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# A review of the conservation status of the woylie, *Bettongia penicillata ogilbyi* (Marsupialia: Potoroidae) using IUCN criteria

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## ABSTRACT

A Recovery Team oversaw implementation of a Recovery Plan for the woylie (*Bettongia penicillata ogilbyi* (Waterhouse 1841)) from 1990 to 1995, and then reviewed its conservation status. Using the 1994 IUCN Red List criteria, the team showed that the species had been recovered from Vulnerable to Lower Risk (Conservation Dependent). Furthermore, it no longer met the requirements for listing as a threatened species under Western Australian or Commonwealth legislation and all but one of the specific targets of the Recovery Plan had been achieved. The exception, at least 7.5 per cent trap-success in a new population at Julimar Conservation Park, had not been met at that time because translocation to Julimar had been delayed. However, a population had been established and was increasing.

Criteria for listing threatened species under Western Australian and Commonwealth legislation are based on the subject's status nationally. South Australian legislation requires consideration of its status within the State. The Recovery Team recommended that the authorities responsible for advising the Western Australian and Commonwealth conservation Ministers should convey to them the Recovery Team's conclusions. The woylie has since been removed from categories of threatened taxa established under those jurisdictions. The team recommended to the South Australian authorities that they should review its status within that State.

The review is an unpublished report addressed to those authorities who would have to progress the Recovery Team's recommendations. However, as it was the first to use the 1994 IUCN criteria to assess the outcome of an Australian Recovery Plan, the issues encountered by the recovery team provide a useful case study for other people preparing Recovery Plans and reviewing the outcomes. Therefore it is published here.

## INTRODUCTION

At European settlement the brush-tailed bettong, *Bettongia penicillata* Gray, 1837 (Marsupialia: Potoroidae) occurred in suitable habitat over most of southern and central Australia (e.g. Christensen 1980, and Nelson *et al.* 1992). The nominate subspecies, which occurred in eastern Australia, is presumed extinct and the Western Australian subspecies, the woylie, *Bettongia penicillata ogilbyi* (Waterhouse, 1841) declined, in the wild, to three small populations in forests and woodlands of the south-west of the State (Start *et al.* 1995; Maxwell *et al.* 1996).

A Recovery Team oversaw the implementation of a Recovery Plan[1] which was written by Hall *et al.* (1991) but substantially revised by Start *et al.* (1995). In 1995, at the conclusion of the Plan's five-year life, the Recovery Team used criteria established by the International Conservation Union (IUCN 1994) to review the conservation status of the woylie and recommend amendments to lists of threatened species maintained under Commonwealth and Western Australian legislation. They were endorsed by the relevant Ministers and the taxon has been removed from Schedule 1 'Listed Species' in the Commonwealth Endangered Species Protection Act (Commonwealth of Australia Gazette, 8 May 1996). It is no longer declared by the Western Australian Minister for the Environment to be 'Fauna which is likely to become extinct or is rare' (Western Australian Government Gazette, 30 April 1996) and it is classified Lower Risk (Conservation Dependent) on the 1996 IUCN List of Threatened Animals (IUCN 1996).

The woylie was the first Australian taxon to be removed from formal lists of threatened taxa because conservation actions had sufficiently improved its conservation status (as opposed to improved knowledge of its status). Furthermore, the review was the first in

[1] The terms Recovery Plan and Recovery Team are defined in Anon (1997): A Recovery Plan is a comprehensive plan that details, schedules and costs all actions including research necessary to support the recovery of the species or ecological community. There should be one national Recovery Plan for a species or ecological community.
Recovery relates to the process of halting or reversing the decline of a species in the wild and ensuring its future chance of survival (and if appropriate, expansion). It is not the process of re-establishing a species throughout its former range. That should be a subsequent action in so far as it is possible.

Australia to use the IUCN Red List criteria (IUCN 1994) to assess the outcome of a Recovery Plan managed by a Recovery Team.

Interpretation of the IUCN requirements posed several problems. In particular, the rules require that transfer from categories of higher to lower risk should be made after none of the criteria for the higher category has been met for five years or more although movement the other way should take place without delay. The Recovery Team assumed that the IUCN had not intended to freeze transfers from categories of higher to lower risk for five years from the date of publication. Therefore it prepared a supplementary review that retrospectively examined the conservation status of the woylie as it had been in 1990, five years previously.

One important lesson concerned the criteria that must be addressed by the reviewers. Most Recovery Plans specify Recovery Actions and set criteria by which the success of those actions will be measured. It is often assumed that successfully meeting the criteria will mean that the subject of the Plan has been recovered. However, if formal lists of threatened taxa developed under the auspices of the IUCN or State or Commonwealth legislation are to reflect the recovered status of the subject, the review process must also address their listing criteria. Therefore, it is necessary for Recovery Teams to foreshadow the latter and set success criteria that will, if attained, satisfy them. Indeed it is desirable that the Plan clearly specifies all the criteria that will have to be considered when the conservation status of the subject is reviewed.

The review and its supplement are unpublished reports addressed to the people who had to consider and, if they concurred, implement the recommendations. However, our approach to various issues may be useful to people drafting Recovery Plans or addressing the review process for other taxa. Therefore we reproduce them here, in full, except that reference lists have been amalgamated and Tables that were common to both reports are not duplicated, necessitating some renumbering. Some text passages were also common to both and have been treated similarly (e.g. the recommendations of the Recovery Team). Three appendices have been deleted. They comprised copies of relevant sections from the IUCN criteria (IUCN 1994) and the Recovery Plan (Start *et al.* 1995) and a list of the Recovery Team members. The latter is incorporated into our Acknowledgements. We have also corrected some typographical, grammatical and other minor errors and changed 'personal communications' to text references where data have been published since the review was written.

# WOYLIE (*BETTONGIA PENICILLATA OGILBYI*): A REVIEW OF ITS STATUS. DECEMBER 1995[2]

## 1. Background

### 1.1 Historical Distribution of *Bettongia*

The genus *Bettongia* is currently recognized as having had four species at European settlement (Table 1). The most widespread were *B. lesueur* and *B. penicillata*. Two subspecies of *B. penicillata* are recognized; typical *B. p. penicillata* (brush-tailed bettong) in eastern Australia and *B. p. ogilbyi* (woylie) in Western Australia (WA).

TABLE 1

The distribution and current conservation status of *Bettongia* species (including subspecies of *B. penicillata*) that were present in Australia at European settlement.

| TAXON | COMMON NAME | FORMER DISTRIBUTION | CURRENT STATUS |
|---|---|---|---|
| *B. gaimardi* | Tasmanian Bettong | South-eastern Australia and Tasmania | Secure |
| *B. lesueur* | Burrowing Bettong | Most of southern and western Australia | Endangered |
| *B. p. ogilbyi* | Woylie | South-western mainland Australia | Endangered |
| *B. p. penicillata* | Brush-tailed Bettong | South-eastern mainland Australia | Presumed Extinct |
| *B. tropica* | Northern Bettong | North-eastern Queensland | Endangered |

The geographical relationship between the two subspecies and the subspecific status of central Australian *B. penicillata* is not clear. Indeed the former distribution of the species is not fully known. Figure 1 presents the locations at which it is known to have lived. The map was compiled by Nelson *et al.* 1992. The data come from two sources, European (including specimen) records (adapted from Finlayson 1958; the north Queensland record is now referred to *Bettongia tropica*) and the knowledge of Aboriginal people who used to hunt it for food (Burbidge *et al.* 1988). The incomplete status of both data sets is emphasized by their differences. The species may have been present in some of the large areas south of the Tropic of Capricorn for which there are no records. However, it was probably not widespread in the wet-dry tropics.

