the Request for Quotation (RQ), March 2021, four sites in western Sydney are under consideration for the reintroduction program, including Castlereagh Nature Reserve (NR) (entire reserve or smaller, internally fenced option), Windsor Downs NR, Shanes Park and Wianamatta Regional Park (RQ, Attachment A). All sites contain remnants of 2 – 5 vegetation communities that have been listed as threatened communities under state (Biodiversity Conservation [BC] Act) or national (Environment Protection and Biodiversity Conservation [EPBC] Act) legislation, although remnant condition is highly varied.

Following consultation with NPWS, and in line with the Request for Quotation, this report provides:

a) A review of the indicative list of 13 species identified for reintroduction to western Sydney (RQ, Attachment B) and 2 "other species" identified for consideration (RQ, Attachment C), including:
    - For each species, advice on whether each site lies within the historic distribution/range for that species, and
    - Advice on whether any other species has its historic range within the four sites but is no longer likely to be present;
b) For each species identified as being within the historic distribution/range for each site, an estimate of the likely population (or population range) for that site, taking into account the available habitat at each site, and
    - Identification of any habitat augmentation (other than removal of feral animals) that might support an increase in estimate provided in (b) above.

In carrying out this review, use was made of primary literature sources, historical records, Australian Museum Records and the databases provided by the Atlas of Living Australia (ALA). However, it is recognised that historical records are often incomplete and can be inaccurate, both in terms of species' identification and the precision of locality records. For this reason, some judgements have been made about species' likely early presence in the four potential reintroduction sites based on the authors' experience in working with these taxa in other places and contexts. Species distribution modelling using ALA records was carried out in the ALA's Spatial Portal to improve judgements about whether the subject species were likely to occur, or not, in the reintroduction sites, although it is noted that modelling at very small scales can be subject to error and, on its own, should not be taken as a reliable indicator of species' former presence or absence.

A) Indicative list of species identified as possible candidates for reintroduction to sites in western Sydney, including two 'other species' identified for consideration

1) Brown Antechinus *Antechinus stuartii* - Not listed in the BC Act or EPBC Act

2) Yellow-footed Antechinus *Antechinus flavipes*[1] - Not listed in the schedules of the BC Act or EPBC Act

Both species occur commonly in coastal and sub-coastal areas in New South Wales and, based on climatic criteria, are predicted to occur in western Sydney (Sumner and Dickman 1998; Crowther 2002). The two species have been shown to occur in narrow sympatry in some areas, including Yengo NP in the north west of the Sydney Basin (Mowat et al. 2015), but the similarity in size of these and other ecologically equivalent antechinuses suggests that they are precluded from occurring in extensive sympatry by competition (Dickman 1986). Early specimen records suggest that *A. flavipes* was present in the Cumberland Plain woodland or Castlereagh forest habitats (Australian Museum [AM] records, summarised in Ridgeway nd), although the specific identity of these specimens is contentious and yet to be confirmed. Most definite records of *A. stuartii* from western Sydney have been obtained in recent decades (e.g., Bents Basin - Craven 1983; ALA 2021; Cobbity - Dickman unpub.), and the species remains widespread and patchily abundant in the lower Blue Mountains and reserves such as Royal NP and Ku-ring-gai Chase NP in the east. There is some evidence that *A. flavipes* is less tolerant of disturbances such as habitat fragmentation and fire than *A. stuartii* (Mowat et al. 2015), perhaps in part because the often diurnal habits of *A. flavipes* place it at greater risk of exposure to day-active predators than the nocturnal *A. stuartii*.

These observations suggest two possible explanations. First, *A. flavipes* was historically more widely distributed in western Sydney, and has now become scarce or absent due to continuing fragmentation and disturbance of its habitat. This explanation is supported by the open nature of much of the available woodland, including that in the proposed sites for species reintroductions, that is more usually the province of this species than of *A. stuartii*. As disturbances increased with increasing settlement, this may have favoured the ingress of *A. stuartii* and thus account for the relative recency of most records for this species. Second, because the two species seldom occur in broad sympatry, climate- or fire-driven fluxes could be expected to have occurred along the local distributional boundaries of the two species such that either would have been present historically in the proposed reintroduction sites depending on prevailing conditions. In other words, both species could be considered as potential candidates for reintroduction on the grounds that both used to be present in

[1] *The Yellow-footed Antechinus is one of the two 'other species' identified, along with the Brush-tailed Bettong; both are considered for convenience with their respective congeners.

the designated sites at different times. However, because of high overlap in the use of resources, the likelihood of competition and the small area of the reintroduction sites, only one of the two species should be considered for potential reintroduction. Based on the habitat and degree of disturbance of the potential reintroduction sites, Castlereagh NR would appear to be most suitable currently for *A. flavipes*, whereas Shanes Park is more suitable for *A. stuartii*.

