

# Historical record shows broad habitat use and rapid decline of the greater bilby *Macrotis lagotis* in eastern Australia

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## ABSTRACT

**Context.** Understanding historical distributions of species informs their ecology and response to threats, which can support management of surviving and translocated populations. Like many critical weight-range mammals in Australia, the greater bilby (*Macrotis lagotis*) has experienced major declines since European colonisation. The past distribution of bilbies in eastern Australia remains uncertain owing to the rapidity of their decline, their cryptic and nocturnal nature, and the paucity of specimen records. **Aims.** We aimed to systematically collate, geo-reference and attribute bilby records from eastern Australia to better inform their historical distribution, habitat preferences, patterns of decline and response to threats. **Methods.** We searched explorer and early settler journals, the digitised newspaper archive, interviews with long-term residents, Aboriginal language resources and ethnographies, place and property names, unpublished datasets, and documented locations of now-inactive bilby burrows. Records were geo-referenced and attributed with date, record type, source, location precision, bioregion, habitat and local abundance. The former distribution of bilby habitat in Queensland was modelled using Maxent, and the likely former occupancy of bilbies was identified using vegetation mapping. **Key results.** More than 250 bilby records were found, only 34 of which appear in the Atlas of Living Australia. Sixty-five per cent of the records were attributed either 'certain' or 'good' reliability. Bilbies formerly occurred over most of inland New South Wales and the southern half of Queensland in areas receiving <600 mm average annual rainfall, in a wide variety of habitats. By the 1930s, bilbies were largely restricted to their current core range in south-western Queensland. This contraction in range coincided with the northward spread of rabbits and foxes. **Conclusions.** Bilbies had a more contiguous distribution and occupied a wider range of habitats than was previously recognised. The species persisted in apparently isolated patches to the south-east, west and north of its present distribution until the 1970s, suggesting recent declines around the peripheries of its current range. By the 1990s, bilbies occupied <3% of their pre-1900 range in eastern Australia. **Implications.** This work details changes in bilby distribution and provides key context for interpreting contemporary survey results. It also identifies areas where further surveys are required and may assist in selecting habitat for future translocations.

**Keywords:** Aboriginal, Bilby, critical weight range, extinction, historical, mammals, New South Wales, Queensland, threatened species, Trove.

## Introduction

Since European settlement of Australia in 1788, 25 mainland terrestrial mammals have become extinct, accounting for one-third of global mammal extinctions in the past 200 years (Johnson 2006; Woinarski *et al.* 2015). The range and abundance of many other species have declined dramatically. This wave of extinctions and declines was so rapid, in some cases beginning in the first decades of European settlement and nearly always predating scientific surveys, that for many species we are left with limited understanding of their historical distribution and the spatial and temporal patterns of their decline (Abbott 2001; Johnson 2006).

Understanding historical distributions of species informs fundamental aspects of biology and ecology, including habitat requirements and response to threats (Rookmaaker 2004; Peacock and Abbott 2014; Rutrough *et al.* 2019). This knowledge can underpin conservation of surviving populations, through defining realistic recovery objectives and facilitating targeted management of key threats (Sovada *et al.* 2009; Zhang *et al.* 2020). Accurate documentation of former distributions is also essential to identify changes in occupancy and extent, including recolonisation of, or contraction from, formerly occupied areas (McClenachan *et al.* 2012). It can also guide future reintroduction efforts through improved selection of sites and management of threats (Hendricks *et al.* 2016; Lentini *et al.* 2018; Rutrough *et al.* 2019).

The potential for reconstructing historic distributions has been demonstrated using multiple techniques, including interviews with Aboriginal communities (Burbidge *et al.* 1988; Ziembicki *et al.* 2013; Trageser *et al.* 2017) and other long-term residents (Abbott 2001, 2006), natural history collections (DeWalt *et al.* 2009; Saarinen and Daniels 2012), journals of explorers and early naturalists and travellers (Kerle *et al.* 1992; Denny 1994; Silcock *et al.* 2013), and, increasingly, digitised newspaper archives (Cochran and Elliott 2012; Fairfax 2019; Cooke 2020; Hudgins *et al.* 2020).

In common with many critical weight-range mammals (Johnson and Isaacs 2009), the greater bilby (*Macrotis lagotis*; hereafter referred to as the bilby), has suffered a severe range contraction across mainland Australia since it was first described by Reid in 1837 (Kreffft 1862; Wood Jones 1923; Finlayson 1961; Smyth and Philpott 1968; Southgate 1990a). At the time of European settlement, bilbies occurred across ~70% of the Australian mainland; today they occupy <20% of their former range (Southgate 1990b). Declines occurred from the south of the continent, resulting in the apparent extinction of the species in New South Wales by 1912 (Troughton 1932) and in South Australia by the early 1930s (Kemper 1990). No definite records of the species exist for Victoria, but comments by Krefft (1862), specimens collected from near the South Australian and New South Wales borders with Victoria, and their apparent presence in Victorian Aboriginal languages suggest that the species formerly occurred south of the Murray River (Scarlett 1969; Menkhorst and Seebeck 1990). Southgate (1990b) reported on this confusion and considered it not unreasonable to accept that bilbies existed at least in the northern mallee areas of Victoria at the turn of the century.

Bilbies are still extant in Western Australia; however, they have declined dramatically from the south-west, with local extinction in south-western districts probably by 1940 (Abbott 2001). Southgate (1990a) reported similar declines from the South Australian border to Alice Springs and in the northern pastoral country of the Northern Territory. In Queensland, bilbies have declined from the east, resulting in an isolated and fragmented extant population in the far south-west of the State (Gordon *et al.* 1990). By about 1970,

all existing mainland populations occurred north of approximately latitude 29°S, with declines apparently continuing into the 1970s and 1980s (Southgate 1990b).

The past distribution of bilbies in eastern Australia remains uncertain, owing to the rapidity of their decline, their cryptic and nocturnal nature, and the relative paucity of specimen records particularly from Queensland. Numerous authors have provided brief accounts of the historical distribution of bilbies in parts of eastern Australia (Troughton 1932; Ashby *et al.* 1990; Gordon *et al.* 1990; Menkhorst and Seebeck 1990; Southgate 1990a), the most detailed being those of Southgate (1990b) and McRae (2004). These studies preceded the widespread availability of digitised museum collections, explorer journals and newspaper articles, which are now available via the National Library of Australia 'Trove' database.

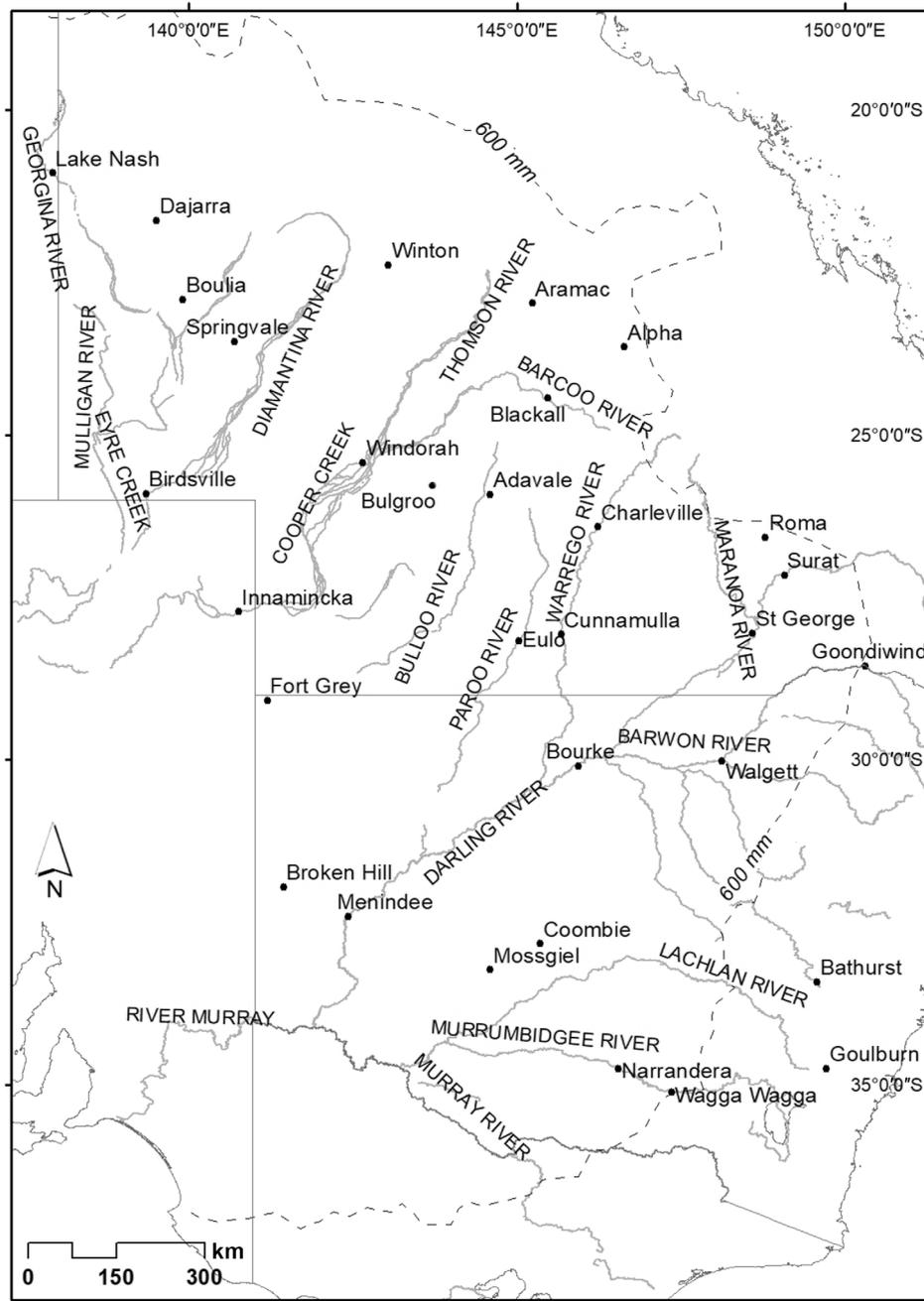
Here we collate, geo-reference and attribute records of the bilby in eastern Australia from specimen records, scientific literature, explorer and early settler journals and writings, newspaper articles, interviews with long-term residents, place and property names, poetry and novels, and locations of now-inactive bilby burrows. We also model former distribution and examine habitat preferences and occupancy, apparent abundance, spatial and temporal patterns of decline, and consider the implications of this study for survey and conservation of the remaining wild bilby populations in eastern Australia.

