Vertebrate monitoring and re-sampling in Kakadu National Park

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SUMMARY

*This report describes the results for the period January to December 2001 in the project **Vertebrate Monitoring and Re-Sampling at Kakadu National Park (KNP)**, a collaborative project involving Parks Australia (North), Parks and Wildlife Commission of the Northern Territory, and the Tropical Savannas Cooperative Research Centre.*

The explicit <u>*objectives*</u> *of this consultancy were to:*

- *assess change in the vertebrate (and particularly mammal) fauna of KNP by re-sampling sites previously sampled;*
- *assess the response of the mammal fauna to fire regimes, through sampling a set of sites selected to represent contrasting fire regimes;*
- *establish a set of terrestrial vertebrate fauna samples which will contribute to the assessment of cane toad impacts;*
- *sample terrestrial vertebrate fauna at a selection of existing KNP fire monitoring plots;*
- *train Parks Australia staff in vertebrate sampling; and*
- *collate all available data on terrestrial vertebrate fauna sampling, and deliver this to Parks Australia as GIS and other curated data bases.*

Note that this project will continue for a further year (2002). Hence, for some aspects of this project, the information presented here describes progress results rather than completed actions.

<u>monitoring and the Kakadu mammal fauna</u>

Prior to this work, there was no integrated monitoring program for terrestrial biodiversity across Kakadu NP. The development of such a program is important to assess the extent to which the Park's values are being maintained and to help assess and guide management actions. Monitoring of mammals is considered especially significant, given the probable or possible extinction of three species from the Kakadu area, a recently reported decline of a large suite of species from the Kapalga area within Kakadu, and broad-scale decline of many mammal species across northern Australia generally. We develop here a monitoring program for terrestrial vertebrate fauna which employs a widely-used standard procedure and is based on re-samples of a large set of sites previously sampled and on an additional set of sites selected from the existing vegetation fire monitoring plots.

<u>re-sampling of Kakadu Stage 3 sites (Mary River district)</u>

Between February and December 2001, we re-sampled a total of 263 of the 380 quadrats in southern Kakadu, which had previously been sampled by CSIRO in 1988-90. Each quadrat visited was re-sampled at the same time of year as when originally sampled. We used matched-pair statistics to test for overall changes in the abundance of individual species and in the total mammal fauna over this 11 year period.

Of 18 native mammal species recorded from at least 10 quadrats in either or both sampling periods, 5 species showed significant decline (antilopine wallaroo, common planigale, Arnhem rock-rat, delicate mouse and lakeland downs mouse) whereas one species (northern brown bandicoot) showed significant increase. Six native species (echidna,

antilopine wallaroo, northern nailtail wallaby, short-eared rock-wallaby, common planigale, and lakeland downs mouse) recorded in these quadrats in 1988-90 were not recorded during the 2001 re-sampling, however there were very few records of three of these species (echidna, common planigale, and lakeland downs mouse) in the original sampling. One native species (brush-tailed phascogale) was recorded in the re-sampling (but from only one quadrat) and not in the original sampling.

Two exotic species (water buffalo and cattle) declined significantly over the 1988-90 to 2001 period, and one (pig) increased significantly. Two non-native mammal species (black rat and donkey) were recorded in the 2001 sampling, but not in the original sampling of these quadrats, however the donkey was recorded in other quadrats sampled in 1988-90 that were not re-visited in 2001.

The pattern of change was mapped, to investigate any possible geographic association with trends in mammal abundance. There was some indication of geographic patchiness in status change, particularly with a tendency for decrease in the area between Coronation Hill and Gunlom, and increase in the lowland areas between Mary River ranger station and Gerowie Creek.

The pattern of change was examined against broad habitat types. There was a pronounced trend, which was not quite statistically significant, for greater decline in rocky areas and lowland woodlands, whereas there was an increase in total mammal abundance in riparian areas-rainforests-swamps. Change in the abundance of one native species (fawn antechinus) exhibited a significant difference among habitats, with decrease in eucalypt open forests and woodlands on stony hills, but increase in lowland woodlands and riparian areas-rainforests-swamps.

25 of the 263 re-sampled quadrats were colonised by cane toads prior to the 2001 re-sampling (probably 3 months to 2 years previously). Over the period 1988-90 to 2001, there was no significant difference in changes in mammal fauna between this set of quadrats and the larger set which remained toad-free: indeed, there was a weak increase in native mammals in the toad-invaded areas, compared with decrease in the toad-free areas. However, any interpretation of this result should be highly qualified, as the original sampling included very few records of dasyurids (the mammal group considered most susceptible to toads) in those 25 quadrats which were subsequently invaded by toads.

For each of the 263 re-sampled quadrats, we derived 11-year fire histories based on the library of interpretations of satellite imagery. The imagery suggested that the sample quadrats were exposed to a broad range of fire regimes, including some which were burnt every year over the period and some which were not burnt at all in those 11 years between mammal sampling events. There were relatively few clear relationships between fire history and changes in mammal abundance across these sites.

<u>Vertebrate sampling coordinated with the existing fire vegetation monitoring plots</u>.

During 2001, we sampled 21 of the 135 established fire monitoring plots across Kakadu National Park. A more substantial proportion will be sampled in 2002. Of the 21 sampled plots, 15 had been sampled previously, in 1996. Total abundance of native mammals per quadrat declined by 24% over this 5 year period, however this change was not significant.

Of 6 native species recorded from at least 5 quadrats in the two sampling events combined, one species (black-footed tree-rat) declined significantly, and no species increased significantly.

<u>Response to fire regimes</u>

The response of the mammal fauna to varying fire regimes was investigated by sampling 12 large grids in Eucalyptus miniata - Eucalyptus tetrodonta (Darwin woollybutt - Darwin stringybark) open forests exposed to contrasting 21-year fire histories. There was an extraordinary level of variation in the number and diversity of mammal species caught in the grids, with the total number of animals trapped in grids differing by up to 2 orders of magnitude. Variation across grids in the abundance of many mammal species was significantly related to fire histories and/or vegetation factors. Brushtail possums and black-footed tree-rats showed a pronounced association with infrequent but fine-scale fire, and the total mammal fauna increased at sites subjected to the most patchy fire regimes. However, the marked variation in mammal numbers between grids was by no means due only to fire and vegetation factors.

<u>Establishment of sites suitable for monitoring the impact of cane toads</u>

All of the 284 quadrats (and 12 large grids) sampled to date are amenable for use as cane toad monitoring sites, and a high proportion of these will be re-sampled in 2002 in order to derive an assessment of the short-term impact immediately following cane toad arrival.

<u>Involvement of Parks Australia staff</u>

To date, over 50 Parks Australia staff and Bininj landowners have participated in fauna survey work carried out throughout KNP. The rationale for the surveys, as well as all relevant sampling methodologies, has been communicated to all participants to a level which would enable replication of these surveys in most districts of KNP. Some aspects of the survey work (particularly identification of birds and herpetofauna) may require more intensive training for some Parks staff who have limited experience with these diverse groups.

<u>Data bases and summary accounts for individual mammal species</u>

The data collected to date during this consultancy have been compiled into a database which will be linked with a GIS to provide ready access to fauna and habitat information for all sites sampled during this consultancy, as well as data collated from other studies of the mammal fauna of KNP. Maps of records and summary accounts of the status of 28 mammal species are presented.

<u>Conclusions and progress</u>

Our results show that the Kapalga effect is not pervasive across the Park, that most of the species which were shown to have declined at Kapalga had not declined in the southern half of the Park. However, our results don't provide a clean bill of health. A set of species *which were absent or unreported in the Kapalga area (notably arnhem rock-rat, lakeland downs mouse and common planigale) declined significantly in the southern part of the park over the period 1988-90 to 2001. Also, some of the species reported to have declined in Kapalga (notably brushtail possum and black-footed tree-rat) were very poorly represented in the original and subsequent sampling of Stage 3, so no trend can realistically be assigned to them in that area. Further, our sampling of 12 large grids in eucalypt open forests across the northern half of Kakadu showed that some forest areas were empty of mammals, or had very low abundance and diversity, suggesting a highly patchy pattern of decline.*

Our work now provides a firm baseline for ongoing monitoring of terrestrial vertebrates, and will provide an immediate pre-toad baseline from which to assess the impacts of the imminent arrival of cane toads. Additional sites will be added in 2002, especially to augment the representation of sandstone and floodplain habitats, and to provide further sampling of fire monitoring plots.

CONTENTS

1. INTRODUCTION - *project background*

Kakadu National Park ("KNP") is one of Australia's premier conservation areas. It is recognised to be of world heritage value, at least partly on the criterion of harbouring a rich, distinctive and intact fauna. The current Kakadu Plan of Management (Kakadu Board of Management and Parks Australia 1999) explicitly recognises this asset and accepts responsibility for its monitoring, maintenance and sustenance.

Monitoring of faunal biodiversity has not been a major management priority in KNP, nor for that matter for any other conservation reserve in northern Australia. Most activity concerning terrestrial vertebrate fauna has been related primarily to inventory (e.g. Braithwaite 1985; Woinarski and Braithwaite 1990, 1991), the assessment of habitat relationships and conservation status (e.g. Begg *1981a,b,c*; Kerle and Burgman 1984; Kerle 1985, 1998; Friend 1985, 1987; Friend and Taylor 1985; Press 1988; Oakwood 1997), and/or the response to some management or threatening factors, particularly fire regime (e.g. Begg *et al*. 1981). Before the onset of this project, the only formal monitoring activities for native fauna in KNP comprised (i) a small set of recording stations aimed at monitoring the responses of frog assemblages to the invasion of cane toads *Bufo marinus*, (ii) a set of aquatic and riparian sites aimed at monitoring the impacts of wetland species to possible contamination associated with mining, and (iii) continuing assessment of the distribution, abundance and size of estuarine crocodiles *Crocodylus porosus*, largely because of their potential menace to human populations.

This previous lack of a formal fauna monitoring program contrasts with the substantial monitoring program established for vegetation, focusing particularly on the landscape-wide response to fire (Russell-Smith and Ryan 1996; Russell-Smith *et al*. 1997; Edwards *et al*. 2002). It also contrasts to the substantial biodiversity monitoring programs in place in many major conservation reserves elsewhere in the world (e.g. National Environmental Research Council 1994; Royal Society of Canada 1995; National Science and Technology Council 1997; http://www.mp1-pwrc.usgs.gov/powcase/index.html).

So far as we are aware, there has been no explicit rationale given for the apparently low priority given to fauna monitoring in KNP. Four main factors are probably involved:

> (1) There has been an implicit (and occasionally explicit: Braithwaite and Werner 1987) assumption that the biota is well safeguarded within Kakadu (because of its large size, its naturalness, its situation within a context of vast natural landscapes in northern Australia, and because of an assumed benevolence of its management), and, hence, it is wasteful to allocate resources to assess change when no change is likely.
>
> (2) An implicit assumption that if there is significant change in the Park's biodiversity, then this would be likely to be noticed by ranger staff and/or Aboriginal landowners, with sufficient rapidity to invoke some timely management response.
>
> (3) A perception that scientists have had a fair go already, mostly through the major resource inventory studies and the major research effort at Kapalga (Andersen *et al*. 1998), and that there is little more that they can contribute to the Park's management.

(4) Related to (3) above, that the allocation of the finite management resources available may need to consider more equity for the park's Aboriginal landowners in order to realise the aims of joint management.

However, some of these assumptions can be challenged, and some more sustained monitoring may be a cost-effective and efficient means of evaluating and continually refining and improving management, and a necessary insurance to achieve the broadly-held objective of sustaining an intact and rich biota in Kakadu.

The most notable argument for the establishment of a fauna monitoring program in KNP is the recognition that the fauna is undergoing change. Much of this change appears to be occurring broadly across northern Australia, as indicated by recent analyses of trends in the abundance and distribution of granivorous birds (Franklin 1999) and mammals (Woinarski *et al*. 2001). It is by no means a phenomenon restricted to Kakadu, but nor is it necessarily a change against which Kakadu is somehow innately quarantined.

In the case of the Kakadu mammal fauna, the evidence suggesting change comprises the lack of recent records for some taxa, and recent data suggesting reduced abundance for several species.

There have been no recent definite records for three mammal species reported from Kakadu National Park:

- the **false water-rat** *Xeromys myoides* was last reported in Kakadu in 1903 from the lower reaches of the South Alligator River (Parker 1973);
- the **golden bandicoot** *Isoodon auratus* was last reported from Kakadu in 1967, from near Old Goodparla homestead;
- the **golden-backed tree-rat** *Mesembriomys macrurus* was last confirmed from Kakadu in 1969, at Deaf Adder Creek.

These species may have become extinct within Kakadu, given the lack of records over the last 30+ years, despite substantial sampling effort. Qualifying this, there was at least one unconfirmed sight record of golden-backed tree-rat within the last decade, and there has been relatively little trapping in the habitats preferred by false water-rat.

In addition to these cases of possible regional (park) extinctions, there is evidence of decline in other species. Some of this information is from the limited studies which have considered *Bining* knowledge of their environments and wildlife. For example, Churchill (1997) noted that

> "*In Kakadu National Park, local aboriginal people regarded it (the nabarlek Petrogale concinna) as formerly common in areas where it is now rare or non-existent (Press 1988)*".

There are also some data from recent scientific studies. The most substantial of these has been the 1999 re-sampling of mammals at Kapalga (Woinarski *et al*. 2001), which indicated substantially reduced abundance there over the period 1986 - 1999 of fawn antechinus *Antechinus bellus*, pale field-rat *Rattus tunneyi*, northern quoll *Dasyurus hallucatus*, northern brown bandicoot *Isoodon macrourus*, common brushtail possum *Trichosurus vulpecula*, black-footed tree-rat *Mesembriomys gouldii* and dusky rat *Rattus* *colletti*. Recent local declines for at least northern quoll have also been reported for some other areas within Kakadu (Oakwood 2002). There is also some historical evidence for declines or local extinction of many of these species elsewhere in northern Australia (Kitchener 1978; McKenzie 1981).

Given this concern, Parks Australia (North) instigated this cooperative project in January 2001 as a consultancy with the Tropical Savannas Cooperative Research Centre and Parks and Wildlife Commission of the Northern Territory. The outputs sought from the project are listed in the following box.

Specific outputs sought in the project schedule

- establishment of a monitoring program (for terrestrial vertebrate fauna) which will contribute to the assessment of impacts of cane toads;
- assessment of vertebrate fauna at the existing fire monitoring plots (and hence establishment of the baseline for ongoing monitoring of the impacts of fire upon fauna at these plots;
- investigation of change in vertebrate (and especially mammal) species composition at sites sampled in historic surveys;
- investigation of relationships of mammal fauna with fire regimes (through sampling in eucalypt forest sites of contrasting fire history);
- training for Parks Australia staff in fauna survey; and
- compilation of data bases and GIS layers showing existing and current fauna records.

Although the contract was written for this project to be completed within 12 months, it was recognised that the work would be developed further to cover a 2-year period, coinciding in part with the arrival of cane toads *Bufo marinus* in KNP.

By agreement of all parties, the work concentrated in the southern half of the park (mostly the Mary River district), because (i) this was the area in which cane toads were likely to arrive first; (ii) this area had the most comprehensive pre-existing sampling baseline (the Kakadu Stage III surveys by CSIRO: Woinarski and Braithwaite 1990, 1991); and (iii) this provided the best geographic counterpoint to the results from Kapalga, in the north of the Park.