3) Eastern Quoll *Dasyurus viverrinus* - Endangered in the schedules of the BC Act and EPBC Act

This species used to be widespread in eastern NSW, occupying a wide variety of lightly and heavily wooded habitats in coastal and sub-coastal areas (Caughley 1980; Woinarski et al. 2014). It was last recorded in a coastal location in the eastern suburbs of Sydney in the mid-1960s (Dickman 1994), but appears to have persisted for longer in the Great Dividing Range. Frankham et al. (2017) reported the discovery of a road-killed specimen from the northern Barrington Tops NP area in 1989, and discussions with naturalists D. Burt and W. Dowling (Dungog) suggest that it may have occurred (or still occurs) in heavily forested country north of Dungog (D. Burt, W. Dowling, pers. comms). This quoll has been successfully released into Booderee NP on the south coast of NSW in the last three years, and it still occurs in Tasmania where it occupies open woodland, dry eucalypt forest and grassy habitats including farm pastures (Jones and Rose 1996). Ridgeway (nd) notes that specimens were collected from the Cumberland Plain woodland or Castlereagh ironbark forest by local residents around the turn of the 20th century. These records, the former distribution of the Eastern Quoll from many coastal areas west to the Great Dividing Range, its ability to exploit a wide variety of habitats and distribution modelling using the ALA Spatial Portal confirm that the sites designated for possible reintroduction were within the historic range of *D. viverrinus*.

4) Brush-tailed Phascogale *Phascogale tapoatafa* - Vulnerable in the BC Act, not listed in the EPBC Act

This species is highly arboreal and occupies dry, lightly timbered woodland as well as dense wet forest in coastal areas and along the Great Dividing Range. There have been no records from western Sydney for over a century, but it was collected from at least two sites near Camden and Kingswood in the 19th century (Ridgeway nd). The disappearance of this phascogale from the Sydney region foreshadowed its disappearance from large areas of NSW in the 20th century, with most recent records for the state now coming from northern coastal and sub-coastal forest areas (Woinarski et al. 2014; ALA 2021). Although the causes of decline of this phascogale have not been identified, the records indicate that the sites

designated for possible reintroduction of *P. tapoatafa* were within the species' historic range.

5) Common Dunnart *Sminthopsis murina* - Not listed in the schedules of the BC Act or EPBC Act

Widespread but patchily distributed and partly eruptive in its population dynamics, *S. murina* has been recorded in many localities on the fringe of Sydney and in habitats that vary from open heath to wet forest. Although it is not well represented by specimen records in Sydney, historical ALA records from eastern Sydney, and more recent records from near Holsworthy Military Reserve, Narellan, Smithfield and especially Cranebrook, in 1969, indicate nonetheless that this dunnart was widespread through the Sydney region. Its capture in very close proximity to Wianamatta Regional Park confirms that its historic (and present) distribution almost certainly encompassed the four sites earmarked as possible sites for future reintroductions.

6) Southern Brown Bandicoot *Isoodon obesulus obesulus* - Endangered in the schedules of the BC Act and EPBC Act

Most records in the Sydney region for this species come from Ku-ring-gai Chase NP, Garigal NP and Dharawal NP, with a small scatter of early records from Botany and other eastern suburban localities (Atkins 1999; ALA 2021). Small numbers of records occur in the ALA database for the upper Blue Mountains but, even if these somewhat dubious records are confirmed, provide little indication that the eastern form of the Southern Brown Bandicoot occurs, or occurred widely, in western Sydney. The closest records appears to be of a specimen captured to the north east of Holsworthy Military Reserve, east of Heathcote Road, and of hair ostensibly from this bandicoot recovered from fox scats at Maroota forest in 1996 (Parker 1996). *Isoodon obesulus obesulus* prefers dense ground-level vegetation, structurally complex heathland and dense vegetation on the fringes of wetlands (Woinarski et al. 2014). In Garigal NP it has been captured primarily on friable substrates that permit easy excavation of prey from the soil (Dickman unpub.). It is not clear that suitable habitat occurs over sufficiently large areas in the four sites that have been designated as possible reintroduction sites to have supported populations of this bandicoot, and the soils of the Wianamatta shale are probably not ideal for the superficial and deeper digging behaviour that this bandicoot uses to obtain most of its food. It is therefore more likely that any translocations of this species would represent introductions rather than reintroductions.

As noted further below, it is more likely that the Southern Long-nosed Bandicoot occurred in the four earmarked reintroduction sites, and more broadly through the Cumberland Plain. In this case it would be less likely still that the eastern form of the Southern Brown

Bandicoot occurred there owing to the strong inverse numerical and spatial associations that the two species show in localities where these or closely related congeneric species co-occur (Heinsohn 1966; Dickman 1984).