## Methods

### Study area and historical overview

Our study area was defined loosely as the inland portions of Queensland, New South Wales (including the Australian Capital Territory) and Victoria west of the Great Dividing Range. Records from within 50 km of the Queensland border in South Australia and the Northern Territory were also included. This area lies between latitudes 20°S and 36°S and longitudes 138°E and 151°E and covers an area of some two million square kilometres (Fig. 1). Rainfall ranges from ~800 mm per annum in the south-east to 150 mm per annum in the far central-west, decreasing in volume and increasing in variability heading west. Most of the study area is arid to semi-arid, receiving <500 mm of rainfall per annum. The diversity of climate and landforms is reflected in the variety of vegetation types, encompassing desert sand dunes, floodplains, grasslands, shrublands and woodlands (Sattler and Williams 1999; Keith 2004). The area encompasses 15 of Australia's 89 mapped biogeographic regions (DAWE 2012).

People have lived in inland eastern Australia for at least 45 000 years (Hiscock 2008) and the area was home to more than 50 Aboriginal nations at the time of European colonisation (AIATSIS 1996). The first European colonisers arrived in Sydney, New South Wales (NSW) in 1788, and



**Fig. 1.** Eastern Australia, showing locations mentioned in text, including towns, rivers and pastoral stations, State borders and 600 mm rainfall isohyet (dashed line).

pastoral expansion spread inland from Sydney and, later, Melbourne. In Queensland, pastoralism spread from the south and west from Brisbane from the 1850s. By 1870, most of the study area was occupied by pastoralists, although this was largely restricted to rivers until bore drilling became widespread around the turn of the century.

Whereas Aboriginal and Torres Strait Islander peoples altered the ecology of inland Australia, including through fire management and harvesting and promotion of resources

(Johnson 2006), European colonisation greatly accelerated anthropogenic changes, most drastically through extensive clearing for agriculture, introduction of domestic and feral herbivores and non-native plants, and changes to fire regimes (Keith 2017). Cats (*Felis catus*) were present across most of the study area by the 1870s (Abbott 2002), and foxes (*Vulpes vulpes*) spread north from initial releases around Melbourne in 1871 and occurred across most of the area by 1910 (Fairfax 2019). Today, the vast majority of the study

area is used for agriculture, with some cropping in the higher-rainfall areas in the south and east and extensive rangeland pastoralism in the drier western and northern areas.

## Compilation of sources

We compiled and geo-referenced historical records of bilbies in eastern Australia. Records included specimen and sighting records accessed through the Atlas of Living Australia (ALA; <https://spatial.ala.org.au>), scientific publications (book chapters, monographs, reports, theses), a systematic review of explorer records and early settler journals and writings for the region (including Silcock *et al.* (2013), interviews with long-term residents and researchers between 1988 and 2003 (McRae 2004), further interviews with residents and researchers in 2021, and examination of unpublished data, notes and records in the archives of Peter McRae and Dick Kimber. Southgate (1990b). Place names containing the word 'bilby' (or any alternative spellings) were also included in the database, as were literary and poetic references to bilbies. Available Aboriginal language resources for the study area were searched for words for 'bilby' and added to the list compiled by Southgate (1990b).

Systematic searches of the online newspaper database Trove (<https://trove.nla.gov.au>) were a major source of new information. Bilbies are unusual-looking and charismatic creatures that create conspicuous burrow systems and were of considerable interest to bush folk. Search terms in Trove were 'bilby', 'bilbie', 'bilbi', 'bilbee', 'beilbi', 'beilby', 'bilba', 'bilbah' (all alternative spellings), 'bandicoot' (as the bilby was often referred to as the rabbit-bandicoot), 'native rabbit', 'native hare', as well as commonly used Aboriginal names including 'dalgitte/dalgyte/dulgite', 'pinku/pinkie' and 'thulka'. We also searched for 'bilby/bilbi/bilbee/beilbi/bilbah holes' and 'warrens'. The lesser bilby, *Macrotis leucura*, also occurred in the far west of the study area in the Northern Territory and South Australia (Woinarski *et al.* 2014); however, all records from this area were considered likely to be the greater bilby on the basis of habitat and descriptions. Walter Smith, who observed bilbies in the area where the two species are likely to have co-occurred, distinctly recognised them as two different species and gave them different names (R.G. Kimber, unpubl. data).

Where specimens held in museums and accessed through ALA were undated or with imprecise location notes, we searched for the collector name and district in Trove, Australian Dictionary of Biography (<https://adb.anu.edu.au/>), and other historical sources to inform likely collection date and place the locality as accurately as possible (usually to a property or district). The paper of Parnaby *et al.* (2017) was particularly helpful in this respect.

From the 1970s, bilby research and surveys were conducted in south-western Queensland (Watts and Aslin 1974; Southgate 1990a, 1990b; McRae 2004). The locations of bilbies recorded in the 1981–1985 Diamantina Fauna Survey (Atherton *et al.*

1985), provided as grid references in an unpublished report, were geo-referenced with coordinates. Scientists observed the first live bilbies in the area while spotlighting in 1988 (McRae 2004), and systematic surveys by air and on ground were conducted in the 1990s (Southgate 1990b; McRae 2004). Post-1990 records from within the known contemporary core range of the bilby in south-western Queensland (McRae 2004) that do not contribute to knowledge of the species' distribution were not included in this study.

Records from reintroduced populations (Scotia, Mallee Cliffs, Pilliga, Sturt National Park and Currawinya in the present study area) were not included. A 2009 sighting record north-east of Charleville was considered likely to be an escaped bilby from the captive-breeding program (P. McRae, unpubl. data), and was excluded. A 2013 bilby record from central NSW in ALA was investigated and has been flagged as 'suspect' (D. Plowman, pers. comm., November 2021), and was also excluded. Fossil records of bilbies were not included, including museum specimens from Wellington Caves in north-eastern NSW (Dawson 1985) and one from Iona Station west of Bourke, which was collected from 1 m below the ground apparently on a scientific dig by CSIRO (ALA 2021), although no further information could be found. These fossils may be thousands of years old and do not necessarily represent currently climatically suitable habitat for the species.

The locations of inactive burrows outside the core contemporary range of the bilby were recorded during extensive field work in south-western Queensland and northern NSW between 1990 and 2021. Bilby burrows may remain present in some soil types, particularly clay and rocky soils, for decades following the local extinction of the species. They can be distinguished from other burrowing animals, including goannas and rabbits, by their larger entrances and 'spoil heaps', often containing subsurface calcrete or silcrete (McRae 2004; Thompson and Thompson 2008). They can appear similar to burrowing bettong (*Bettongia lesueur*) warrens, which also occur in the study area; however, burrowing bettong warren complexes tend to cover a larger area (up to 40 m across) and have more entrances (up to 50) (Van Dyck 2005; James and Eldridge 2007; Noble *et al.* 2007). Goannas, rabbits, long-haired rats and other animals often use inactive bilby burrows (Hofstede and Dziminski 2017; Dawson *et al.* 2019), but can be readily distinguished from bilbies, which have distinctive tracks, scats and diggings (Southgate *et al.* 2019).

## Attributing records

Records were entered into a Microsoft Excel spreadsheet; fields are shown in Table 1. Where multiple specimens were collected from the same geographic area at the same time, or where sightings were recorded in multiple sources but obviously reference the same event, these were counted as a single record. Archival records were assessed as 'certain'

**Table 1.** Fields included in historical *Macrotis lagotis* spreadsheet for eastern Australia.

Field header	Data/explanation
Observer	Name (Anon. if unknown)
Date	Year if known, otherwise decade or period
State	Qld, NSW, Vic., NT or SA
Location	Description of location, e.g. property, distance from known location
Bioregion	Biogeographic region where record is from (DAWE 2012); if not able to be ascertained accurately, left blank. Some records encompass >1 bioregion
Latitude and longitude	Decimal degrees; n/a if a record not able to be located to within 500 km
Location precision (km)	Precision of geo-referencing in km. For records with GPS coordinates, precision is <1 km; where a known geographic feature is stated, precision is <10 km; map grid references are assigned as precision of 20 km; where distances and/or directions are provided to a known location, precision is provided accordingly; where a property name is given, this is based on the size of the property; where a town is provided, precision is given as 0 km; a district or First Nation 100–500 km depending on its size; n/a if unable to be located within 500 km
Record type	Specimen (held in a museum); sighting (can be multiple or single, live or dead; sometimes trapped); materials (skins, tails, artefacts); burrows (active, inactive, status unknown); other signs (feed scrapes, tracks, scats; recent or old); cartographic or language name; second-hand or anecdotal; literary
Reliability	Assessed as certain (specimen or materials held at a museum or Government records of skins or identifiable photograph); good (credible account by a witness who is familiar with bilbies, often a trapped animal sometimes kept as a pet or skinned); moderate (record seems plausible, description fits bilby); low (record unable to be verified and seems suspect, e.g. description does not match bilby appearance or behaviour)
Local abundance	If stated
Broad habitat	If stated. Either provided in description or notes, or inferred from vegetation mapping or local knowledge if geographic precision is sufficiently accurate
Reference	Citation of record
Source summary	Atlas of Living Australia; published book or journal; unpublished thesis or report; Trove (newspaper or magazine); Interview; Burrow observation; unpublished data; Aboriginal language; cartographic name
Notes	Any further details or evidence

if a specimen or materials were held at a museum, if the observation was made by a scientist familiar with bilbies, or if the record was accompanied by an identifiable photo. Official Government records of skins were also assessed as certain. ‘Good’ reliability denotes a credible account by a witness who was familiar with bilbies, or with a sufficiently

detailed description of the animal and its defining features, particularly its white tail-tip and long ears. Good sightings often involved trapped animals that were sometimes kept as pets or shown in the district. Records that described names of bilbies in Aboriginal languages and/or as a source of food or materials were regarded as good evidence that they occurred historically in that district. Moderate reliability was assigned where the record appeared plausible and the description matched with a bilby, but no specific defining features were mentioned. These records were credible but typically with less detail owing to the second-hand or general nature of accounts or related to place names that suggested presence of bilbies but could not be verified. Accounts of inactive bilby burrows by observers who were not familiar with bilbies in the field, or where burrows were assessed as probably having been made by bilbies but burrowing bettongs could not be ruled out, were assigned as moderate reliability. Low-reliability records seemed suspect; for example, description did not match bilby appearance or behaviour, or were from obviously fictionalised accounts; these are discussed below but were excluded from further analysis and mapping.