Together, the project objectives serve to establish a monitoring program for terrestrial vertebrates in KNP. This report describes progress towards this program. The main body of the report describes results from re-sampling in 2001 of the largest baseline of mammal data available in Kakadu, the 1988-90 survey of Stage 3 of KNP. Other components of this report describe vertebrate sampling of some of the existing fire monitoring plots, a study of the mammal fauna at sites selected to represent very different fire histories, the collation of historic data bases, and a brief account of the status of small mammals in KNP. Appendices include details of methodology and examples of the sampling site descriptions. Files containing hard copies of all quadrat descriptions and data are provided to KNP headquarters and relevant district offices. This report considers terrestrial mammals only. Results for other terrestrial vertebrates will be reported subsequently.

2. MONITORING

Given substantial changes in biodiversity in many regions, and indeed globally, and the uncertainty about the responses of biodiversity to many land management practices, monitoring is widely seen as an essential component of natural resource management.

However, biodiversity monitoring has much baggage. Many monitoring programs have been established only to wither when resources dry up, or when the initiating personnel move on. Many have been perpetuated blithely, almost as an activity trap, divorced from the NRM questions of highest priority. Indeed, many have no effective link to management, and hence can't be used to gauge the efficacy of existing management or to measure the benefits or costs of a range of possible management alternatives. Some programs have monitored their focal organisms to death, progressively counting fewer and fewer without any clearly-defined trigger for instigating remedial actions.

In a recent review of biodiversity monitoring programs, Yoccoz *et al*. (2001) recognised this chequered history, and noted that the deficiencies arose largely because many monitoring programs failed to adequately define three basic questions: (1) why monitor?; (2) what should be monitored?; and (3) how should monitoring be carried out? We use these three issues as a framework for introducing the monitoring program established here.

<u>Why monitor?</u>

The rationale for this program was partly examined in the Introduction section. The primary reason is that the management agency (Parks Australia North) has a responsibility to maintain the biodiversity assets of the area managed. This obligation includes statutory responsibilities for the maintenance of World Heritage values (including that of an intact fauna); expectations owing to the Aboriginal landowners; and more general moral responsibilities, as one of the nation's premier conservation agencies, to demonstrate success in sustaining and nurturing biodiversity.

Biodiversity monitoring provides a gauge with which the success of this management may be measured, or an accounting mechanism appropriate for auditing the effect of that management.

But monitoring can be more than a passive measure of biodiversity trends. When coupled with information on management activities, it can provide an effective measure of the efficacy of different management options, and thence can be used to refine and improve that management.

In this context, this monitoring program aims to address the question:

> *Is Kakadu's biodiversity being maintained?*

Supplementary questions include:

- *What are the biodiversity costs and benefits of different management actions?*

- *Are there some components of the biodiversity which are particularly susceptible to decline, and hence may merit especially targetted management responses?*

<u>What should be monitored?</u>

Kakadu is recognised at international scale as possessing an extraordinarily rich biodiversity. That very attribute poses a problem for biodiversity monitoring: there are simply too many things to monitor.

There are three broad mechanisms for simplifying the list, in order to prioritise species for monitoring.

> 1) *regulation*. Some species are formally listed as threatened, or recognised as of special importance by virtue of their inclusion on bilateral or international treaties. There are legislative responsibilities for managing such species, notably under the *Environment Protection and Biodiversity Conservation Act*, and especially so on lands managed by federal agencies.
>
> 2) *ecological significance or shorthand*. There is a large body of scientific literature which proposes and evaluates a range of schema (e.g., umbrella species, focal species, indicator species, flagship species, keystone species) designed for selecting a few species to represent a far broader body of species. The issue is vexed and inconclusive, and no schema has achieved anything like universal acceptance.
>
> 3) *pragmatism*. To measure as many species from as many groups as is practicable, with the assumption that the ecological breadth sampled should include insight into trends for all other taxa.

Here, we develop a set of studies which monitor the abundance of all terrestrial vertebrates. In this report we consider only terrestrial mammals, because there is recent concern about their fate in Kakadu (Woinarski *et al*. 2001), and because this group (along with frogs in parts of Australia) has been shown to be the most susceptible component of Australia's biodiversity to decline and extinction (Whitehead *et al*. 2001). Our process emphasises the full range of species, sampled over a broad range of environments. Such emphasis will generally serve to provide relatively meagre information on rare species, and the broad-brush approach we adopt may need to be complemented by more specific and focused monitoring activity aimed at threatened species.

<u>How should monitoring be carried out?</u>

Over the last decade we have developed a standard protocol for sampling terrestrial vertebrate fauna, which is now used routinely across much of northern Australia (Appendix A). This provides a consistent approach appropriate for the assessment of temporal change in vertebrate assemblage, and the broad application of the methodology allows for comparison of change at any site with that occurring in very different areas.

There is merit in linking the monitoring program at KNP to the broader landscape. Decline of some species in Kakadu may not be directly attributable to management practices within Kakadu (nor a good measure of the efficacy of those practices), but rather a component of a far broader pattern which affects those species across all landscapes, tenures and management regimes. In such cases, it may be futile to attempt remedial action within Kakadu alone. Linked monitoring beyond Kakadu also allows some consideration of the effectiveness (or detrimental impacts) of management practices which perhaps are not currently part of the menu of management actions practised within the Kakadu borders.

The standard PWCNT fauna sampling protocol is focused mainly on small and medium-sized mammals, bush birds, and small and medium-sized reptiles. The approach may provide less precise assessments for larger reptiles, frogs, water birds and large mammals (Woinarski *et al*. 2000a), and other approaches may be better for these groups.

Previous sampling of terrestrial vertebrates in Kakadu - e.g. the CSIRO fauna surveys of Stages 1 and 2 (Braithwaite 1985), and Stage 3 (Woinarski and Braithwaite 1990, 1991), the Alligator Rivers Fact-finding Study (Calaby 1973), of the Jabiluka area (Kerle and Burgman 1984), of Little Nourlangie Rock (Begg *et al*. 1981) and of Kapalga (Braithwaite and Muller 1997) - have all used idiosyncratic approaches, which greatly constrains the interpretability of possible changes in mammal status between those studies and now, and constrains comparisons between these studies. Of these sampling approaches, that used in the original Stage 3 surveys is most similar to the standard now used (Appendix A). We consider that the best approach is to adopt the standard henceforth, albeit where possible, when comparing with historical records, also attempting to calibrate this methodology against the idiosyncratic approach previously used. Thus there is some inevitable patching-up of diverse methodologies when comparing results from historic sampling to those undertaken now. However, the adoption now of a standard protocol will mean that there should be no such problem with future comparisons.

There are a number of other simple ingredients in a monitoring protocol. Monitoring should sample representatively across the range of environments present, across the geographic area, and across seasons. Given the extreme seasonality of the Kakadu area, it is important that subsequent samples from any one monitoring site be undertaken at more or less the same time of year as the previous sampling of that site.

An ideal monitoring program for terrestrial vertebrates in Kakadu might select a large suite of new sampling points randomly across the Park. However, such an approach ignores the wealth of information associated with sites already surveyed for fauna, and hence prevents any direct comparison of historical changes. It also would fail to recognise that there is a large array of sites already formally recognised as monitoring plots within Kakadu, those established to monitor the effects of fire upon vegetation. The monitoring program that we develop here is based on combining a large set of sites which were previously used as part of the historic fauna surveys, with a set including many of the existing fire monitoring plots. The incorporation of the latter provides the advantages of some logistical efficiency, access to detailed vegetation and fire history information, and helps to streamline a coherent and manageable overall monitoring program within Kakadu NP.

3. RE-SAMPLING OF THE STAGE 3 FAUNA PLOTS

3.1. Introduction

The three year (1988-1990) CSIRO survey (Woinarski and Braithwaite 1991) of the Stage 3 area of Kakadu (the Mary River district) provides the most extensive data base available for terrestrial vertebrate fauna in Kakadu, and hence was chosen here as a baseline from which to establish an ongoing monitoring program.

The original survey sampled 380 quadrats, comprising 20 groups each of 15 quadrats, two groups of 5 quadrats, and a set of 70 quadrats located within the then "Conservation Zone", between Coronation Hill and El Sherana (Woinarski and Braithwaite 1990, 1991). The locations of these sites are shown in the accompanying A0 map. Note that the individual quadrats in the CSIRO Kakadu Stage 3 survey were not originally GPSd nor permanently marked.

We re-located the original quadrat locations as precisely as possible by using personnel from the original study (Nic Gambold, John Woinarski, Martin Armstrong) and archived records of site descriptions. In the re-sampling, all quadrat positions have now been GPSd, which will allow for more precision in any subsequent re-sampling.

Between February and November 2001, we re-sampled a total of 263 of these 380 quadrats (Table 1). The full set could not be re-sampled because of problems with access (in some cases tracks had degraded and become impassable over the 10-12 year period), inability to relocate with sufficient certainty, and/or constraints on personnel. Nonetheless, the re-sample size is large. It represents a very substantial field effort within one year, given that the initial sampling spanned three years.

In re-sampling, we visited each site at the same time of year (plus or minus 6-8 weeks) as the previous sampling, to minimise apparent change due to seasonal effects.

Sampling methodology is described in Appendix A. For each quadrat, we derived an index of abundance for each mammal species, which was the total number of captures plus the number recorded in quadrat searches.

Note that there are some minor differences in procedure between the original sampling and the subsequent re-sampling, with these differences largely reflecting improvements in sampling efficiency and greater consistency with the sampling procedure now used routinely across the Top End of the Northern Territory. The differences equate to 10% less Elliott and cage trapnights per quadrat in 2001 sampling and 25% less pitfall trapnights in 2001 sampling.

The Stage 3 sampling was originally designed under the constraint of limited access (at many sites personnel were dropped off by helicopter and picked up on completion of sampling), hence sites were sampled with a cluster of quadrats, all located within walking distance of each other. This clustering reduces the independence of results from nearby quadrats, although the minimum distance between quadrats is greater than that of the home range size for most small mammal species. A more even spread of quadrats across the study area would have provided greater statistical leverage, albeit this would have come at greatly increased logistic cost.

The original design was also based mainly on stratified sampling (sites chosen to represent all main vegetation types), rather than random sampling. However, at least 5 quadrats within each cluster of 15 quadrats were located in a random direction from a central point.

The Stage 3 design represented a reasonable pragmatic compromise between sampling efficiency, representativeness of geographic areas and environments, and statistical rigour. However, it was set up to meet the immediate need for inventory rather than as an ongoing baseline for subsequent monitoring. We consider that the Stage 3 sites represent an essential component of an ongoing fauna monitoring program, but recognise that they need to be augmented by additional sites dispersed more widely across the park. The most obviously suitable candidates include the set of sites used for vegetation assessment as part of Kakadu's fire monitoring program (see Section 4 below).

Table 1. Location of fauna survey sites, Kakadu Stage 3 survey.

site	*name*	*initial sampling*		*repeat sampling*	
		no. of quadrats	*date*	*no. of quadrats**	*date*
1	Coirwong	15	5-9 Sept 1988	13	24-28 Sept 2001
2	Mundogie Hills	15	10-14 Sept 1988	10	1-5 Nov 2001
3	Sleisbeck Plateau	15	21-25 Sept 1988	12 (+2)	29 Sept-2 Oct 2001
4	Upper Katherine	15	26-30 Sept 1988	13	3-7 Oct 2001
5	El Sherana	15	1-5 Oct 1988	12	17-20 Nov 2001
6	Inbarin Hills	15	11-15 Oct 1988	9	5-10 Nov 2001
7	Bukbukluk	15	16-20 Oct 1988	11	22-25 Nov 2001
8	Marrawal Plateau	15	27-31 Oct 1988	-	-
9	Koolpin Gorge	15	5-10 Nov 1988	11	14-17 Nov 2001
10	Mary River	15	11-15 Nov 1988	8	11-14 Nov 2001
11	Plumtree Creek	15	23-27 Feb 1989	15	23-27 Feb 2001
12	Billiard Creek Rd	15	1-4 March 1989	15	27-30 Feb, 12-15 Mar 2001
13	Gerowie	15	16-20 Mar 1989	15	20-24 Feb 2001
14	Mt Evelyn	15	4-9 April 1989	(7)	May 2001
15	Bloomfield Springs	15	10-15 April 1989	14	26-30 April 2001
16	Snake Plain	15	6-11 May 1989	15	8-12 June 2001
17	Birdie Creek	15	19-23 April 1990	12	19-22 April 2001
18	Turnoff Creek	15	24-28 April 1990	15	22-26 April 2001
19	Black Jungle Spring	15	10-14 May 1990	14	13-17 June 2001
20	Sleisbeck Plateau	15	15-19 May 1990	(12)	May 2001
X	Koolpin Gorge	5	17-21 May 1989	4	May 2001
Y	Shovel Billabong	5	22-25 May 1989	5	4-7 June 2001
	conservation zone	70	17 July - 4 Aug 1990	40	31 Aug - 12 Sept 2001

* bracketed tallies refer to re-sampled quadrats which were located with insufficiently precision: these have been excluded from all analyses.

Table 2. Change in mammal abundance over the period 1988-2001, across the 263 quadrats re-sampled in Kakadu Stage 3 (Mary River district).

species	**1988-1990 sampling**		**2001 resampling**		**z-score**	**prob.**	**trend**
	no. of quadrats in which recorded	*mean abundance across all quadrats*	*no. of quadrats in which recorded*	*mean abundance across all quadrats*			
macropods							
agile wallaby *Macropus agilis*	20	.091	15	.068	0.76	0.44	
antilopine wallaroo *M. antilopinus*	12	.099	0	0	3.06	0.002	decline
black wallaroo *M. bernardus*	4	.015	1	.004	1.21	0.225	
euro *M. robustus*	13	.061	9	.042	0.81	0.417	
northern nailtail wallaby *Onychogalea unguifera*	1	.004	0	0	-	-	
short-eared rock-wallaby *Petrogale brachyotis*	1	.004	0	0	-	-	
dasyurids							
northern quoll *Dasyurus hallucatus*	43	.418	34	.338	1.02	0.309	
brush-tailed phascogale *Phascogale pirata*	0	0	1	.008	-	-	
fawn antechinus *Antechinus bellus*	5	.061	6	.042	0.27	0.79	
sandstone antechinus *Pseudantechinus bilarni*	5	.019	1	.004	1.47	0.14	
kakadu dunnart *Sminthopsis bindi*	8	.030	6	.030	0.03	0.98	
red-cheeked dunnart *S. virginiae*	14	.053	9	.053	0.54	0.59	
common planigale *Planigale maculata*	10	.061	0	0	2.80	0.005	decline
rodents							
black-footed tree-rat *Mesembriomys gouldii*	2	.015	8	.038	1.07	0.29	
water-rat *Hydromys chrysogaster*	6	.023	2	.011	0.84	0.40	
pale field-rat *Rattus tunneyi*	61	1.563	101	1.430	0.98	0.33	
dusky rat *R. colletti*	2	.008	5	.027	1.35	0.18	

grassland melomys *Melomys burtoni*	17	.232	20	.483	0.55	0.58	
common rock-rat *Zyzomys argurus*	38	.856	45	.650	0.80	0.42	
Arnhem rock-rat *Z. maini*	18	.244	2	.038	2.80	0.005	decline
western chestnut mouse *Pseudomys nanus*	19	.130	21	.160	0.80	0.43	
delicate mouse *P. delicatulus*	37	.243	13	.057	3.97	0.0001	decline
kakadu pebble-mound mouse *P. calabyi*	18	.084	10	.080	0.91	0.36	
Lakeland Downs mouse *Leggadina lakedownensis*	13	.049	0	0	3.18	0.0015	decline
other native mammals							
echidna *Tachyglossus aculeatus*	3	.011	0	0	1.60	0.11	
northern brown bandicoot *Isoodon macrourus*	12	.061	35	.224	3.81	0.0001	increase
sugar glider *Petaurus breviceps*	1	.004	4	.015	1.21	0.23	
brushtail possum *Trichosurus vulpecula*	1	.004	1	.004	0	-	
rock ringtail possum *Petropseudes dahli*	6	.030	1	.008	1.35	0.18	
feral mammals							
water buffalo *Bubalus bubalis*	45	.293	1	.004	5.71	0.0001	decline
cow *Bos taurus*	31	.175	0	0	4.86	0.0001	decline
pig *Sus scrofa*	7	.061	25	.095	1.96	0.050	increase
donkey *Equus asinus*	0	-	1	.004	-	-	
horse *E. caballus*	6	.046	4	.015	0.76	0.45	
dingo/dog *Canis vulpes*	10	.038	3	.011	1.87	0.061	
cat *Felis cattus*	3	.011	2	.008	0.40	0.69	
black rat *Rattus rattus*	0	-	2	.008	-	-	
total native mammals							
abundance		4.45		3.81	0.30	0.76	
no. of species		1.48		1.33	1.63	0.10	

3.2. Overall pattern of change

Changes in the terrestrial mammal fauna between the original and subsequent re-sampling are given in Table 2. For this comparison, we use the Wilcoxon Matched-Pairs test, which is a powerful test for change as it directly compares results from matched samples (i.e. the same quadrat sampled at two different times), eliminating unwanted variation due to locational and environmental factors. Given the priority assigned in the contract brief to mammals, we have not yet analysed the re-sampling data for birds, reptiles, frogs or bats.