7) Southern Long-nosed Bandicoot *Perameles nasuta* - Not listed in the schedules of the BC Act or EPBC Act

This bandicoot is represented by many thousands of records in south-eastern Australia, including records from the large National Parks north and south of the city of Sydney, scattered (but mostly old) locations through the eastern suburbs, and in the foothills and higher elevation areas of the Blue Mountains (ALA 2021). Atlas records show that it has been recorded also in western Sydney in Windsor Downs Nature Reserve, Agnes Banks Nature Reserve, just south of Wianamatta Nature Reserve, and close to Castlereagh Nature Reserve. *Perameles nasuta* exploits a wide range of habitats, often sheltering by day in dense ground level vegetation in forest or swamp fringe vegetation, emerging by night into open grassy areas to forage (Scott et al. 1999; Dickman 2015). Animals maintain their ranges after fire and other disturbances providing that some dense intact vegetation is available for diurnal shelter, and are a familiar sight in suburban gardens and backyards in Sydney and other east coast towns and cities (Scott et al. 1999). Intensive surveys were carried out by Tanya Leary at Agnes Banks NR, Windsor Downs NR, Castlereagh NR and Mulgoa NR in 2013 but failed to detect any signs of the Southern Long-nosed Bandicoot (T. Leary unpublished data, in RQ, Attachment B). Early records indicate that this bandicoot occurred commonly in forest and woodland habitats on alluvial soils in the area, but the species also occupies diverse vegetation types on sand, loams, sandstone sites throughout its range (Dickman 2015), and it can be expected to have encompassed all four sites earmarked for potential reintroductions in future.

8) Eastern Bettong *Bettongia gaimardi gaimardi* - Presumed Extinct (as *B. gaimardi*) in the schedules of the BC Act, Extinct in the schedules of the EPBC Act

9) Brush-tailed Bettong *Bettongia penicillata* - Presumed Extinct in the schedules of the BC Act, Endangered in the schedules of the EPBC Act

The nominate form of the Eastern Bettong disappeared from the mainland of Australia around the turn of the 20th century, and specimens that survive in the collections of the Australian Museum and Museum Victoria are both poorly dated and often have unreliable provenance (Short 1998). The Tasmanian subspecies of the Eastern Bettong still persists and is widespread and patchily common in central and eastern parts of Tasmania (Woinarski et al. 2014). Species distribution modelling using ALA records, and Woinarski et al. (2014), suggest that *B. gaimardi gaimardi* occurred in coastal and sub-coastal localities along the

east coast of NSW and into Victoria, although the paucity of reliable records and coarseness of the mapping preclude detailed insight into exactly which habitats this subspecies may have preferred. Using historical records and inferences drawn from observations of the Tasmanian form of the Eastern Bettong, Lunney et al. (2000) considered *B. gaimardi gaimardi* to have occupied woodland and open forest and to have occurred in north-east and south-east regions of NSW. Haouchar et al. (2016) showed the distribution as encompassing Sydney, and early specimens and subfossil material referrable to this taxon from the Sydney region indicate that the mainland Eastern Bettong was present. It is not clear whether this taxon occurred persistently or in large numbers in the four sites where reintroductions may take place, but it can be said with a reasonable degree of certainty that it occurred there or in the close vicinity.

By contrast, the suggestion that Brush-tailed Bettongs may have occurred in the Sydney region is much harder to sustain. Some putative early records of this taxon from the Cumberland Plain woodland, such as specimen M.944 registered at the Australian Museum, cannot now be located or verified, and all bettong material from the Sydney region has been identified as belonging to *B. gaimardi gaimardi* (Fred Ford, cited in RQ, Attachment C). Examination of this bettong material by one of us (CD) confirms this diagnosis. An extensive search for historical, literature, specimen and other records of *B. penicillata* has failed to find evidence of this species crossing the Blue Mountains or indeed, coming close to the western slopes (Dickman et al. 1993; Dickman 1994). Its former presence anywhere in western Sydney is considered extremely doubtful.

10) Koala *Phascolarctos cinereus* - Vulnerable in the schedules of the BC Act and EPBC Act

Koalas are well known in some parts of Sydney, most notably in areas east of Campbelltown and south to Wilton, but also in the lower Blue Mountains near Kurrajong, sites along Bells Line of Road and the Great Western Highway, Ku-ring-gai Chase NP and other scattered sites where large enough stands of food-trees have been retained. Recent records in the ALA database indicate Koala presence in the Cumberland Plain, and older records show its former presence near Castlereagh NR and in and close to Shanes Park. Taken together, these records confirm that the potential reintroduction sites lie within the historic range of the Koala.

11) Bush Rat *Rattus fuscipes* - Not listed in the schedules of the BC Act or EPBC Act

This species is widespread and abundant in open woodland, heathland and densely forested areas to the east and west of the Cumberland Plain woodland and at several scattered locations where large bushland remnants have been retained. It occurs very commonly in sandstone country outside the plains. ALA records show that *R. fuscipes* was recorded from

a predator scat in Castlereagh NR in 2013. However, as the species attribution was based on analysis of hair it is possible that the record could relate to the Black Rat *Rattus rattus*, the hair structure of which is very similar to that of *R. fuscipes*. As predators are also likely to defecate at some distance from where prey was ingested, this record cannot be regarded as reliable. However, an ostensibly reliable record has been obtained from the Elderslie Banksia Scrub in 1981 based on an individual *R. fuscipes* captured by University of Sydney mammalogist Alan Hodgson.

