Evaluating the status of species using Indigenous knowledge: novel evidence for major native mammal declines in northern Australia

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Abstract

A small series of recent monitoring studies has reported major declines for many native mammal species in localised regions in northern Australia. However, the broader spatial context of these studies is uncertain. This study aims to assess the extent and timing of change in mammal status across a broad area of northern Australia (the monsoonal tropics of the Northern Territory). Indigenous information about terrestrial native mammal fauna (excluding bats) was compiled from a large series of interviews conducted across Indigenous communities. A collection of mammal skins was used to help facilitate discussions and verify identifications. The resulting information was analysed with non-parametric statistics to test for changes in mammal status across different time periods, between different regions, and between different groups of mammal species. Declines were reported as extending from the earliest memory of informants, but the rate of decline has increased recently. These changes were reported across all five regions within the broad study area and were greater for "critical weight range" species than for other species. Indigenous participants suggested several factors were associated with the changing status of species. The study's results reveal a pattern of widespread decline in the mammal fauna of the monsoonal tropics of northern Australia, thereby corroborating the conclusions of recent more local wildlife monitoring studies. The study also demonstrates the value and capability of Indigenous ecological knowledge to complement and corroborate more intensive and local scientific studies. The results reinforce concern for the conservation status of the mammal fauna of northern Australia.

Keywords: conservation, threatened species, traditional ecological knowledge, ecological monitoring

1. Introduction

Since European colonisation, Australia has suffered a catastrophic loss of native mammals, with the extinction of at least 22 species, and a further eight species persisting only as residual populations on offshore islands. The extinctions have been non-random, being more likely in larger rodents, larger dasyurids (quolls and phascogales), smaller macropods and bandicoots (species characterised as “Critical Weight Range” (CWR): (Burbidge and McKenzie 1989; Chisholm and Taylor 2007). A feature of the declines and extinctions is that they are not so much in regions characterised by intensive development and land clearing (the driving force of biodiversity decline across much of the world), but rather in relatively natural arid and semi-arid areas, such as central Australia (McKenzie et al. 2007). Further, the declines and extinctions are not some now closed and regrettable episode of past colonial history, but rather an ongoing pattern, with continuing decline for many species. Even some of the extinctions have been relatively recent: for example the last known records of the central hare-wallaby (*Lagorchestes asomatus*) and the desert bandicoot (*Perameles eremiana*) were reported by Aboriginal informants to Burbidge *et al*. (1988) to be around 1960 and around 1970 respectively.

Recent evidence indicates a major decline in components of the mammal fauna of parts of monsoonal northern Australia, a region previously considered relatively secure (Burbidge and McKenzie 1989). Evidence for that decline derives from monitoring programs (Russell-Smith et al. 2009a; Woinarski et al. 2010; Woinarski et al. 2004b; Woinarski et al. 2001) and comparisons of recent surveys with historical accounts or – in a few cases only – subfossil material (Braithwaite and Griffiths 1994; Cramb and Hocknull 2010; Dahl 1897; Kitchener 1978; Kutt et al. 2005; McKenzie 1981; Short and Calaby 2001; Start et al. 2011; Winter and Allison 1980). However, this evidence base is sparse and localised and there are examples of inconsistency with the predominant trends of decline, most notably in the higher rainfall and most rugged areas of the north Kimberley, where the mammal fauna remains relatively stable (Start et al. 2011; Start et al. 2007). The limited number of monitoring programs, their relatively brief temporal span, and the sparse historical record all serve to constrain extrapolations or interpretations of coherent spatial and temporal patterns of change, and hence of the causal factors contributing to such change (Woinarski et al. 2011a).

To attempt to overcome these limitations, we sought to document Indigenous knowledge of the changing status of the native terrestrial mammal fauna in a systematic assessment across a large component of northern Australia, the monsoonal tropics of the Northern Territory. We focussed especially on areas that were under-represented in scientific surveys such as Aboriginal lands. The use of local and/or Indigenous knowledge is increasingly recognised for its value to contemporary natural resource management and biodiversity conservation (Berkes et al. 2000; Huntington 2000), and has been applied to help assess species status and distribution and to aid ecological monitoring (Anadon et al. 2009; Ferguson et al. 1998; López-Arévalo et al. 2011; Mallory et al. 2003; Moller et al. 2004; Ramstad et al. 2007; van der Hoeven et al. 2004; Ziembicki and Woinarski 2007). The present study is based on and complements a comprehensive review of Indigenous knowledge of the changing status of the mammal fauna of central Australia (Burbidge et al. 1988), which provided a historical depth and continuity, and geographic breadth, far surpassing the information base derived from non-Indigenous sources.

As with all ethno-ecological studies, there are constraints in the approach and its interpretation. Particularly in more traditional communities, there may be linguistic and interpretational challenges; scientific taxonomy may poorly match Indigenous classification systems (e.g., Bradley et al. 2006; Davis 1981; Waddy 1988), particularly for some small mammal groups that have little cultural importance; some Indigenous knowledge may be culturally sensitive and considered not appropriate for public sharing; chronology may be imprecise; without the context of live animals behaving naturally in the wild, identification from pictures or specimens may be artificial, challenging or ambiguous; most Indigenous people have moved from permanently living on their clan estates to more centralised living in larger towns; in many communities, lifestyles have changed such that far fewer people are still involved in regular and traditional bush activities leading to 'shifting baselines' and the loss of knowledge between generations (Turvey et al. 2010); information from an individual source may be difficult to corroborate; validation and integration of indigenous and scientific knowledge systems may be challenging (Gratani et al. 2011); across most communities in this study area, decades of involvement with pastoralism may have overlaid the tenets of traditional management; it may be difficult to contextualise highly localised expertise (Wohling 2009); and lamentable health standards in most Indigenous communities have resulted in the survival of few individuals with long connection to their lands. At least some of these characteristics were more pronounced for this study than they were for the study of Burbidge *et al*. (1988) in central Australia more than 20 years previously. Where possible, we attempted to design our approach to accommodate these constraints or minimise their impacts, and our results are interpreted with regard to these factors.

The principal objective of this study was to document Indigenous knowledge of changes in the status of the native mammal fauna of the monsoonal tropics of the Northern Territory over a period of the last 50 or so years, the memory span of older Aboriginal people. More detailed information collated in this study concerning ecological knowledge of mammal species, uses made of those species, and language names will be documented separately.

We sought to assess the extent to which changes in status were consistent across different regions, whether any change in the status of native mammals was considered to be associated with a potentially causal factor, and the extent to which Indigenous information was consistent with the current scientific record. Where possible, we complement or corroborate the information derived in this study with some previous local ethno-biological accounts (Bradley et al. 2006; Dixon and Huxley 1985; Jones et al. 2010; Liddy et al. 2006; Raymond et al. 1999; Waddy 1988; Widijburru et al. 2010) although noting that these latter typically take the form of language dictionaries rather than documentation of conservation status.

This study has a particular focus inspired by concern about the conservation of native wildlife in northern Australia. But this study also seeks to illustrate the valuable and different environmental perspective of Indigenous people. There is only limited documentation of such information in contemporary Australian ecological literature, perhaps to the detriment of our ability to manage our natural environments.

2. Methods

2.1 Study region

The study area comprised the monsoonal tropics of the Northern Territory, extending south to about 19°S, approximately the northern border of the area considered in the analogous previous study by Burbidge et al. (1988). Except where indicated, our study was restricted to mainland areas. The study region is characterised by marked seasonality with distinctive wet and dry seasons, with rainfall declining steeply from the northern coast to the inland south (Hobbs et al. 1998).

There is relatively little topographic variation across this area, although the rugged terrain of the western Arnhem Land escarpment and plateau is notable in providing some microclimatic and fire refuge to many plant, and some animal, species (Woinarski et al. 2006; Woinarski et al. 2009). Eucalypt open forests and savanna woodlands comprise the most extensive vegetation types, with smaller areas of tussock grasslands, hummock grasslands, *Acacia* woodlands, *Melaleuca* forests and woodlands, mangroves and other coastal communities, *Terminalia w*oodlands and monsoon rainforests. In contrast to savannas in other parts of the world, Australia's tropical savannas are relatively intact (Woinarski et al. 2007a), with less than 2% of the region's native vegetation cleared (Woinarski and Dawson 2002). Pastoralism is the most widespread and dominant land use, extending over 46% of the study area (Hosking 2002), with other main land types comprising Indigenous lands (see below), mining, military training, and conservation reserves.

Approximately one third of the study region's population is Indigenous and a similar proportion of land is under Aboriginal control. Relative to some other parts of Australia, Aboriginal culture in the study area is relatively robust, particularly in Arnhem Land, one of the country's largest Aboriginal reserves. At the time of European settlement there were an estimated 48 Indigenous languages spoken across the region, with much of that diversity found along the coast (Horton 1994). However, largely as a consequence of historical events and past government policies (for example, the aggregation of Aboriginal people from their lands to centralised settlements), there has been a significant diminution in traditional Aboriginal practices and an associated erosion of traditional ecological knowledge and loss of Aboriginal languages (AIATSIS 2005; Nettle and Romaine 2000).

In terms of knowledge specific to wildlife, a fundamental change in familiarity and use was associated with the transition of Indigenous people's diet from traditional bush foods to western foods (NHMRC 2000; O'Dea et al. 1991). In general, Indigenous people no longer hunt or search for many of the mammal species that were formerly subsistence foods (REF; Altman 1987?). In such cases, the retention of knowledge associated with animals that are less used may become less relevant and the knowledge less detailed (Gilchrist et al. 2005; Turvey et al. 2010; Woinarski 2005). In Australia, the extent to which cultural relationships to the environment have been maintained differs between regions, groups, generations and individuals such that the intactness of traditional ecological knowledge is highly variable (Blythe and Wightman 2003; Chase and Sutton 1981). In addition, and regardless of cultural background or historical influences, much of the information solicited in this study is inherently susceptible to fading memories, mistakes and biases. To account for potential sources of variability and error we developed methods to help validate the information collated in this study (see below).