For bilby signs and burrows, in instances where the observer was a scientist or long-term resident familiar with active bilby burrows and/or other signs were seen (scats, tracks, live animals), ‘good’ reliability was given. Bilby burrow observations, where not made by a zoologist familiar with bilby burrows in the field, or supported by other evidence, were assessed as ‘moderate’ reliability.

We also made note of ‘negative records’. This refers to the absence of reliable observations from localities where observations were made of other mammals (Abbott 2001). Although caution is required in interpreting these negative records, particularly for a cryptic species such as the bilby, and they were not considered in the habitat modelling, they can inform patchiness in distribution.

### Distribution modelling, habitat mapping and examination of decline

A potential habitat model was built using Maxent (Phillips *et al.* 2006) to model the historical distribution of the bilby in Queensland. Potential habitat models predict the relative likelihood of occupancy on the basis of the following seven variables nominated by experts and tested to remove those that were highly correlated: four climatic variables (annual mean temperature, temperature seasonality (coefficient of variation), annual precipitation and mean moisture index of the lowest quarter moisture index), pre-clearing broad vegetation group, land zone (which is a surrogate for soil and geomorphology mapping in Queensland) and terrain ruggedness (Laidlaw and Butler 2021). Only records that were attributed as good or certain reliability and had spatial precision of <30 km ( $n = 74$ ) were used for modelling. The majority (73%) of these records were post-1970, meaning

that the model is biased towards the species' current range. These were supplemented by more recent 2021–2022 survey records (Southgate RL, Silcock JL, Bradley K, Fairfax RJ, Arkinstall C, unpubl. data). A bias layer was used in the model to account for sampling bias, as per Laidlaw and Butler (2021). Potential habitat models are necessarily restricted to the Queensland part of the bilby's distribution as pre-clearing broad vegetation and land-zone mapping are available only for Queensland.

To provide finer-scale detail on habitat use and occupancy across eastern Australia, habitat associations were examined in more detail with reference to pre-clear vegetation mapping layers. Records that had spatial precision of 30 km or better were overlaid with pre-clearing vegetation mapping, namely. Regional Ecosystem (RE) mapping for Queensland (Queensland Herbarium 2021) and State Vegetation Type Mapping (SVTM) in NSW (Department of Planning and Environment 2022; Roff et al. 2022). Twenty-five historical records contained habitat descriptions, allowing some cross-referencing of the mapping. Regional Ecosystems (Qld) and Plant Community Types (NSW) that contained bilby records were mapped to explore the likely historical occupancy of bilbies.

Extent of occurrence (IUCN 2019) in eastern Australia was calculated each decade by drawing a minimum convex polygon around all 'good' and 'certain' reliability records from that decade. This allowed pattern of decline to be examined over time.

## Results

In total, 260 records of bilby occurrence in eastern Australia were found, 154 from Queensland, 98 from NSW, and one (possibly two) from Victoria, as well as five from the Northern Territory and one from north-eastern South Australia within 50 km of the Queensland border. One-hundred-and-nineteen records already existed in the public sphere (i.e. had been published in journals or books and/or were represented by a museum specimen), although only 34 of these appear in the ALA (Fig. 2); 141 were 'new' records, primarily from newspapers and unpublished data. All records are included as Supplementary material, available from the journal's website.

### Reliability and precision of records

Seventy-six records were attributed to a bilby with certainty (i.e. included a specimen or bilby material ( $n = 29$ ), were sightings or activity recorded by zoologists familiar with bilbies ( $n = 42$ ), were trapped animals with credible photographs ( $n = 4$ ), or were official Government Gazette records of skins ( $n = 1$ )). Ninety-four records were assessed as 'good' reliability and 75 records were assessed as 'moderate' reliability (see Methods).

Fifteen records were assessed as being of low reliability; these are retained in the Supplementary material but were

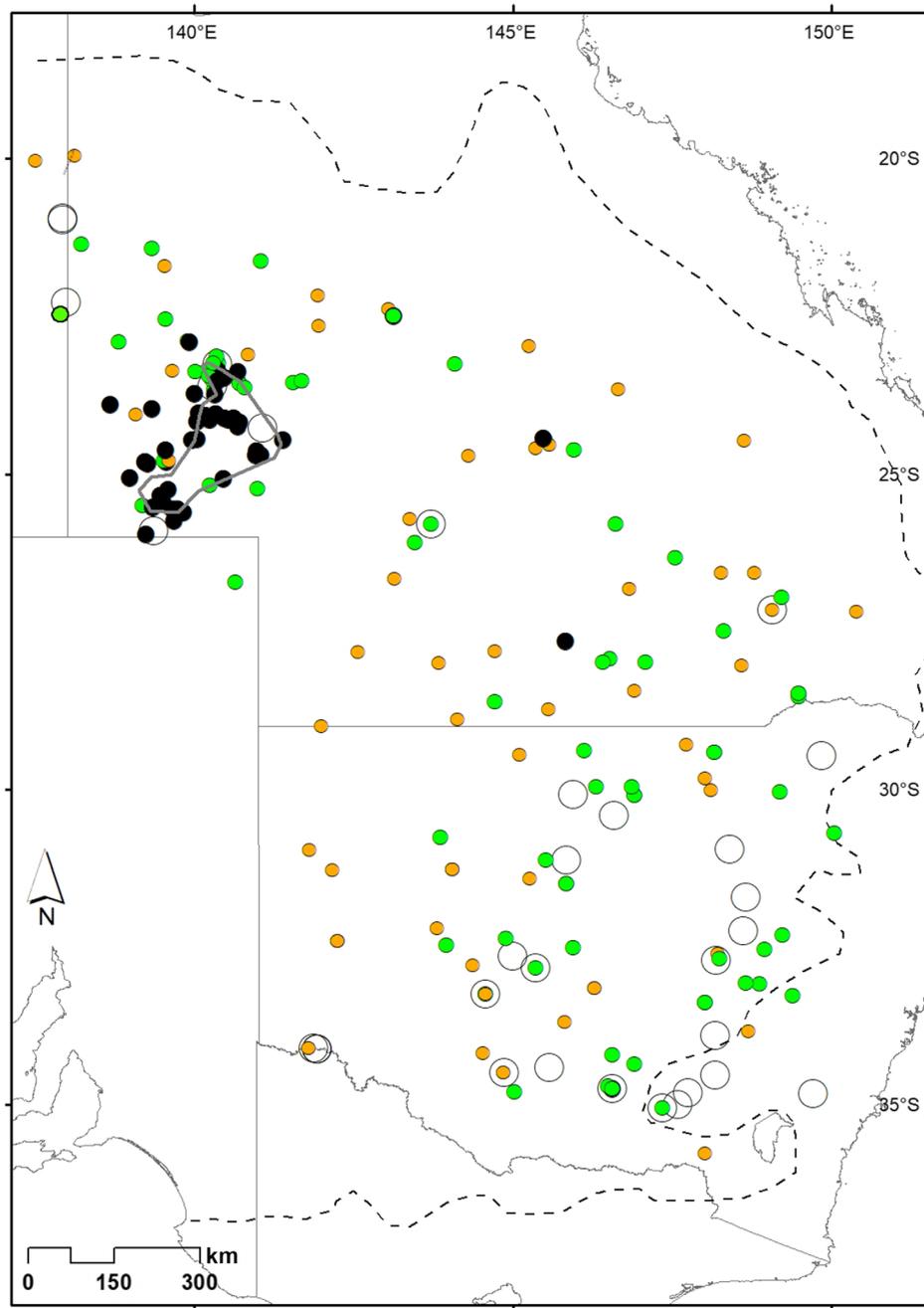
not included in this paper. Five were burrow records from north of Winton made during macropod helicopter surveys in 2002 but not ground-truthed (G. Lundie-Jenkins, pers. comm., January 2022); we were not confident from the photos that the diggings were made by bilbies. Four were from the short stories of J. Hurtle Lewis, which were based on extensive experience in the bush but were highly fictionalised and impossible to geo-reference. Four were from explorer journals that seem more likely to have been other species: three 'Dipus' sightings along the Mulligan River in south-western Queensland and near Fort Grey in north-western NSW by Charles Sturt (8 and 14 September 1845) and Daniel Brock (9 October 1845), which may have included both pig-footed bandicoots and bilbies (Brock 1975; Davis 2002), and a sighting of an animal along the upper Maranoa River in central Queensland by Thomas Mitchell (15 October 1846 Mitchell 1847) that seems likely to have been a stick-nest rat. Two implausible and unverified sighting records from near Adavale (Agricola 1899) and Goondiwindi (Peter McRae, unpubl. data) were also considered low reliability.

Of the 244 records of at least moderate reliability, 59 were able to be geo-referenced to within 10 km precision, 113 to within 50 km (typically to property or township surrounds), and 47 to within 200 km (typically district or broad locality, or Aboriginal language group). Twenty-five records were not able to be located accurately within 500 km; bioregions are not provided for these records and they are not shown on the maps.