Despite the paucity of unambiguous evidence for the former presence of *R. fuscipes* in the four potential reintroduction sites, three lines of evidence suggest that these sites very likely formed part of the species' former range. First, the Bush Rat occupies a very wide range of habitats provided that a threshold density of ground cover is available. One of us (CD) has captured this species in open woodland with a high density of fallen timber, in low heathland and in tall dense forest including rainforest on a variety of substrates. Lunney et al. (2000) considered it to occur in all terrestrial habitats except open grassland. As the Bush Rat occurs abundantly in suitable habitat all around the Cumberland Plain, there is little reason to suspect that it would not have occurred in the woodland communities on the Plain prior to their disturbance and fragmentation. Second, predictive habitat modelling apparently indicates that high quality habitat exists across most of Castlereagh NR (Ecotone 2008, cited in RQ, Attachment B). Third, ALA records show an almost inverse distribution between *R. fuscipes* and the introduced *R. rattus*, with the latter species scarce in the less disturbed habitats that are the stronghold of *R. fuscipes* but numerous in suburban areas, habitat fragments and also in Castlereagh NR and Windsor Downs NR. In an historical review of rats in Sydney, Banks et al. (2011) noted that, in 1900, *R. rattus* arrived in Sydney carrying bubonic plague and suggested that this led to a disease-induced reduction in Bush Rat populations in Sydney's foreshore areas and beyond. In addition, public hysteria led to the wholesale killing of all rats that were accessible to them, further reducing the numbers of *R. fuscipes*. As much of Sydney's natural habitat was fragmented by the turn of the 20th century, Bush Rats that had been killed or displaced from remnant habitat patches could not later reinvade them, and the patches were usurped by Black Rats that are more tolerant of disturbance. If this scenario is correct, Bush Rats were likely to have been present throughout western Sydney despite the lack of contemporary records of their occurrence.

12) New Holland Mouse *Pseudomys novaehollandiae* - Not listed in the schedules of the BC Act, Vulnerable in the schedules of the EPBC Act

Knowledge of the current and former distribution of this small rodent is clouded by taxonomic uncertainties, patchy collecting and recording effort (possibly because of the superficial resemblance of this species to the introduced House Mouse *Mus musculus*), and the propensity of the species itself to fluctuate dramatically in abundance. It was, for example, not recorded for more than 100 years before a small population was discovered in

Ku-ring-gai Chase NP in 1967 (Kemper and Wilson 2008), and it has fluctuated erratically in numbers in long term monitoring in Royal NP (Crowther et al. 2018). The ALA database records specimens prior to 2000 in the Holsworthy Military Reserve and just outside Castlereagh NR. The species is generally coastal but has been recorded up to 400 km inland in NSW, and occurs in heathland, woodland, open forest and swamp habitats on sandy, rocky or loam-dominated soils (Kemper and Wilson 2008). It has been described as an early post-fire disturbance specialist (Fox 1983; but *cf*. Crowther et al. 2018), and may take advantage of fire-induced reductions in the abundance of larger and more dominant rodent species that re-invade local areas only when vegetation has recovered sufficiently to support them. If this is the case, it is plausible that the ubiquity and abundance of the Black Rat has suppressed, and continues to suppress, populations of the New Holland Mouse throughout western Sydney in a manner similar to that described for its current dominance over the native Bush Rat. Despite the paucity of reliable records, the weight of evidence (specimens, known habitat and ecological requirements) indicates that *P. novaehollandiae* is likely to have occurred in the four potential reintroduction sites.

13) Bush Stone-curlew *Burhinus grallarius* - Endangered in the schedules of the BC Act, not listed in the schedules of the EPBC Act

Broadly distributed across much of northern and western Australia, the stronghold of the Bush Stone-curlew lies outside NSW in open forest and grassy woodland habitats, including open grasslands and improved pastures. In NSW this species occurs principally on flat and undulating country along the coast, the western slopes of the Great Dividing Range and Riverina; it is usually absent from densely forested habitats at higher elevations. Although there are no records from the specific sites that have been earmarked for reintroductions, *B. grallarius* has been recorded from many sites throughout western Sydney, especially on Wianamatta shale (Hoskin 1991), including the Cumberland Plain woodland and within 2-3 km of Castlereagh NR (ALA 2021). Records in the ALA database suggest that birds, including breeding pairs, were being reported until the 1980s and 1990s, but a lack of recent sightings indicates that local populations may not have persisted. Taken together, the records leave little doubt that the Bush Stone-curlew was formerly resident in much of the open and grassy woodland habitats of western Sydney, and would have occurred in the potential reintroduction sites.

14) Emu *Dromaius novaehollandiae* - Not listed in the schedules of the BC Act or EPBC Act

Many records and reports of the former presence of Emus in western Sydney have been lodged in the ALA database, and the species is known to have occurred broadly across the open forested and open grassy habitats of the Cumberland Plain woodland. Although few

records are recent (20+ years old), sightings of Emu have been made at Shanes Park, Wianamatta Regional Park and within 2-3 km of both Castlereagh NR and Windsor Downs NR. There is evidence that some records of Emu derive from animals that had been kept at, and then released from, military bases in the mid decades of the 20th century, including those from Wianamatta Regional Park, but it is not clear whether these animals had been captured locally or from further afield. Nonetheless, the ubiquity and abundance of Emu records near to and far from military facilities leaves no doubt that this unmistakeable species was, until recently, widespread in western Sydney and would have been an occupant of the four earmarked reintroduction sites.