Of 18 native mammal species which were recorded from at least 10 quadrats in the combined 1988-90 and 2001 sampling, the abundance of five mammal species declined significantly (antilopine wallaroo, common planigale, Arnhem rock-rat, delicate mouse, and lakeland downs mouse) and one increased significantly (northern brown bandicoot). Six native species (antilopine wallaroo, northern nailtail wallaby, short-eared rock-wallaby, common planigale, lakeland downs mouse and echidna) which were recorded in the original sampling of these 263 quadrats, were not recorded in any of the re-sampled quadrats. However, for three of these species (northern nailtail wallaby, short-eared rock-wallaby and echidna), the original sampling included very few records, such that no conclusion can be made from their absence in the subsequent sampling. One native species (brush-tailed phascogale) was recorded in the 2001 sampling (from but one quadrat) and not in the 1988-90 sampling.

This set of changes is unlikely to be due to different trapping effort between the original and subsequent sampling. There were no differences in sampling procedure or effort for the macropods or large feral animals. The observed differences in abundance for the common planigale (100% reduction), lakeland downs mouse (100% reduction) and delicate mouse (77% reduction) were all far greater than the difference in pitfall trapping effort per quadrat (25% reduction from 1988-90 to 2001). The 84% reduction in abundance of arnhem rock-rat was far greater than the 10% reduction in Elliott/cage trapping effort per quadrat.

The overall abundance and species richness of native mammals in quadrats declined (by 14% and 10% respectively) from 1988-90 to 2001, but this decline was far from statistically significant, and may be explained by comparable levels of reduced trapping effort per quadrat. The pattern of change across quadrats was noisy, with some quadrats exhibiting dramatic increases in the total number of mammals and other quadrats exhibiting substantial decrease (Fig.1).

Of 5 feral mammal species which were recorded from at least 10 quadrats in the combined 1988-90 and 2001 sampling, two species (buffalo and cattle) declined significantly and one (pig) increased significantly. A decline in dingo/wild dog numbers was not quite statistically significant.

Two non-native mammal species (donkey and black rat) were recorded in the 2001 sampling but not in the 1988-90 sampling, however the donkey was recorded in other quadrats sampled in 1988-90 which were not re-sampled in 2001. No black rats were recorded over the total 380 quadrats sampled in 1988-90. Note that the 2001 records for this species were both distant from areas of relatively intense disturbance or human impact, at Snake Plain and Black Jungle Springs.

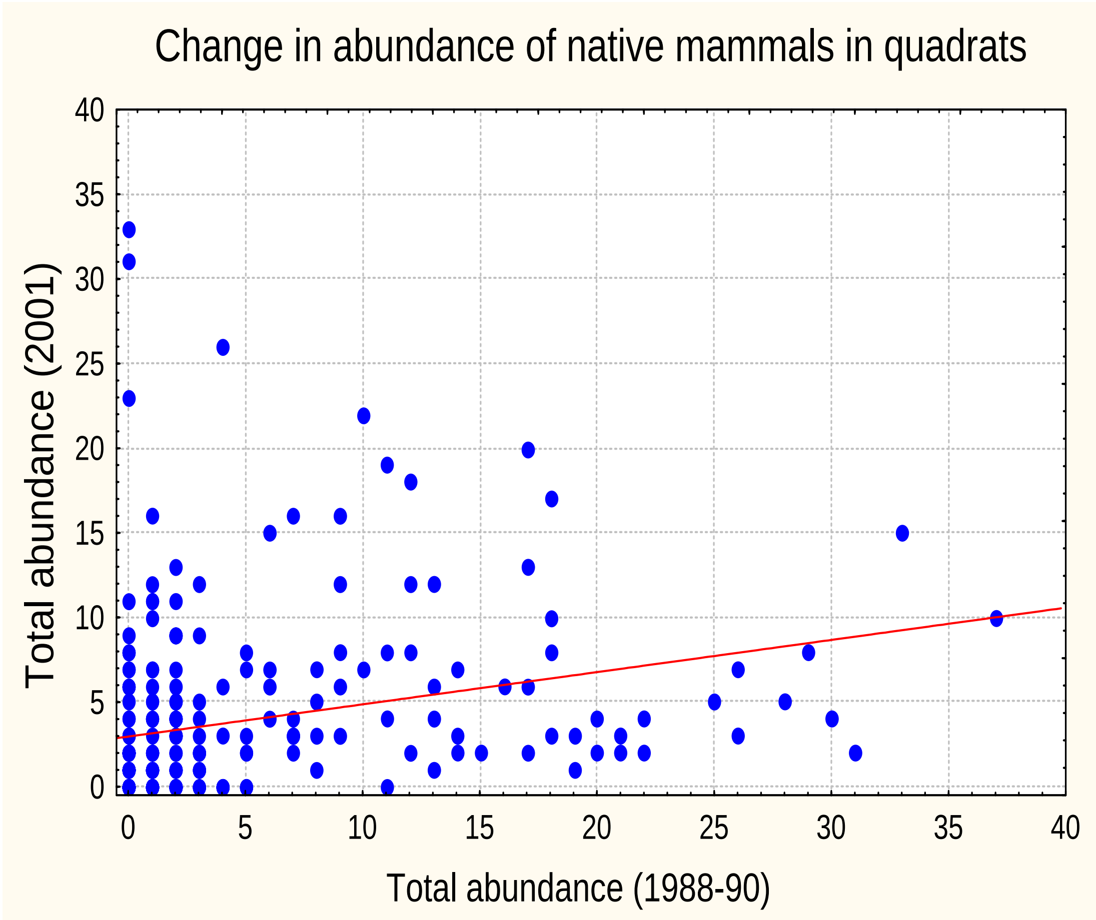


Fig 1. The abundance of all native mammals in individual quadrats sampled in both 1988-90 and 2001.

3.3. correlates of change - geographic trends

For each species in each quadrat, we calculated a change in abundance over the period 1988-90 to 2001. This was simply the abundance value recorded for that species in that quadrat during the 2001 sampling minus that recorded in the 1998-90 sampling. For any given species, quadrats in which the abundance score was 0 in both periods were excluded from analyses.

A consideration of geographic pattern may provide some inference about factors involved in decline. For example, one may expect disease, or localised high densities of predators, to operate patchily, with some clusters of quadrats all showing decline, whereas quadrats in other locations may show no change. Such geographic divergence in trend may also be related to management (e.g. if some areas have been burnt in a consistent way, which is different to that occurring in a different area). However, the analyses relating change in mammal abundance to fire regimes (section 3.6 below) should discriminate this possible cause more precisely.

The geographic pattern of change is illustrated for every species in Fig. 2. The results are mixed. For some species (notably such as fawn antechinus and pale field-rat), and for all species combined, the pattern of change was geographically disparate, with some clusters of sites generally showing decline and other clusters generally showing increase. In most cases, decrease occurred in the area between Coronation Hill and Koolpin Gorge, with increase in the area between Mary River Ranger Station and Gerowie Creek, and at some other lowland sites.

Figure 2 (following pages). Change maps for individual mammal species, and all species combined.

Red circles indicate decrease in abundance in a quadrat from 1988-90 to 2001; green circles indicate an increase; and black circles indicate the abundance score was unchanged. Quadrats where the species was unrecorded in both 1988-90 and 2001 were excluded from the maps.

3.4. correlates of change - habitat

For every species, we examined for differences among habitats in the extent of change in abundance over the two sampling periods, using one-way analysis of variance. For this analysis, we divided all quadrats into 6 broad categories:

- rocky areas;
- eucalypt open forests (dominated by *Eucalyptus miniata* and *E.tetrodonta*);
- riparian strips, swamps and rainforests;
- woodlands on stony hills (dominated by a range of species including *Eucalyptus phoenicea, E. tectifica, E. dichromophloia* and *E. tintinnans*);
- lowland open woodlands (dominated by a range of species including *Melaleuca nervosa*, *Petalostigma* spp. and *Eucalyptus grandifolia*);
- grasslands and open plains.

Of 18 native species recorded from 10 or more quadrats, only one showed significant variation among these habitat types in change in abundance (Table 3). The fawn antechinus decreased in eucalypt open forests and woodlands on stony hills, but increased in lowland woodlands and riparian/swamps/wetlands. For all species combined, there was a trend (not quite significant) for decline to be most marked in rocky areas and lowland woodlands, whereas total mammal abundance generally increased in riparian strips, wetlands and rainforests.

Table 3. Variation among habitats in change of abundance between the sampling periods of 1988-90 and 2001. Negative values indicate decline. Only species recorded from 10 or more quadrats during the combined sampling period are listed.

species	habitat						*F*	*p*
	rocky	*miniata-tetrodonta open forests*	*riparian, swamp, rainforest*	*stony hill woodland*	*lowland woodland*	*grassland*		
macropods								
agile wallaby	0 (2)	0.33 (6)	-0.8 (8)	-0.2 (9)	0 (8)	- (0)	0.68	0.61
antilopine wallaroo	-3.0 (3)	- (0)	-4.0 (2)	-1 (3)	-1.5 (4)	-	3.6	0.07
euro	0 (9)	- (0)	-1.0 (2)	-0.3 (6)	-0.2 (5)	- (0)	0.27	0.84
dasyurids								
northern quoll	-0.07 (28)	-1.0 (4)	-0.4 (8)	-0.4 (10)	-0.4 (20)	- (0)	0.08	0.99
fawn antechinus	- (0)	-4.0 (1)	1.0 (3)	-3.7 (3)	2.0 (3)	1.0 (1)	4.64	0.048
kakadu dunnart	- (0)	- (0)	1.0 (1)	-0.3 (6)	0.3 (6)	-1.0 (1)	0.67	0.59
red-cheeked dunnart	- (0)	-1.0 (2)	- (0)	0 (1)	0.2 (10)	0 (7)	0.31	0.82
common planigale	-2.0 (2)	- (0)	-1.0 (1)	-1.0 (1)	-2.0 (3)	-1.3 (3)	0.25	0.90
rodents								
black-footed tree-rat	0.8 (4)	- (0)	1.0 (1)	1.0 (2)	0 (3)	- (0)	0.18	0.91
pale field-rat	-1.4 (27)	1.2 (6)	0.7 (18)	2.0 (21)	-1.3 (44)	- (0)	1.26	0.29
grassland melomys	- (0)	-2.0 (1)	2.9 (24)	-1.5 (2)	0.3 (7)	- (0)	0.33	0.80
common rock-rat	-0.7 (36)	-4.0 (2)	0.3 (4)	1.20 (10)	-3.3 (10)	- (0)	1.29	0.28
Arnhem rock-rat	-2.7 (17)	- (0)	- (0)	- (0)	-1.0 (3)	- (0)	0.42	0.53
western chestnut mouse	-1.0 (2)	-2.0 (1)	-0.5 (2)	0.83 (6)	0.42 (19)	0 (4)	0.44	0.82
delicate mouse	-1.0 (5)	-0.5 (12)	-0.3 (4)	-2.25 (8)	-1.1 (17)	- (0)	2.09	0.12
kakadu pebble-mound mouse	0 (7)	0.7 (3)	-1.0 (1)	0.8 (5)	-0.6 (8)	-1.0 (1)	0.40	0.84
Lakeland Downs mouse	-1.0 (1)	- (0)	- (0)	-1.0 (1)	-1.0 (10)	-1.0 (1)	-	-
other native mammals								
northern brown bandicoot	0.91 (11)	3.5 (2)	0.83 (6)	1.60 (5)	0.81 (16)	- (0)	1.55	0.21
feral mammals								
water buffalo	-3.0 (1)	-1.8 (11)	-1.7 (9)	-1.5 (13)	-1.2 (9)	-2.3 (3)	0.50	0.77
cow	- (0)	-2.3 (7)	-1.4 (8)	-1.3 (12)	-1.0 (4)	- (0)	0.70	0.56
pig	- (0)	1.0 (4)	-1.3 (8)	1.0 (3)	0.9 (15)	-1.0 (1)	4.83	0.005

horse	- (0)	- (0)	- (0)	0 (2)	-1.0 (6)	-1.0 (2)	0.11	0.90
dingo/dog	1.0 (1)	- (0)	-1.0 (4)	- (0)	-0.4 (5)	-1.0 (2)	3.10	0.09
total native mammals								
abundance	-3.1 (42)	-0.5 (23)	2.1 (36)	0.5 (44)	-1.7 (68)	-0.3 (13)	1.97	0.08
no. of species	-0.5 (42)	0.1 (23)	0.3 (36)	-0.2 (44)	-0.2 (68)	-0.3 (13)	0.82	0.54

3.5. correlates of change - cane toad invasion

In 1999 or 2000, cane toads (*Bufo marinus*) invaded some parts of the southeast of Kakadu NP, including two clusters of quadrats sampled in 1988-90 (upper Katherine River and Birdie Creek). These sites (comprising 25 re-sampled quadrats) were re-sampled in 2001, and the changes in their mammal fauna were compared with the mammal changes at all other sites (comprising 238 quadrats) in which no cane toads had arrived. This comparison was made using Mann-Whitney U tests on the difference in abundance per quadrat between the 2001 sampling and 1988-90 sampling.

This comparison is limited by the relatively sparse mammal fauna at these two sites even before cane toad arrival, and especially so for the dasyurid mammals considered likely to be most susceptible to cane toad impacts. Only five native species (including no dasyurids) were recorded from at least 3 of the 25 quadrats across the combined 1988-90 and 2001 sampling (Table 4). For two of those species (delicate mouse and agile wallaby), changes in abundance between 1988-90 and 2001 were similar for the toad-invaded and toad-free areas. For two species (common rock-rat and pale field-rat), and for all native mammals combined, abundance *increased* in the toad-invaded sites and decreased in the toad-free sites, although this difference was not significant. For one species (euro), there was a significant difference, with decrease in the toad-invaded sites and increase in the toad-free sites. There was no significant difference between toad-invaded and toad-free sites in the change in the native mammal species richness.