### Sources and types of records

The majority of records came from Trove ( $n = 88$ ; mostly newspapers with a handful of magazine articles and Government Gazettes), 62 appeared in various published sources (scientific books and journals, explorer journals, magazine articles, ethnographies, memoirs, novels, poetry, electronic resources), 34 were from Atherton et al. (1985), 34 from the Atlas of Living Australia, 29 from interviews with long-term residents, and 23 from unpublished data (primarily from the records of Kimber and McRae; see Methods). Bilby sightings were the most common type of evidence ( $n = 115$ ), followed by bilby sign ( $n = 85$ ), Aboriginal use and language ( $n = 34$ ), specimens ( $n = 28$ ) and place/property names ( $n = 7$ ). Forty-eight records contained more than one type of evidence.

Of the 115 sighting records, 65 involved sightings of multiple animals. Ninety-three were direct sightings of live animal/s or credible second-hand reports of a sighting event; the remaining 22 were general accounts of past sightings in a district. In 35 cases, at least one animal was shot, trapped (often accidentally in rabbit traps or netting fences) and/or kept as a pet. Six were sightings of already-dead animals. Almost half the sighting records (51) were from newspaper reports, 29 from interviews. Only 10 credible sightings are in the Atlas of Living Australia.



**Fig. 2.** *Macrotis lagotis* records, eastern Australia. Open circles show existing records from Atlas of Living Australia (mostly specimens + 10 reliable sighting records). Solid circles show 'new' records compiled during this study: black circles indicate certain reliability, green circles 'good' and orange circles 'moderate' reliability (see Methods). The contemporary core range of the species is outlined in grey. Post-1990 records from within the contemporary core range are not included. The predicted distribution from the original BIOCLIM model is shown as a dashed line, re-drawn from Southgate (1990b, p. 27).

Eighty-five records related to bilby signs, mostly burrows ( $n = 82$ ), sometimes in combination with feed scrapes ( $n = 22$ ) and tracks ( $n = 4$ ) and scats ( $n = 2$ ). Twenty-nine of these records were historical reports of bilby sign (inactive burrows), the activity status of 11 was not recorded, and 42

had recent evidence of bilby activity. 'Bilby holes' were mentioned in newspaper reports between 1874 and 1926, mostly with reference to the dangers they posed when mustering on horseback and their use by rapidly expanding rabbit populations. Numerous reports from the 1880s to

early 1900s refer to bilbies and rabbits living in the same holes (Anon. 1882; Daveney 1893; Smith 1905), although from the 1880–1890s, there are also reports of rabbits having taken over old bilby burrows (Anon. 1882, 1894; Reid 1908; Rolls 1969).

Twenty-six records related to the use of bilbies by people (First Australians or Europeans). The word ‘bilby’ (also written as ‘bilbi’, ‘bilbie’ or ‘bilbah’) is derived from the Yuwaalayaay language of northern NSW (Longman 1922; Pound 1898; Ash et al. 2003), and a further 10 Aboriginal names for bilbies were found for eastern Australia (Table 2). There are doubtless undocumented names for bilbies from other language groups that existed across the range of bilbies in eastern Australia. There is interesting congruence among names, with most having their origins in words relating to ‘white tails standing up’ (Menkins 2012).

Seven place or property names containing bilby (or variations on that spelling) were found, but only one, namely, ‘Bilbie Well’ in ‘Bilby Paddock’ near Ivanhoe, NSW, was considered good evidence of bilbies having occurred there. The others mostly related to Queensland property names, including ‘Bilbie Park’ south-east of Charleville, ‘Bilbah’ near Tara at the eastern limit of historical distribution, ‘Bilbah Downs’ west of Blackall and ‘Boolbie’ west of Winton, and

**Table 2.** Aboriginal names for bilbies documented for eastern Australia.

Language group or region	Word	Reference
Not stated (lower Darling, NSW)	Jacko	Kreffit (1862)
Not stated (Murray River, NSW/Vic.)	Wuirrapur	Kreffit (1862)
Not stated (Warrego and Darling Rivers, NSW/Qld)	Bilbi	Pound (1898)
Yuwaalayaay (north-central NSW including Brewarrina area)	Dhuluun.gayaa; bilbi, bilbie, bilbah	I. Sim, pers. comm., in Menkins (2012); Longman (1922); Ash et al. (2003)
Not stated (Narrandera, NSW)	Hunhawang ('a lot of bilbies')	Gunther (1896)
Yandruywandha (Innamincka area, SA)	Thalkaparlu (possibly)	Breen (2015)
Kamilaroi/Gamilaraay (northern NSW/southern Qld)	Bilba	Menkins (2012)
Bidjara/Gungabula (north-east of Charleville, Qld)	Dhangu	G. Breen pers. comm., in Southgate (1990b); Menkins (2012)
Muruwari (south-east of Cunnamulla, Qld/NSW)	Thanguu, bohyi, bilba	Menkins (2012)
Mardgany (western Mulga Lands, Qld)	Dhangu	G. Breen pers. comm., in Southgate (1990b)

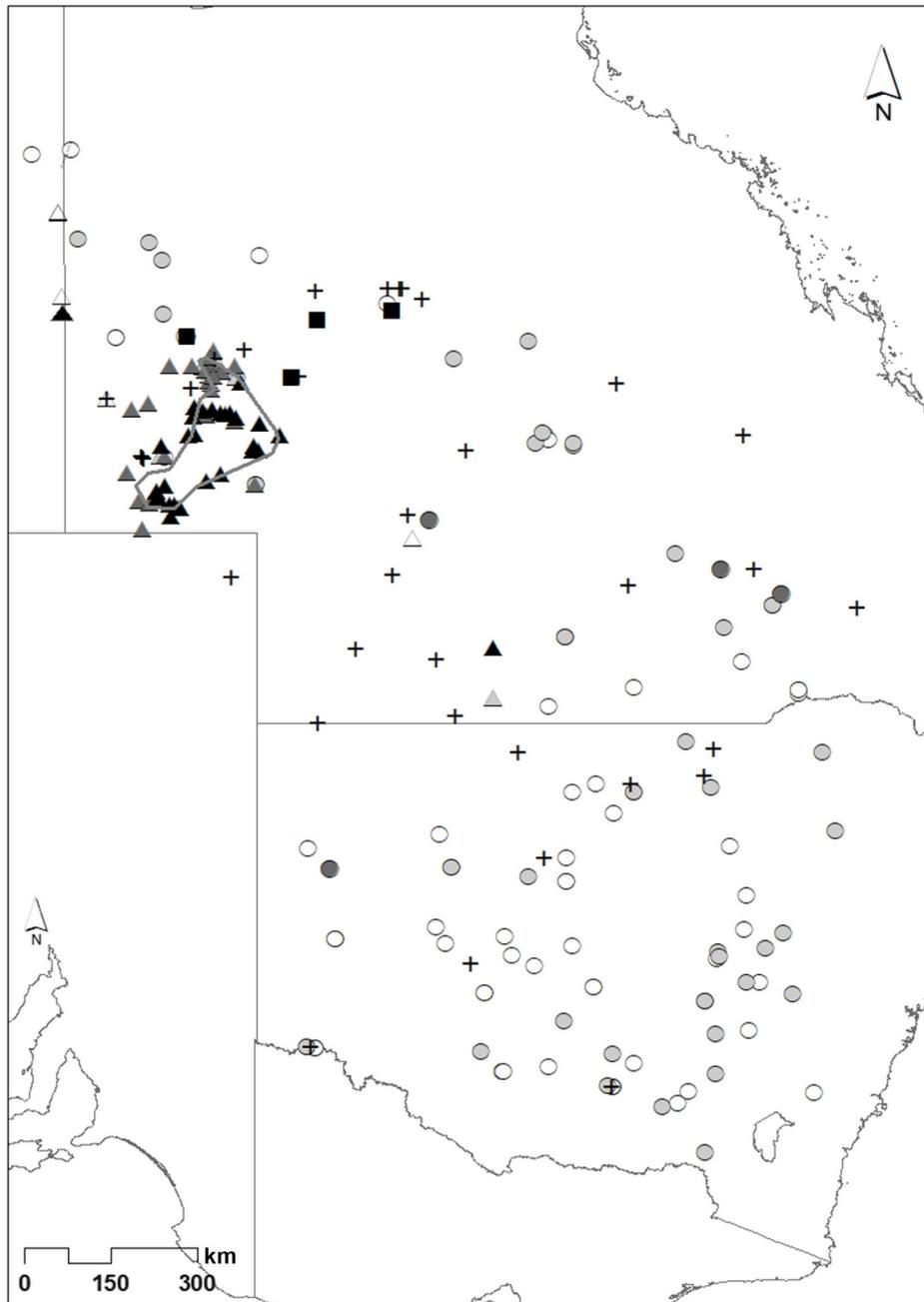
although all are within the historical distribution, the etymology of the names remains uncertain and they were assigned ‘moderate’ reliability.

Twenty-eight records were supported by one or more specimens, although two specimens (Coongoola in 1898; Bourke in 1905) are referenced in newspaper articles (Pound 1898; Anon. 1905), but do not appear in ALA and may not be located in museum collections. Most specimens are from NSW, with only six locations in Queensland represented by specimens (three of these are post-1950 specimens within the present range of the species).