15) Green and Golden Bell Frog *Litoria aurea* - Endangered in the schedules of the BC Act, Vulnerable in the schedules of the EPBC Act

This species was formerly very common in coastal areas of NSW and Victoria, but has declined dramatically in abundance and distribution in recent decades with the arrival of chytrid fungus in Australia and the onset of chytridiomycosis disease. The best known populations in the Sydney region are near the Parramatta River in the vicinity of Sydney Olympic Park, with a large and well-studied population at and surrounding an old quarry (the 'brickpit') (Christy 2001). There is a broad scatter of old (pre-chytrid) records on alluvial soils to the east of the Hawkesbury-Nepean system and throughout sites with temporary or permanent water on Wianamatta shale throughout the Cumberland region (ALA 2021). Although no records are evident in any of the potential reintroduction sites, records of *L. aurea* all around these sites in what would have been similar habitat indicate that all four sites lie within the historic range of the species.

Other, now locally extinct, species that may have occurred historically in the four subject sites in western Sydney

The following list of species that were likely to have occurred in the four sites designated for potential future reintroductions is not exhaustive, but instead focussed primarily on species that could be practically reintroduced once predator free habitat has been established. For this reason little emphasis has been placed on aquatic species such as Platypus *Ornithorhynchus anatinus*, venomous snakes or highly mobile taxa such as most birds.

Spotted-tailed Quoll *Dasyurus maculatus maculatus* - Vulnerable in the schedules of the BC Act, Endangered in the schedules of the EPBC Act

This species appears to be widespread but sparse in the Blue Mountains, including the eastern foothills (Hechinger 2016; B. Murray pers. comm.). There are no records of the nominate subspecies for the Cumberland Plain, but early records suggest that this quoll was at one time widespread in the Sydney region as far east as Manly (Ogilby 1892). Its former presence in western Sydney is therefore possible but cannot be substantiated.

Squirrel Glider *Petaurus norfolcensis* - Vulnerable in the schedules of the BC Act, not listed in the schedules of the EPBC Act, and

Yellow-bellied Glider *Petaurus australis* - Vulnerable in the schedules of the BC Act, not listed in the schedules of the EPBC Act

Records in the ALA database show that the sugar glider *Petaurus breviceps* is widespread across the Cumberland Plain, and occurs in three of the four sites earmarked as possible sites for future reintroductions (only Wianamatta Regional Park lacks records). However, smaller numbers of earlier records (up to the 1980s) indicate that both the Squirrel Glider and Yellow-bellied Glider were present in parts of the Cumberland Plain woodland, with one record of *P. australis* obtained from Windsor Downs Nature Reserve. The latter species is usually associated with denser forest types than those of the Castlereagh forests, but the historical record clearly indicates its former presence. Thus, both *P. australis* and *P. norfolcensis* appear to have occurred formerly in or close to the sites being considered for future reintroductions.

Australian Bustard *Ardeotis australis* - Endangered in the schedules of the BC Act, not listed in the schedules of the EPBC Act

Hoskin (1991) lists two records of this species in the Sydney region, one from Long Bay in 1865 and the second at McGraths Hill near Windsor in 1959. The Australian Bustard is usually associated with open plains country in drier inland regions, and in NSW it occurs primarily to the west of the Great Dividing Range. The early records suggest that it has made occasional forays into the Sydney region, and it is most likely that it has been a temporary visitor when suitable conditions have prevailed, or perhaps a peripheral inhabitant of the region at most.

B) Methodology for estimating population size/size ranges

To estimate the population size that each fenced area could support for each species, we obtained population density estimates from a range of primary sources. For instances where no density estimates could be obtained, expert opinion was sought from researchers familiar with the species in question (Appendix Table 1). Density estimates were reviewed for accuracy and rejected if considered not applicable (i.e., estimates from island populations). For each density estimate, consideration was given to the vegetation community for which it was calculated. Density estimates were directly transposed in instances where the primary vegetation composition was comparable to one of the seven categories described within the proposed fenced reserves. For all other instances, density estimates were averaged to obtain a mean value that was applied to areas where equivalent vegetation communities were lacking. To calculate estimates for minimum population sizes, the lowest density estimate obtained from a review of the literature and/or expert opinion was used in the calculations for areas without equivalent vegetation. This process was repeated using the highest density estimate to calculate maximum population sizes. For vegetation information and calculations using IBRA bioregion data, summaries for QLD, NSW, VIC, and SA were obtained from https://www.environment.gov.au/land/nrs/science/capad/2014

Final estimates of the numbers of each species that could be supported in the four designated sites are shown in Table 1, with details of the calculations used for each species shown on the attached spreadsheet (Appendix Table 2). The estimates clearly vary considerably both within and between species. Low estimates for species such as the Eastern Quoll and Emu reflect the limited availability of studies that present density estimates, with those studies that do provide such information representing low density populations. Almost certainly, larger populations of both species could be sustained in all four of the proposed reintroduction sites, but available information does not permit reliable estimates of how much larger. Nonetheless, for species that would have low estimated populations, questions about population viability would need to be raised if reintroductions were to proceed. By contrast, high estimates for species such as the Brown Antechinus and Bush Rat reflect estimates from studies that have been carried out on higher density populations elsewhere. The estimates also assume that suitable habitat is available in each site to support populations as dense as those in high quality habitats elsewhere. However, site inspections suggest this may not be the case. For example, the western part of the Shanes Park site is heavily disturbed, so the overall size of potentially suitable less disturbed vegetation is only 280-350 ha, depending on the chosen fence alignment should the western part of the area be unsuitable (D. Kelly, pers. comm.). Species such as the Emu, Bush Stone-curlew and Eastern Quoll may have insufficient habitat to maintain populations in this situation.