### 1.2 Pattern of Decline

Regardless of our incomplete knowledge of the former distribution of *B. penicillata* and its infra-specific variation across that distribution, the only form of the species

[2] Prepared by A.N. Start, A.A. Burbidge and D. Armstrong for the Woylie Recovery Tearm.

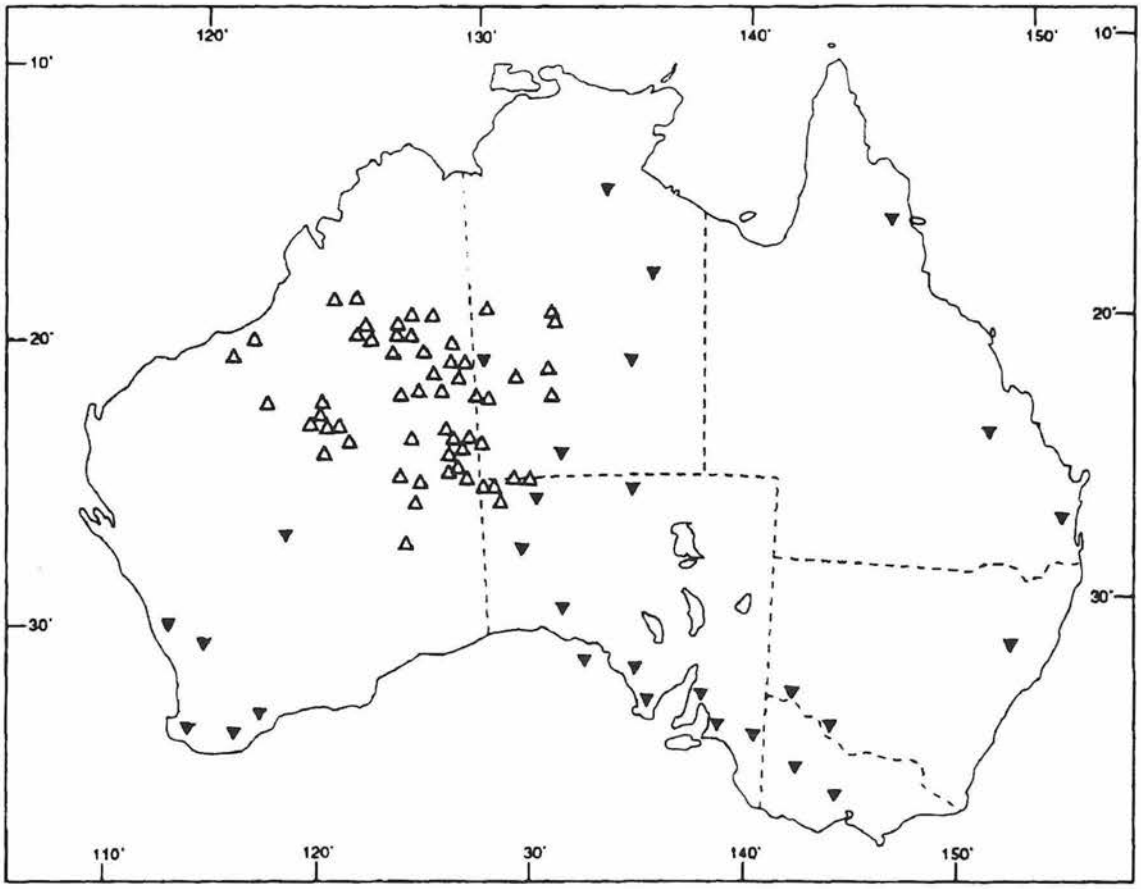


*Figure 1.The historical distribution of* Bettongia penicillata. △ *Aboriginal records from Burbidge* et al. *(1988);* ▼ *Records from Finlayson (1958). Redrawn from Nelson* et al. *(1992). The north Queensland record of Finlayson is now referred to* B. tropica.

known to be extant is the woylie, *B. p. ogilbyi,* which survived in its natural habitat as three relict populations in the forests and adjacent woodlands in the far south-west of WA. Those were declining until active management, principally protection from foxes, was initiated in the last fifteen years or so. There were also some captive animals as well as introduced colonies on four South Australian (SA) islands (Wedge Island, St Peter Island and two other very small islands). The founders were captive-bred, Western Australian stock.

The woylie, like many Australian mammal species, had declined drastically, almost to extinction, since European settlement. Several hypotheses have sought to explain the causes of the declines (see Burbidge and McKenzie 1989, and Morton 1990 for reviews).

Burbidge and McKenzie showed that most non-marine Australian mammals that have become extinct or have significantly declined fall within a Critical Weight Range (CWR), now recognized as 35 g to 5.5 kg mean adult body weight. The decline has been more severe in the arid zone than in better watered areas. The woylie (1-1.5 kg) lies within the CWR and conforms to the typical pattern, surviving in the most mesic part of its former range.

Several authors (e.g. Troughton 1957; Calaby 1971; Christensen 1980; King *et al.* 1981; Christensen and Maisey 1987) implicate the fox as a predator of woylies and this is now supported in the south-west of WA by quantitative data. For example, at Batalling Forest the capture rate was <1 per cent before baiting commenced in February 1991. In areas baited for foxes it rose to about 2 per cent in November 1991, 7.2 per cent in October 1992 and 11.4 per cent in October 1993 (Morris *et al.* 1995) and 24 per cent in July 1995 (Keith Morris[3] personal communication). Data from other sites are presented in Courtenay (1994). At Batalling, woylies are being trapped in adjacent unbaited areas where they were previously not known to occur, probably a consequence of immigration from the baited area. However, trap success in unbaited areas remains <1 per cent (Morris *et al.* 1995).

Calaby (1971) suggested that *B. penicillata* survived in south-west WA because it inhabited vegetation in which thickets of *Gastrolobium* species were abundant. *Gastrolobium* contains monofluoroacetic acid. Compound 1080 (sodium monofluoroacetate) is very toxic to non-indigenous mammals including domestic stock and feral predators such as foxes, but indigenous mammals (and other animals) of the south-west have evolved a high level of tolerance.

*Gastrolobium* thickets are a feature at Perup, Dryandra and Tutanning, the three sites where woylies are known to have survived in the wild. Secondary poisoning of feral predators eating animals that have ingested *Gastrolobium* may account for the phenomenon. Foxes eating rabbits

[3] Principal Research Scientist, CALM

poisoned with compound 1080 have died (Algar and Kinnear 1996). Compound 1080 is the toxin now used in baits to control foxes for protection of threatened fauna in south-western WA and in SA.