## Spatial and temporal overview

The earliest apparent eastern Australian *M. lagotis* record comes from the journals of Charles Sturt and Daniel Brock, in the Menindee Lakes in October 1844 (Brock 1975; Davis 2002). Two animals, which Brock described and skinned, and a head-dress made from tails of this species, were brought to the exploration party by local First Australians while they were camped at Lake Cawndilla. Sturt referred to this animal as a ‘Dipus’, which is commonly regarded as being a pig-footed bandicoot (*Chaeropus ecaudatus*; Wood Jones 1923; Piddocke 2009). However, Brock’s description of the use of tails in a head-dress and use of the Aboriginal term ‘pinkoe’ (known to be a term for bilbies in some Aboriginal languages) suggests that these animals were bilbies. Thus, when Sturt and Brock later refer to the ‘Dipus’ as being numerous along the Mulligan River in far south-western Queensland and near Fort Grey in north-western NSW, it is possible that they were referring to bilbies rather than pig-footed bandicoots. However, a pig-footed bandicoot was caught and kept as a pet by the party, and the presence of bilbies in these locations is attributed ‘low’ reliability (see above). A record in ALA of *Macrotis lagotis* seen by Sturt’s party on 14 March 1845 refers to a ‘Talpero’, which is widely regarded to be a western barred bandicoot rather than a bilby (UNSW 2021).

The occurrence of the species in eastern Australia was not confirmed until 13 years later, when members of the Blandowski expedition observed animals and collected specimens near the junction of the Darling and Murray Rivers in 1857 (Kreffit 1862; Fig. 3). There were no collections or sightings dating to the 1860s, with the next record (of bilby tails in an artefact from Eyre Creek, far western Queensland) in 1872 (Anon. 1872). The 1870s was also when Donald Gunn recalled bilbies having occurred between Goondiwindi and St George in southern Queensland (Gunn 1937). Other sightings and recollections dating from the 1870s are from the ‘backblocks’ of the Darling and Lachlan Rivers (Constant Reader 1905), Moolah and Mossiel Stations in the Riverina (Bennett 1905) and Coombie station on the Cobar Pedepain (Anon. 1877), including specimens from the three latter locations (ALA 2021).



**Fig. 3.** Dates of *Macrotis lagotis* records in eastern Australia. Pre-1900 (open circles), 1901–1910s (light grey circles), 1920s (dark grey circles), 1930s–1955 (open triangles), 1958–1966 (light grey triangles), 1970s (dark grey triangles), 1980s (black triangles), post-1990 (squares). Crosses are undated records. Contemporary core range of bilbies in south-western Queensland is outlined grey. Post-1990 records within the contemporary core range of the bilbies are not shown, nor are ‘low’-reliability records (see Methods).

There was a notable increase in observations in the 1880s–1910s (accounting for 69 records), mostly from inland NSW, with scattered records from south-western Queensland. Records declined to 10 in the 1910s. The last certain record from NSW was in 1912 when two were shot at the Wagga Experimental Farm (Troughton 1932), although there is an

observation of burrows ‘still occupied’ by bilbies in ‘far-western NSW’ in 1926 (J. McG. 1926). 1912 was also the year that the first Queensland specimen was collected, at Surat.

The 1920s–1950s were characterised by occasional sightings (1–3 sightings per decade) from locations scattered

across south-western Queensland. Numerous sightings from the 1950s–1970s, mostly in and around the current core distribution of bilbies, were recorded during interviews conducted between the 1970s and early 2000s (Dent 1972; Watts and Aslin 1974; Atherton *et al.* 1985; McRae 2004). There are also two records from the western Mulga Lands, namely, a dead bilby found south of Eulo in 1964 (I. Pike, pers. comm., November 2021) and two animals reportedly captured in an oil pipeline trench by a digging crew north-west of Eulo 1984 (Gordon *et al.* 1990).

From the 1970s, the majority of records are from zoologists in south-western Queensland and from interviews conducted by these researchers (Atherton *et al.* 1985; Southgate 1990b; McRae 2004). These are clustered within and to the south-east, north and west of the bilby's contemporary range. By the 1980s, the bilby had largely contracted to its present core range, with the notable exception of the Eulo record discussed above, a record from Lake Nash in 1980 (Southgate 1990b), records of active burrows and scats south of Winton in 1991 and 2021 (C. Mitchell, pers. comm., November 2021; P. McRae, unpubl. data), an animal captured at Boulia in 2011 and an unverified sighting in the Middleton district between Boulia and Winton about 2010 (Figs 1, 3).

Bilbies had an estimated extent of occurrence (EOO) in eastern Australia of 1 617 540 km<sup>2</sup> prior to 1900. Declines in EOO are evident from this time. By 1910, EOO had contracted to 1 225 020 km<sup>2</sup>, but the most rapid declines occurred between 1910 and 1930, with an EOO of 454 580 km<sup>2</sup> by 1930, representing a decline of >60%. Declines continued through the 1930s–1980s, with losses of remaining outlying populations to the east, north-west and west of the current contemporary range (Fig. 3). By the 1990s surveys (McRae 2004), EOO was 46 439 km<sup>2</sup>, <3% of the pre-1900 eastern Australian EOO. More recent records to the north over the past two decades have expanded known EOO to ~64 000 km<sup>2</sup>, suggesting that declines may have stabilised although further monitoring of these outlying records is required.

The majority of records were from the bioregions where bilbies still occur, namely, the Mitchell Grass Downs ( $n = 63$ ) and Channel Country ( $n = 40$ ) in Queensland, followed by historical records from bioregions where bilbies are now extinct, including the Mulga Lands (NSW and Qld;  $n = 27$ ), Darling Riverine Plain (NSW and southern Queensland,  $n = 25$ ), NSW South Western Slopes ( $n = 22$ ), Brigalow Belt South (NSW and Queensland;  $n = 19$ ), Riverina (NSW;  $n = 19$ ), Cobar Pedepain (NSW;  $n = 13$ ) and Murray Darling Depression (NSW,  $n = 8$ ). There are three historical records from the South Eastern Highlands in the far south-east of the historical range of the bilby, two each from the Brigalow Belt North and Desert Uplands at the north-eastern limit of the historical range and the North West Highlands, and one each from the Broken Hill Complex and Simpson Strzelecki Dunefields.

A refined set of 150 spatially independent records was used by Maxent to model the historic distribution of the bilby in

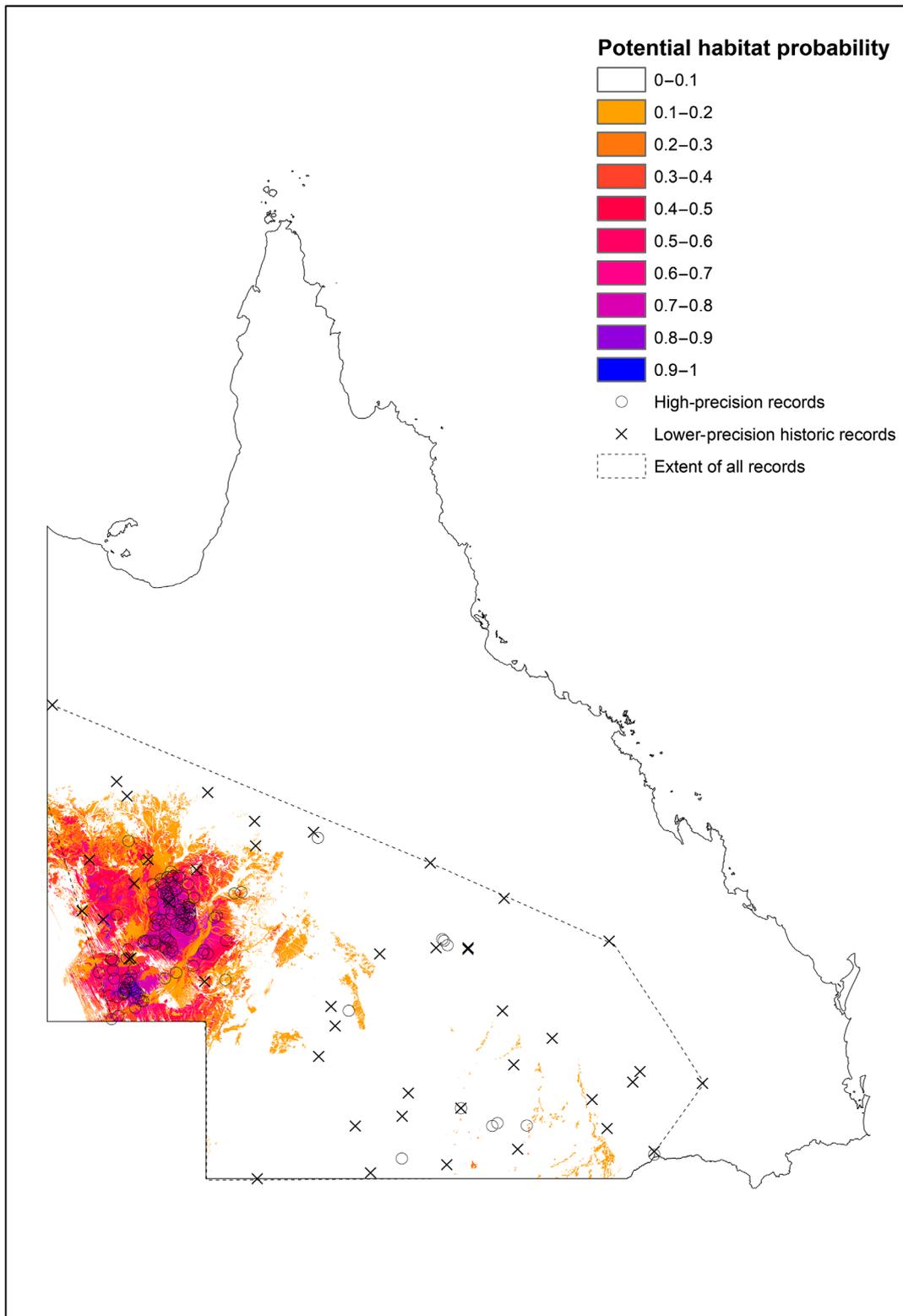
Queensland. The area under the receiver operating characteristic (ROC) curve (training AUC) was 0.94, suggesting high model performance. Modelling suggests a concentration of high relative-likelihood habitat adjacent to, and to the west of, the bilby's current range (Fig. 4). The model identified only limited areas of suitable habitat east of the contemporary range. This is, in part, because few historical records had sufficient geographic precision to be included in the model. The strongest model driver was annual precipitation, with a permutation importance of 57.6%, followed by pre-clear broad vegetation group (19.1%) and temperature seasonality (16.9%).