2.2 Interview methodology

Misidentification of species is a major impediment and source of bias in studies of this type. As an aid to identification and to facilitate discussions, we prepared mounted skins of most species of native terrestrial mammals (and some introduced mammals), wherever possible positioned in life-like postures. Skins were not prepared for some larger species (e.g. larger macropods, dingo), some unmistakable species (short-beaked echidna *Tachyglossus aculeatus*), and most bat species. In addition to specimens, we prepared large format books containing a range of photographs of all species. In some cases, we were able to coincide interviews with wildlife surveys that allowed for presentation of live specimens (e.g., Woinarski et al. 2011b). The native species targeted for consideration are listed in Table 1. Bats were not considered in detail, given that there is little discrimination between species in Indigenous knowledge systems (e.g. Davis 1981; Liddy et al. 2006; Raymond et al. 1999; Waddy 1988). Note also that some of the species listed in Table 1 only enter the study area at its inland margins.

Visits to communities were typically preceded by preliminary contacts with relevant Land Council staff and/or through personal introductions, to identify and seek the permission and involvement of appropriate elders, selected on the basis of in-depth traditional knowledge or continued hunting practice or connections with the land. Interviews were conducted at numerous communities, outstations and locations across the region between July 2005 and August 2009, with records obtained for 213 localities (Fig. 1; Table 2). A total of 134 participants (74 men, 60 women) ranging in age from 25 to 80 were interviewed.

All interviews were semi-structured with open-ended questions within an informal and flexible framework (Fig. 2). Interpreters were used to aid with interviews in order to use the local vernacular whenever possible in those communities where traditional languages are still spoken. Using local dialects is advantageous because much of the detailed traditional ecological knowledge is best conceptualised and more thoroughly expressed in the local vernacular (Maffi 2001; Telfer and Garde 2006). With the exception of the Tiwi people of Bathurst and Melville Islands and the Anandilyakwa people of Groote Eylandt, we interviewed people from most major extant language groups in the Top End.

For each species, informants were asked to provide: local language names; aspects of the species' ecology (i.e. habitat, shelter, diet, breeding biology, behaviour); whether the species was used as a food or for other purposes; and the locations the species is or was found in three general time periods: in the past when the informant was a young man or woman (nominally more than 20 years ago), in the recent past (up to 20 years ago) and the current status. For statistical analyses, these periods were subsequently denoted as ‘past’, ‘recent’ and ‘current’, respectively. When required, determining the timing (dates) of observations relied on using timelines whereby observations were related to significant events relevant to participants. For example, the birth of a child, the introduction of the vote for Aboriginal people or establishment of a settlement are significant events to which observations (such as the last sighting of a particular species) could be related and an approximate date for the observation determined retrospectively.

For each period, informants were asked to indicate whether the species was common (many individuals seen often), present in low numbers (some seen occasionally) or absent. Changes in these general classifications between periods allowed for a general assessment of status changes, but in addition, if notable changes had occurred informants were asked for the timing of changes (with dates identified as described above), and to detail factors thought to have contributed to changes. If the informant was uncertain about mammal status then the record was denoted as ‘unknown’.

In order to account for different levels of knowledge, we developed a system for ranking the reliability of collected information concerning mammal status and perceived changes, with this reliability assessment assigned separately for every record. Reliability codes used were: highly reliable (high confidence that the information was correct), of intermediate reliability (probable but uncertain) or of low reliability. These rankings were derived by cross-referencing each record against five criteria (Table 3). A point was allocated for an affirmative answer for each criterion resulting in a maximum score of 5. Reliability of the record was scored as high (4-5 points), medium (2-3 points) and low (0-1). A proviso for a medium or high score was that criteria (i) and (ii) were both satisfied. That is, that a correct identification was made and that the informant was resident or active at the location for the specified period or had tangible knowledge of the status of a species at the location (see supporting information online for a worked example of the interview technique).

The derived information base comprised a set of records, with each record including informant name, time period, abundance category, species, reliability and location.

2.3 Data presentation and analysis

Records derived for every species were mapped using the GIS software ArcMap v.9.3. Separate maps were included for each period with the location records depicted according to status (common, present, absent) and reliability score (high, medium, low). For records that were duplicated (i.e. where multiple informants gave the same location for a species), the most reliable record was used. Where reliability was even between status categories preference was given to records in the order common, present and absent. We tallied reliability ratings for all species and all time periods. For every species, and for every time period, we calculated a simple mean reliability index, based on the proportion of records with high (assigned a value of 2), medium (1) and low (0) reliability. To examine spatial patterns of changing status, we divided the study area into five broad regions (Table 4; Fig. 1). These regions differ with respect to rainfall, cultural and social history, and land use. Within each of the five regions, we tabulated all status assessments for location records for all species for the three time periods.

The information base in this study is descriptive and subjective. However, we use some simple and straightforward non-parametric statistics to analyse patterning within it. For every record, we assigned a score on an ordinal scale (common = 2, present = 1, absent = 0). Only records of medium and high reliability were used; low and 'unknown' records were omitted from the analyses. An overall measure of change between time periods (past, recent, current) was calculated for every species in every region, by subtracting an earlier record score from a later record score, for records from the same observer (for example, if informant A stated that northern quoll was common (=2) at site X in the past, present (=1) at that site recently, and absent (=0) at that site presently, then the status change score from the past to recent was -1, from recent to the present was -1, and from the past to the present was -2, for that species at that site. An average score was calculated for each species, period and region combination. To assess whether status change for individual species between the past and present was constant or variable between regions, we used Kruskal-Wallis analysis of variance. To assess whether status change for individual species was constant or variable between time periods (past to recent, recent to present), across all regions combined, we used Mann-Whitney U tests. Sites at which a given species was reported to be absent for all time periods were deleted from analyses for that species.

We used Mann-Whitney U tests to compare the status change for the set of CWR species with status change for the set of all other species, for each of the three time periods. We used Wilcoxon matched-pairs tests to compare the rate of decline for the two time periods, for all species combined and for the set of CWR species only.

3. Results

Summary maps of records for a selection of species that have undergone significant status change are presented in Fig. 3 (maps for 15 other species are presented in Fig. S3 in supplementary material online). As described in previous studies (Burbidge et al. 1988; Waddy

1988; White et al. 2009; Widijburru et al. 2010), most Indigenous participants in our study did not discriminate between morphologically similar species of small rodents (*Pseudomys, Leggadina, Melomys* species) or between similar species of small dasyurids (*Sminthopsis, Planigale, Antechinus, Pseudantechinus* species), and consequently little useful species-level information was obtained for these groups.

Table 5 summarises status change information across regions for those species with most records. Most of the 17 species considered declined over the period of the memory of Indigenous participants. Declines were particularly pronounced for the northern quoll, northern brush-tailed phascogale, black-footed tree-rat, northern brown bandicoot, and common brush-tailed possum. Few species increased, and such increases were relatively limited: the most pronounced increase was for agile wallaby.

Critical weight range species showed greater extent of decline than species not in the critical weight range, for all time span comparisons (past to recent $z=4.28$, $p<0.0001$; recent to current $z=3.55$ $p=0.0004$, past to current $z=5.70$, $p<0.001$).

Three species (common brushtail possum, agile wallaby and sugar glider) had status trends that differed significantly between regions. The most pronounced was for common brushtail possum, which increased in region 1 but decreased in all other regions. Three species (northern quoll, sugar glider and northern brush-tailed phascogale) had status trends that differed significantly between the two time periods (past to recent vs. recent to present). In each case, the decline was greater from recent to present than from past to recent; this was particularly the case for the northern quoll.

Across species, the extent of decline was greater for the span from recent to current time periods (mean change = -0.19, s.e.=0.02) than for the span from past to recent (mean change=-0.10, s.e.=0.02: Wilcoxon matched-pair test, z=2.98, p=0.003). This pattern was evident also for CWR species: mean change=-0.23 (s.e.=0.01) for recent to current and mean change =-0.14 (s.e.=0.02) for past to recent: z=2.41, p=0.016).

Across all species, declines occurred across all regions, but were least pronounced in the Victoria River District (VRD) and northern Tanami region. For CWR species, decline was more equitable across regions, although there was significant variation between regions for the time period past to recent, with least decline in the VRD and northern Tanami region (Table 6).

Indigenous participants suggested a range of factors were associated with the changing status of native mammal species. Among the cited reasons for perceived declines were the cessation or changes to traditional land management practices, particularly changes to fire regimes; the breakdown over traditional controls of hunting leading to over-exploitation (although the lack of hunting in at least one area was considered a reason for a local increase in agile wallaby numbers); and the effects of introduced animal species, most notably cane toads (*Rhinella marina*) poisoning northern quolls, feral cats (*Felis catus*) depredating a range of small to medium-sized mammals, and introduced pigs (*Sus scrofa*) adversely affecting the habitat of ground-dwelling species such as bandicoots.