A more detailed account of the history of the status of the woylie is contained in the Recovery Plan (Start *et al.* 1995).

## 1.3 Statutory Status

In WA *Bettongia penicillata* is declared by the Minister to be 'fauna which is likely to become extinct or which is rare' pursuant to the Wildlife Conservation Act. In SA it is listed on Schedule 7 (Endangered Species) pursuant to the National Parks and Wildlife Act. It is listed as endangered nationally by ANZECC (Anon. 1991) and is included in Schedule 1, Part 1 (species that are endangered) of the Commonwealth Endangered Species Protection Act. The 1992 Marsupial and Monotreme Action Plan (Kennedy 1992) listed the woylie as Endangered.[4]

## 2. Recovery Plan

In 1990 The Australian Nature Conservation Agency (ANCA)[5] introduced to Australia the concept of preparing and implementing Recovery Plans for threatened species. A Recovery Plan for the woylie (Hall *et al.* 1991) was one of the first to be written. That edition specified recovery actions to be implemented during the next ten years in SA and WA by a Recovery Team comprising people from the Western Australian Department of Conservation and Land Management (CALM) the South Australian Department of Environment and Natural Resources (DENR) and ANCA. However, there were so many positive developments during the first two years that the Recovery Team revised the plan extensively (Start *et al.* 1995). A major change was the foreshortening of the life of the plan to five years (to December 1995).

The specific objectives of the revised Woylie Recovery Plan were to:

(1) Determine the current wild distribution of the woylie in WA;
(2) Establish a population of woylies on a mainland area in SA without using predator-proof fences;
(3) Develop prescriptions for the maintenance and extension of woylie populations in multiple-use forest in WA;
(4) Ensure that translocated woylie populations maintain genetic variability;
(5) Review the conservation status of the woylie using internationally accepted criteria, and recommend changes if necessary.

The actions implemented by the Recovery Team comprised:

(1) Control of exotic predators, particularly foxes;
(2) Survey and establishment of monitoring programs;
(3) Range expansion (where feasible) and translocation;
(4) Setting up experiments to determine the effects of forest management practices;
(5) Genetic assessment and restocking;
(6) Employment of a scientist, SA;
(7) Education and publicity.

## 3. Purpose of this Review

The Recovery Plan requires the Recovery Team to 'Review the conservation status of the woylie, using internationally accepted criteria, and recommend changes if necessary' at the conclusion of its recovery action program in December 1995 (Objective 5). This paper constitutes the Recovery Team's review using the current IUCN Red List criteria (IUCN 1994). The Recovery Plan also contains criteria which, being specific to woylies, enabled the Recovery Team to set specific targets for its actions program. They are also reviewed. Nevertheless it is the IUCN criteria that are definitive.

## 3.1. International Criteria

The IUCN Red List Categories: Version 2.2 (IUCN 1994) details the criteria that are currently used to classify the conservation status of species. It uses five independent topics to allocate the conservation status of a species to one of the categories outlined in Table 2 and Figure 2.

TABLE 2

Definitions of the categories used in the IUCN (1994) Red Lists.

| CATEGORY | SUMMARY EXPLANATION |
|---|---|
| EX Extinct | No reasonable doubt the last individual has died |
| EW Extinct in the Wild | Survives but not wild in its natural range |
| CR Critically Endangered | Extremely high risk of extinction in the wild in the immediate future |
| EN Endangered | Not CR but very high risk of extinction in near future |
| VU Vulnerable | Not EN but high risk of extinction in mid-term future |
| LR Lower Risk | None of the above nor DD but warrants monitoring |
| DD Data Deficient | Insufficient data to classify |
| NE Not Evaluated | Not yet assessed against the criteria |

The category Lower Risk has three sub-categories.

| LOWER RISK SUB-CATEGORIES | SUMMARY EXPLANATION |
|---|---|
| cd Conservation Dependent | Cessation of management would result in qualification for a threatened category within 5 years |
| nt Near Threatened | Not qualifying for cd but close to qualifying for VU |
| lc Least Concern | Not qualifying for cd or nt |

The species being assessed is allocated to the highest category determined by any one of five topics (A to E below). In the following analysis we assessed the woylie against the lowest of the Threatened classifications

[4] In the 1996 Action Plan for Australian Marsupials and Monotremes (Maxwell *et al.* 1996) it is listed as Lower Risk (Conservation Dependent) as a consequence of the review's outcome.

[5] Now Environment Australia

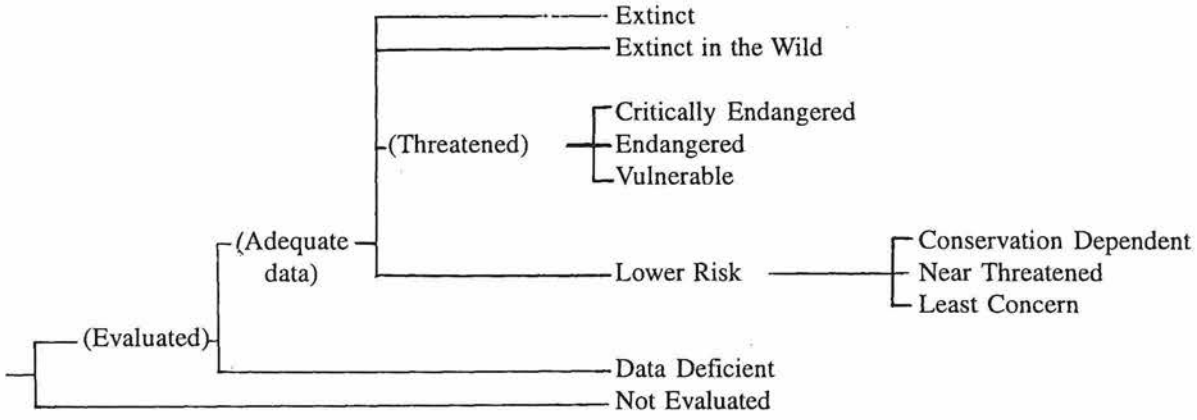


*Figure 2. The Structure of the IUCN Red List categories (IUCN 1994).*

(Vulnerable). Had it met that classification we would have assessed it against the next (Endangered) etc.

## A. *Substantial past or projected future decreasing population trends*

For woylies to qualify as vulnerable there must have been a reduction in population size of at least 20 per cent over the last ten years or a projected reduction of 20 per cent in the next ten years. Table 3 summarizes the conservation status of woylies 20 years ago compared with now. Data to 1994 are detailed in Courtenay (1994) or Morris *et al.* (1995) and data since then have been supplied by various people implementing the monitoring program established as Action 2 of the Recovery Plan.

The increase in the number of populations has resulted from translocations after fox (and, at Venus Bay Peninsula, cat) control. In WA the increase in population density (measured by trap success) has occurred since fox control measures have been introduced.

The population at Yookamurra is contained within a fox-proof fence. The managers, Earth Sanctuaries, plan to maintain the population in a wild state within the fence. Introduced populations on two additional, small SA islands with carrying capacity of <50 animals were recognized by the Recovery Team to be too small to maintain in the long-term as viable populations. One became extinct in early 1994. The other persists but will not be maintained if it declines.