Table 4. Change over the period 1988-90 to 2001 in abundance for individual mammal species and total species, for toad-invaded and toad-free sites. Note that the table lists only those species recorded from at least 3 quadrats in the toad-invaded area, in either or both the 1988-90 and 2001 sampling. Note also that mean change in abundance is expressed as the abundance in 2001 minus the abundance in the same quadrat in 1988-90 (i.e. a negative value indicates decline).

species	*toad free sites (238 quadrats)*		*toad-invaded sites (25 quadrats)*		*z-score*	*p*
	mean change	no. of quadrats in which recorded	mean change	no. of quadrats in which recorded		
agile wallaby	-0.19	27	-0.17	6	-0.02	0.98
euro	0.27	15	-1.29	7	2.44	0.015
delicate mouse	-1.11	38	-0.88	8	-0.68	0.58
common rock-rat	-1.13	56	1.50	6	-1.63	0.10
pale field-rat	-0.35	111	0.80	5	0.14	0.89
total native mammal abundance	-0.87	202	0.29	24	-0.36	0.72
no. of native mammal species	-0.18	202	-0.17	24	-0.15	0.88

3.6. correlates of change - fire history

Fire history may influence the change in abundance of mammal species over the sampling period. We used the library of interpreted imagery to derive an 11-year (1990-2000) fire history for each of the 263 re-sampled quadrats. This fire history was based on fine resolution (pixels of 0.06 ha) LANDSAT-TM monitoring for the period 1996-2000. Over each year of this period, each quadrat was scored as burnt or unburnt over two time periods - early dry season (May-July) and late dry season (August-November). Fire history over the period 1990-1995 was based on coarser resolution (pixel size 0.5 ha) LANDSAT-MSS satellite monitoring (Russell-Smith *et al*. 1997). Fires in this period were also divided into early and late dry season.

Thus every quadrat was associated with a fire history data set comprising a run of either 0 (unburnt) or 1 (burnt) values for early and late dry seasons over the years between the two sampling periods. From this set we derived four summary variables representing fire history:

- *the total number of years in which the quadrat was burnt* (TFIRE);
- *the number of late dry season fires* (TLATEFIRE);
- *the longest run of years without fire* (FFREEINT); and
- *the number of years since the last fire at the time of re-sampling* (LASTFIRE).

Recognising also that the precision of fire mapping was substantially better in the 1996-2000 period than in the 1990-95 period, we also calculated two fire variables for only the later period:

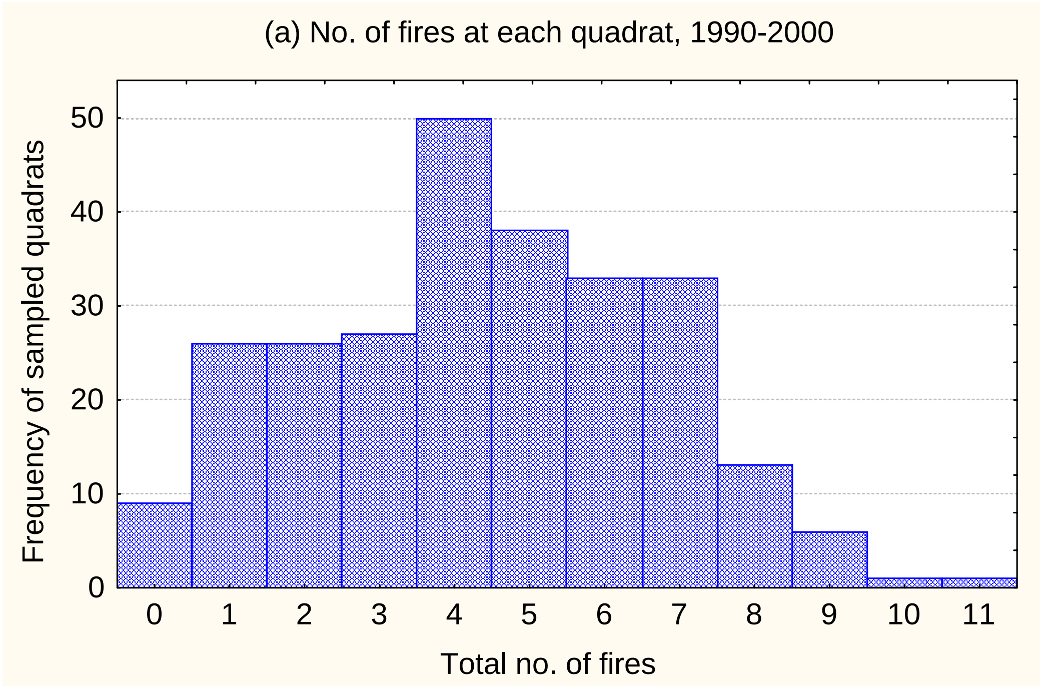
- *total number of years in which the quadrat was burnt during the period 1996-2000* (TFIRE9600); and
- *the number of late dry season fires during the period 1996-2000* (LFIRE9600).

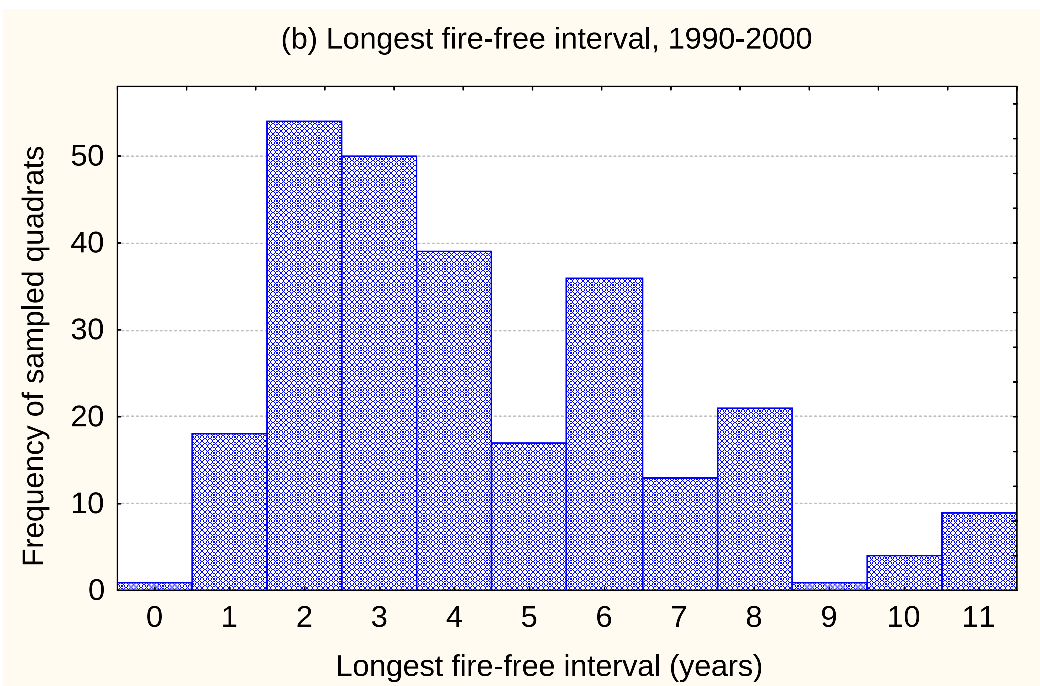
These calculations of fire history reveal that the monitored quadrats were subjected to a diverse range of fire history, including some which were burnt every year and others which were not burnt at all over the 1988-90 to 2001 period (Fig 3).

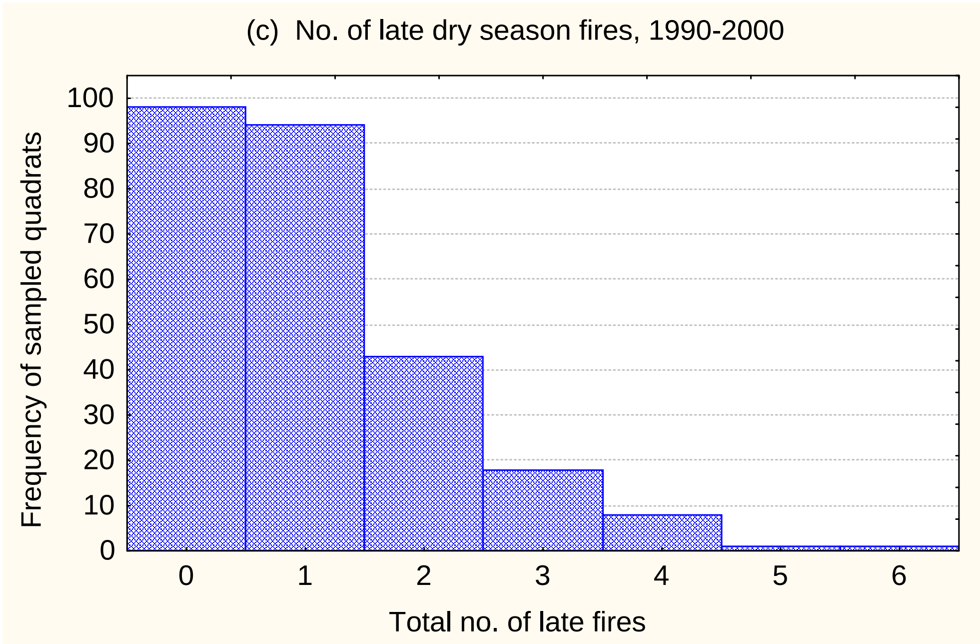
There are three caveats for this analysis and its interpretation. Firstly, there is inevitably some imprecision in ascribing fires correctly at the quadrat-scale, especially over this period 1990-95, when the quadrat size is comparable to the pixel size. Notwithstanding the scale issue, there is also some error in coding fires, with some fire scars not evident in the imagery and some unburnt areas incorrectly coded as burnt (Russell-Smith *et al*. 1997). These errors compound over several years of assessment. For example, if the accuracy of recording fire correctly at any pixel in any year is 90%, then the probability of deriving a correct five-year fire history for that point is $(0.9)^5$, that is only 59%. Thirdly, the set of six fire parameters that we use are inevitably somewhat inter-correlated, so that models with multiple terms may be difficult to interpret.

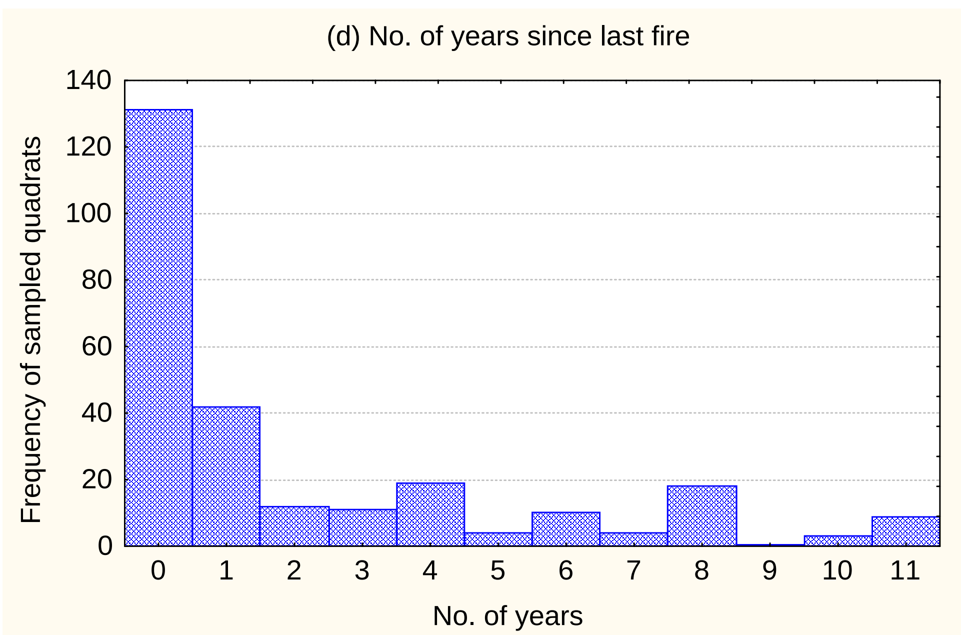
Figure 3. Summary of fire histories of the 263 re-sampled quadrats, over the period 1990-2000. Histograms show the number of quadrats within each value for each of four fire parameters: (a) the total number of years in which the quadrat was burnt;

(b) the longest fire-free interval; (c) the number of late dry season fires; and (d) the number of years elapsed since the last fire, at the time of re-sampling (2001).









We relate the observed change in the abundance of any mammal species at a given quadrat to the fire history of that quadrat over the period between the two sampling events. We used generalised linear modelling for this analysis, with the dependent variable being the observed change in abundance. To fit the model, we first standardised each distribution to remove negative terms, by adding to each observed change in abundance the absolute value of the largest negative term. This had no effect on the relationship between the dependent and independent variables, but meant that all models had intercept terms that differed markedly from 0. In the models described below, the explained deviance provides a measure of the goodness of fit, and the sign on the estimate term signifies whether there is a positive or negative association between the dependent and explanatory variable. Only species that were recorded from at least 20 quadrats were modelled.

The resulting models are summarised in Table 5 below. Of the 10 native species with sufficient records, six species had significant relationships with the derived fire regimes. For four species (agile wallaby, common rock-rat, kakadu pebble-mound mouse and western chestnut mouse), the change in abundance over the period 1988-90 to 2001 could not be related significantly to fire history. The significant relationships were:

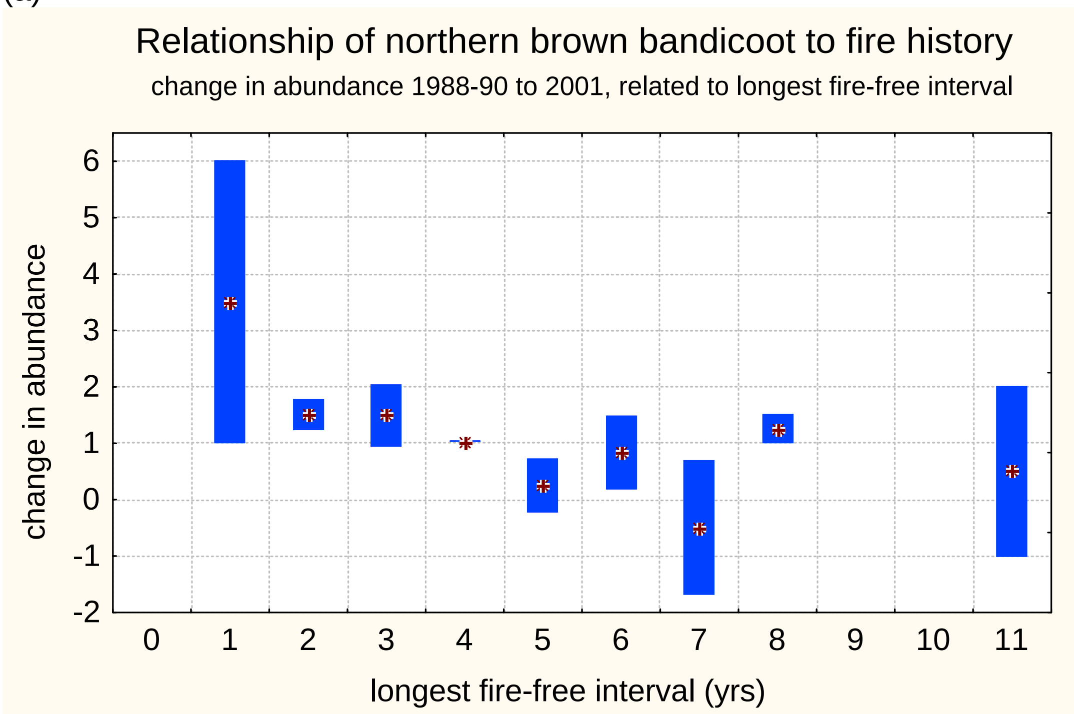
- **northern brown bandicoot** become more abundant at quadrats in which fire recurred frequently, and less abundant in those quadrats which had a long gap between fires (Figure 4a);
- **delicate mouse** became more abundant in quadrats which were relatively long unburnt at the time of re-sampling (Figure 4b);
- the **euro** showed a relative increase in abundance in those quadrats which had fewest late fires in the period 1996-2000, and in quadrats in which fire recurred frequently, perhaps suggesting a preference for early dry season burning;
- the **northern quoll, pale field-rat** and **total abundance of native mammal species** all had similar, weakly significant models, which included the somewhat contradictory relationships of becoming more abundant in quadrats with relatively many fires over the 1990 to 2000 period, but less abundant in quadrats with relatively many fires over the 1996 to 2000 period;
- the model for **species richness** was similarly weak and unclear, with a trend for increase in species richness for quadrats relatively long unburnt when re-sampled, but also an increase in those quadrats in which fire recurred frequently.