Table 7 summarises the reliability scores assigned to all records for the most frequently reported species. The species for which records were most reliable were mainly larger species, those (still) hunted and those that are most unmistakeable. An apparent anomaly is the low reliability scores assigned for black wallaroo. For this relatively uncommon and restricted species, we had no display skin, and records may readily be confused with dark-furred individuals of the more abundant euro. There was a notable disparity between species in historic trends of reliability. For example, there was no historical trend in the reliability of records for the agile wallaby, a common species still avidly hunted. However, for many of the smaller species and for species for which hunting is no longer much practised (e.g. common brush-tailed possum), there is a clear trend for decreasing reliability in records from the past to current periods. Over all species, the mean reliability index declined significantly across the three time periods (past=1.83, recent=1.71, current=1.51; χ^2=139.6 (df=4), p<0.001).

4. Discussion

The results reported in this study are generally consistent with the relatively few and more localised considerations of change in the status of mammals reported in more general ethno-biological accounts and dictionaries. For example, White et al. (2009) reported that Warray speakers from the upper Adelaide and upper Finniss Rivers area (within our North-West Top End region) recognised decline in northern quoll up to the 1990s, with an accelerated rate of decline following the arrival of cane toads in that area since 2005, and decline in black-footed tree-rat and antilopine wallaroo. In the Victoria River area (within our VRD and northern Tanami region), Ngarinyman speakers reported declines of common brush-tailed possum, northern brush-tailed phascogale, and spectacled hare-wallaby (Widijburru et al. 2010). In the Daly River area (within our Central East Top End region), Malakmalak and Matngala speakers reported declines in common brush-tailed possum and water-rat. In the Katherine area (within our Central East Top End region), Jawoyn speakers reported decline in northern brush-tailed phascogale and brush-tailed rabbit-rat (Wiynjorrotj et al. 2005). In the Borroloola and Sir Edward Pellew Islands area (in our South-east Top End region), Yanyuwa people reported decline in northern quoll, northern brown bandicoot and common brush-tail possum (Bradley et al. 2006). In one contrast to our results, Liddy et al. (2006) reported that Wagiman speakers noted decline in agile wallaby in the Daly River area (within our Central East Top End region).

Our study sought to collate such local-scale information across broader regions, in order to develop a coherent and cross-validating pattern describing change in the status of mammal species in this extensive study area. Such combination of local-scale expertise serves to overcome the limitation of parochialism in Indigenous knowledge described by Wohling (2009). In our case, the consistency in results across different language groups and disjunct communities provides a compelling corroboration of broad-scale decline in much of this mammal fauna.

We recognise some limitations in this study. Indigenous participants provided little information about many of the smaller native mammal species, and hence can provide no new insight for some of the smaller species of conservation concern, such as the Carpentarian rock-rat (*Zyzomys palatalis*) and water mouse (*Xeromys myoides*). Many of the participants were elderly, and no longer actively hunting in or managing their country, and hence their perception of the current status of mammal species may have been less reliable than the information supplied for past status. If so, this may not necessarily have introduced any consistent bias: such informants may simply have assumed that species were still as abundant as formerly (thereby falsely indicating a continued abundant status), or they may have equated their lack of recent sightings (due to their reduced time on country) as reduced abundance for these species (thereby falsely indicating a reduced abundance status).

The primary purpose of this study was to complement and contextualise a small set of recent monitoring studies that have reported substantial current decline of much of the mammal fauna of the monsoonal tropics of northern Australia (Woinarski et al. 2001, 2010). Those studies offer some numerical precision and were carefully designed to focus on trends in abundance, but they were undertaken in a relatively small area and extended over a relatively short time frame. The current study provides a very different approach, emphasising instead a broad geographic scope and a longer time frame. Our most compelling conclusion is that this approach strongly supports the results from those more localised monitoring studies: the mammal fauna of this area is undergoing substantial decline.

Across all regions demarked in this study, our informants reported declines for many native mammal species, with this decline most marked and/or uniform for a set of critical weight range species that were also shown to be declining in the localised monitoring studies. Such species include northern quoll, northern brush-tailed phascogale, northern brown bandicoot, black-footed tree-rat, and common brush-tailed possum. This study provided less evidence of decline for some other species considered threatened in the study area (Table 1), such as brush-tailed rabbit-rat, northern hopping-mouse, golden-backed tree-rat, golden bandicoot, Carpentarian rock-rat, Arnhem rock-rat and water mouse. In most cases, this is because these species are highly localised in the study area, and hence we were unable to obtain sufficient records from Indigenous participants to provide a statistical assessment from those sources of patterns of status change. However, in most cases, the few records we obtained for these species were consistent with ongoing decline (Fig. S1).

Information from Indigenous sources is consistent with published scientific accounts also for the species rated by Indigenous participants as showing most increase, the agile wallaby. A range of studies has shown this species to be increasing across much of the study area, particularly in pastoral areas, associated with the proliferation of artificial water points, baiting of dingoes, relaxed pressure from traditional hunting, and pastoral fire and stock management activities that seek to maintain “green pick” (Gooding and Harrison 1954).

Indigenous participants consistently reported declines for many species for the time period termed here “past” to “recent”. In most cases this period preceded the establishment of most current monitoring programs, and indicates that declines have been ongoing for at least several decades, although the trend data from the Indigenous informants suggests that the rate of this decline has accelerated to the current time period. This temporal patterning provides some limited insight into causality, suggesting factors that have been pervasive, cumulative and gradual in their operation, rather than sudden and episodic. As an example, the Indigenous participants consistently reported declines for northern quolls across all regions (as reported also through non-Indigenous information: Braithwaite and Griffiths 1994), with such decline preceding the arrival of cane toads, a factor that has more recently caused a marked increase in that decline rate.

Indigenous participants suggested a range of causal factors as having contributed to changes in mammal status. These generally correspond to prevailing scientific explanations. Foremost was the perceived effect of changes to traditional land management, especially the change to fire regimes. Under traditional fire management, small-scale, low intensity fires resulted in a mosaic of fire histories across the landscape (Bowman 1998). In contrast, contemporary fire regimes in northern Australia are dominated by more frequent, large-scale and intense fires (add ref: JRS book will do). Most respondents in this study generally referred to localised consequences of frequent, hot fires in terms of their effects on specific habitat attributes important to mammals (e.g., the destruction of hollow logs for shelter and reduced food availability). While few respondents specifically referred to the net effect of a landscape-scale mosaic of fire histories, some respondents highlighted the need for mammals to be able to move to adjacent unburnt patches, noting that they would return to feed on regenerating grasses on burnt patches later. Others suggested that areas that are not burnt frequently, such as rainforest patches and riparian zones, act as important refuges. Such statements at least implicitly suggest that many species prefer a mosaic of heterogeneous habitats and fire histories as documented by scientific studies (Pardon et al. 2003; Woinarski et al. 2004a).

Some elders explicitly highlighted the link between traditional land management and customary social and ceremonial practices, noting that the cessation of specific ceremonies (and associated land management practices) has directly led to the demise of particular species. Said one elder from central Arnhem Land: "We no longer do ceremony for those animals. That is why they have left". In this case, the elder was specifically referring to the cessation of burning a tract of land at a sacred site as part of a ceremony that occurred in the early dry season, a practice that resulted in favourable habitat conditions for bandicoots and wallabies.

Several respondents suggested the breakdown of traditional controls over hunting has led to over-exploitation in some cases. Other factors described that contributed to lower hunting sustainability included changes in tools and technology, such as the availability of vehicles and firearms that have made hunting potentially more efficient, changes to traditional systems of land tenure, fewer restrictions on seasonal rules for hunting and quantity and type of resource taken, and the diminution of laws associated with using taboo areas and totemic species. Introduced animals were also regarded as having negatively affected some mammal populations. Feral pigs were blamed for altering the habitat of ground-dwelling species (see also Robinson et al. 2005); feral cats were often implicated as predators of small to medium sized mammals; and cane toads were blamed for the decline of northern quolls. While no respondents specifically cited disease as a factor contributing to status change in the present study, Raymond et al. (1999) documented the concern of some Wardaman people of the central-east 'Top End' region of disease affecting common brush-tail possum populations in their region in the past.

Based mostly on historical evidence, the prevailing scientific perspective is that declines in the mammal fauna of northern Australia occurred initially and most severely in lower rainfall inland areas, and have extended into higher rainfall, coastal and more rugged areas appreciably more recently, if at all (Kitchener 1978; McKenzie 1981; Start et al. 2011; Woinarski et al. 2011a; Woinarski et al. 2001). The results from this study are inconsistent with that pattern of spatial progression. Instead, Indigenous participants reported declines occurring across all of the five regions defined for this study area, albeit with least decline in the lowest rainfall region, the VRD and northern Tanami. This inconsistency merits further attention. One possible explanation is that the declines in the lower rainfall areas preceded the memory span of our Indigenous participants, with some mammal species disappearing from these regions more than 50 years ago.

This study reflected on a period that spanned the gradual or acute diminution of fine-scale Indigenous management of country across much of monsoonal northern Australia and, with that reduced management input, a gradual erosion of aspects of traditional culture and knowledge (Woinarski 2005). In this study we were fortunate to work with some of the older generation most responsible for and most experienced in traditional management, with sometimes encyclopaedic knowledge of the nature of their country. This is an opportunity lost for many regions in Australia. However, in this region, it is an opportunity that has been capitalised on with cultural revival and the establishment of Indigenous ranger groups that seek to re-establish traditional management practices over large areas in order to maintain or restore ecological function. Part of this cultural regeneration has included closer collaborative ties between Aboriginal landowners and scientists through, for example, joint management of national parks (Smyth 2001), the re-introduction of traditional fire regimes (Russell-Smith et al. 2009b; Yibarbuk et al. 2001), and collaborative species management, research and conservation initiatives (Ens et al. 2010; Kennett et al. 2004; Telfer and Garde 2006). In this region, the fate of the native mammal fauna, and biodiversity more generally, may hinge on the retention, valuation and broader application of traditional knowledge (Russell-Smith et al. 2009b).