Table 3 demonstrates that a substantial increase has occurred over the past 20 years in population density as well as the number of populations and area occupied at sites identified in the Recovery Plan for key populations. A substantial proportion of the increase occurred in the last ten years.

Woylies do not qualify as Vulnerable under this category.

Besides sites identified in the Recovery Plan for protection or introduction of woylies, there are a number of other relevant sites. In WA fox control has now been extended to 550 000 ha of jarrah/wandoo forest, much of which is probably suitable habitat[6]. Woylies have been translocated to ten sites within that area under another program (Operation Foxglove and Project 3.4 of the Co-operative Research Centre for the Biological Control

TABLE 3

Change in the conservation status of *Bettongia penicillata* populations during the past 20 years.

| STATE | LOCATION | AREA (ha) | PAST | STATUS NOW (December 1995) |
|---|---|---|---|---|
| WA | Batalling | 3 617 | Presumed extinct | Re-introduced 1983; TS 24% (July 1995) |
| WA | Boyagin | 4 781 | Presumed extinct | Re-introduced 1992; TS 47% (Oct 1995)[a] |
| WA | Dryandra | 12 192 | TS <1% (1975) | TS variable but consistently >50% |
| WA | Julimar | 24 117 | Presumed extinct | Re-introduced 1995; established |
| WA | Perup | 37 640 | TS 3-10% (1974)[b] | TS 35% (Feb 1994)[c] |
| SA | St Peter Island | 3 493 | Not naturally present | Introduced 1989; TS 53% (March 1995) |
| WA | Tutanning | 2 369 | TS 0 - 6% (1984) | TS 13% (July 1995) |
| SA | Venus Bay | 1 600 | Presumed extinct | Re-Introduced 1994; established |
| SA | Wedge Island | 947 | Not naturally present | Introduced 1983; TS 77% (June 1995) |
| SA | Yookamurra | 1 100 | Presumed extinct | Re-introduced 1991; established |

TS = Trap success expressed as a percentage.

[a] Data from West Boyagin recorded by Jackie Courtenay. Woylies are present in the east and west blocks of this reserve.

[b] Boyicup. The forest block at Perup monitored by Christensen 1974-1981. Data using cage traps (as in present monitoring program) and excluding additional pre-baited funnel traps.

[c] Yendicup. The forest block at Perup monitored by Burrows 1989-1994 using cage traps.

[6] Western Shield, a program to extend the area baited for foxes to >5 million hectares, has commenced since the review was written.

of Vertebrate Pest Populations (VB CRC)). That program will translocate woylies to another eight sites before the end of 1995[7]. Providing feral predator control is maintained, all populations that are still below carrying capacity throughout the accessible habitat are likely to increase in density and area of occupancy in future. CALM is committed to protecting or expanding these populations.

## B. *Extent of occurrence and areas of occupancy*
*(see IUCN 1994 for definitions)*

To qualify as Vulnerable, a species will have an extent of occurrence of less than 20 000 km² or area of occupancy of less than 2000 km² and furthermore meet two out of three additional criteria. Woylies now have an extent of occurrence many times 20 000 km² extending from WA to SA. The extent of occurrence in WA alone exceeds 17 000 km². However, the area of occupancy is difficult to determine in forested areas where populations are expanding in the shelter of effective fox control. Although it probably exceeds 2000 km² the additional requirements are considered.

(1) *Populations are severely fragmented (no population is estimated to contain more than 1000 mature individuals) or found at no more than ten locations*
The Dryandra population is estimated at about 6000 individuals (Jackie Courtenay, unpublished data). The Perup (including Kingston to Lake Muir) area contains a much larger population, Batalling supports several thousand individuals and there are more than 1000 on Wedge and St Peter islands. There are ten populations (six in WA and four in SA) even recognizing the Lake Muir-Perup-Kingston (>40 km across) as one population and excluding the small SA island population and the area covered by Operation Foxglove.

(2) *The species continues to decline in any of the following*
(a) Extent of occurrence: it has been increasing in WA and SA (Table 3).
(b) Area of occupancy: it has been increasing in WA and SA (Table 3).
(c) Area, extent or quality of habitat: these factors are increasing/improving with extension of fox control in natural vegetation on State lands in WA and SA.
(d) Number of locations or sub-populations: they are projected to expand in WA until populations coalesce.
(e) Number of mature individuals: Woylies breed in their first year. Therefore populations that have been increasing in recent years (Table 3) will contain increasing numbers of mature individuals in WA and SA.

(3) *Extreme fluctuations in any of the following*
(a) Extent of occurrence: they are increasing in WA and stable in SA (Table 3).
(b) Area of occupancy: they are either stable or increasing, depending on site, in WA and SA (Table 3).
(c) Number of locations or sub-populations: they are increasing in WA and stable in SA (Table 3).
(d) Number of mature individuals: they are more or less stable or increasing, depending on site, in WA and SA (Table 3).

Woylies do not meet any of the additional characters. Thus they do not qualify as Vulnerable under this category.

## C. *Population size (for larger populations) and predicted decreasing trends*

For woylies to be assessed as Vulnerable this category requires that the total number of individuals is less than 10 000 and, either there is an estimated continuing decline of at least 10 per cent in ten years, or there is a continuing decline in the number of mature individuals or population structure (severe fragmentation or all mature animals in one sub-population).

The Dryandra population is estimated at about 6000 individuals (Jackie Courtenay, unpublished data). The Perup area (including Kingston to Lake Muir) contains a much larger population, Batalling supports several thousand individuals and there are more than 1000 on both Wedge and St Peter Islands. Furthermore, the total number of mature individuals is increasing as Western Australian populations spread with the extension of fox baiting and a continuing translocation program.

Woylies do not qualify as Vulnerable under this category.

## D. *Population size (of smaller populations) irrespective of population trends*

To qualify as Vulnerable this category requires the population to be very small (<1000 individuals) or the population to be acutely restricted in its area of occupancy (typically <100 km²) or number of locations (typically <5). Data presented above clearly indicate that woylies can not be classified as Vulnerable under this category.

## E. *Quantitative analysis showing probability of extinction in specified time units or generations*

To qualify as Vulnerable this category requires a quantitative analysis showing probability of extinction is at least 10 per cent within 100 years. No analysis has been undertaken for woylies. Given the population size and trends discussed above, a population viability analysis would be unlikely to show a significant probability of extinction. Assuming climatic change does not eliminate suitable habitat, current feral predator controls are sustained or improved and State lands which now support woylie populations are not alienated, and that there are adequate monitoring programs, there is no reason to believe factors operating at present will reverse the current trend of increasing populations and densities (where populations are still below carrying capacity). Thus woylies would not qualify as Vulnerable under this category.

[7] The number of translocation sites under this program has risen to 20 since the review was written.