Table 5. Generalised linear models showing relationship of change in abundance of mammal species over the period 1988-90 to 2000 with the fire history of those quadrats over the periods 1990 to 2000 and 1996 to 2000. See text above for abbreviations for fire terms.

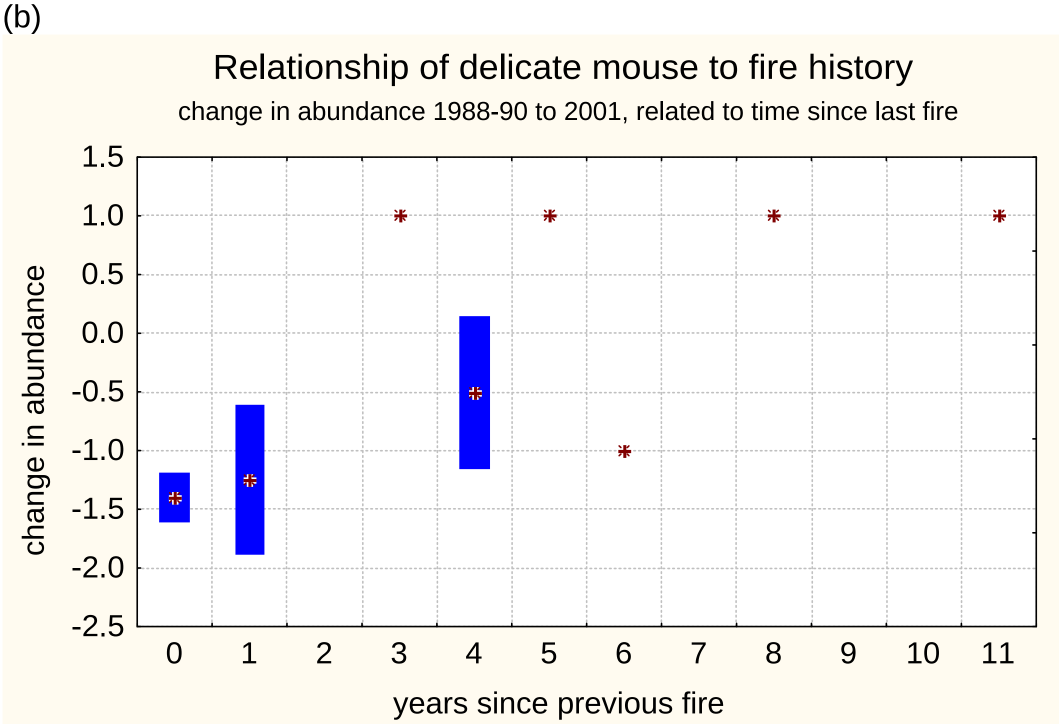
species	*explained deviance*	*N*	*term*	*Wald statistic*	*estimate*	*s.e.*	*prob.*
agile wallaby	no significant model						
northern brown bandicoot	12.7%	39	intercept	403.0	1.83	0.91	<.00001
			FFREEINT	5.8	-0.46	0.02	.016
common rock-rat	no significant model						
delicate mouse	11.9%	45	intercept	961.1	1.53	0.05	<.00001
			LASTFIRE	9.8	0.044	0.014	.0017
euro	54.1%	21	intercept	117.4	1.60	0.15	<.00001
			FFREEINT	5.9	-0.065	0.03	.015
			LFIRE9600	16.8	-0.66	0.16	.00004
kakadu pebble-mound mouse	no significant model						
grassland melomys	13.8%	33	intercept	152.0	3.00	0.24	<.00001
			FFREEINT	5.0	-0.14	0.06	.026
western chestnut mouse	no significant model						
northern quoll	10.8%	69	intercept	370.9	1.94	0.10	<.00001
			TFIRE9600	7.6	-0.15	0.05	.006
			TFIRE	7.7	0.10	0.04	.006
pale field-rat	7.5%	113	intercept	2874	3.09	0.06	<.00001
			TFIRE9600	7.2	-0.072	0.03	.007
			TFIRE	8.6	0.055	0.019	.003
abundance of all native mammals	5.8%	225	intercept	5559	3.25	0.04	<.00001
			TFIRE	13.1	0.049	0.014	.0003
			TFIRE9600	8.2	-0.062	0.022	.004
species richness of all native mammals	5.3%	225	intercept	2911	2.02	0.037	<.00001
			LASTFIRE	9.6	0.029	0.009	.002
			FFREEINT	11.0	-0.038	0.011	.0009

Figure 4. Relationship of change in mammal abundance in quadrats with fire history of those quadrats. Bars show standard error and crosses show means. (a) northern brown bandicoot. (b) delicate mouse.

(a)



(b)



3.7. discussion and conclusion

The re-sampling results from southern Kakadu provide some marked contrasts with those reported for Kapalga in the north of the park (Woinarski *et al*. 2001). In the southern parts, there is no indication of the major decline in the large rodents, bandicoots, possums and larger dasyurids which was evident at Kapalga over roughly the same period (1986-1999), although this conclusion should be tempered by recognition that at least some of these species (e.g. common brushtail possum, black-footed tree-rat) are relatively uncommon anyway in the southern parts, so trends in these species may not be conspicuous. In contrast to the decline observed at Kapalga, re-sampling showed a significant increase in abundance for northern brown bandicoots in the southern part of Kakadu.

However, the re-sampling of southern Kakadu suggested major decreases for three species which were not reported from Kapalga - the lakeland downs mouse, common planigale and arnhem rock-rat - and for the delicate mouse (in contrast to its increase in Kapalga). Hence, as with Kapalga, there is a signal that more of the mammal fauna is declining than is increasing under current management of the southern part of Kakadu NP. This is a somewhat vexatious result, as the baseline sampling was undertaken within 2-3 years of the resumption of the Goodparla and Gimbat pastoral leases, when large numbers of unmustered stock still roamed widely across the sampled area, and when no fire management strategy was established. It would not have been an unreasonable expectation to presume that the mammal fauna may have benefited over the 10-12 years since the inception of National Park management, including stock removal and a more considered approach to burning. But such does not seem to be the case.

But perhaps the holding pattern observed in Stage 3 for the set of mammals which declined in Kapalga actually represents a response to favourable management of the southern part of the Park, or at least the keeping at bay of some otherwise relatively pervasive threatening processes.

Much of the impetus of this project was to examine whether the decline which was reported for Kapalga was pervasive across the Park. Our results show that it isn't, although the story is complicated, with a different set of species declining in the southern half. We cannot yet say why a set of mammals declined at Kapalga but the same set did not decline in the southern half of the Park.

The Stage 3 re-sample results are also noisy, in that there is no consistent pattern of change across the sampled quadrats, but rather a pattern marked by some sites showing increase and a larger set of sites showing decrease. Comparably, Braithwaite (1985) noted that this substantial almost unpatterned fluctuation in numbers was a feature of the mammal fauna in Stages 1 and 2 of Kakadu.

In the results reported here, we can examine some influences of fire management and the arrival of cane toads, and look for possible geographic pattern to changing status. Our results show some relationships between changing abundance at any quadrat and the fire history of that quadrat, although there were simple significant relationships for relatively few species, and these generally explained only a relatively low proportion of the deviance. The results also showed that, in the small set of quadrats which had been invaded by cane toads, there was no marked impact upon the mammal fauna However, these quadrats had few or no dasyurid marsupials (the predatory mammals presumed to be most susceptible to cane toads) at the time of original sampling, so no firm conclusions should be drawn from the lack of change observed.

4. VERTEBRATE SAMPLING AT FIRE MONITORING PLOTS

In 1995, a set of 135 permanent sites was established across Kakadu NP to monitor vegetation and especially its response to fire regimes (Edwards *et al.* 2002). These sites include samples from almost all of the park's environments and are well-dispersed across the park's extent (see attached A0 map).

There is an obvious efficiency and synergy in integrating fauna monitoring with these existing vegetation fire monitoring sites. However, the siting of the fire plots is not ideal for fauna sampling. Many are remote and isolated from each other. This is not a major problem for vegetation sampling, because assessment of any one plot can be completed within one day. But the relative inaccessibility of many plots presents a formidable logistical problem for sampling fauna, given that traps need to be set over a 3-day period and checked early each morning, that spotlighting is part of the assessment procedure, and that an efficient fauna sampling regime generally includes sampling about 10 plots simultaneously. Consequently, it would be impractical and extremely expensive to sample all Fire Plots for fauna.

During 2001, we sampled 21 of these fire plots (16% of the total: Table 6, and attached A0 map), essentially to provide baseline information for subsequent monitoring. We intend to sample fauna at a larger proportion of these monitoring sites during 2002. Sampling methodology used was identical to that used for re-sampling of the Stage 3 fauna sites (Appendix A).

Table 6. Fire plots sampled for fauna during 2001.

Fire Plot	*district*	*sampled date*	
		previous	*2001*
3. Gunlom	Mary River	-	17-19 March
5. Pul Pul	Mary River	Jan-Feb 1996	24-27 Feb
9. Butterfly Gorge	Mary River	Jan-Feb 1996	22-25 Feb
10. Bukbukluk	Mary River	Jan-Feb 1996	26-28 Feb
11. plateau SE Mary R. RS	Mary River	-	25-27 Feb
15. start Gunlom Rd	Mary River	Jan-Feb 1996	20-23 Feb
18. Patonga Rd	Jim Jim	Jan-Feb 1996	21-23 March
23. Gunlom	Mary River	-	17-19 March
25. Top of Gunlom track	Mary River	-	16-18 March
30. Mirrai	Jim Jim	Jan-Feb 1996	20-22 March
31. Bloomfield Springs	Mary River	Jan-Feb 1996	25-27 Feb
33. Plumtree Creek	Mary River	Jan-Feb 1996	22-25 Feb
36. *Euc. koolpinensis*	Mary River	Jan-Feb 1996	24-27 Feb
37. Koolpin campground	Mary River	Jan-Feb 1996	24-27 Feb
38. Cooinda turnoff	Jim Jim	Jan-Feb 1996	21-23 March
41. Mary R. RS	Mary River	Jan-Feb 1996	22-25 Feb
43. buffalo farm	Jim Jim	Jan-Feb 1996	20-22 March
44. Jim Jim turnoff	Jim Jim	Jan-Feb 1996	21-23 March

48. Nourlangie Camp	Jim Jim	Jan-Feb 1996	20-22 March
60. Jim Jim jump-up	Jim Jim	-	2-6 July
96. Field Island	Sth Alligator	-	August

Fifteen of these fire monitoring plots were previously sampled for fauna in January-February 1996 (Woinarski and Griffiths 1996), using identical sampling procedure to that used in the 2001 re-sampling. Recognising that this is a small sample set, and that it examines change over 5 years only (rather than the 10-12 years for the re-sampling of the Stage 3 fauna sites, described in section 3 above), a comparison of the results from these plots over the two sampling periods is presented in Table 7.

Table 7. Comparison of mammal abundance in fire monitoring plots sampled in 1996 and re-sampled in 2001. Only species recorded from at least 5 quadrats in the two sampling periods combined are listed. Z-score based on Wilcoxon matched-pairs test.

species	*1996 sampling*		*2001 re-sampling*		*z-score*	*p*
	mean abundance over all 15 quadrats	no. of quadrats recorded from	mean abundance over all 15 quadrats	no. of quadrats recorded from		
fawn antechinus	0.65	7	1.88	8	1.54	0.12
northern quoll	2.06	7	0.71	8	1.18	0.24
northern brown bandicoot	0.71	7	0.41	5	0.59	0.55
black-footed tree-rat	0.12	5	0	0	2.02	0.04
pale field-rat	5.71	9	2.76	7	1.36	0.17
common rock-rat	0.35	2	0.53	4	0.40	0.69
abundance of all native mammals	10.24	15	7.82	15	0.36	0.72
species richness of native mammals	2.41	15	2.47	15	0.24	0.81

Within this set of quadrats, the mean abundance of all native mammals combined declined by 24% over the period, however this change was not significant. There was a significant decline for black-footed tree-rat, and pronounced declines (but not significant) for northern quoll and pale field-rat, and pronounced (but not significant) increase for fawn antechinus.

Note that this set of quadrats generally held a substantially richer mammal fauna than that for the Stage 3 sites as a whole (Section 3 above): the mean abundance of mammals in the two sampling periods for the fire plot sites was 10.2 and 7.8, compared with 4.5 and 3.8 for the Stage 3 sites, and the mean number of species for the fire plot sites in the two periods was 2.4 and 2.5, compared with 1.3 and 1.5 for the Stage 3 sites as a whole.

The set of fire plots sampled was spread far more widely across the park than for the Stage 3 sites, and included sites in the northern half of the park. To some extent, this geographic disparity between the two sets of sites re-sampled (the fire plots and Kakadu

Stage 3) may contribute to the differences in results observed. The differences in species identified as undergoing significant change is also partly due to the small sample size for the fire plot monitoring data, and the low frequency of occurrence of some species in the Stage 3 data set.

5. RELATIONSHIP OF MAMMAL FAUNA TO FIRE HISTORY: 12 large grids in eucalypt open forests

5.1. Introduction

This objective was met through sampling mammals in 12 large grids within *Eucalyptus miniata - E. tetrodonta* (Darwin Woollybutt-Darwin Stringybark) forests, with sites selected to represent contrasting fire regimes. The location of sites sampled is shown in the accompanying A0 map.

Fire histories were derived by collating and analysing 21 years of fire data for KNP. For the purpose of this study, the landscape (across the extent of KNP) was broken into 25m x 25m pixels. A number of summary layers was created from the 21 years of fire data, for each of these pixels. These layers included:

1. Longest fire free interval – the largest gap in years between successive fires over the course of the entire 21 year history.
2. Total number of fires – the total number of years in which a fire was reported for that pixel (maximum possible = 21).
3. Total number of late dry season fires – the total number of years in which a fire was reported during the late dry season (maximum possible = 21).
4. Cumulative fire trace – a compound index weighting fires by their recency. If the cell was burnt in the year preceding our sampling, it scored 21, if in the year preceding that it scored 20, etc., and then all scores were added.