## Habitat inferences

One-hundred-and-fourteen records contained habitat descriptions or had sufficient geographic precision to allow likely habitat occupied to be identified from State vegetation-mapping products. The majority of these ( $n = 54$ ) was from clay soil habitats that are still occupied by bilbies (stony downs, clayey downs, Mitchell grasslands) within or close to their contemporary range. Outside of this area, the bilby seems to have preferred sandy soils ( $n = 23$ ), with numerous records stating the bilby was 'most common' or 'found especially' in sandy areas (Constant Reader 1905; Dunbar 1943–44). There are records from sand ridges adjacent to major river systems, including the Diamantina, Barcoo, Warrego and Maranoa rivers in Queensland (Anon. 1894; R.A.R. 1898; W.H.F. 1900), and the Lachlan, Murrumbidgee, Darling, Murray and Barwon Rivers in NSW (Scotty the Wrinkler 1900; The Flaneur 1900; Xerxes 1900; Anon. 1906; Murrungurru 1934; ALA 2021). Walter Smith knew the greater bilby, i.e. 'Arritta' (Ahrete) in Aranda, well, having seen it in the Northern Territory and western Queensland; he stated that its habitat was the sandy soil of the major rivers and creeks: 'Always alongside a big sandy creek' (R.G. Kimber, unpubl. data). In other conversations, Smith observed that habitat could include rocky as well as sandy country, and that favoured ground was 'firm', such as in limestone country (R.G. Kimber, unpubl. data).

There were also records from low dunefields and pine sand ridges away from major watercourses, including on Wittenburra Station south-west of Eulo (a habitat similar to the nearby Currawinya reintroduction) and between St George and Cunnamulla in southern Queensland (Daveney 1893), and an apparent old bilby burrow west of Walgett in low dunefields along the Barwon palaeochannels. A record from north of the Barcoo River was from 'desert country' (Anon. 1949), which is a local term for sandy soils supporting low woodlands and shrublands.

Bilbies also had an apparent preference for areas with calcrete and/or limestone in the subsoil profile ( $n = 8$ ), sometimes with outcropping of these sediments. Five records are from rocky hills and stony rises, including the last record in NSW from Wagga Wagga (Troughton 1932). The Sturt/Brock



**Fig. 4.** Modelled historical distribution of *Macrotis lagotis* in Queensland, showing potential habitat probability (shaded), high-precision (<30 km) records used in the model (circles) and lower-precision records that were not used in the model (crosses).

records were from Menindee Lakes, and a record east of Cunnamulla was adjacent to an ephemeral lake (Daveney 1893). Bilbies may also have inhabited the more clayey plains in their former range. Harry ‘The Breaker’ Morant, who worked extensively in south-western Queensland and north-western NSW in the 1890s, wrote of ‘the grassless bilbee plains’ (apparently along Nebine Creek east of Cunnamulla) and ‘Bilbee Flat’ (Tinnenburra south of Cunnamulla) in two of his poems (Morant 1892; Morant 1898).

In total, 56 vegetation communities were identified as likely former bilby habitat on the basis of pre-clearing vegetation mapping, including 24 Regional Ecosystems in Queensland and 32 Plant Community Types (PCTs) in NSW (Table 3). Fourteen of these are still occupied by bilbies in south-western Queensland, mostly grasslands and herblands on alluvial and Cretaceous plains ( $n = 10$ ), but also two residual (stony hills), one sand dune and one watercourse Regional Ecosystem. A further nine vegetation communities on clay plains were identified as likely having been used by bilbies historically, namely, Mitchell grassland north of Boulia and herblands on alluvial plains in central-southern Queensland, two Mitchell grassland communities in western NSW, and five Chenopod-dominated shrublands and herblands also in western NSW (Table 3).

Ten vegetation communities on sand ridges and sandplains bordering major river systems from southern NSW to central Queensland are also likely to have been occupied by bilbies. These are mostly mixed open woodlands dominated by *Eucalyptus* spp. and/or white cypress pine (*Callitris glaucophylla*). At least 11 sandplain and loamy plain communities also provided likely habitat, mostly in NSW (Table 3). Five residual landforms (stony hills and rises), including the two still currently occupied in south-western Queensland, were also occupied by bilbies; burrows tend to remain visible in these systems for decades, and most records were of long-inactive burrows. Seven wetland communities were identified as likely bilby habitat, mostly around ephemeral lakes in southern Queensland and the Menindee Lakes system in south-western NSW. At the south-east of the bilby’s historical range, three grassy woodland communities dominated by *Eucalyptus* spp. were identified as the most likely habitat (Table 3).

When these vegetation communities are mapped, the potential historical occupancy of the bilby in eastern Australia is broad but patchy (Fig. 5). Suitable habitat apparently became patchier heading east into higher-rainfall areas in both states, although this may partly be an artefact of few spatially precise records. There are large areas of suitable but apparently historically unoccupied clay soil habitat to the north-east of the current contemporary range in Queensland.

### Abundance inferences

Sixty-eight records contained abundance information, with 37 of these describing bilbies as ‘very numerous’, ‘numerous’,

‘abundant’, ‘in their thousands’, ‘common’ or ‘plentiful’ and a further 16 as ‘fairly plentiful’, ‘fairly numerous’ or ‘not uncommon’ (Table 3). Fifteen records described them as ‘not common’, ‘rare’, ‘seldom seen’, ‘not plentiful’ or ‘apparently rare’. Bilbies were described as ‘numerous’ across large areas of inland NSW, particularly the south-central parts, and in Queensland within and to the north of their contemporary core range. They seem to have been patchily abundant in other parts of Queensland, notably along the upper Barcoo River in the 1880s–1990s and in the Goondiwindi–St George area in the 1890s.

Seldom are these records quantified. Correspondent Scotty the Wrinkler (1900) wrote that he had caught ‘at least 40 this season in my rabbit traps’ in the sandhills four miles south of Narrandera. Bilbies were sufficiently numerous in the Narrandera Sheep District in the late 1880s to be regarded as an agricultural pest, and thus legally able to be destroyed under the *Pastures and Stock Protection Act Amendment* 1881 (Carrington 1887). A price of five shillings was paid for each whole bilby skin, and in 1887 the Government Gazette recorded that 101 skins were taken for the calendar year (NSW Government 1888). In 1889, only 16 bilbies were officially taken in the Narrandera district (Anon. 1889).

Six bilbies were trapped on the western portion of Leichhardt Rabbit Board fence (west of Roma) in 1904, when they were burrowing under the netting (Harris 1904). Byron Nathan, a stockman from Springvale, wrote of seeing bilby skins hanging on poles, stretched out on the ground and being spun into yarn by Aboriginal people, but had only ever seen two live animals (Dent 1972). Six or seven animals were seen regularly while kangaroo shooting at night on Lorna Downs near Boulia and Springvale to the north of the present core range (G. Robinson, pers. comm., 1993,) and 10 were seen at one site on Lorna Downs in 1971 (E. Ogilvy, pers. comm. 1993). Walter Smith noted that they were not as plentiful around Boulia and Dajarra, north of their present range, as they were in parts of the eastern Northern Territory (R.G. Kimber, unpubl. data).

Mr J. W. Horsington of Bulgroo Station, west of Adavale, wrote to *The Australasian* in 1913 that ‘When I came to the bush 40 years ago the bilbi was in thousands. Then they disappeared, but now they are about again and increasing . . .’ (Horsington 1923, p. 50). Horsington seems to have worked on multiple properties around Windorah and Quilpie before taking up a series of properties east of Windorah sometime before 1917. A general comment by Ne-er-do-well (1905, p. 19) that ‘. . . all over Southern Queensland, west of the range, [the bilby] is fairly common. Rabbits get plenty of them, and their burrows are pitfalls, in places, for the unwary horseman. Bilby is not often seen, as his habits are nocturnal, but he is not particularly hard to catch. His winter coat is beautifully thick and soft, and a bilby-skin rug is more to be prized than many ‘possum rugs’ (Table 4).

**Table 3.** Vegetation communities likely to have been used historically by bilbies in Queensland (Qld) and New South Wales (NSW), on the basis of Regional Ecosystem (RE; Qld) and Plant Community Type (PCT; NSW) mapping, sorted by broad habitat type.