## Conclusion on the status of woylies as assessed by the 1994 IUCN Red List criteria

Woylies do not qualify as Vulnerable, the least critical of the Threatened group of categories (Table 2 and Figure 2). However, they would probably be Endangered or Critically Endangered if remnant populations had not been protected from fox predation and new populations established in the safety of feral predator control. Undoubtedly their status would revert to a Threatened category if active management, particularly of feral predators, were to be discontinued. Woylies are therefore unequivocally classified as 'Lower Risk (Conservation Dependent)'. Conservation Dependent taxa are those which are the focus of a continuing taxon-specific or habitat-conservation program, the cessation of which would result in the taxon qualifying for one of the threatened categories within five years (IUCN 1994).

## 3.2 Recovery Plan Criteria

The criteria set by the Recovery Team for successfully achieving the objectives are:

### 3.2.1 Western Australia

*At least six populations of woylies, each occurring in areas of at least 1500 ha of suitable habitat and each increasing in density (and area where there is contiguous suitable habitat) or plateaued at a trap-success rate greater than 7.5 per cent*

In WA the six primary sites selected by the Recovery Team for achieving this criterion are listed in Table 4 which also indicates recent trap success rates. At all sites except for Julimar, woylies occupy substantially more than 1500 ha at densities that yield trap success rates substantially greater than 7.5 per cent (Table 4).

Woylies were not translocated to Julimar until early 1995 and the trap success rate has not reached 7.5 per cent. Animals were released at two points. One group has established well but there was high predation of the other to begin with. Fox control has been intensified in that area and the prognosis is now good for woylies at Julimar.

It is difficult to provide precise area data and trap success data for the forest site at Batalling because woylies are still spreading into contiguous suitable habitat. The population of woylies in the Perup region is actually considerably larger than indicated in Tables 3 and 4. The trap success data in Table 4 is from the proposed Perup Nature Reserve, about 37 640 ha. Woylies are also abundant in Kingston and Warrup Forests up to 25 km west of Perup and have been caught in the intervening Corbal and Dwalgan Forests (16 per cent and 7 per cent trap success respectively). They have also been caught in low numbers in several forest areas at least 15 km south of Perup along the Muir Highway between Tone Forest and Lake Muir (Courtenay 1994). Thus woylies probably occur over an area of at least 60 000 ha in this region, but in variable densities.

It should be noted that interpretation of trap success (TS) becomes increasingly difficult as populations of fauna recover. This is illustrated by data from Tutanning. In July 1995 fifty traps were set over three nights to give 150 trap nights. Table 5 presents the results.

Woylie trap success is:

- 13.3 per cent using all captures
- 10.6 per cent using all individuals but excluding recaptures during the session
- 24.6 per cent assuming all traps that caught other species were unavailable to woylies.

In presenting trap success data we have used total woylie captures because some early data did not differentiate new from recaptured animals during any one trapping session. Our assumption that all traps were available means that, in many instances, the data are conservative.

TABLE 4

Area, trap success (expressed as a percentage of traps-nights on which woylies were captured) and notes on the six Western Australian sites identified in the Woylie Recovery Plan (Start *et al.* 1995) as key sites for recovery of woylies.

| SITE | TRAP | AREA (ha) | NOTES |
|---|---|---|---|
| Batalling | 24% | 3617 | 33 565 ha now baited. Woylie density varies as they spread from the original Batalling site |
| Boyagin | 47% | 4781 | Data from West Boyagin but woylies are present in both Blocks of this reserve |
| Dryandra | >50% | 12192 | Population estimated about 6 000 woylies. This has been the source of animals sent to SA |
| Julimar | New | 24117 | There is approx. 16 000 ha additional, contiguous, fox-baited forest on Commonwealth land to the north |
| Perup | 35% | 37640 | Excludes areas outside proposed Perup Nature Reserve, e.g. Kingston and Lake Muir where there are woylies |
| Tutanning | 13% | 2369 | 69 of 150 traps caught other species and were at least partially unavailable to woylies |

TABLE 5

Fauna captured in traps set in mid-1995 on a transect established for routine woylie monitoring at Tutanning Nature Reserve. (Numbers in parentheses exclude animals recaptured during the trap session.)

| DATE | WOYLIE | POSSUM | QUENDA | BIRD |
|---|---|---|---|---|
| 31 July 1995 | 6 (6) | 22 (22) | 2 | 1 |
| 1 August 1995 | 8 (7) | 14 (12) | 4 | 2 |
| 2 August 1995 | 6 (3) | 19 (15) | 5 | 0 |
| TOTAL | 20 (16) | 55 (49) | 11 | 3 |

*Clarification of the status of the woylie in conservation reserves and State forest of the south-west of WA*

The discovery of a woylie population at Kingston Forest and a road kill near Lake Muir were among the factors prompting the revision of the first edition of the Recovery Plan. Courtenay (1994) surveyed for woylies in forests between Perup and Kingston and also between Perup and Lake Muir. She found woylies in all but one of the areas she surveyed as far south as the Muir Highway, although trap rates were low in areas south of Perup. This suggests that woylies are probably present in varying numbers from Kingston to Lake Muir (see above for more detail).

*Establishment of experiments to determine the effects of timber harvesting (at Kingston Forest) and fuel-reduction prescribed burning (at Batalling Forest) on woylies and commitment in a Wildlife Management Program to modify forest management prescriptions to ensure compatibility with maintaining woylie populations*

The discovery of woylies at Kingston was made during a pre-logging fauna survey. There were also other threatened mammals present. These species occupied unlogged forest as well as forest logged about six years previously. Logging was postponed to allow time to set up experiments to quantify the impact of operational timber harvesting on fauna in the jarrah forest. Information from the experiment will be used to determine whether it is necessary to modify management prescriptions so that the species like woylies can recolonize all suitable forest habitat irrespective of tenure or use but under cover of fox control.

The experiments have been set up. Pre-logging data have been collected. Logging took place this year (1995). Preliminary results indicate woylies were not seriously affected by the operation. The experiment will run its full, planned course and CALM will assess the suitability of the current prescriptions when the results are available. The results of the experiment will be published.

An experiment to assess the impact of prescribed fuel-reduction fire on woylies and other mammals has been set up at Batalling. Preliminary results indicate woylies were not seriously affected by the operation. The experiment will run its full, planned course and CALM will assess the suitability of the current prescriptions when the results are available. The results of the experiment will be published.

## 3.2.2 South Australia

*Maintenance of two island populations, on Wedge and St Peter Islands*

Populations on Wedge and St Peter Islands are thriving. Trap success rates have commonly exceeded 50 per cent. David Groth and John Wetherall of Curtin University of Technology, assessed DNA profiles of animals from Wedge and St Peter Islands compared with animals from Tutanning. They reported to the Recovery Team that the island stocks (0.80 band-sharing) had very limited genetic variability and considerably less than the Tutanning stock which, at 0.50 band-sharing, approached that 'seen in a well maintained population of sheep or cattle'. Therefore wild-caught woylies from Dryandra have been introduced to Wedge Island in an attempt to increase the genetic variability of that population. If successful this process will be extended to St Peter Island.