However, even in the region considered here, the information provided by the Indigenous participants decreased in reliability from the past to current reports, with the exception mostly of species still subject to targeted hunting. We interpret this superficially paradoxical result to the diminishing contact that many of these custodians now have with their country, perhaps along with diminishing acuity of observational skills for older participants. This interpretation suggests that the intimate knowledge of country that characterised the youth of these people is fading. Unfortunately, in many cases, the generational transfer of knowledge has been lost, and it is likely that this will erode particularly the information base for species that are no longer valued for food or cultural reasons – the so-called ‘shifting baselines’ phenomenon (Pauly 1995; Turvey et al. 2010). Perhaps another reason for the diminishing reliability of these wildlife observations is the rapidity of status change in many native species, including some that were the major focus of this project. For many of the Indigenous people consulted in this study, the unexpected disappearance of many native animals – and in some cases, their usurpation by non-native species - renders their country increasingly unfamiliar, and destabilises their former certainty of knowledge.

This study introduces methods that may be more broadly applicable to similar studies that aim to use local or indigenous knowledge in other cultural and conservation contexts. The inherent nature of the information collected here, the variability in the intactness and detail of knowledge, the differing approaches of local or Indigenous knowledge systems compared with science and that such information is largely qualitative point to the need for validating such information (Gilchrist and Mallory 2007; Gilchrist et al. 2005; Sinclair et al. 2010). We note that there are varying opinions on the need and means by which to do this (Brook and McLachlan 2005; Dickison 2009; Gilchrist and Mallory 2007; Gilchrist et al. 2005; Gratani et al. 2011). The present study, building on the work of Burbidge et al. (1988), uses a system to assess reliability of data that compares information both against itself (i.e. by corroborating against knowledge from indigenous participants collected within the study) and against data collected from scientific studies. In doing so it enables a more rigorous use of such information while using the richness of Indigenous knowledge in a meaningful and respectful way. By demonstrating congruence between Indigenous and scientific perspectives, Gratani et al (2011) noted that their Aboriginal collaborators supported the scientific validation of their knowledge because it proved to scientists the legitimacy of their knowledge and thereby offered better opportunity to engage with government agencies and non-indigenous communities. Our study similarly demonstrates the value and capability of Indigenous ecological knowledge to help address one of Australia's most pressing biodiversity conservation issues, the decline of a its native mammal fauna, and it supports arguments for greater recognition of this perspective.

In concert with more localized studies, our investigation contributes to an increasing body of evidence suggesting ongoing, extensive and rapid declines of small- and medium-sized mammals in northern Australia. Given the entirely independent and contrasting protocols used here compared with conventional scientific monitoring approaches this general conclusion is increasingly robust and reinforces the concern for the conservation status of the region's mammal fauna.

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Table 1. List of target mammals considered in this study. Critical Weight Range (CWR) mammals are those weighing between 35 g to 5.5 kg. Identification cues (ID) used in interviews included; mounted life-like specimen (M), museum skin (S), photograph (P), not specifically discussed (-). Status relates to conservation status in the Northern Territory (Woinarski et al. 2007b): Extinct (EX), Critically Endangered (CR), Endangered (EN), Vulnerable (V), Near Threatened (NT), Least Concern (LC) and Data Deficient (DD). Note that this listing excludes bats and introduced species which were not considered in the current study, and includes some species whose occurrence is marginal.

Species name	Common name	CWR	ID	Status
Antechinus bellus	fawn antechinus	no	M	DD
Bettongia lesueur	burrowing bettong	yes	M	EX
Canis lupus dingo	dingo	no	P	LC
Conilurus penicillatus [b c]	brush-tailed rabbit-rat	yes	M	VU
Dasyurus hallucatus [a c]	northern quoll	yes	M	EN
Hydromys chrysogaster [b c]	water-rat	yes	M	LC
Isoodon auratus	golden bandicoot	yes	S	EN
Isoodon macrourus [a c]	northern brown bandicoot	yes	M	LC
Lagorchestes conspicillatus [b c]	spectacled hare-wallaby	yes	S	NT
Leggadina lakedownensis	tropical short-tailed mouse	no	P	LC
Macropus agilis [a c]	agile wallaby	no	M	LC
Macropus antilopinus [b c]	antilopine wallaroo	no	P	LC
Macropus bernardus [b c]	black wallaroo	no	P	DD
Macropus robustus [b c]	euro	no	P	LC
Macropus rufus	red kangaroo	no	P	LC
Macrotis lagotis	bilby	yes	P	VU
Melomys burtoni	grassland melomys	no	S	LC
Mesembriomys gouldii [a c]	black-footed tree-rat	yes	M	NT
Mesembriomys macrurus	golden-backed tree-rat	yes	M	CR
Notomys aquilo [b]	northern hopping-mouse	yes	M	VU
Notoryctes typhlops [b]	marsupial mole	no	P	VU
Onychogalea unguifera [b c]	northern nail-tail wallaby	no	M	NT
Petaurus breviceps [b c]	sugar glider	yes	M	LC
Petrogale brachyotis [b c]	short-eared rock-wallaby	yes	S	LC
Petrogale concinna [b]	nabarlek	yes	S	NT
Petropseudes dahli [b c]	rock ringtail	yes	P	LC
Phascogale pirata [a c]	northern brush-tailed phascogale	yes	M	VU
Planigale ingrami	long-tailed planigale	no	P	LC
Planigale maculata	common planigale	no	M	LC
Pseudantechinus bilarni	sandstone antechinus	no	P	LC
Pseudantechinus mimulus	carpentarian antechinus	no	P	EN
Pseudantechinus ningbing	ningbing antechinus	no	P	NT
Pseudomys calabyi	Kakadu pebble-mound mouse	no	P	NT
Pseudomys delicatulus	delicate mouse	no	P	LC
Pseudomys desertor	desert mouse	no	-	LC
Pseudomys hermannsburgensis	sandy Inland mouse	no	-	LC
Pseudomys johnsoni	central pebble-mound mouse	no	P	NT
Pseudomys nanus	western chestnut mouse	yes	P	NT
Rattus colletti [b]	dusky rat	yes	M	LC
Rattus tunneyi	pale field-rat	yes	M	NT
Rattus villosissimus	long-haired rat	yes	S	NT
Sminthopsis bindi	Kakadu dunnart	no	P	LC
Sminthopsis butleri	Butler's dunnart	no	P	VU
Sminthopsis macroura	stripe-faced dunnart	no	P	LC
Sminthopsis virginiae	red-cheeked dunnart	yes	M	LC
Tachyglossus aculeatus [b c]	short-beaked echidna	yes	P	LC
Trichosurus vulpecula [a c]	common brushtail possum	yes	M	LC
Xeromys myoides [b]	water mouse	yes	P	DD
Zyzomys argurus	common rock-rat	yes	P	LC

Zyzomys maini	Arnhem Land rock-rat	yes	P	VU
Zyzomys palatalis	Carpentarian rock-rat	yes	P	CR

[a] species for which status maps are presented in Figure 3.
[b] species for which status maps are presented online in Figure S3.
[c] species for which adequate data facilitated quantitative assessment of status change (Table 5).

Table 2. Summary of interviews conducted during the study. Note that interviews were often held in larger communities or outstations and that participants may have originated from or referred to surrounding locations (see also Fig.1 and Table S2).

ID	Interview location	Region	Date (month/year)	Number of interviews	Number of participants
1	Araru	1	Jul-06	1	2
2	Balma	3	Oct-06	1	1
3	Binjarri	2	Aug-07	2	4
4	Borroloola	5	May-08	3	6
5	Bulman	3	Aug-06	2	4
6	Darwin	1	Nov-07, May-08	2	4
7	Dhalingbuy	3	Oct-06	1	3
8	Gapuwiyak	3	Oct-06	1	1
9	Jilkmiggnan	2	Oct-07	1	2
10	Kabulwarnamyo	3	Aug-06	2	7
11	Kakadu	2	Sep-05	3	4
12	Kalkarindji	4	May-08	2	6
13	Kamargawan	3	Jun-06, Oct-06	2	4
14	Kuy	2	Jul-06	1	3
15	Kybrook Farm	2	May-06	2	4
16	Lingarra	4	Jun-06	2	5
17	Maningrida	3	Nov-06	1	3
18	Mapuru	3	Nov-06	1	2
19	Mata Mata	3	Oct-05	2	7
20	Menngen	4	Aug-07	1	1
21	Minjilang	1	Jul-06	1	3
22	Minyerri	5	Oct-07	1	3
23	Ngukkur	3	Oct-07	1	3
24	Numbulwarr	3	Oct-07	2	8
25	Ramingining	3	Oct-06	1	1
26	Raymangirr	3	Oct-06	4	14
27	Robinson River	5	May-08	1	2
28	Timber Creek	4	Jul-06, Aug-07	2	5
29	Vanderlin Island	5	Aug-09	1	2
30	Wadeye	2	Jun-07	3	10
31	Wilgi	1	Jul-06	1	5
32	Yarralin	4	Jun-06, Jul-06	4	5
	TOTAL			55	134

Table 3. Criteria for assessing reliability of mammal status data.