RE/PCT	Short description	Record areas
Clay plains		
4.3.17	Mitchell grassland on alluvial plains	South-western Qld <sup>A</sup>
4.3.20	Short grasses ± Mitchell grass and Chenopod spp. grassland to herbland on alluvial plains	South-western Qld <sup>A</sup>
4.4.1	Barley Mitchell ± other perennial grassland on clay overlying limestone	South-western/central-western Qld <sup>A</sup>
4.9.1a	Barley Mitchell ± other perennial grassland on Cretaceous sediments	Winton area, Qld <sup>A</sup>
4.9.2	Mitchell grassland on Cretaceous sediments	South-western Qld <sup>A</sup>
4.9.4	Mitchell grass and herbs grassland on Cretaceous sediments	Central-western Qld (north of Boulia)
4.9.5	Mosaic of Mitchell grassland to sparse forbland on Cretaceous sediments	South-western Qld <sup>A</sup>
5.3.21	Open herbland, <i>Cassia</i> open shrubland and bare scalded areas on infrequently flooded plains of watercourses	South-western Qld <sup>A</sup>
5.9.3	Mitchell grass and herbs on Cretaceous sediments	South-western Qld <sup>A</sup>
5.9.4	Keronsene grass sparse grassland on Cretaceous sediments with dense gravel cover	South-western Qld <sup>A</sup>
5.9.5	Chenopod-dominated open herbland on Cretaceous sediments	South-western Qld <sup>A</sup>
6.3.13	Chenopod and Asteraceae spp., and/or short grasses open herbland on alluvial plains	Central-southern Qld (Tinnenburra, Bulgroo)
43	Mitchell grass grassland–chenopod low open shrubland on floodplains	Western NSW (Menindee, Tambua)
60	Black oak–western rosewood–bluebush/saltbush low sparse woodland on gravel downs	Western NSW (Menindee, Tambua Ivanhoe)
61	Mitchell grass–saltbush grassland/shrubland of the gibber downs	Western NSW (Menindee)
150	Bottleshaker–copperburr grassland	Western NSW (Fowlers Gap, Tambua)
153	Black bluebush low open shrubland on alluvial plains and sandplains	Western NSW (Ivanhoe, Mossgiel)
164	Cotton bush open shrubland on plains	Western NSW (Ivanhoe, Mossgiel)
166	Disturbed annual saltbush forbland on clay plains and inundation zones mainly of south-western NSW	Western NSW (Menindee, Ivanhoe, Moolah)
Alluvial sand ridges/plains		
4.3.10	Western bloodwood and ghost gum open woodland on levees of major watercourses	Central Qld (Barcoo River)
6.3.16	White cypress pine, ironwood, wilga ± mulga woodland on alluvial dunes	Central-southern Qld (Bollon)
6.3.17	Bloodwood/ironbark/coolibah apple/white cypress pine woodland on levees of major watercourses	Central Qld (Maranoa and Warrego Rivers)
6.6.1	Mixed tall open shrublands on reticulate dunes over alluvium	South-central Qld (Bollon)
	White cypress pine/bloodwood/silver-leaf ironbark woodland on alluvial plains	Central-southern Qld (St George)
1z1.3.19		
19	White cypress pine woodland of dunes mainly on the Murray and Murrumbidgee River floodplains	Central-southern NSW (including Narrandera)
28	White cypress pine open woodland of sand plains, prior streams and dunes	Central-southern and western NSW
80	Western grey box–white cypress pine tall woodland on loam soil on alluvial plains	South-western NSW (Peak Hill, Barrabadeen, Ardlethan, Illabo)
248	Mixed box eucalypt woodland on low sandy-loam rises on alluvial plains	Central-western NSW (Gilgandra, Dubbo)
376	Mixed scrub low open woodland on sand rises and dunes on floodplains	North-central NSW (Darling Riverine Plains and Brigalow Belt South Bioregions)
Other sand dunes		
5.6.8	Sandhill canegrass ± spinifex and shrubs on mobile crests and slopes of sand dunes	South-western Qld <sup>A</sup>
Sandplains/loamy flats		
5.6.6	Spinifex hummock grassland wooded with mixed shrubs and trees on sandplains	South-western Qld (east of current range)

(Continued on next page)

Table 3. (Continued).

RE/PCT	Short description	Record areas
23	Yarran tall open shrubland of sandplains and plains	Western NSW (Ivanhoe, Moolah)
57	Belah/black oak–western rosewood–wilga woodland	Central-western NSW (Ivanhoe, Mossgiel, Hillston)
58	Black oak–western rosewood open woodland on deep sandy loams	Western NSW (Menindee, Mt Manara, Moolah)
59	Belah–western rosewood–leopardwood low open woodland on sandplain and sandy flats	Central and north-central NSW (Tambua, Gingie)
70	White cypress pin woodland on sandy loams	Central NSW (Dubbo, Ardlethan)
82	Western grey box–poplar box–white cypress Pine tall woodland on red loams	Central-western NSW (Barellan)
125	Mulga–ironwood shrubland on loams and clays	Central-western NSW (Cobar)
128	Nelia tall open shrubland of semi-arid sandplains	Western NSW (Menindee, Mount Manara, Fowlers Gap)
139	Prickly wattle tall open shrubland of dunes and sandplains	Western NSW (Menindee, Fowlers Gap)
174	Mallee–gum coolabah woodland on red earth flats	Western-central NSW (Mossgiel, Hillston)
Residuals		
4.7.1	Lancewood ± <i>Eucalyptus</i> spp. low woodland on scarps and margins of lateritic plateaus	South-western Qld (east of Boulia)
4.9.13	<i>Senna</i> spp. ± <i>Acacia</i> spp. open shrubland on Cambrian limestone residuals	South-western Qld <sup>A</sup>
5.7.10	Sparse annual grassland with scattered shrubs on weathered Cretaceous sediments	South-western Qld <sup>A</sup>
108	Gum coolabah–mulga open woodland on gravel ridges	Central-western NSW (Cobar)
155	Bluebush shrubland on stony rises and downs	Western NSW
Wetlands		
4.3.4	Coolibah open woodland on drainage lines in clay and limestone landscapes	South-western Qld <sup>A</sup>
6.3.11	Seasonal swamps; mixed herblands and eucalypts in closed depressions on broad sand sheets	South-central Qld (Bollon)
24	Canegrass swamp tall grassland wetland of drainage depressions, lakes and pans of the inland plains	Western NSW (Menindee Lakes, Riverina)
62	Samphire saline shrubland/forbland wetland of lake beds and lake margins	Western NSW (Menindee Lakes)
152	Lunette chenopod shrubland	South-western NSW (Menindee Lakes)
198	Sparse saltbush forbland wetland of the irregularly inundated lakes	Western NSW (Menindee Lakes)
212	Chenopod low open shrubland–ephemeral forbland saline wetland on occasionally flooded pale clays	North-central NSW
NSW South Western Slopes		
266	White box grassy woodland on gentle slopes	Central-southern NSW (Gumble, Molong, Pine View)
267	White box–white cypress pine–western grey box shrub/grass/forb woodland	Central-southern NSW (Wagga Wagga, Illabo)
277	Blakely's red gum–yellow box grassy tall woodland	Central-southern NSW (Wagga Wagga, Illabo, Wallendabean)

<sup>A</sup>Denotes currently occupied by bilbies in south-western Queensland.

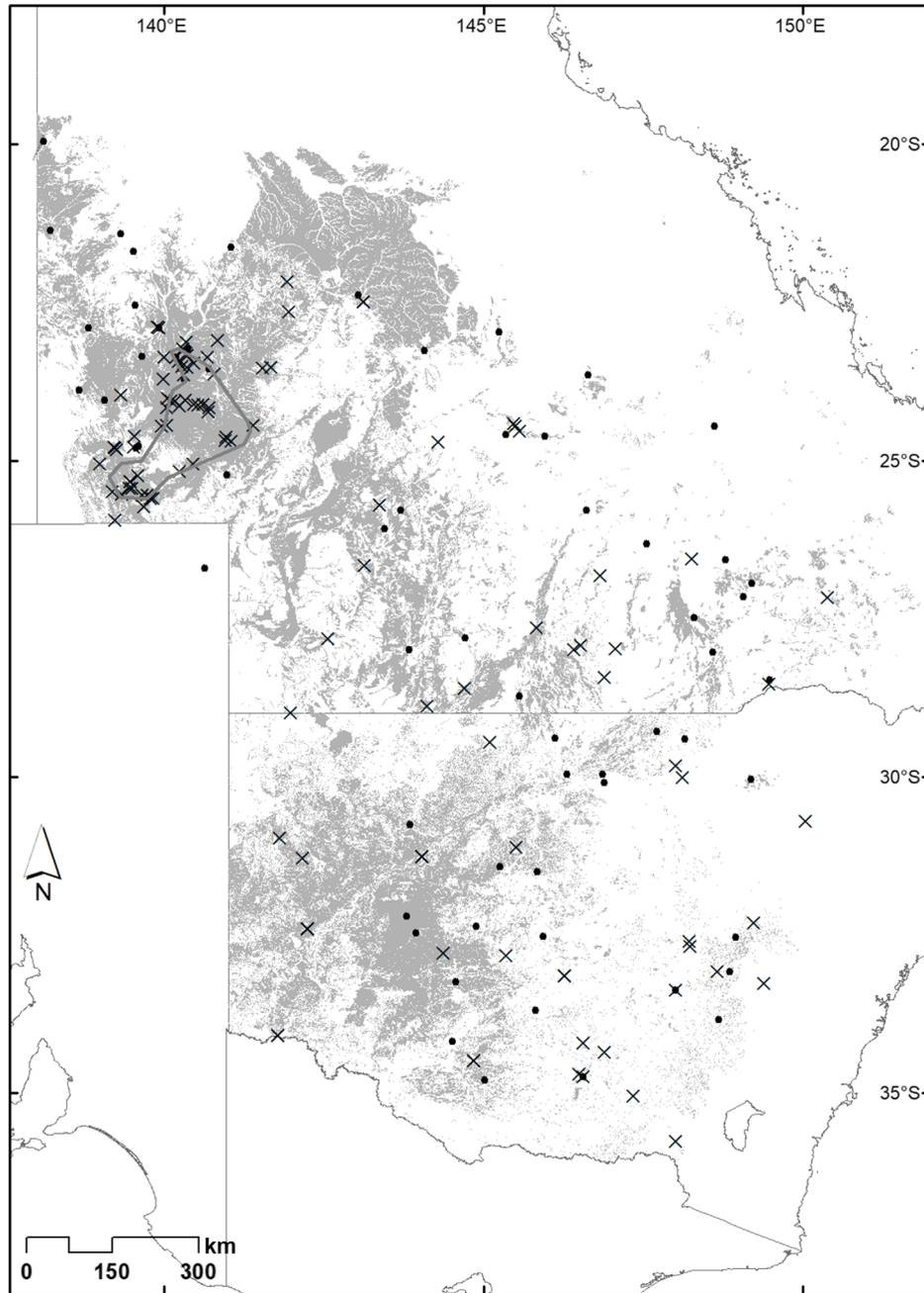
## Discussion

### Increase in known historical range and occupancy

This study has provided improved certainty around the historical range of bilbies in eastern Australia. The broad distribution remains similar to the estimated 1836 distribution presented in Southgate (1990b). However, Southgate's (1990b) BIOCLIM modelling of sparse records predicted a wider northern and eastern former distribution in Queensland

than our study suggests, and a more southern distribution into Victoria (Fig. 2). Conversely, the records presented here have substantially increased the known and predicted south-eastern range of the species. Our work adds substantially to the most recent collation of historical records presented in Woinarski et al. (2014).