Table 1 Upper, lower and mean population estimates for 13 species that have been identified as potential candidates for reintroduction to four designated sites in western Sydney

	Castlereagh	Castlereagh Internal Fenced Area	Windsor Downs NR	Shanes Park	Wianamatta RP
Species	**Estimate (min-max)**	**Estimate (min–max)**	**Estimate (min–max)**	**Estimate (min–max)**	**Estimate (min–max)**
Brown Antechinus	2078 (1842 – 2434)	1623 (1393 – 1969)	1202 (872 – 1696)	1422 (909 – 2192)	934 (849 – 1060)
Eastern Bettong	94 (NA)	76 (NA)	65 (NA)	86 (NA)	69 (NA)
Eastern Quoll	5 (NA)	4 (NA)	3 (NA)	5 (NA)	4 (NA)
Southern Brown Bandicoot	553 (94 – 1047) **Note: *this***	447 (76 – 846) ***species is***	382 (65 – 723) ***not considered to***	506 (86 – 958) ***have been present***	407 (69 – 770) ***in the sites***
Southern Long-nosed Bandicoot	214 (198 – 230)	171 (160 – 183)	148 (136 – 160)	198 (181 – 215)	163 (145 – 182)
New Holland Mouse	1526 (641 – 5084)	1350 (489 – 4815)	1553 (321 – 6513)	2382 (345 – 10580)	1950 (269 – 8714)
Brush-tailed Phascogale	49 (49 – 191)	40 (40 – 154)	34 (34 – 132)	45 (45 – 175)	36 (36 – 141)
Common Dunnart	494 (124 – 1853)	399 (100 – 1496)	341 (85 – 1280)	452 (113 – 1695)	363 (91 – 1362)
Bush Rat	5140 (4834 – 6143)	4578 (4338 – 5363)	4576 (2482 – 11426)	6555 (2319 – 20414)	4707 (577 – 18222)
Emu	3 (0 – 13)	3 (0 – 10)	2 (0 – 9)	3 (0 – 12)	3 (0 – 9)
Koala	32 (8 – 49)	26 (7 – 40)	22 (6 – 34)	29 (8 – 45)	24 (6 – 36)
Bush Stone-curlew	9 (2 – 24)	7 (2 – 17)	4 (0 – 8)	5 (0 – 8)	11 (2 – 28)
Green and Golden Bell Frog	NA*	NA*	NA*	NA*	NA*

NA = not applicable owing to the paucity of available estimates

NA* = not applicable as this species is dependent on localised moist conditions; uniform density estimates over large areas are not possible or appropriate.

Caveats to methodology

A key caveat with respect to clarifying the list of species that occurred historically in western Sydney and, in particular, the sites identified as possible reintroduction sites for those species, is the quality and reliability of records. As we have noted above, many records for

the listed species are old, and both the correct identity and provenance of the records often remain uncertain. Uncritical use of such records in compiled databases can lead to erroneous conclusions about species' distributions. As an example, use of the ALA interactive map for *Antechinus f. flavipes* (this is the nominate subspecies that occurs widely in NSW) revealed just six records for the entire state, with no records in the vicinity of Sydney. The interactive map for *A. flavipes*, by contrast, documents many hundreds of records for the state, but many of these occur in areas where *A. flavipes* is known not to occur, such as in dense forest on the eastern slopes of the Great Dividing Range south of Sydney and along the NSW south coast. Although species distribution modelling using ALA records was carried out to assist judgements about whether each of the subject species was likely to occur in the reintroduction sites, considerable discretion and caution had to be exercised to ensure that erroneous records did not lead to misleading results.

There are several caveats to consider also when assessing the reliability and efficacy of the population estimates. Firstly, density estimates for some species were difficult to obtain and were at times limited to one survey of a single population. This presents obvious problems with transferability due to the unknown specifics of vegetation composition, recent rainfall events, predation levels and further site-specific details. Secondly, while effort was taken to consider and incorporate the different vegetation communities present in the four designated sites, the vegetation composition between the surveyed sites and the categories to which they were transposed are unlikely to represent direct comparisons. Finally, for some of the species considered, the habitats they require are more specialised than those that may be available in the dominant vegetation communities. For example, *L. aurea* may exist at high densities around centralised locations of high-quality habitat near water (e.g., 5–6 /ha: Christy 2001) yet remain absent from large areas with similar vegetation composition if water is not available. The Koala's numbers are likely to be most affected by the number and age of suitable food-trees. It should also be noted that issues with the initial methodology of calculating density estimates will have been incorporated into these results. These effects are likely to be pronounced for transient species that provide inherent difficulties in the measurement of density; for example, one breeding pair of *D. novaehollandiae* across a survey site of 1 hectare results in a density estimate of 2/ha; expanding the survey site to 10 ha and locating no additional individuals now reveals an estimate of 0.2/ha.