	Criteria	Description
i	Correct identification or knowledge of local language name	• correct identification of species a prerequisite. • correct identification (and satisfaction of criterion) possible without knowledge of language name
ii	Informant is resident, is active in or is otherwise familiar with the specified location	• knowledge of status is contingent on familiarity with stated location specified for the given period either through residence at the location, use of the area or tangible experience (e.g. a relative recently collected a specimen from the location)
iii	Information is corroborated by others in the region	• data cross-validated by others in the region who gave the same or similar information but generally not by different individuals during the same interview (unless the interviewer was certain that information supplied was independent and not influenced by other group members).
iv	Consistency with scientific and/or historical data	• data cross-validated with other information sources • since scientific data do not exist for most specific locations, regional information may be acceptable if data are from relatively close proximity and consistent with habitat requirements.
v	Overall knowledge of informant is reliable	• informant is a recognised knowledge holder in the community and consistently scores medium to high reliability for other species

Table 4. Environmental, cultural and historical characteristics of five regional areas defined in the study for analysis of regional differences (see also Fig.1)

	Region	Environmental attributes	Cultural and historical attributes
1	North-west Top End	Highest rainfall area; relatively extensive modification; several large rivers	Includes a major urban area and rural properties, and large conservation reserves (Kakadu and Gurig National Parks)
2	Arnhem Land	High rainfall; includes the most rugged escarpment country	Incorporates most of Arnhem Land; recognised as the most culturally intact of the five regions
3	Central-east Top End	Moderate rainfall; major rivers include the Daly; some horticultural development	Mix of pastoral and extensive Indigenous lands; major Aboriginal communities include Wadeye
4	Victoria River District & northern Tanami Desert	Lower rainfall; some rugged areas; major rivers include the Victoria	Major pastoral region, with one large conservation reserve (Gregory National Park)
5	South-east Top End	Semi-arid; open woodland, Barkly Tableland includes areas of extensive open treeless black soil plains	Major pastoral region, with some extensive Indigenous lands

Table 5. Summary table of status change between time periods, and across regions. Time periods: T_0 = past, T_1=recent, T_2=current. Note that status change can vary between +2 (increase from absent to abundant) and -2 (decrease from abundant to absent). H is the statistic from Kruskal-Wallis ANOVA; p is probability level; z is z-score; and n/a is not applicable (unrecorded). Species are listed in alphabetical order of scientific names.

Species	Common name	Regional variation (T_0 to T_2): H (p)	Time period variation: Z (p)	Time period	Region (summary change index, (N of locations))					Whole study area
					North-west Top End	Arnhem Land	Central East Top End	VRD and northern Tanami	South-east Top End	
Conilurus penicillatus	brush-tailed rabbit-rat	n/a	1.00 (0.32)	T_0 to T_1	0 (3)	n/a	n/a	n/a	n/a	0 (3)
				T_1 to T_2	-0.33 (3)	n/a	n/a	n/a	n/a	-0.33 (3)
				T_0 to T_2	-0.33 (3)	n/a	n/a	n/a	n/a	-0.33 (3)
Dasyurus hallucatus	northern quoll	0 (1.0)	4.62 (0.0001)	T_0 to T_1	0 (13)	-0.86 (7)	-0.22 (23)	n/a	-1.00 (3)	-0.30 (46)
				T_1 to T_2	-1.80 (10)	-0.60 (5)	-1.21 (14)	n/a	-0.33 (3)	-1.22 (32)
				T_0 to T_2	-1.80 (10)	-1.83 (6)	-1.60 (15)	n/a	-1.33 (3)	-1.68 (34)
Hydromys chrysogaster	water-rat	8.0 (0.09)	0.07 (0.95)	T_0 to T_1	-0.11 (9)	0 (11)	-0.10 (21)	0 (6)	-0.38 (8)	-0.11 (55)
				T_1 to T_2	-0.13 (8)	-0.18 (11)	0 (21)	0 (5)	-0.38 (8)	-0.11 (53)
				T_0 to T_2	-0.25 (8)	-0.20 (10)	-0.10 (20)	0 (5)	-0.75 (8)	-0.24 (51)
Isoodon macrourus	northern brown bandicoot	19.5 (0.001)	1.72 (0.09)	T_0 to T_1	0 (12)	-0.08 (13)	-0.39 (23)	-0.67 (6)	-0.80 (5)	-0.31 (59)
				T_1 to T_2	-0.08 (12)	-0.55 (11)	-0.72 (18)	0 (6)	-1.00 (3)	-0.46 (50)
				T_0 to T_2	-0.08 (12)	-0.64 (11)	-1.17 (18)	-0.67 (6)	-1.67 (3)	-0.76 (50)

Lagorchestes conspicillatus	spectacled hare-wallaby	0 (1.0)	1.48 (0.14)	T_0 to T_1	n/a	0 (1)	0.07 (15)	0 (6)	0 (8)	0.03 (30)
				T_1 to T_2	n/a	0 (1)	-0.17 (6)	0 (2)	0 (6)	-0.07 (15)
				T_0 to T_2	n/a	0 (1)	0 (6)	0 (2)	0 (6)	0 (15)
Macropus agilis	agile wallaby	11.0 (0.03)	3.02 (0.003)	T_0 to T_1	0.33 (12)	0.08 (13)	0 (19)	0.15 (13)	0 (6)	0.11 (63)
				T_1 to T_2	0 (12)	0 (13)	-0.11 (19)	0 (13)	0 (6)	-0.03 (63)
				T_0 to T_2	0.33 (12)	0.08 (13)	-0.11 (19)	0.15 (13)	0 (6)	0.08 (63)
Macropus antilopinus	antilopine wallaroo	6.7 (0.16)	1.06 (0.29)	T_0 to T_1	-0.43 (7)	0 (10)	0 (9)	0 (6)	0 (5)	-0.08 (37)
				T_1 to T_2	-0.29 (7)	-0.30 (10)	-0.11 (9)	0 (6)	0 (5)	-0.16 (37)
				T_0 to T_2	-0.71 (7)	-0.30 (10)	-0.11 (9)	0 (6)	0 (5)	-0.24 (37)
Macropus bernardus	black wallaroo	0 (1.0)	0.94 (0.35)	T_0 to T_1	-0.33 (3)	0 (1)	0 (4)	n/a	n/a	-0.13 (8)
				T_1 to T_2	0 (3)	0 (1)	0 (3)	n/a	n/a	0 (7)
				T_0 to T_2	-0.33 (3)	0 (1)	0 (3)	n/a	n/a	-0.14 (7)
Macropus robustus	euro	7.2 (0.13)	0 (1.0)	T_0 to T_1	0 (3)	0 (4)	0 (19)	0 (8)	0 (2)	0 (26)
				T_1 to T_2	0.50 (2)	0 (4)	0 (8)	-0.13 (8)	0 (2)	0 (24)
				T_0 to T_2	0.50 (2)	0 (4)	0 (8)	-0.13 (8)	0 (2)	0 (24)
Mesembriomys gouldii	black-footed tree-rat	0 (1.0)	0.48 (0.63)	T_0 to T_1	-0.11 (9)	-1.00 (4)	-0.40 (10)	n/a	-1.00 (1)	-0.42 (24)
				T_1 to T_2	-0.50 (6)	0 (4)	0 (1)	n/a	0 (1)	-0.25 (12)
				T_0 to T_2	-0.67 (6)	-1.00 (4)	-1.00 (1)	n/a	-1.00 (1)	-0.83 (12)

Onychogalea unguifera	northern nail-tail wallaby	3.6 (0.46)	0.99 (0.32)	T_0 to T_1	0 (1)	0 (11)	0 (13)	0 (15)	0 (12)	0 (52)
				T_1 to T_2	0 (1)	-0.08 (13)	0 (12)	0 (15)	0 (12)	-0.02 (53)
				T_0 to T_2	0 (1)	-0.09 (11)	0 (12)	0 (15)	0 (12)	-0.02 (51)
Petaurus breviceps	sugar glider	9.7 (0.05)	2.60 (0.009)	T_0 to T_1	0 (10)	0 (16)	0 (23)	0 (2)	0 (5)	0 (56)
				T_1 to T_2	0 (10)	-0.29 (14)	0 (21)	-0.50 (2)	-0.20 (5)	-0.12 (52)
				T_0 to T_2	0 (10)	-0.29 (14)	0 (21)	-0.33 (3)	-0.20 (5)	-0.11 (53)
Petrogale brachyotis	short-eared rock-wallaby	0 (1.0)	0 (1.0)	T_0 to T_1	0 (3)	0 (6)	0 (8)	0 (7)	0 (9)	0 (33)
				T_1 to T_2	0 (2)	0 (7)	0 (7)	0 (7)	0 (9)	0 (32)
				T_0 to T_2	0 (2)	0 (6)	0 (7)	0 (7)	0 (9)	0 (31)
Petropseudes dahli	rock ringtail possum	0 (1.0)	1.06 (0.29)	T_0 to T_1	0 (3)	0 (3)	0 (10)	n/a	0(2)	0 (18)
				T_1 to T_2	0 (3)	0 (3)	-0.13 (8)	n/a	0 (2)	-0.06 (16)
				T_0 to T_2	0 (3)	0 (3)	-0.13 (8)	n/a	0 (2)	-0.06 (16)
Phascogale pirata	northern brush-tailed phascogale	0 (1.0)	2.48 (0.01)	T_0 to T_1	0 (6)	0 (2)	-0.60 (5)	n/a	n/a	-0.23 (13)
				T_1 to T_2	-0.60 (5)	n/a	-1.00 (4)	n/a	n/a	-0.78 (9)
				T_0 to T_2	-0.60 (5)	n/a	-1.38 (8)	n/a	n/a	-1.08 (13)
Tachyglossus aculeatus	short-beaked echidna	3.5 (0.48)	0.77 (0.44)	T_0 to T_1	-0.10 (10)	0 (14)	-0.11 (19)	0 (13)	0 (11)	-0.04 (67)
				T_1 to T_2	-0.11 (9)	0 (12)	-0.10 (20)	-0.08	-0.09	-0.08 (65)

								(13)	(11)	
				T_0 to T_2	-0.22 (9)	0 (12)	-0.21 (19)	-0.08 (13)	-0.09 (11)	-0.13 (64)
Trichosurus vulpecula	common brush-tailed possum	14.0 (0.007)	0.43 (0.66)	T_0 to T_1	0.09 (11)	-0.75 (12)	-0.29 (28)	-0.09 (11)	0 (7)	-0.25 (69)
				T_1 to T_2	0 (7)	0 (10)	-0.33 (27)	0 (3)	-0.20 (5)	-0.19 (52)
				T_0 to T_2	0.14 (7)	-0.90 (10)	-0.63 (27)	-0.33 (3)	-0.20 (5)	-0.52 (52)

Table 6. Summary of status change for groups of species (all species, CWR species), compared between regions and time periods. H is the statistic from Kruskal-Wallis ANOVA, and p is the probability level. Time periods as for Table 5.