In addition to these values for each pixel, we also considered the extent of spatial variation or patchiness of fire histories, to stratify sampled sites according to whether they occurred in sites typically affected by small localised fires or whether they occurred in landscapes which were extensively burned or even extensively unburned. So, for each of the four variables above, we also calculated the variability in these values around each pixel. Variability was expressed as the coefficient of variation of values across a network of 20 pixels x 20 pixels centred on each pixel in the sampled grid in turn. A high value indicates that that pixel is surrounded by areas which have highly heterogeneous fire histories. A low value indicates that the pixel falls within an area subjected to very homogeneous burning regimes.

These “windows” of cells (which represent an area of 500m x 500m on the ground) were then used to locate potential trapping locations (Figure 5). These sites were evaluated for access, leading to the selection of 12 sites located in Jim Jim, Nourlangie, South Alligator and East Alligator districts. Fire histories of these sites are summarised in Table 8.

At each site, mammals were sampled in a grid of 16 x 16 traps, with neighbouring traps placed 20 m apart (i.e. grid area of 9 ha). Traps were set over a 4-night period, and comprised a mix of 216 small Elliott traps and 40 cage (or large Elliott) traps. Individual mammals caught were marked and released, to provide for an assessment of population density. Sampling was undertaken over five weeks between June and August 2001.

A broad range of environmental variables was assessed on every grid, to allow an evaluation of the response of some key habitat factors (e.g. availability of tree hollows and hollow logs, shrubby understorey, and tree size classes) to fire histories.

As described in section 3.6. above, there are some important caveats to consider in assessing this fire history, mostly relating to inaccuracies in the interpretation of fire from satellite imagery, and this inaccuracy becomes greatly magnified over long periods, and when attempting to consider histories at the relatively fine scale of the sampling grids used here.

5.2. Results

There was an extraordinary variation among grids in the numbers of mammals caught (Table 8; Figure 5). The grids at Mardugal, Muirella Park and Bindji Waters yielded the greatest number of animals. The most common species at these sites were pale field-rat *Rattus tunneyi*, fawn antechinus *Antechinus bellus* and northern brown bandicoot *Isoodon macrourus*. The grids in Jim Jim and Nourlangie Districts also exhibited the highest diversity of mammals, with up to seven species being recorded in some grids (notably Mardugal and Nelly's turn-off).

In contrast to this, the grids in the East and South Alligator Districts yielded very few animals, with absolutely no animals being trapped at the Four Mile grid and only one possum and two introduced black rats recorded at the Entrance Station grid. The remaining grids in the South Alligator District and the Bindjil Bindjil grid in the East Alligator District also exhibited very low species diversity, with only 2 or 3 species being captured.

There were complicated relationships between the derived fire histories and vegetation patterns recorded at the 12 grids. For example, seldom burnt sites predictably had a more extensive canopy cover, especially of tall shrubs in the 5-10m height layer, and had a relatively dense layer of fallen leaf litter (Fig. 6a,b,c), but the occurrence of tree hollows and of hollow logs showed a humped response to fire frequency, and that of dead trees showed no clear relationship with any of the fire parameters considered (Figs 6d,e,f).

Figure 5. Summary of mammal results from sampling eucalypt forest sites with contrasting fire histories. Numbers in blue next to sites indicate the total number of different individuals of native mammal species captured.

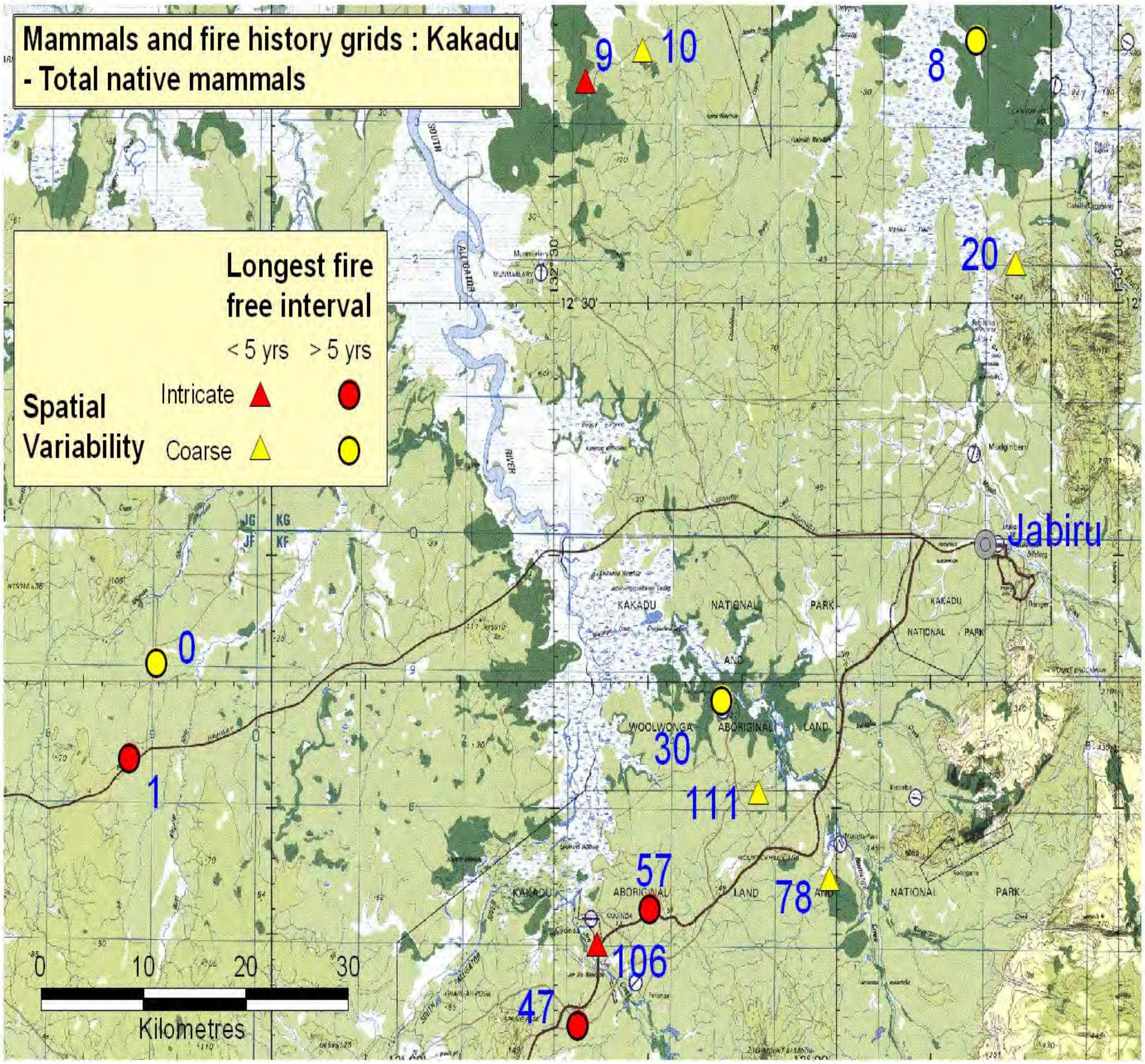


Figure 6. Relationship of some habitat parameters measured at the 12 large grids to fire histories derived from imagery.

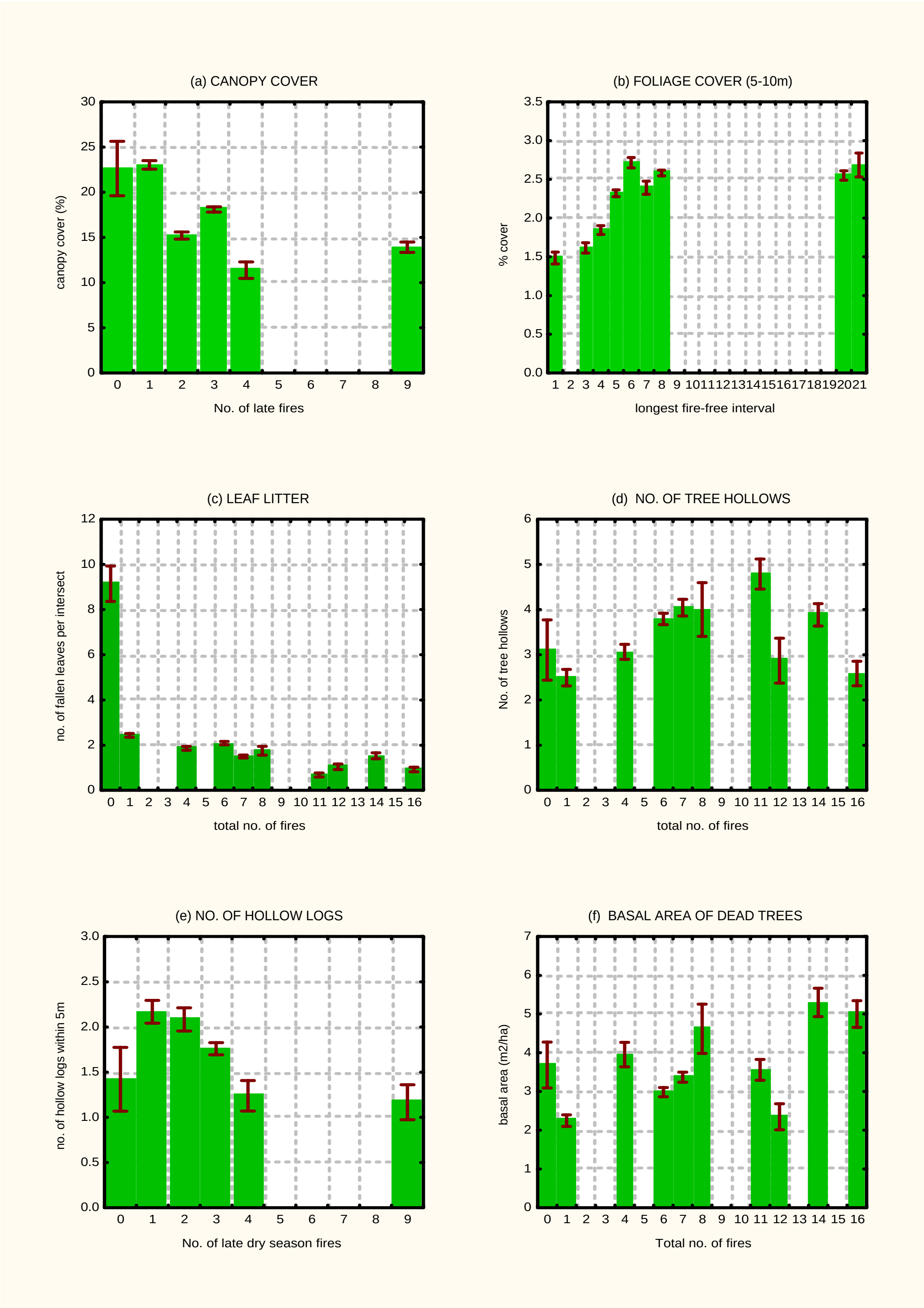


Table 8. Summary of fire histories and number of mammal captures at 12 grids selected to represent contrasting fire regimes. No. of captures is the total number of different individuals captured from 1024 trap-nights. See text for definition of fire indices.

Attribute	Grid											
	1. Mardugal	2 Nelly's Turn-Off	3 Muirella Park	4 Nourlangie Camp	5 Near Old Darwin Rd	6 Bindji Waters	7. Bindjil bindjil	8. Ngarradj	9. Munmarlary	10. Munmarlary	11 Entrance Station	12 Four Mile Track
District	Jim Jim	Jim Jim	Nourlangie	Jim Jim	Jim Jim	Jim Jim	East Alligator	East Alligator	Sth Alligator	Sth Alligator	Sth Alligator	Sth Alligator
Longest fire-free interval (years): mode (coefficient of variation)	5 (40.4)	20 (37.6)	4 (28.9)	21 (0)	8 (24.4)	3 (12.8)	6 (11.6)	4 (37.9)	1 (35.3)	3 (34.3)	7 (29.0)	5 (0)
Total number of fires over 21 yrs: mode (coefficient of variation)	6 (24.9)	1 (48.2)	8 (17.9)	0 (0)	7 (19.7)	12 (11.5)	11 (15.0)	6 (14.7)	16 (4.9)	14 (13.2)	7 (24.9)	4 (9.7)
Total no. of late dry season fires: mode (coefficient of variation)	3 (20.6)	1 (45.4)	4 (12.7)	0 (0)	3 (15.6)	2 (0)	1 (60.3)	2 (21.5)	9 (7.7)	2 (25.1)	2 (35.2)	3 (12.7)
Cumulative fire trace: mode (coefficient of variation)	53 (44.9)	1 (89.4)	76 (17.8)	0 (0)	47 (38.2)	148 (13.0)	165 (16.3)	73 (18.2)	175 (5.3)	126 (15.2)	83 (32.9)	51 (3.9)
No. of years since last fire: mode (coefficient of variation)	5 (92.0)	20 (50.8)	0 (346.0)	21 (0)	8 (49.5)	3 (25.8)	5 (40.6)	3 (29.5)	3 (0)	3 (31.8)	0 (172.8)	7 (0)
echidna	0	0	0	0	0	0	0	0	1	0	0	0
fawn antechinus	30	24	20	14	13	18	0	3	0	0	0	0
northern quoll	0	1	3	1	5	2	2	4	4	1	0	0
brush-tailed phascogale	0	0	0	1	0	0	0	0	0	0	0	0
red-cheeked dunnart	0	0	0	0	0	0	0	1	0	0	0	0
northern brown bandicoot	14	9	9	6	4	26	1	7	0	0	0	0

common brushtail possum	2	3	2	3	2	0	0	3	0	6	1	0
brush-tailed rabbit-rat	11	1	0	0	0	0	0	0	0	0	0	0
black-footed tree-rat	1	6	2	4	0	4	0	0	0	0	0	0
grassland melomys	0	0	0	1	0	0	0	0	0	0	0	0
kakadu pebble-mound mouse	0	0	0	0	5	0	0	0	0	0	0	0
delicate mouse	0	0	1	0	0	8	5	1	5	2	0	0
western chestnut mouse	1	0	5	0	14	0	0	0	0	0	0	0
pale field-rat	47	13	36	0	4	43	0	0	0	0	0	0
common rock-rat	0	0	0	0	0	0	0	1	0	0	0	0
black rat	0	0	0	0	0	0	0	0	0	0	2	0
TOTAL*	**106**	**57**	**78**	**30**	**47**	**111**	**8**	**20**	**10**	**9**	**1**	**0**

* excluding the introduced black rat.

Variation among the grids in mammal abundance was related to fire history and vegetation parameters using generalised linear modelling. Variables included for consideration in this modelling were:

fire parameters

- total number of fires (over the 21 year period);
- number of late dry season fires;
- longest fire-free interval;
- fire trace;
- time to last fire;
- coefficient of variation (CV) of total number of fires;
- CV of number of late dry season fires;
- CV of longest fire-free interval;
- CV of fire trace;
- CV of time to last fire;
- mean of all fire CVs;

habitat parameters

- number of small hollow logs;
- number of large hollow logs;
- number of tree hollows;
- canopy height;
- canopy cover;
- foliage cover (>10m);
- foliage cover (5-10m);
- foliage cover (3-5m);
- foliage cover (1-3m);
- foliage cover (0.5-1m);
- foliage cover (0-0.5m);
- amount of leaf litter;
- total basal area;
- basal area of dead trees;
- basal area (trees with diameter 1-5cm);
- basal area (trees with diameter 5-20 cm);
- basal area (trees with diameter 20-50cm); and
- basal area (trees with diameter >50 cm).