The former distribution of the bilby falls roughly within the 600 mm rainfall isohyet (Fig. 1), with the exception of the south-eastern NSW records that are in higher-rainfall areas. Some of the outlying records in eastern Queensland and north-western NSW are of only moderate reliability and are



**Fig. 5.** Vegetation communities that were likely to be occupied by *Macrotis lagotis* in Queensland and New South Wales in 1850. This encompasses 18 Regional Ecosystems in Queensland (Queensland Herbarium 2021) and 28 Plant Community Types in NSW (Department of Planning and Environment 2022). High-precision records (<30 km) are shown as crosses, lower-precision records as dots.

likely to remain unverified. However, the Alpha sighting record in eastern Queensland reported by Gordon *et al.* (1990) was previously 400 km from the nearest known record, but is only 100 km from newly documented records along the Barcoo River (Figs 1, 3) and now appears plausible. This study has provided context for other formerly outlying records, notably the Surat and Bulgroo specimens in Queensland

(Figs 1, 3), which were previously separated from the nearest known populations by hundreds of kilometres. The results presented here have shown a much more contiguous occupancy within eastern Australia than was previously recognised.

We found limited new evidence to support the inferences of Scarlett (1969), Menkhorst and Seebeck (1990) and Southgate (1990b) that bilbies once occurred in Victoria.

**Table 4.** Localities and dates with *Macrotis lagotis* abundance recorded, eastern Australia. Observations appear chronologically.

Location (bioregion)	Date	Quotes	References
Coombie (Cobar Pedepain)	1877	'[the bilby] . . . is found everywhere, almost, up here, in great number.hey swarm here in almost incredible numbers.'	Anon. (1877)
St George–Surat–Goondiwindi (Brigalow Belt South)	~1870s	'When I was a lad . . . bilbies were numerous from Goondiwindi to St. George . . . ' However, V.E. Wehl, writing of the Warroo Shire just to the north considered '[the bilby] has always been scarce and, only if caught in a beam at night is it seen. So it is rather difficult to judge their numbers. The fact that they are rarely seen, suggests they are a rarity.'	Gunn (1937); Armstrong (1970)
Lower Lachlan River and Darling Pastoral District (Riverina, Murray Darling Depression)	Pre-1880s	'Upon one run where bilbah warrens were very numerous, out of 50 of which our correspondent examined, 20 were inhabited by rabbits. It appears from the numerous deserted warrens throughout the scrubby country in this district, that bilbahs have been very numerous, they are now seldom seen..'	Anon. (1882)
Barcoo River between Tambo and Blackall (Mitchell Grass Downs)	Early to mid-1880s	'Fifteen years ago [~mid-1800s; the bilbi] was to be found on many of the sand ridges upon the Barcoo River, between Tambo and Blackall, where their burrows were often to be met with . . . My wife kept one as a pet for nearly 12 months . . . ' An area of burrows ~1/4 acre noted two miles from Blackall in 1894.	Anon. (1894); R.A.R. (1898); Anon. (1912)
Narrandera (Riverina, NSW South Western Slopes)	Late 1880s–1900s	Bilbies able to be legally destroyed by pastoralists; 101 skins taken in 1887. 40 apparently taken in rabbit traps four miles from Narrandera in 1900. Two seen circa 1919 near Barellan appear to have been the last seen in the district. Word 'Hunthawang' recorded as meaning 'a lot of bilbies' in a list of Aboriginal words recorded around Narrandera.	Gunther (1896); Scotty the Wrinkler (1900); Gow (1947)
'Upper Lachlan' (NSW South Western Slopes)	Late 1880s	' . . . there are any number of [bilbies] on the upper Lachlan. I have now in my possession over fifty pure bilby skins.'	Bunny (1888)
Glenormiston area (Mitchell Grass Downs)	1890s	'Bilbies are fairly numerous'	Coghlan (1895)
Cobar area (Cobar Pedepain)	1890s	' . . . so well known in the district about 60 years ago'	Kinghorn (1949)
Wagga district (NSW South Western Slopes)	1895	'rarely found'	Anon. (1895)
Goulburn district (South Eastern Highlands)	1890s	' . . . a night prowler [bilby] that was common'; one reared as a pet	Anon. (1897)
Yanda Station, south of Bourke (Cobar Pedepain)	Until early 1900s	'The bilby . . . was very plentiful and was an important article of food obtained by the women, because it was possible to dig it out of its burrow.'	Dunbar (1943–44)
Yuwaalayaay and Ngiyampaa country, north-central NSW (Darling Riverine Plain; Brigalow Belt South)	Early 1900s	'Common'; important part of diet of Ngiyampaa people on Darling River	Langloh-Parker (1905); Kamien (1978)

One correspondent wrote that 'So far as I know, the bilby has never been found in Victoria, though I should have expected to hear of it in the Mallee country . . .' (Anon. 1912, p. 50). Twenty years later, from Shepparton, C. W. (1932, p. 4) inquired to 'Nature Notes' as to the status of the bilby, which was 'once familiar in parts of Victoria, NSW and South Australia'. The description of 'C. W.' makes it clear that he was familiar with bilbies. The former occurrence of the bilby in Victoria thus remains uncertain; however, it is considered to be likely, especially given the occurrences in NSW within 20 km of the Victorian border in multiple locations (Fig. 2; Southgate 1990b).

There are also interesting absences. Zoological collector Kendall Broadbent spent over 2 months in Charleville in the spring of 1885 and collected burrowing bettongs and a bridled nail-tail wallaby (Van Dyck 2005), but did not mention or

collect bilbies. Bilbies are recorded from the south, west, east and north of Charleville, and stated to have been 'common along the Warrego . . . especially in the region between Charleville and Aramac' (W. H. F. 1900). However, it is possible that their distribution along the Warrego was patchy rather than continuous. Similarly, bilbies are recorded south of Mitchell along the Maranoa River (Smith 1905) and inferred to have occurred generally throughout the district (Covacevich and Couper 1996); however, long-term residents on the upper to mid-reaches have no recollections of bilbies or historical bilby records (B. Struss, pers. comm. October 2021).

### Habitat use

The habitat preferences of bilbies in eastern Australia were much wider than recorded for central and western Australia and within their present range in western Queensland

(McRae 2004; Woinarski *et al.* 2014). Bilbies were commonly recorded as occurring on sand ridges and palaeochannels along major river systems throughout their range in eastern Australia, and other widespread habitat types including limestone and calcrete outcrops, sandy and loamy plains and the margins of ephemeral lakes were also widely used. This suggests that their environmental tolerances at a range of scales are broad, provided suitable burrowing substrate and food resources are present. Nevertheless, mapping of likely former habitat shows that their distribution was probably patchy particularly in the more mesic eastern part of their distribution. The role of bilbies as ecosystem engineers is well established (Read *et al.* 2008; Bowker *et al.* 2013; Chapman 2013), and the results presented here showed that they were sufficiently widespread and numerous to have had substantial effects across much of inland eastern Australia prior to the 1920s.

### Pattern and apparent drivers of decline

The decline of the bilby in eastern Australia was noted as early as the 1860s (Krefft 1862). However, the major contractions in range seem to have occurred in the first decade of the 1900s in western NSW, and possibly a decade later in Queensland (Fig. 3). Up until 1900, bilbies were described as abundant in many places throughout eastern Australia; however, they were not described as being 'abundant' or 'common' outside of their current range in south-western Queensland after about 1905. They went from being abundant in many areas of NSW in the early 1880s to rare and being on the verge of local extinction within two decades. The last ones were seen around Bathurst, NSW, in about 1910 (Kinghorn 1949). They had disappeared from St George in southern Queensland by the 1930s (Gunn 1937).

Their demise seems to have been quite uniform across habitat types, and to have occurred in a wave from the south (Fig. 3). Observers in many districts dated the bilby's demise to the arrival of rabbits from the 1880s ('Westerner' 1926; Rolls 1969), sometimes in conjunction with stock (McDonald 1923). The decline coincides most closely with the expansion of rabbits and foxes from the south (Fairfax 2019), although other factors, including livestock grazing, cat predation and direct human hunting may also have contributed to declines. The apparently central role of foxes in the bilby's decline is supported by the fact that bilbies typically persist in areas with no or low density of foxes (Southgate 1990b; McRae 2004). Although bilbies have declined from pastoral country across much of Australia, the majority of their current range in Queensland is grazed by cattle. The impact of grazing on bilbies remains a major knowledge gap.

There seem to have been seasonal fluctuations in bilby numbers, as has been noted in Western Australia, the Northern Territory, NSW and south-western Queensland (Rolls 1969; Southgate 1990b; McRae 2004), and ongoing monitoring of

remaining populations is required to discern long-term trends.

### Future research directions

This study has highlighted the value of Trove and other digitised resources for natural history research. Other archives, particularly personal ones such as R. G. Kimber's (a small section of which was utilised in this study) remain undigitised, and this work should be a priority. Aerial burrow sightings from Winton and Julia Creek remain unverified and should be ground-truthed, because they occur within suitable habitat and close to areas identified as potential habitat using Maxent. The data presented here provide important context for identifying key threats and suggesting potential areas for future translocations, which will become necessary as existing translocated populations increase within predator-proof enclosures with finite carrying capacities (Woinarski *et al.* 2014; Berry *et al.* 2019).

Surveys are currently underway throughout the contemporary range of the bilby in Queensland, including revisiting 1990s sites. These surveys will provide detailed data on changes in distribution and occupancy between the 1990s and present. The historical records collated here, improved knowledge of suitable habitats and Maxent modelling based on the historical records, will inform additional locations for these surveys, particularly to the west, south-east and north of the bilby's known contemporary range, and provide important context for inferring long-term trends in bilby distribution.

### Supplementary material

Supplementary material is available [online](#).

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