		Region (mean change, N)						
Time period	Mammal group	North-west Top End	Arnhem Land	Central East Top End	VRD and northern Tanami	South-east Top End	H	p
T_0 to T_1	all species	-0.06 (15)	-0.22 (14)	-0.12 (16)	-0.12 (11)	-0.19 (12)	1.66	0.77
	CWR species	-0.01 (11)	-0.31 (10)	-0.17 (11)	-0.21 (7)	-0.25 (9)	4.01	0.40
T_1 to T_2	all species	-0.26 (15)	-0.21 (14)	-0.26 (16)	-0.23 (11)	-0.29 (12)	0.50	0.97
	CWR species	-0.44 (11)	-0.26 (10)	-0.46 (11)	-0.33 (7)	-0.39 (9)	0.30	0.99
T_0 to T_2	all species	-0.39 (15)	-0.43 (14)	-0.45 (16)	-0.35 (11)	-0.44 (12)	0.80	0.94
	CWR species	-0.46 (11)	-0.57 (10)	-0.63 (11)	-0.55 (7)	-0.64 (9)	0.39	0.98

Table 7. Summary of reliability scores assigned for every record, tallied by species and time period. Species are ordered from those with the highest reliability index. Reliability classes: H=high; M=medium; L=low.

Species	Common name	Time period (no. H,M,L reliability records)			Total no. records	Mean reliability	Notes
		past	recent	current			
Macropus agilis	agile wallaby	H64 M2 L0	H66 M0 L0	H64 M2 L0	198	1.98	much hunted; unmistakeable
Petrogale brachyotis	short-eared rock-wallaby	H38 M1 L0	H39 M1 L0	H31 M6 L0	116	1.93	
Macropus robustus	euro	H26 M0 L0	H24 M2 L0	H21 M4 L0	77	1.92	much hunted
Onychogalea unguifera	northern nail-tail wallaby	H53 M2 L1	H55 M2 L1	H51 M5 L1	171	1.90	hunted; unmistakeable
Petaurus breviceps	sugar glider	H58 M0 L0	H54 M2 L2	H43 M10 L1	170	1.89	unmistakeable
Macropus antilopinus	antilopine wallaroo	H31 M7 L0	H29 M9 L0	H28 M10 L0	114	1.77	much hunted; unmistakeable
Tachyglossus aculeatus	short-beaked echidna	H56 M2 L0	H57 M13 L0	H27 M39 L0	194	1.72	hunted; unmistakeable
Petropseudes dahli	rock ringtail possum	H18 M0 L2	H17 M1 L2	H10 M6 L1	57	1.70	
Lagorchestes conspicillatus	spectacled hare-wallaby	H21 M10 L1	H21 M10 L1	H9 M9 L0	82	1.60	unmistakeable
Isoodon macrourus	northern brown bandicoot	H53 M9 L1	H41 M21 L2	H16 M37 L5	185	1.55	hunted (esp. formerly)
Trichosurus vulpecula	common brush-tailed possum	H69 M11 L0	H43 M34 L1	H20 M38 L12	226	1.54	hunted (esp. formerly)
Hydromys chrysogaster	water-rat	H41 M18 L2	H39 M23 L1	H28 M30 L4	186	1.54	unmistakeable
Dasyurus hallucatus	northern quoll	H49 M12 L0	H31 M19 L6	H19 M19 L8	163	1.52	unmistakeable
Mesembriomys gouldii	black-footed tree-rat	H31 M2 L2	H17 M11 L2	H5 M11 L8	89	1.46	unmistakeable
Phascogale pirata	northern brush-tailed phascogale	H13 M14 L3	H9 M9 L2	H8 M11 L2	71	1.32	
Conilurus penicillatus	brush-tailed rabbit-rat	H3 M2 L1	H3 M1 L2	H3 M2 L1	18	1.27	

Macropus bernardus	black wallaroo	H7 M2 L2	H6 M2 L3	L3 M4 L3	32	1.25	hunted
Total records		H631 M94 L15	H551 M160 L25	H396 M243 L46			

List of Figures

Figure 1. Map of study area showing interview locations (triangle symbols; see Table 2), locations of all mammal records given by Indigenous participants (circle symbols; see also Table S2) and zones used to assess regional differences (bottom right).

Figure 2. Illustration of typical setting for interviews, showing some of the mammal specimens used (photo by Ian Morris).

Figure 3. Change in status of six native mammals in northern Australia for three time periods (more than 20 years ago, 5-20 years ago and present-day). Each record is based on interviews with one or more Indigenous informants, who scored individual mammal species as common, present or absent, and each record was given a reliability code of high – H, medium – M, or low – L.

Figure S3. Change in status of fifteen native mammals in northern Australia for three time periods (more than 20 years ago, 5-20 years ago and present-day). Each record is based on interviews with one or more Indigenous informants, who scored individual mammal species as common, present or absent, and each record was given a reliability code of high – H, medium – M, or low – L.