*Establishment of at least one mainland population in addition to the Yookamurra population*

On 5 April 1994, after extensive work to control feral predators and rabbits, wild-caught woylies from Dryandra were released at Venus Bay Nature Reserve on Eyre Peninsula. The future of this reintroduction appears secure, with recent systematic trapping (September 1995) producing 33 per cent trap success (20 captures from 60 trap nights) five of which were new (untagged) animals. No further losses of radio-collared woylies to predators have occurred since the capture of a large male cat in March and seven of the 14 collared females were observed with large young at foot. In addition, all females handled were found to have pouch young and weights of all animals continue to be above weight at release, reaffirming the suitability of habitat and availability of adequate food resources.

The population at Yookamurra persists. DENR staff assist with monitoring. The status of genetic diversity of the Yookamurra population is probably similar to that of the SA island populations as it is derived from the same founder stock. Any decision to introduce wild-caught animals from elsewhere to broaden the genetic base will be for the managers to make. The DENR will continue to assist with monitoring for the time being.

## 3.2.3. Both States

*Establishment of monitoring programs (to include genetic diversity) and action plans to address any adverse trends detected*

In SA the annual monitoring of woylie populations on Wedge and St Peter Islands will continue. Fixed transects have been established to ensure comparability of data from year to year. Intensive monitoring of the establishing Venus Bay population, including systematic trapping three times per year and on-going radio tracking, will continue at least to the end of 1996 by research staff. DENR will determine the responsible personnel and program for monitoring thereafter.

In WA a monitoring program using standardized transects, with permanently marked trap locations, has been established (Courtenay 1994) and regular monitoring, at least annually, will be undertaken by CALM staff responsible for the management of the areas occupied by each of the woylie populations. This will be added to as more populations are established by translocation or as woylies extend into new districts under cover of CALM's program to control foxes in the south-west of WA. Samples from all populations have been collected to provide base line data on the genetic variability of wild woylie populations.

## 3.3 Criteria under CALM Policy

CALM Policy Statement No. 33 'Conservation of Threatened and Specially Protected Fauna in the Wild' (endorsed 1991) provides the mechanism and criteria by which species are assessed for inclusion and removal from the Schedule of 'fauna which is likely to become extinct or which is rare' pursuant to the Western Australian Wildlife Conservation Act.

It establishes a Threatened Fauna Scientific Advisory Committee[8] to review and advise the Executive Director on all proposals to amend the schedule. An indigenous taxon may be recommended for inclusion on the list if it is:

• ***presumed to be extinct*** The woylie is not presumed extinct.

• ***in imminent danger of or threatened with extinction, i.e. it is likely to decrease in numbers and possibly become extinct if factors causing its decline continue to operate*** The number of woylie populations and, where there is natural vegetation adjacent to that already containing woylies, the area occupied by woylies, are increasing.

• ***dependent on or restricted to habitats that are vulnerable and/or subject to factors that may cause its decline*** This criterion is pertinent to situations such as salt encroachment threatening habitat. Although woylies could decline to extinction if fox control were to cease, there is an on-going commitment by CALM to maintain fox control in all areas occupied by woylies (which also contain other threatened fauna in need of protection from foxes). Given that commitment, habitat occupied by woylies is not vulnerable or subject to factors that may cause their decline (see below).

• ***very uncommon, even if widespread*** The woylie is now very common in several locations in the south-west of WA in addition to the populations in SA.

Policy Statement No. 33 provides for the Threatened Fauna Scientific Advisory Committee to recommend that a taxon be removed from the schedule where:

• ***recent zoological survey has shown that the taxon no longer meets the above criteria***

• ***the taxon is no longer threatened because it has been adequately protected by habitat protection and its numbers have increased beyond the danger point*** This point clarifies the third dot-point in the criteria for listing (above).

Policy Statement No. 33 also requires the Threatened Fauna Scientific Advisory Committee to prepare a 'Reserve List' listing (among other categories) taxa that have recently been removed from the schedule of threatened fauna.

The Recovery Team considers that the woylie no longer meets the criteria for inclusion on the schedule of threatened fauna. It satisfies both requirements for removal from the schedule and should be placed on the Reserve List. The Recovery team recognizes that the Policy will require the Executive Director to refer its recommendations (below) to the Threatened Fauna Scientific Advisory Committee for review.

[8] This committee has been replaced by the Western Australian Threatened Species Scientific Committee which considers fauna and flora issues.

## 3.4 Criteria under South Australian Legislation

The South Australian National Parks and Wildlife Act requires assessment for declaration be in accordance with a species status within that State's borders, irrespective of its status elsewhere (unlike the Western Australian and Commonwealth legislation). The Recovery Team has implemented a National Recovery Plan and its conclusions pertain to the global status of woylies. It is the prerogative of the South Australian Government to assess the status of the woylie within that State, but the Recovery Team draws its conclusions to the attention of the SA Government and would be pleased to see its status reviewed in SA.

## 3.5 Criteria under Commonwealth Legislation

The Endangered Species Protection Act lists Endangered and Vulnerable native species on Schedule 1, Parts 1 and 2 respectively. It defines a species as endangered if:

(a) *it is likely to become extinct unless the circumstances and factors threatening its abundance, survival or evolutionary development cease to operate; or*

(b) *its numbers have been reduced to such a critical level, or its habitats have been so drastically reduced, that it is in immediate danger of extinction; or*

(c) *it might already be extinct, but is not presumed extinct.*

It defines a species as vulnerable if, ***within the next 25 years, the species is likely to become endangered unless the circumstances and factors affecting its abundance, survival or evolutionary development cease to operate.***

In the areas it now inhabits, the principal threat has been predation. That threat has been sufficiently controlled to allow substantial increases in population density as well as in area of occupancy. Translocations have increased the number of populations and will continue to do so. The increases which will be sustainable as long as foxes are controlled mean that the woylie no longer meets criteria as Endangered or Vulnerable.

## 4. Recommendations

1. We recommend to the Chief Executive Officers of CALM and ANCA and to ANZECC that our conclusions are conveyed to their Ministers together with a recommendation that *Bettongia penicillata* be downgraded:

• under the Commonwealth Endangered Species Protection Act, by deletion from Schedule 1, 'Listed Species';

• under the Western Australian Wildlife Conservation Act, by removal from listing as 'fauna which is likely to become extinct or which is rare' and addition to the Reserve List as defined by Policy Statement No. 33.

And we recommend to the Chief Executive Officer of DENR that in South Australia its conservation status within the State be reviewed.

2. CALM and DENR write or review monitoring and management programs to ensure that the management necessary to maintain woylies as Conservation Dependent species is implemented and effective[9]. The plans should:
• provide for further improvement in the conservation status of woylies, and
• commit to action to address any significant decline detected by the monitoring programs.

# WOYLIE (*BETTONGIA PENICILLATA OGILBYI*):A REVIEW OF ITS STATUS IN DECEMBER 1995. SUPPLEMENT: THE STATUS OF WOYLIES IN 1990.[10]

## 1. The Purpose of this Review

The Woylie Recovery Plan required the Recovery Team to 'Review the conservation status of the woylie, using internationally accepted criteria, and recommend changes if necessary' at the conclusion of its program of recovery actions in December 1995 (Start *et al.* 1995). That review was undertaken (above) using the IUCN Red List criteria (IUCN 1994). The Recovery Team found that the woylie did not qualify as Threatened but did qualify as Lower Risk (Conservation Dependent). The Recovery Team made the following recommendations[11].