Ecological factors that will affect estimates of population size/size ranges

A key factor that will affect the numbers of most of the species considered for reintroduction is that predation from feral predators would be removed should a fence be erected, and the impacts of these predators would thus be eliminated. For all species except perhaps the Emu, populations could be expected to rise. If an effect size of 3 – 4 is considered possible (Salo et al. 2007), populations of several of the small ground-dwelling

species could be expected to increase up to 3 – 4 fold above the estimates provided. Such increases would be most likely for the mid-sized marsupials (e.g., Eastern Quoll, Eastern Bettong), with smaller increases for species such as the Brown Antechinus or Brush-tailed Phascogale that are partly or largely arboreal.

In the Mulligans Flat Woodland Sanctuary, a 485-ha fenced reserve in the Australian Capital Territory, Manning et al. (2019) documented how an introduced population of 32 Eastern Bettongs grew to 192 individuals within four years, before experiencing a density-dependent drop to an estimated 151 individuals two years later. If extrapolated to western Sydney, the latter two density estimates (0.4 and 0.31 animals /ha, respectively), would suggest that some 124–160 Eastern Bettongs could be supported in the fenced area of Castlereagh NR and 135–175 in Shanes Park (although in practice the large disturbed area would reduce these numbers), with fewer in the other two potential reintroduction sites. These estimates are double those provided in Table 1 but less than the maximal numbers that would follow from 3 – 4 fold increases and perhaps reflect the most realistic numbers of animals that could be potentially supported.

Further studies in the Mulligans Flat Woodland Sanctuary indicate that an area of 485 ha is sufficient to maintain a viable population of Eastern Quolls. Unfortunately these studies have not reported the numbers of quolls sustained within the Sanctuary, but factors such as introducing disease-free animals, selecting females post-mating with pouch young and regular monitoring have been shown to improve reintroduction success (Portas et al. 2020; Wilson et al. 2020). The similarity in area of Mulligans Flat Woodland Sanctuary to Castlereagh NR and Shanes Park suggests that a viable population of Eastern Quolls could be supported in the Sydney sites despite the low numbers presented in Table 1, especially if adaptive management tactics such as those described by Wilson et al. (2020) were deployed in the reintroduction program.

Assuming the successful reintroduction of engineering species such as the Eastern Bettong and Southern Long-nosed Bandicoot, improvements in habitat condition could be expected over time that would in turn foster increases in carrying capacity. Such 'ecosystem engineer' species turn the soil by their digging and burrowing activities, and are well known to improve the infiltration of water after rain, assist in the restoration of nutrient cycles, trap organic materials such as leaf litter and seeds, and thus improve soil health (e.g., Munro et al. 2019). Improvements in soil health in turn could be expected to allow faster growth and greater biomass of green plants, increasing the food resources for all consumer species. Although such effects have not been quantified, increased primary productivity should directly (for herbivores) and indirectly (for insectivores, omnivores and carnivores) elevate the carrying capacity for all the species being considered for reintroduction. In this case, the population sizes of all species could be expected to be larger than those presented in Table 1, although it may be 5 – 10 years before the full effects of improved soil health are felt.

The effects of removal of feral predators, improvement in soil and habitat condition and factors such as the 'fence effect' (whereby populations increase in size due to limited dispersal; Ostfeld 1994) are all likely to increase species' population sizes in the four designated sites in western Sydney considerably above those indicated in Table 1. However, a potentially negative effect may arise due to the loss of genetic integrity (e.g., by inbreeding or drift) if the numbers of any species that are reintroduced remain very low. From the estimates presented in Table 1, the species least likely to be able to sustain genetically viable populations would include Eastern Quolls, Koalas, Emus, Bush Stone-curlews, and possibly Brush-tailed Phascogales. However, such genetic considerations could be potentially managed by adding new individuals from time to time or removing dominant individuals that contribute disproportionately to the production of offspring. Excess animals may also be useful as founding stock or for genetic reinforcement at other reintroduction or rewilding sites. Although relatively intensive, management of this kind is carried out commonly in fenced populations, and may be important if there are educational, cultural, social or other considerations that are associated with the reintroduction of particular species.

A further factor that will affect population sizes of all the species being considered for reintroduction is the quality of the habitat at each of the four potential reintroduction sites. Although every effort was made to match estimates of population density to the diversity of habitat types that are available, habitat condition could not be adequately assessed. Because of their position in western Sydney, all sites have been subject to human disturbance and are degraded to greater or lesser extents. The most disturbed is Shanes Park, where the western section has been so heavily disturbed that, for some species, only 280–350 ha may provide suitable habitat. This site also has a notable lack of tree hollows, numbers of wet patches / soaks on clay, and areas of laterite that may not be suitable for digging or burrowing species, and a high coverage of invasive weeds (e.g., riparian weeds and African Love Grass).