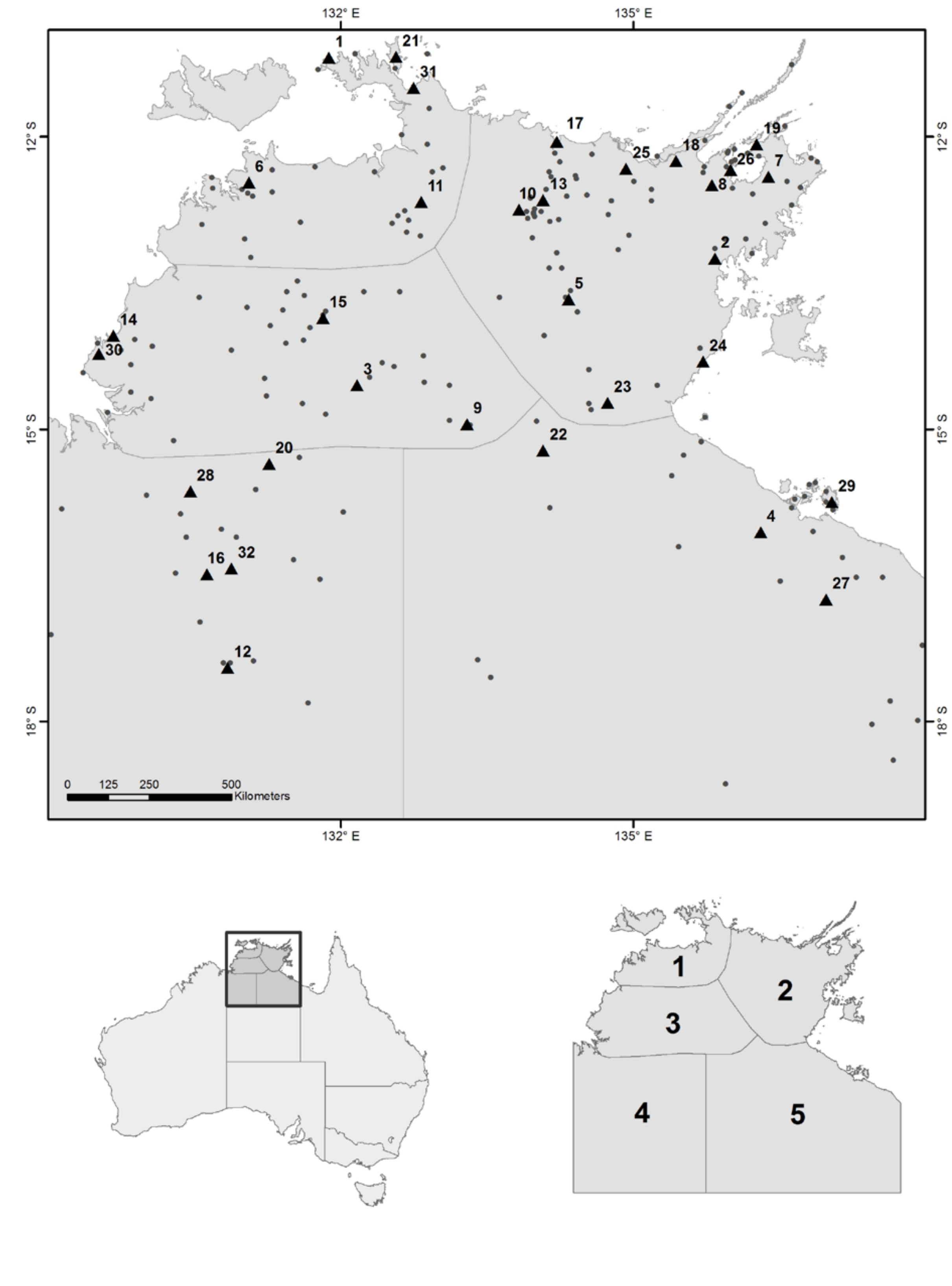
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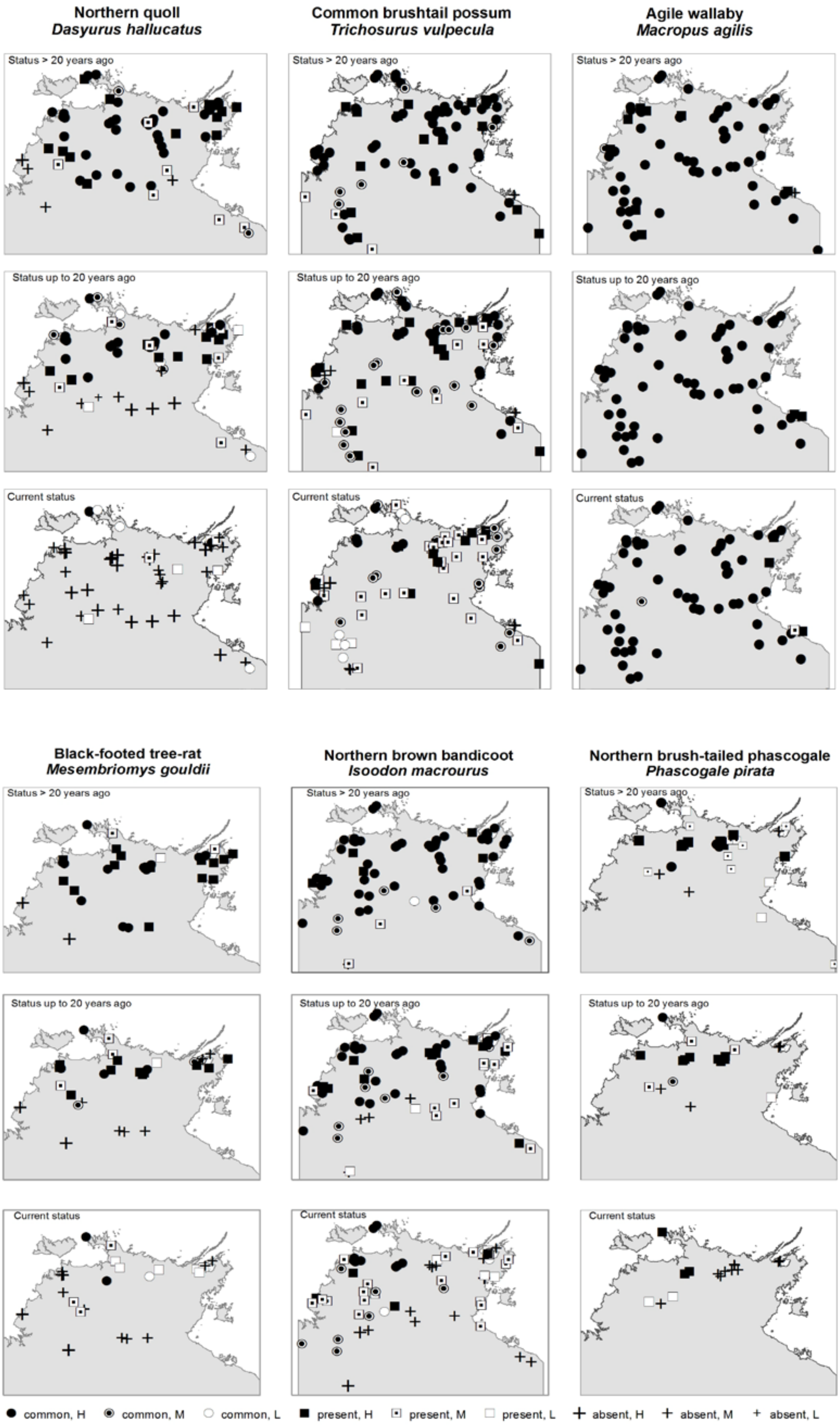
Fig.1

Fig. 2



Northern quoll
Dasyurus hallucatus
Common brushtail possum
Trichosurus vulpecula
Agile wallaby
Macropus agilis
Black-footed tree-rat
Mesembriomys gouldii
Northern brown bandicoot
Isoodon macrourus
Northern brush-tailed phascogale
Phascogale pirata
Status > 20 years ago
Status up to 20 years ago
Current status
common, H
common, M
common, L
present, H
present, M
present, L
absent, H
absent, M
absent, L

Fig.3

ONLINE SUPPORTING INFORMATION

A worked example of the interview technique

To illustrate the practical application of the reliability assessment technique, and to demonstrate how dialogue was constructed and information corroborated during interviews, an example using the black-footed tree-rat *Mesembriomys gouldii* is presented that represents different scenarios and results in different reliability rankings. A sample of all the records for this species is presented from four different informants (Table S1). Each record is divided into three sub-records which list the status of the black-footed tree rat in the three periods defined in the study. For the first record below as each specific criterion (Table 3) is satisfied it is listed in parentheses.

Informant ‘1’ was a respected, knowledgeable elder (criterion ‘v’) from north-east Arnhem Land who listed Gapuru as one of the locations where the black-footed tree-rat was present in the ‘past’ based on occasional sightings when the informant was young and frequented the area (criterion ‘ii’). The informant was familiar with the species and gave its local language name *man’bul*, which is widely used in the region and has been recorded by linguists previously (criterion ‘i’). This record was also corroborated by other residents of the area (criterion ‘iii’) and it scores for consistency with scientific and historical data because Donald Thomson collected specimens and sighted the species at several nearby locations in north-eastern Arnhem Land (Dixon and Huxley 1985) (criterion ‘iv’). All criteria for the species’ status in the ‘past’ period, therefore, were well satisfied so this sub-record was considered of high reliability. The informant admitted that she had not spent much time at Gapuru for many years, therefore, the current and recent status of the species at the location were subsequently listed as unknown.

A similar record was given for the Bunhanura locality by another informant (Informant ‘11’) with all criteria similarly satisfied for the ‘past’ period. However, this informant suggested that the black-footed tree-rat was still present in the area, although it had generally declined in the region. In these cases, reliability rankings for the two more recent periods were lower because fewer of the criteria were satisfied. That is, no other informants had explicitly named this as a location and there were no scientific data available for the area for either the recent (up to 20 years) or the current period. Furthermore, although the informant believed the species was still present in the region they had not been to the location for some time. Consequently, the current status was considered of low reliability.

The third record presented is for the community of Jilkmingan from an elder Aboriginal woman who was a life-long resident of the location (Informant '76'). She gave a name for the species and described aspects of its ecology that were consistent with what is known about the species from other sources, therefore, correct identification was assumed and the criteria of consistent reliable data satisfied. Although there was limited reliable scientific or historical information for the location, the information was corroborated by other locals for the 'past' period. The 'absent' status for the recent and current period are ranked as of medium reliability because although it is probable that the species is no longer found at the site, there is some uncertainty with the record because it is based on one individual's experience and no formal surveys have been conducted in the area.

The final record demonstrates a scenario when a record is void and disregarded because a correct identification could not be established. In this case, Informant '21' gave the local language name of the common brush-tailed possum in place of the black-footed tree-rat and he spoke of how it used to be hunted and used by elders in the past in a manner consistent with how other informants described uses of the possum. For individuals not familiar with both species, at least superficially, the two share similar features (i.e. large ears, brushy tail and grey-brown colour), and also overlap in habitats and diet, hence one may be confused with the other.

In cases when identification was incorrect or the respondent did not immediately recognise the species, prompts were given by the interviewer to help informants recall information. In many cases informants had not seen a specific mammal for an extended period either because they were themselves no longer active on the land or hunting the species or the species had disappeared from the region. As such, prompts sometimes served to jog the memory. If it still could not be determined that the species was known then the record was disregarded.

Table S1. An example of scoring reliability of status information using a sample of four records for the black-footed tree-rat. Status of the species is denoted as: C = common, P = present, A = absent, U = unknown. ✓ denotes that the criterion was satisfied; x that the criterion was not satisfied. Reliability is scored as high (H = 4-5 criteria satisfied), medium (M = 2-3 criteria satisfied), low (L = 0-1 criteria satisfied) and status unknown (U). Each record consists of three components according to the three periods defined (past = >20 years (left), recent = up to 20 years and current).