In addition to defining criteria for classification of species the 1994 IUCN Red List document states 'There are rules to govern the movement of taxa between categories. These are as follows: (A) A taxon may be moved from a category of higher threat to a category of lower threat if none of the criteria for the higher category has been met for five years or more...' (the other rules are irrelevant here). In the woylie's case the subject has a short generation time and a rapid recovery rate when protected from adverse factors such as predation. New populations are readily established from translocated stock and woylies are now secure in conservation reserves where there is an on-going commitment to fox control (a key factor).

Furthermore, there are commitments to on-going monitoring and State and Commonwealth legislation would require relisting in a Threatened category if its status again declined. In view of those factors, and given that its status will be under review routinely through the monitoring program, the Recovery Team recommended re-classification immediately and not pending yet another review in five years.

It must be understood that the IUCN Red List Categories used here were not published until 1994 and that they were not available five years ago for use in classifying woylies. Nevertheless, the Recovery Team thought it would be useful to examine the status of woylies five years ago. We have used the current IUCN criteria to retrospectively assess the conservation status of the woylie as it would have been in 1990.

## 2. The Status of Woylies in 1990

The IUCN Red List categories (IUCN 1994) details the criteria that are currently used to classify the conservation status of species. It uses five independent topics to allocate the conservation status of a species to one of the categories (Table 2 and Figure 2). The species being assessed is allocated to the highest category determined by any one of five topics (A to E below). In the following analysis we assessed the woylie against the lowest of the Threatened classifications (Vulnerable). Had it met that classification we would have assessed it against the next (Endangered) etc. This was the method used in the principal review.

### A. *Substantial past or projected future decreasing population trends*

For woylies to qualify as vulnerable there must have been a reduction in population size of at least 20 per cent over the last ten years or a projected reduction of 20 per cent in the next ten years. Table 6 summarizes woylie status in 1980 compared with that five years prior to the review, i.e. December 1990.

Introduced populations on two additional, small SA islands with carrying capacity of <50 animals were recognized by the Recovery Team to be too small to remain viable in the long-term (one became extinct in early 1994).

There is no evidence of a net deterioration in the size or number of populations between 1980 and 1990. Instead there were improvements in both factors. At Dryandra and Tutanning the increase in population density (as measured by trap success) had occurred since fox control measures were introduced and, at Perup, since habitat management and some fox control had been implemented. Although the improvement was not as dramatic as it has been in five years since 1990, the criterion of a reduction of at least 20 per cent in the decade preceding 1990 clearly had not happened. As the prospect of recovery after 1990 improved with the endorsement of the first Recovery Plan (Hall *et al.* 1991) there were no grounds for anticipating a decline in the succeeding ten years. Indeed improvements in the last five years have vindicated the optimism for improvement after 1990.

Woylies would not have qualified as Vulnerable under this category in 1990.

[9] In WA, Western Shield has incorporated woylies into monitoring and fauna reconstruction programs. The latter will establish new populations in many conservation reserves.
[10] Prepared by A.N. Start, and A.A. Burbidge for the Woylie Recovery Team.
[11] The original supplementary review reiterated the recommendations. For reasons of economy they are not repeated here.

TABLE 6

Change in the conservation status of *Bettongia penicillata* between 1980 and December 1990.

| LOCATION | STATUS IN 1980 | STATUS IN DECEMBER 1990 |
|---|---|---|
| Batalling | Presumed extinct | Re-introduced 1983. Small, but established, new population |
| Dryandra | TS 0% in 1975[a] No data for 1980 | TS variable but mean 16% in baited area in 1989. Data not available for December 1990 |
| Perup | TS 24.6%[b] | TS variable but consistently >39.5% in December 1989; 62% in April 1990[c] |
| St Peter Island | Not naturally occurring | Introduced 1989; established new population |
| Tutanning | TS mean 2.7% 1984[d] | TS mean 21.5% in 1989 Data not available for 1990 |
| Wedge Island | Not naturally occurring | Introduced 1983; well established new population |

TS = Trap success expressed as a percentage.

[a] None could be trapped but woylies must have been present in very low numbers. Baiting of a small part of Dryandra commenced in 1982.

[b] Boyicup Block, the forest block at Perup that was monitored by Christensen 1974-1981. Data include captures in cage traps (as in the present monitoring program) as well as pre-baited funnel traps.

[c] Yendicup Block, the forest block at Perup monitored by Burrows 1989-1994. Cage traps only.

[d] No data available when fox-baiting began.

## B. *Extent of occurrence and areas of occupancy*
## *(see IUCN 1994 for definitions)*

To qualify as Vulnerable a species will have an extent of occurrence of less than 20 000 km² or area of occupancy of less than 2000 km² and, furthermore, meet two out of three additional criteria. In 1990 woylies had an extent of occurrence many times 20 000 km² extending from WA to SA. However, the area of occupancy is difficult to determine where populations were expanding in the shelter of fox control so the additional requirements are considered.

(1) *Populations are severely fragmented (no population is estimated to contain more than 1000 mature individuals) or found at no more than ten locations*

The Dryandra population is estimated at about 6000 individuals (1994, Jackie Courtenay, unpublished data). Trap success rates in 1990 (mean = 16 per cent in baited areas and half that in unbaited areas) suggest that in that year there were many more than 1000 individuals. Perup (including the area from Kingston to Lake Muir) contains a much larger population which has persisted without regular fox control over much of the area. It too would have contained more than 1000 individuals in 1990.

(2) *The species continues to decline in any of the following*

(a) Extent of occurrence: it had been extended from south-western WA to SA.

(b) Area of occupancy: by 1990 it was increasing with introductions in WA and SA.

(c) Area, extent or quality of habitat: in 1990 these were increasing/improving with expansion of fox control in WA and translocations to SA islands and Batalling in WA.

(d) Number of locations or sub-populations: these had increased in WA and SA.

(e) Number of mature individuals: Woylies breed in their first year. Therefore populations that had been increasing prior to 1990 would have contained increasing numbers of mature individuals in WA and SA.

(3) *Extreme fluctuations in any of the following*

(a) Extent of occurrence: this was increasing with translocation to SA islands.

(b) Area of occupancy: it was stable or increasing, depending on site, in WA and SA.

(c) Number of locations or sub-populations: it had increased in WA and SA.

(d) Number of mature individuals: this was presumed to have stabilized or increased, depending on site, in WA and SA.

Woylies did not meet any of the additional characters. Thus they would not have qualified as Vulnerable under this category in 1990.

## C. *Population size (for larger populations) and predicted decreasing trends*

For woylies to be assessed as Vulnerable, this category requires that the total number of individuals is less than 10 000 and either there is an estimated continuing decline of at least 10 per cent in ten years or there is a continuing decline in the number of mature individuals or population structure (severe fragmentation or all mature animals in one sub-population).

Although it is not possible to estimate the total number of woylies in 1980 and 1990 it has been shown above that woylie populations had improved, not declined in the decade preceding 1990. Furthermore, there was a good prospect over the decade from 1990 for increases in the number of mature individuals in populations and an associated expectation of improvement in the fragmented nature of habitat occupation. These would be the outcomes of actions spelled out in the Recovery Plan. Progress since 1990 shows that these were realistic expectations.