Additional terms related to grass species composition will be included in the modelling following more complete ground layer inventory currently being undertaken (the period in which mammals were sampled in 2001 was not favourable for comprehensive ground layer floristic inventory). We also haven't yet included consideration in the modelling of the species composition of trees and shrubs. These data were collected at each of the 12 grids.

Given the large number of variables and the sample size of 12 grids, modelling involved many iterations of 1-4 terms being introduced and dropped out until a relatively robust model which explained as much of the deviance as possible was derived. Model complexity was limited to three variables.

Models for the eight species with most records, and the abundance of all native mammal species combined, are summarised in Table 9. All models explain a high proportion of the total deviance, in part reflecting the relatively small *N*. Fire history parameters are included as significant explanatory terms in four of the nine models.

Among these eucalypt open forest grids, the abundance of:

- *northern quoll* increased where foliage cover in the >10m layer was least extensive;
- *fawn antechinus* increased with decreasing total basal area and basal area of dead trees;
- *brushtailed possum* increased with increasing basal area, with increasing spatial heterogeneity of fire-free interval, and with least recent burning;
- *northern brown bandicoot* increased with fewer small hollow logs (surprisingly) and less basal area;
- *black-footed tree-rat* increased with denser more extensive leaf litter and greater spatial heterogeneity of fire trace;
- *delicate mouse* increased with the total number of fires and decreased with greater spatial heterogeneity of fire-free intervals;
- *western chestnut mouse* increased with greater foliage cover in the 0-0.5m height layer;
- *pale field-rat* increased with greater foliage cover in the 0.5-1m height layer and with reduced total basal area;
- *all native mammals combined* increased with spatial heterogeneity of the total number of fires, with fewer small hollow logs and with reduced total basal area.

These data will not be analysed further at this stage, because the ground layer information is not yet available. The important points evident at this stage of this project component are that: (1) there is a major geographic disparity in the richness of the small mammal fauna within Kakadu NP, even within the same broad habitat type (*Eucalyptus tetrodonta-E.miniata* open forest); (2) some of this variability can be explained by fire history and vegetation factors (some of which themselves are related to fire history); (3) spatial heterogeneity of fire history is a significant factor for at least three native mammal species, and the total native mammal fauna, with abundance of black-footed tree-rat, brush-tailed possum and all native mammal species combined increasing in areas burnt with more intricate pattern; (4) however, these relationships with fire history by no means account for all of the extraordinary variation in mammal abundance and diversity evident from this sampling, most notably the absence or sparseness of mammals from some of these sites.

Table 9. Generalised linear models relating mammal abundance to fire history and habitat factors, from sampling 12 large grids in *Eucalyptus miniata- E. tetrodonta* forest.

species	*explained deviance*	*df*	*term*	*Wald statistic*	*estimate*	*s.e.*	*prob.*
northern brown bandicoot	81.7%	9	intercept	126.9	6.4	0.6	<.00001
			hollow logs (small)	37.1	-1.06	0.17	<.00001
			total basal area	30.8	-0.83	0.015	<.00001
delicate mouse	82.0%	9	intercept	3.7	-1.81	0.94	.054
			CV (fire free interval)	8.6	-0.075	.025	.0033
			total fires	15.7	0.39	0.097	.00007
black-footed tree-rat	39.6%	9	intercept	4.3	-1.24	0.60	.037
			leaf litter	10.0	0.285	0.09	.0016
			CV (fire trace)	10.0	0.024	0.008	.0016
western chestnut mouse	66.4%	10	intercept	20.9	-8.48	1.85	<.00001
			foliage cover (0-0.5m)	30.4	2.44	0.44	<.00001
northern quoll	25.4%	10	intercept	7.7	4.80	1.73	.0055
			foliage cover (>10m)	5.54	-1.67	0.71	.019
fawn antechinus	50.2%	9	intercept	275.3	5.48	0.33	<.00001
			basal area (dead trees)	7.1	-0.36	0.14	.008
			total basal area	16.2	-0.054	0.013	.00006
pale field-rat	74.9%	9	intercept	75.5	3.70	0.43	<.00001
			foliage cover (0.5-1m)	74.2	0.93	0.11	<.00001
			total basal area	102.1	-0.103	0.010	<.00001
brushtail possum	63.3%	8	intercept	4.72	-2.60	1.20	.030
			fire trace	7.3	-0.015	.0055	.0071
			cv (fire-free interval)	4.9	0.041	0.018	.026
			total basal area	7.6	0.076	0.028	.006
abundance of all native mammals	98.0%	8	intercept	908.4	7.10	0.24	<.00001
			hollow logs (small)	118.6	-0.81	0.07	<.00001
			total basal area	132.5	-0.07	0.006	<.00001
			cv (total fires)	12.4	0.014	0.004	.0004

6. FAUNA DATA BASES AND SUMMARY ACCOUNTS FOR INDIVIDUAL SPECIES

Outputs of this project will include:

- an assessment of the status and management requirements for all small mammal species in Kakadu National Park; and
- a collated data base of all accessible mammal records within the Park.

These will be dealt with more completely in the final report of the second year of this project, but here we provide some progress results.

In this section, we provide distributional maps for all small mammal species, based on our collation of a range of data bases. One striking feature of these maps is the paucity of records. Most sightings of fauna in Kakadu go unreported, and hence the data base represents but a fragment of the known and real distribution. Hopefully, this mismatch between recorded and known distributions may prompt more effort to establish and consolidate a program for compiling fauna records within the Park.

The records we map here are based on the results from the 2001 sampling, the records from the CSIRO Stage 3 survey of 1988-90, specimen records from the Alligator Rivers Fact-finding Study from the 1960s and 1970s, specimens held in all Australian museums, most records from the Kakadu Stages 1 and 2 surveys, and historical records from a broad range of published sources. We have not yet included a large data set of CSIRO records from Kapalga, nor from studies conducted by EWL.

historical records, data bases and meta-data

The most substantial previous fauna sampling data base was that of the CSIRO Kakadu Stages 1 and 2 surveys (Braithwaite 1985). At the outset of this project, all survey data was only in hard copy form in 120 pages of written Appendices to the final report (Braithwaite 1985). We re-entered all of these data (terrestrial vertebrates and plants) to FoxPro data files.

Unfortunately, Braithwaite (1985) did not provide accurate locations for their sampled sites (with sites simply marked roughly on an A4 map of Kakadu). In 1994, Parks Australia staff (Lisa Roeger) attempted to re-find all of these 30 sites, and produced a report describing this re-location. However, despite many searches for this report in PA offices in Darwin and Kakadu, CSIRO Darwin, and by relevant former PA staff (Lisa Roeger, Jeremy Russell-Smith, Piers Barrow), no copies were found. We eventually searched archives in CSIRO Canberra in May 2001, and located one copy of that report. That has now been re-copied, with copies deposited again with PA Kakadu. Unfortunately, not all of the 30 CSIRO survey sites were re-found by Lisa Roeger, and almost all the coordinates given in that report place the sites in the Gulf of Carpentaria. However, despite these problems, there is enough information available in the report to accurately place almost all of the original sites, and these amended coordinates have been added to the FoxPro database.

We also searched the CSIRO Canberra archives for locational information concerning the CSIRO fauna sampling for the Alligator Rivers Fact-finding Study, in the early 1970s (Calaby 1973). Some good locational information is available for the sampling of birds in that study. Unfortunately, the sampling procedure for mammals was not written down in any explicit manner, the sites sampled for mammals were not precisely recorded, and the scientist responsible (John Calaby) died several years ago. So, it will not be possible to reproduce that sampling in a manner which will be very comparable.

As indicated in Objective 1 above, most of our re-sampling effort has been directed at the CSIRO Kakadu Stage III surveys, undertaken initially between 1988 and 1990. All fauna and habitat data from these surveys have now been transferred to a FoxPro database.

For all quadrats/sites that we have (re-)sampled during 2001, we have compiled a dossier including digital photograph, fauna recorded (during 2001 sampling and any preceding sampling), location and environmental variables. This dossier will be linked to GIS to provide ready display of sites and results; and electronic and hard copies of all information will be deposited at both district ranger stations and PA headquarters.

There are three other main studies of mammals in Kakadu which could provide useful baselines for re-sampling: that of Begg (1981a,b,c; Begg *et al*. 1981; Dunlop and Begg 1981) at Little Nourlangie Rock between 1977 and 1979; that of CSIRO at Kapalga (Friend 1985, 1987, 1990; Friend and Taylor 1985; Braithwaite and Muller 1997); and that of Kerle and Burgman (1984) between 1979 and 1981 as part of the EIS process for Jabiluka. For the former, there may be no precise locations of sampling sites, no electronic copies of raw data, and possibly no remaining hard copies of raw data: however the published papers would provide sufficient material to gauge some measure of change. There are electronic copies of some of the original Kapalga data (notably the study of Braithwaite and Muller 1997), but these are not currently held by us. Raw data from earlier work at Kapalga (e.g., Friend and Taylor 1985) may no longer exist.

There are also some localised studies of particular species, which may serve as less general baselines for examining change: the most notable of these are those on common brushtail possums by Kerle (1985, 1998) and on northern quoll by Oakwood (1997, 2000). We haven't sought to attempt to collate the data sets from these studies nor to resample these.

In addition, there is some ongoing terrestrial vertebrate sampling work conducted by EWL, to which we have not yet sought access.

accounts for individual species

echidna *Tachyglossus aculeatus*
There is no evidence for change in status in the echidna across Kakadu or in northern Australia generally, although this assessment should be qualified by recognition that the echidna is generally very poorly sampled in general mammal surveys, because it is not readily captured in the mammal traps generally used.

fawn antechinus *Antechinus bellus*
The fawn antechinus declined substantially in Kapalga over the period 1986 to 1999, but no such decline was evident for the southern part of Kakadu over the period 1988-90 to 2001. There is no clear pattern of change across the rest of its range in northern Australia. Our results suggested no strong relationship with fire regime.

sandstone antechinus *Pseudantechinus bilarni*
The sandstone antechinus is not present in Kapalga, and the few records from the re-sampling of Kakadu Stage 3 provide no clear picture of changed abundance. Begg *et al*. (1981) found a population decline immediately following fire, with this decline persisting for at least a year following fire.

northern quoll *Dasyurus hallucatus*
The northern quoll declined markedly at Kapalga over the period 1986 to 1999, and some other sites within Kakadu (Oakwood 2002), but no such decline was evident for the southern part of Kakadu over the period 1988-90 to 2001. There is reasonable evidence for decline and local extinctions across much of the rest of its northern Australian range (Kitchener 1978; McKenzie 1981; Braithwaite and Griffiths 1994). Our data showed no consistent simple relationship between change in abundance and fire history. In Kapalga, Oakwood (2000) found that mortality was generally higher in burnt areas.

northern brush-tailed phascogale *Phascogale pirata*
The northern brush-tailed phascogale has declined across at least parts of its northern Australian range (Woinarski *et al*. 2001). There were too few records from either Kapalga or Stage 3 to detect changes in abundance. The species is now known from few sites in the Northern Territory, and the populations at Jabiru and between Jim Jim ranger station and Cooinda may represent the largest colonies or highest density sites known.

common planigale *Planigale maculata*
The common planigale was not reported in the Kapalga results, probably because it is very rarely captured in Elliott or cage traps. We did not record it in the 2001 re-sampling of Stage 2 quadrats, a highly significant decline from 1988-90. There is no evidence of change elsewhere in northern Australia, although it has generally not been very well systematically sampled.

kakadu dunnart *Sminthopsis bindi*
The kakadu dunnart is not known from Kapalga. There is no evidence of change in abundance in Stage 3. Given the recency of its discovery, and the relatively few sites from which it has been recorded, there is no evidence from which to assess change in abundance more broadly across northern Australia.

red-cheeked dunnart *S. virginiae*
The red-cheeked dunnart increased at Kapalga over the period 1987 to 1999. There was no evidence of change in Stage 3 over the period 1988-90 to 2001, nor any evidence of change across northern Australia generally. Our data showed no consistent simple relationship between change in abundance and fire history.

golden bandicoot ***Isoodon auratus***
The golden bandicoot is known in Kakadu from an early twentieth century record in the South Alligator River area (Parker 1973) and a juvenile collected near old Goodparla homestead in 1967. There are no other known records from Kakadu. It has disappeared across almost all of its formerly vast range, and is now known in the Northern Territory only from Marchinbar Island (Southgate *et al*. 1996).

northern brown bandicoot ***Isoodon macrourus***
The northern brown bandicoot declined substantially in Kapalga over the period 1987 to 1999, but paradoxically increased significantly in Stage 3 over the period 1988-90 to 2001. The Stage 3 results suggested a decrease with long fire-free intervals, but Kerle and Burgman (1984) noted that it may be adversely affected by regular firing, and that it disappeared from one site at Jabiluka for one year after fire. There is some suggestion of decline elsewhere, especially in lower rainfall areas of the tropical savannas (Kitchener 1978; McKenzie 1981).

brushtail possum ***Trichosurus vulpecula***
The brushtail possum declined substantially in Kapalga over the period 1987 to 1999. There were insufficient records to assess change in Stage 3. The results from our large grids showed a strong relationship with fire regimes, with decrease in sites which had a recent history of fire, and an increase in sites with a fine mosaic of fire histories. Kerle (1985, 1998) and Kerle and Burgman (1984) also found a clear association with unburnt or infrequently burnt areas. This species has declined extensively across northern Australia (Kitchener 1978; McKenzie 1981).

sugar glider ***Petaurus breviceps***
There are too few records of this species to assess change in either Kapalga or Stage 3. There is no suggestion of change elsewhere in northern Australia, however the information base is sparse.

rock ringtail possum ***Petropseudes dahli***
This species does not occur at Kapalga, and there were too few records to detect change in Stage 3, although there was a trend for decline there. As with the sugar glider, there is no suggestion of change elsewhere in northern Australia, however the information base is sparse.

brush-tailed rabbit-rat ***Conilurus penicillatus***
There were too few records to assess change at Kapalga, and this species was not recorded in the Stage 3 surveys. We recorded it at only one site (Mardugal campground) during our surveys, and this may be the only site in Kakadu at which it persists. Elsewhere in northern Australia it has declined substantially (Woinarski 2000), and its current status no longer matches that described by Collett (1897): *"Numerous all over Arnhem Land, and in great numbers on the rivers on the lowlands*". The current restriction now largely to islands suggests that disease or predation by feral cats may be involved in the decline.

water-rat ***Hydromys chrysogaster***
There are too few records in either the Kapalga or Stage 3 data sets to assess change in status, but there is no indication of decline. Nor is there any evidence of decline elsewhere in northern Australia (Woinarski 2000).