A simple approach to the issue of habitat disturbance would be to estimate the area that is unsuitable for each species in each site and reduce the estimates in Table 1 accordingly. At Shanes Park, for example, omission of the heavily disturbed western section (100–170 ha, depending on any future fence alignment) would reduce the estimates in Table 1 to between 62% and 78% of the presented population sizes. However, this simple approach is flawed for several reasons. First, several species (e.g., Brown Antechinus, Southern Long-nosed Bandicoot, New Holland Mouse, Common Dunnart, Bush Rat, Emu, Green and Golden Bell Frog) can and do exploit disturbed habitats. Second, over time, ecosystem engineer species could be expected to help ameliorate disturbed habitats. Third, many small and medium-sized vertebrate species in Australia have broad habitat tolerances and can maintain their populations if a single key factor—predation—is removed (e.g., Legge et al. 2018). Hence, although some diminution in overall population sizes might be expected, most species could be expected to make some use of disturbed habitat provided that it

occurs within a predator-proof fence where feral predators have been removed. For species that use tree hollows or other critical resources, there is also likely to be value in augmenting these resources, as discussed further below.

Habitat augmentation to increase species' population sizes

Augmentation of habitat or other resources will be most successful if key resources that limit each species' population size can be identified and increased. For some species these may be well known. The Koala, for example, should respond positively to an increased availability of high quality food-trees, while the Green and Golden Bell Frog could be expected to increase if moist habitats and small bodies of shallow water were augmented. For gliders, should either the Squirrel Glider or Yellow-bellied Glider be considered for reintroduction, trees with hollows would need to be assured or, alternatively, high quality nest boxes would need to be provisioned. The Brush-tailed Phascogale is also known to use nest boxes, and could be expected to use them if suitable tree hollows are limiting. However, for some species a tension will likely exist for access to particular resources. Brown Antechinus and Bush rats require dense ground-level vegetation or structures such as logs (e.g., Dickman 1991), and would likely respond positively if these were augmented. However, the Common Dunnart, Southern Long-nosed Bandicoot and probably New Holland Mouse prefer patches of open ground amid dense vegetation and would decline if ground cover became too dense. Judicious and small scale patch burning thus is likely to be required to ensure that the divergent requirements of these taxa are catered for and to ensure increases in their populations.

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Appendix Table 1: Sources used to estimate species' potential population sizes in designated reserve sites in western Sydney if reintroductions were to take place

Species	Common name	Number of density estimates utilised	Expert opinion utilised	Sources*
Antechinus stuartii	Brown Antechinus	7		Watt (1997) Statham & Harden (1982) Cox (2003) Kemper (1990)
Bettongia gaimardi	Eastern Bettong	1		Taylor (1993)
Dasyurus viverrinus	Eastern Quoll	1		Godsell (1982)
Isoodon obesulus obesulus	Southern Brown Bandicoot	4		Godsell (1982) Heinsohn (1966) Stoddart & Braithwaite (1979) Copley et al. (1990)
Perameles nasuta	Southern Long-nosed Bandicoot	2		Downes et al. (1997) Banks (2004)
Pseudomys novaehollandiae	New Holland Mouse	4		Fox & McKay (1981) Wilson (1991) Haering & Fox (1997) Kemper (1990)
Phascogale tapoatafa	Brush-tailed Phascogale	2	Prof. Chris Dickman	Cuttle (1982)
Sminthopsis murina	Common Dunnart	1		Crowther and Dickman (unpub.)
Rattus fuscipes	Bush Rat	23		Peakall, Ebert, Cunningham & Lindenmayer (2006) S. Burnett (pers. comm.) Dickman (unpub) Wheeler (1970)

				Fox & McKay (1981) Woodside (1983) Carron (1985) Barnett, How & Humphreys (1978) Wood (1971) Braithwaite et al. (1978) Hall & Lee (1982) Robinson (1987) Wilson et al. (1986) Watts & Aslin (1981)
Dromaius novaehollandiae	Emu	2		Grice et al. (1985) Wilson et al. (1987)
Phascolarctos cinereus	Koala	4	Prof. Mathew Crowther	Adams-Hosking et al. (2016) Hagan et al. (in prep) DPIE report
Litoria aurea	Green and Golden Bell Frog	2		White 7 Pyke (1996) Christy (2001)
Burhinus grallarius	Bush Stone-curlew	2	Dr. Catherine Price	Gates and Paton (2005)

* All sources are provided in van Eeden et al. (2020): van Eeden, L. M., Nimmo, D., Mahony, M., Herman, K., Ehmke, G., Driessen, J., O'Connor, J., Bino, G., Taylor, M. & Dickman, C. R. (2020). *Impacts of the Unprecedented 2019-2020 Bushfires on Australian Animals*. WWF-Australia, Sydney. 55 pages.

Appendix Table 2: Density estimates, numbers per habitat and per species for species identified as potential candidates for reintroduction to four sites in western Sydney

Please note: this is an attached spreadsheet