	Location	Gapuru	Bunhanura	Jilkmingan	Jilkmingan
	Informant	1	11	76	21
	Record number	180	103	842	11
	Status category	P U U	C C P	C A A	P P P
i	Correct ID or language name known	✓	✓	✓	x
ii	Informant is resident &/or active on country	✓ - -	✓ ✓ x	✓ ✓ ✓	✓ x x
iii	Corroborated by other informants	✓ - -	✓ x x	✓ x x	x x x
iv	Consistent with scientific/historical data	✓ - -	✓ x x	x x x	x x x
v	Information consistently reliable	✓	✓	✓	x
	TOTAL	5 - -	5 3 2	4 3 3	0
	RELIABILITY	H U U	H M L	H M M	void

Table S2: Coordinates for all record locations mentioned by Indigenous participants

ID	Location	Lat	Long
1	Adelaide River floodplain	-12.34	131.30
2	Arafura Swamp	-12.46	135.01
3	Araru	-11.19	131.88
4	Auvergne station	-15.68	130.01
5	Babungi	-15.75	136.98
6	Badjakkuwayi Creek	-12.80	134.75
7	Balma	-13.25	135.84
8	Banambarrnga (Rainbow Cliff)	-12.22	136.83
9	Baniyala	-13.20	136.22
10	Baralmana River	-12.53	136.02
11	Barbara Cove	-15.64	136.98
12	Barrak Barrak	-15.87	130.36
13	Barrapunta (Emu Springs)	-13.16	134.85
14	Barunga	-14.52	132.86
15	Batchelor	-13.05	131.02
16	Bauhinia Downs	-16.21	135.47
17	Baygurrutji	-13.15	135.84
18	Bees Creek	-12.58	131.05
19	Belyuen	-12.53	130.69
20	Beswick	-14.55	133.12
21	Binjari	-14.55	132.17
22	Black Point	-11.15	132.15
23	Bloodwood Soak	-18.40	137.67
24	Bolkdjam	-12.40	134.41
25	Borroloola	-16.06	136.31
26	Bradshaw Station	-15.12	130.29
27	Brunette Downs	-18.64	135.95
28	Buckingham River	-12.31	135.73
29	Buffalo Farm, Kakadu NP	-12.81	132.59
30	Bullita	-16.11	130.42
31	Bulman	-13.67	134.34
32	Buluhkadaru	-12.43	134.42
33	Bunhanura	-12.37	135.72
34	Burrum	-12.31	135.96
35	Buymarr	-12.70	136.63
36	Cadell River	-12.18	134.58
37	Calvert River	-16.52	137.56
38	Cannon Hill	-12.36	132.94
39	Cape Don	-11.31	131.77
40	Cape Wilberforce	-11.89	136.56
41	Cattle Creek	-17.81	131.67
42	Centre Island	-15.69	136.76
43	China Wall	-17.79	137.64
44	Clarkson Point	-15.83	137.05
45	Clump Island	-14.83	129.61
46	Cooinda	-12.89	132.53
47	Coronation Hill	-13.59	132.61
48	Daguragu	-17.40	130.80
49	Daly River floodplain	-13.65	130.55
50	Deaf Adder Gorge (Anburdkorrang)	-13.02	132.82
51	Dhalingbuy	-12.41	136.39
52	Dhaniya	-12.52	136.72
53	Dillinya	-15.85	132.03
54	Djohmi (Mann River)	-13.04	133.97
55	Djolok Gorge	-12.77	134.06
56	Djurruputjpi	-13.05	136.16
57	Dorcherty Island	-14.12	129.51
58	Dorisvale	-14.66	131.24
59	Douglas River Hot Springs	-13.78	131.41
60	Drysdale Island	-11.69	135.99
61	Elliott	-17.55	133.54
62	Elsey Station	-14.96	133.33
63	Emerald Springs	-13.63	131.63
64	Finniss River	-12.90	130.58
65	Fish River	-14.19	130.88
66	Flinders Peninsula	-12.15	135.98
67	Flora River	-14.74	131.61
68	Fogg Dam	-12.57	131.30
69	Frances Creek	-13.79	131.85
70	Galiwinku	-12.20	135.25
71	Gan Gan	-13.05	135.94
72	Ganduwarra	-18.03	137.45
73	Gapuru	-12.46	136.58
74	Gapuwiyak	-12.50	135.81
75	Garlarram	-12.85	134.24
76	Garrata	-12.17	135.97
77	Gomburr	-12.74	133.99
78	Gorpulyul	-13.35	134.14
79	Grant Island	-11.15	132.89
80	Gregory National Park	-16.48	130.31
81	Grove Hill	-13.48	131.56
82	Gulung Mardrulk	-13.65	133.63
83	Gunbalanya (Oenpelli)	-12.32	133.05
84	Gurruwurru	-12.59	136.23
85	Harney Beach	-12.42	130.68
86	Hayes Creek	-13.59	131.45
87	Howard Springs	-12.47	131.06
88	Jabiru	-12.67	132.83
89	Jasper Gorge	-16.03	130.78
90	Jilkmingan	-14.95	133.30
91	Jindare	-14.09	131.62
92	Kabulwarnamyo	-12.75	133.83
93	Kakodbabuldi	-12.41	134.16
94	Kalardadj	-12.62	133.95
95	Kalkarindji	-17.45	130.84
96	Kamargawan	-12.65	134.08
97	Kangaroo Island	-15.81	136.63
98	Katherine	-14.47	132.30

99	Keep River NP	-15.82	129.14	151	Nalyindi	-12.54	135.19
100	Kidman Springs	-16.11	130.93	152	Napier Peninsula	-12.04	135.74
101	Kieren Springs	-16.52	137.29	153	Nathan River	-15.27	135.52
102	Kolorbidahdah	-12.61	134.32	154	Newcastle Waters	-17.37	133.41
103	Kundakundgen	-12.82	133.99	155	Ngalengkerl	-12.77	133.91
104	Kuy	-14.04	129.67	156	Ngukkur	-14.73	134.74
105	Kybrook Farm	-13.86	131.82	157	Nicholson River (south)	-17.99	137.92
106	Limmen Bight	-15.48	135.40	158	Nimbilmin	-14.19	129.75
107	Limmen Bight River	-15.13	135.70	159	Nitmiluk	-14.32	132.43
108	Lingarra	-16.49	130.63	160	North Island	-15.55	136.87
109	Macadam Range	-14.62	129.85	161	Nourlangie Camp	-12.76	132.66
110	Madjelindi Valley	-14.69	130.06	162	Numbulwarr	-14.31	135.72
111	Mainouru	-14.04	134.09	163	Nutwood Downs	-15.81	134.15
112	Malakajalmol	-13.19	134.22	164	Oolloo Station	-13.94	131.28
113	Malgawa	-12.84	133.92	165	Palumpa	-14.34	129.85
114	Malnjangarnak	-12.66	134.78	166	Paw Paw Beach	-11.98	132.63
115	Manangoora	-16.05	136.85	167	Pearce Point	-14.42	129.36
116	Maningrida	-12.05	134.22	168	Peppimenarti	-14.15	130.07
117	Manmoyi	-12.54	134.11	169	Phelp River	-14.55	135.25
118	Mann River floodplain	-12.17	134.20	170	Pine Creek mine	-13.83	131.82
119	Manyallaluk	-14.25	132.85	171	Probable Island	-12.13	136.04
120	Mapuru	-12.25	135.44	172	Ramingining	-12.33	134.93
121	Marchinbar Island	-11.26	136.63	173	Raymangirr	-12.34	136.00
122	Maria Island	-14.88	135.74	174	Robinson River (south)	-16.75	136.98
123	Marramarrani	-11.30	132.56	175	Roper Bar	-14.74	134.55
124	Mary River Ranger Station	-13.59	132.24	176	Roper Valley	-14.92	134.01
125	Mata Mata	-12.08	136.27	177	Rorruwuy	-12.20	136.29
126	Mataranka	-14.91	133.12	178	Sawmill Daly River Crossing	-14.36	132.55
127	Menngen (Innesvale)	-15.36	131.27	179	Scott Creek	-14.85	131.85
128	Mimburrng	-12.87	134.15	180	Seven Emu Station	-16.32	137.15
129	Minimy	-13.01	134.96	181	Six mile Creek	-14.80	134.57
130	Minjilang	-11.18	132.57	182	Solar Village, Humpty Doo	-12.61	131.10
131	Minyerri (Hodgson Downs)	-15.22	134.08	183	South Alligator River floodplain	-12.36	132.35
132	Mirringatja	-12.66	135.19	184	South-west Island	-15.72	136.66
133	Mistake Creek	-17.11	129.03	185	Spring Creek	-16.56	136.51
134	Mitchell Creek	-12.54	130.99	186	Stevens Island	-11.55	136.12
135	Miyuku	-12.79	133.98	187	Stray Creek	-14.12	131.44
136	Mobarn (Bluewater)	-13.58	134.36	188	Timber Creek	-15.64	130.46
137	Mokmek	-12.63	133.95	189	Tipperary Station	-13.75	131.04
138	Momob	-13.35	134.27	190	Tomkinson River	-12.26	134.25
139	Moolooloo	-16.34	131.52	191	Tommy Cut Creek	-12.31	131.74
140	Mount Basedow	-12.98	132.68	192	Top Springs	-16.54	131.79
141	Mount Borradale	-12.08	132.89	193	Umbrawarra Gorge	-13.96	131.69
142	Mount Bundey	-12.88	131.59	194	Upper Adelaide River	-13.24	131.08
143	Mount Cahill	-12.86	132.70	195	Vanderlin Island	-15.75	137.04
144	Mount Catt	-13.80	134.43	196	Victoria River Crossing	-15.62	131.13
145	Mount Sanford	-16.98	130.56	197	Wadeye	-14.23	129.52
146	Moyle River	-14.08	129.89	198	Wandaway	-12.89	136.36
147	Mudhamul	-12.17	136.18	199	Waterbag Creek	-14.48	131.22
148	Mudwangewange	-12.78	133.98	200	Watson Island	-15.57	136.81
149	Mumeka	-12.36	134.14	201	Wattle Creek	-17.40	130.87
150	Murgenella	-11.71	132.91	202	Wave Hill	-17.38	131.11

203	Weemol	-13.65	134.31
204	Wilgi	-11.50	132.75
205	Willeroo	-15.29	131.58
206	Wilton River	-14.39	134.55
207	Wollogorang	-17.22	137.97
208	Wumadjbarr	-14.17	135.69
209	Yallquin	-12.26	136.01
210	Yarralin	-16.43	130.88
211	Yarringurr	-12.24	136.05
212	Yaymini	-12.60	134.53
213	Yirrkala	-12.26	136.89

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