Lakeland Downs mouse ***Leggadina lakedownensis***
This species was not recorded in Kapalga. It showed a pronounced decline in Stage 3 to the point of not being recorded at all in the 2001 re-sampling. Little is known of the biology of this species, and it may be irruptive (Watts 1976). There is no indication for or against a change in status from elsewhere in northern Australia.

grassland melomys ***Melomys burtoni***
The grassland melomys increased in abundance in Kapalga over the period 1987 to 1999. There was also a trend for increase in Stage 3, however this trend was not significant. Around Jabiluka,

Kerle and Burgman (1984) found that this species could undergo rapid and marked change in distribution and abundance, but that it showed a pronounced short-term decrease after fire. There is no evidence for change in status from elsewhere in northern Australia (Woinarski 2000).

black-footed tree-rat *Mesembriomys gouldii*
The black-footed tree-rat declined substantially in Kapalga over the period 1987 to 1999, and declined significantly in the set of fire plots resampled by us over the period 1996-2001. However, in Stage 3 there was a (non-significant) trend for increase over the period 1988-90 to 2001. As with the brushtail possum, the results from our large grids showed a strong relationship with fire regimes, with decrease in sites which had a recent history of fire, and an increase in sites with a fine mosaic of fire histories. At several sites in Kapalga, Friend (1987) also found a preference for infrequently burnt areas, and an association with a complex floristically rich tall shrub layer. There is some evidence of decline elsewhere in northern Australia, although the data are scant (Woinarski 2000).

golden-backed tree-rat *Mesembriomys macrurus*
The golden-backed tree-rat was not recorded in either the Kapalga or Stage 3 studies. There are only three confirmed records from the Northern Territory, of which one was in Nellie Creek (near Mary River ranger station) in 1903 and one was at Deaf Adder Gorge in 1969 (Woinarski 2000). Its range extends to the Kimberley, where it has disappeared from much of its former range over the last century (Kitchener 1978; McKenzie 1981).

kakadu pebble-mound mouse *P. calabyi*
The Kakadu pebble-mound mouse is not known from Kapalga. Our results show no evidence of change in Stage 3. There is no evidence of change in status across the rest of its range outside Kakadu, but especially given the recency of its discovery, there is very little baseline information from which to assess change.

delicate mouse *P. delicatulus*
The delicate mouse increased in Kapalga over the period 1987 to 1999, but paradoxically declined significantly in Stage 3 over the period 1988-90 to 2001. Our results suggest that it becomes more abundant with increasing time since fire. At Kapalga, Braithwaite and Brady (1993) considered that it declined immediately after hot fires, but that it was one of the first of the rodents to recolonise, and may then irrupt to unusually high densities. There is no evidence of change in status elsewhere in its range, although the information base is relatively meagre (Woinarski 2000).

western chestnut mouse *Pseudomys nanus*
The western chestnut mouse increased at Kapalga over the period 1987 to 1999, and showed no significant change in Stage 3 over the period 1988-90 to 2001. Kerle and Burgman 91984) found no simple relationship with fire, although they conjectured that it may be able to recolonise rapidly after fire. Our results also showed no clear association with fire regimes. There is no evidence of change elsewhere in its northern Australian range (Woinarski 2000).

dusky rat *Rattus colletti*
This species declined at Kapalga over the period 1987 to 1999. It was relatively uncommon in Stage 3, but the few records showed a non-significant trend for increase. Its preferred habitat of floodplain grasslands was not adequately sampled during these studies. There is no evidence of decline elsewhere across its northern Australian range (Woinarski 2000).

black rat *Rattus rattus*
This exotic species was not recorded in the intensive sampling of Kapalga over the period 1987 to 1993, nor in the more limited repeat sampling there in 1999. Nor was it recorded in the initial Stage 3 sampling of 1988-90. However, in 2001, we recorded four individuals in widely separated locations. Likewise, there have been increasing numbers of records in relatively remote open forest elsewhere in the Top End (Griffiths 1997), suggesting a possible expansion recently beyond from the urban areas in which it has formerly been largely confined.

pale field-rat *Rattus tunneyi*
The pale field-rat declined sharply at Kapalga over the period 1987 to 1999, but showed no change in Stage 3 over the period 1988-90 to 2001. Our results showed no clear association with fire regime. Beyond its Top End range, the pale field-rat has disappeared from much of its former range (Braithwaite and Griffiths 1996), but there is no suggestion of substantial change elsewhere in the Top End (Woinarski 2000).

false water-rat *Xeromys myoides*
The false water-rat is known from Kakadu only from a specimen collected in 1903 from the South Alligator River area (Parker 1973). There is no suggestion of change in status across its Northern Territory range, however there are very few records from which to assess status (Woinarski *et al*. 2000b).

common rock-rat *Zyzomys argurus*
The common rock-rat is not recorded from Kapalga. We found no evidence of change in status in Kakadu Stage 3 over the period 1988-90 to 2001. From our data, there was no relationship between changing status and fire regimes. Begg *et al.* (1981) and Kerle and Burgman (1984) likewise found that the species was relatively tolerant of fire. There is no suggestion of change in status elsewhere in its northern Australian range (Woinarski 2000).

Arnhem rock-rat *Z. maini*
The arnhem rock-rat is not recorded from Kapalga. In Kakadu Stage 3, it declined significantly over the period 1988-90 to 2001. From a group of mammal species studied at Little Nourlangie Rock, Begg *et al*. (1981) found that the arnhem rock-rat was most affected by a hot wildfire, with reduced reproduction for the season following fire, and no recovery at least two years post-fire. In the Jabiluka area, Kerle and Burgman (1984) similarly found a marked reduction for at least a year after fire. This species is restricted to the western Arnhem Land sandstone massif, and there are no other data on changes in its abundance beyond Kakadu (Woinarski 2000).

7. PARTICIPATION OF PARKS AUSTRALIA STAFF IN VERTEBRATE SAMPLING.

Over the course of the field work to date 42 Parks Australia staff (including seasonal rangers) have participated in the sampling. In addition, many *Bininj* people have been involved, and contributed information on mammals caught. The rationale and methodologies used in sampling was explained to all participants, and could be replicated by Parks staff readily in most districts. Most staff contributed to, and understood, the habitat descriptions recorded during quadrat sampling.

Most staff gained good skills in animal handling and identification, at least of the commonly-caught mammals. For many PA staff, the birds and herpetofauna (reptiles and frogs) may pose more formidable training obstacles, as there are many more species involved, many species are very similar, sampling involves a high proportion of searching rather than capture with traps, and some visual/aural cues may be especially subtle. Nonetheless, some PA staff are highly skilled naturalists, very capable of sampling these groups.

Many of the PA staff cooperating in this survey found the work extremely interesting and rewarding, and were enthusiastic for more participation.

Kakadu Staff who were involved in fauna surveys

<u>Mary River:</u>
Greg Ryan
Andrew Turner
Anne Ferguson
Anna Pickworth
Beryl Smith
Michelle Hatt
Jason Koh
Steve Heggie
Steve Johns
Jo Horigan (seasonal)

<u>Jim Jim</u>
Patrick Shaugnessy
Russell Manning
Kathy Wilson
Jessie Alderson
Stefanie Hamann
Paddy Cahill
Peter Christopherson

<u>Nourlangie</u>
Rob Muller
Matthew Large
David Cahill
Dallas Nabalwud

East Alligator
Lyndall McLean
Joelene Patterson
Scott Morrison
Jennifer Hunter
Jonathon Nadji
Nicole (??) seasonal
Shane Rowe seasonal

South Alligator
William Fordham
Margaret Rawlinson
Violet Lawson

Head Office
Sarah Pizzey
Rod Kennett
Don Arnold
Zig Madycki
Kate Turk
Alex Dudley
Kathy Bannister
Jarrad Mitchell

NRM
Buck Salau
Freddy Baird
Freddy Hunter

Traditional landowners
Cedric Blittner (Mary River)
Joe Markham (Mary River)
Sissy Caddell (Mary River)
Craig Caddell (Mary River)
Des (Mary River)
Mel Cooper (Jim Jim)
Warren Baird (Jim Jim)
Elsie Smith (Jim Jim)
Eric Pattersson (Jim Jim)

8. CONCLUSION AND SUMMARY OF PROGRESS

Although nominally a final report, this publication represents more a half-way mark of a two-year project. Our main aims were to:

(1) assess whether the declines reported for the mammal fauna in Kapalga (Woinarski *et al*. 2001) were manifest elsewhere across the Park;

(2) establish a current baseline of mammal abundance against which change due to the imminent arrival of cane toads could be assessed;

(3) develop a monitoring program for terrestrial vertebrate fauna, where possible in conjunction with the already established vegetation fire monitoring plots;

(4) construct a data base of vertebrate records for Kakadu NP; and

(5) investigate possible factors involved in changing status of the mammal fauna.

With respect to (1), our results show that the Kapalga effect is not pervasive across the Park, that most of the species which were shown to have declined at Kapalga had not declined in the southern half of the Park. However, our results don't provide a clean bill of health. A set of species which were absent or unreported in the Kapalga area (notably arnhem rock-rat, lakeland downs mouse and common planigale) declined significantly in the southern part of the park over the period 1988-90 to 2001. Also, some of the species reported to have declined in Kapalga (notably brushtail possum and black-footed tree-rat) were very poorly represented in the original and subsequent sampling of Stage 3, so no trend can realistically be assigned to them in that area. Further, our sampling of 12 large grids in eucalypt open forests across the northern half of Kakadu showed that some forest areas were empty of mammals, or had very low abundance and diversity, suggesting a highly patchy pattern of decline.

With respect to (2), we now have a good up to date baseline of the abundance of mammals (and indeed, other terrestrial vertebrates) at very many sites across a broad range of habitats and areas across Kakadu. In 2002, most of these will be re-sampled to assess change due to the arrival of cane toads.

With respect to (3), we now have a large set of sites (263 quadrats within the Stage 3 re-sampling, and a further 21 quadrats from the fire monitoring plots) which can form an ongoing monitoring program for terrestrial fauna. This set is currently biased geographically to the southern part of the Park, and includes relatively few floodplain sites and escarpment sites. In 2002, we will augment this set to include substantially more (probably a further 50) of the existing fire monitoring plots, particularly in sandstone areas and floodplains. We have used a consistent sampling protocol at each site, and this is identical to that now used routinely elsewhere in the Top End.

With respect to (4), we have collated all vertebrate records from the original sampling of Stage 3, from all our sampling in 2001, and from a broad range of other sources, into a data base readily linked to GIS. A hard copy and electronic copy of all data bases will be stored at Park headquarters. Some existing major data bases remain to be collated, but this will be done in 2002.

With respect to (5), we have investigated the relationship of mammal abundance to fire histories, based both on the 11 year fire history and re-sampling of Stage 3, and the 21-year fire history of our 12 large grids in eucalypt open forests. Our results suggest that fire management is an important factor in the status of many of the mammal species, but that this is by no means the whole explanation of apparent mammal decline.

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Appendix A. Sampling methodology used for re-survey of Kakadu Stage 3 sites, and for survey of fire monitoring plots.

2001 sampling protocol

The basic sampling area is a quadrat of 50x50m. Rectangular quadrats, with an equivalent area, may be used to sample narrow patches eg. riparian strips. Quadrats should be located within substantial areas of relatively homogeneous vegetation and landform, and not near boundaries, fences roads etc. The location of each quadrat is determined as precisely as possible, preferably using averaged GPS reading.

Traps

The layout of traps in the quadrat is:

- 4 cage traps – one in each corner
- 20 Elliott traps around the perimeter – 5 on each side, c. 8m apart
- 2 pit traps scattered within the quadrat. Pits are 20l plastic buckets and each pit has 10m of drift-fence.
- Mark all the traps clearly with flagging so they can be easily located.
- Traps are opened for 3 nights
- Traps must be checked early each morning and should be rechecked at midday. Elliotts and cages should be rebaited each afternoon
- Bait is a mixture of oats, peanut butter & honey. Vanilla essence, cat biscuits and tuna can be added. Cages can be baited with fruit or meat scraps
- trapped animals are identified and released near the capture point, or retained for as short a time as possible for identification, measurement etc.

Bird counts

For birds, sampling is based on a 100m x 100m quadrat centred on the 50m x 50m trapping quadrat. Each 1 ha quadrat is censused for birds eight times (in daylight; additionally birds are recorded during two nocturnal visits – see below). The majority of bird counts should be done in the early morning, with a few spread through the day. Avoid visiting the quadrats in the same order every day.

Each count is theoretically an <u>instantaneous</u> count of all the birds within the quadrat. In practice this will involve briefly walking through the quadrat but it is not a count over an extended period of time. The number of individuals of each species are recorded for each count. Only count birds <u>using</u> the quadrat – birds merely flying across overhead are not included. Raptors etc are included if they are hunting overhead.

Searches

Each quadrat is actively searched five times for herps, mammals, scats and signs etc.

- three searches during the day (morning, midday, late afternoon)
- two searches at night using spotlights
- each search should take c. 10min and involves turning rocks and logs, raking through leaf litter, looking under bark, in crevices etc.
- the number of individuals of each species seen is recorded

- scats, bones and other signs should be recorded where these can confidently be attributed to species
- carnivore scats should be collected for hair analysis and labeled with quad number and date

Incidental records

Species that are seen in the vicinity of the quadrat <u>and</u> in the same habitat should be recorded as incidental records for that site, with an abundance of zero to indicate they were not within the quadrat

Other species seen in the general area that are not attributable to a quadrat should be recorded separately on a list for the general area. Where possible, note the exact location and brief habitat details for the species. This is most important for species that have some significance (eg. rare, restricted, range extension)

Data recording

There is a proforma that all fauna data can be entered onto. Each species from the quadrat is recorded, along with a total abundance (the sum of all records from captures, searches, bird counts). Incidental records adjacent to the quadrat get an abundance of zero. At BAU data is transferred from proformas to the database FOXPRO, but data can be stored in other databases (eg Access, dBase) or species x sites spreadsheets (eg. Excel).

Bat sampling

A systematic method for censusing bats involves timed recordings using Anabat in each quadrat.

Bats may also be opportunistically sampled using harp traps and mist nets, by sightings or captures in caves, and identification of audible calls for a few species. For each, record details of location and brief habitat notes. For trapping, also record trapping time. It is usually appropriate to take basic measurements of all bats trapped. Reference calls on Anabat may be recorded from captured individuals.

1988-90 sampling protocol

The 1988-90 Stage 3 survey was generally based on clusters of 15 quadrats at each main sampling location. The 15 quadrats comprised three lines, each of 5 quadrats spaced along a 900m transect.

For mammal trapping and herpetological sampling, each quadrat was an 80m x 20m rectangle, nestled within a 100m x 100m quadrat used for bird survey. Mammal traps (16 regular-sized Elliott traps and 4 large Elliott traps or cage traps) were placed at 5-10m spacing around the core quadrat perimeter. These were baited and checked in the same manner as for the 2001 protocol, but left open for 4 days and nights. Two pitfall traps were established in each core quadrat, again left open for 4 days and nights.

All quadrats were searched for mammals, herpetofauna and birds in the same manner as for the 2001 sampling.

Hence, the main differences in procedure between the original sampling and the subsequent re-sampling relate to the size and shape of the quadrats used for mammal, reptile and frog sampling (80m x 20m in 1988-90 compared with 50m x 50m in 2001) and the total trapping effort per quadrat (80 mammal trapnights and 8 pitfall-trap nights in 1988-90 compared with 72 mammal trapnights and 6 pitfall-trap nights in 2001).

The difference in quadrat size and shape is unlikely to have affected the abundance measures used here for mammals, as trap separation was reasonably similar between the original and subsequent sampling. The reduction in pitfall trapping effort may have led to lower estimates of abundance (by 25%) for some of the small mammal species (delicate mouse, kakadu pebble-mound mouse, kakadu dunnart, lakeland downs mouse and common planigale) for which pitfall trapping is effective. The reduction in Elliott/cage trapnights may have led to lower estimates of abundance (by 10%) for these and medium-sized mammals in 2001 compared with 1988-90. In subsequent analyses, this issue may be better resolved by expressing abundance as an index of number of individuals caught per trapnight.