Woylies did not meet either of the additional characters. Thus they would not have qualified as Vulnerable under this criterion in 1990.

### D. *Population size (of smaller populations) irrespective of population trends*

To qualify as Vulnerable, this category requires the total population to be very small (<1000 individuals) or the population to be acutely restricted in its area of occupancy (typically <100 $km^2$ = 10 000 ha) or number of locations (typically <5).

Table 6 identifies six locations at which woylies were present in 1990. At Dryandra they occupied an area exceeding 12 000 ha and Perup comprises an area of 37 640 ha but it has since been found that woylies extended up to 25 km west of Perup to Kingston Forest and 15 km south to near Lake Muir. Populations at Dryandra and Perup (and probably one of the SA islands) would have exceeded 1000 individuals.

Woylies would not have been classified as Vulnerable under this category in 1990.

### E. *Quantitative analysis showing probability of extinction in specified time units or generations*

To qualify as Vulnerable by this category a quantitative analysis must show a probability of extinction of at least 10 per cent within 100 years. No analysis was undertaken for woylies in 1990. However, by then the key factor (fox predation) in the decline of woylies in south-western WA had been identified and successfully addressed and translocation had been shown to be an effective means of establishing new populations. The status of woylies had already improved and a recovery plan which built on the factors that had produced the improvements had been written and endorsed. The principal recovery actions were to be fox control and increasing the number of populations in WA and SA through translocation. Monitoring was also an essential component. Given these factors, a population viability analysis would have been unlikely to show a significant probability of extinction.

Thus woylies would probably not have qualified as Vulnerable under this category in 1990.

## 3. Conclusion

Woylies would not have qualified as Vulnerable, the least critical of the Threatened group of categories, if assessed in 1990 by the 1994 IUCN Red List criteria. They would have been classified as 'Lower Risk (Conservation Dependent)' if the classification system had existed then. Never-the-less they were much less secure than they are now (compare Table 6 with Tables 3 and 4).

We do not believe that the 1994 IUCN Red List rules for transfer intended a moratorium on reclassification for five years from publication. Rather we believe that in adopting the new criteria, it is sensible to re-evaluate species by them and, if appropriate, adjust their conservation classification. In the case of woylies the species has met the criteria for 'Lower Risk (Conservation Dependent)' for at least five years and its status continues to improve.

The Recovery Team firmly believes that its recommendations are sound and that to postpone reclassification of woylies pending a further review in five years time is unnecessarily bureaucratic, is not the intention of the IUCN system, will debase the credibility of the classification Threatened when a species clearly no longer meets the criteria and will divert resources and attention from much more critically threatened species.

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# Bibliography of scientific documentation authored by staff of the CALM**Science** Division, Department of Conservation and Land Management

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## ABSTRACT

This bibliography, based on an electronic database of all written scientific outputs by CALM**Science** Division staff since 1985, contains 1509 items. Most of these items are papers published and reviewed outside the Department of Conservation and Land Management (429), papers in journals published by CALM (235), papers popularizing science and published in CALM's *Landscope* magazine (209), chapters in books or reports published external to CALM (192) and reports to agencies which have funded research (145).

## INTRODUCTION

This is a bibliography of scientific papers written by Research Division (RD), Science and Information Division (SID) and CALM**Science** Division (CSD) staff since the formation of the Department of Conservation and Land Management (CALM) in March 1985. Research Division was formed in 1985 by amalgamating the scientific programs of the Forests Department and the Wildlife Branch of the Department of Fisheries and Wildlife. In 1988 the Western Australian Herbarium was incorporated into the Research Division. This Division was replaced in 1992 by the Science and Information Division, of which the Perth Observatory became part in 1996. The Division was renamed CALM**Science** Division in April 1998.

The bibliography has been extracted from SIDPUBS, an Inmagic database which contains all papers written by RD/SID/CSD staff. The main guideline for this database was that the paper had to have been written under the auspices of RD/SID/CSD, therefore, Herbarium staff papers were included after July 1988, and Observatory staff after January 1996 (when they became part of CALM). The database includes items of a non-scientific nature which have been omitted from this printed list. The database will be maintained constantly, so that an up-to-date listing of papers (including submitted and in press titles) can be extracted or viewed at any time.

The initial database was started as a means of extracting publications of current staff, from the CALM Library Catalogue for exporting to WASPP[1]. Only 10 fields were present, because of the limited requirements of the WASPP database. As the function of SIDPUBS expanded to become a bibliographic database, it underwent several changes, as other features were decided as necessary for the completeness of the information. The database now has 25 fields, which were added as required. With the new purpose of SIDPUBS it was realised that a list of staff who had been with RD/SID/CSD since 1985 was needed.

Thirty-one sources of staff names were accessed, and a spreadsheet compiled with the names, and presence of that name within a source document. All names in WASPP have an author code and so all new names were assigned a code as well. Once the list was compiled the names not already known were checked in the Library Catalogue, and any records added to SIDPUBS.

All the records taken from the Library Catalogue had to be amended to comply with the differences imposed by a bibliographic database. This involved the moving of information around the record, and changing its format in many cases.

The publication lists in the RD/SID research plans were checked against the existing database, and papers not there were added. It was noted that some papers entered in the research plans had not been written under the auspices of RD/SID/CSD, and therefore were either removed or not entered into SIDPUBS. Annual appraisals which contain lists of publications were also checked for new titles that were not already present in the database.

Many publications were also checked for papers that had not been included in the database. This included Departmental newsletters, *CALM News* and various others.

[1] The WASPP database is an on-line interactive Paradox for Windows application, that provides comprehensive input, update, interrogation and reporting facilities for Science Project Plans (SPPs). These SPPs (formerly Research Project Plans (RPPs)) are seen by the Science and Information Management Council as the best method for planning the research done by the scientists and technical staff of SID. Each SPP/RPP has an assigned number.

It was found that a large number of records were added from these various sources.

The material was initially classed as being in one of six categories. This enabled a consistent format for each type of paper being added to the database. These categories were expanded out to 17, and further expanded to 29, as new requirements for the database were discovered.

Once it was decided that the database was as complete as possible (2442 records), a list of papers was produced for all author codes present in the database. All staff still in CALM were sent the list with the instructions to check, amend or add to it as required, add SPP/RPP numbers, note any authors who had been employed by RD/SID/CSD as consultants, and to supply the Library Archives with any papers indicated as not being held.

Every effort was made to locate and send the listing to staff who were no longer with the Department. Consultants and contractors were more difficult to locate, and often it was a case a waiting for the scientist responsible for them to return their listing, with all the required details on.

As the lists were returned, SIDPUBS was amended, and added to. Further sources were noted and even more records added from these. Authors were followed up for the return of their lists, and as of 25 September 1997 there were 2720 records in the database. There are 1509 titles in this bibliography.

## SOURCES OF INFORMATION

CALM Library catalogue
Research plan : July 1987-June 1992
5 year plan : July 1988-June 1993
Research plan : 1989-1990
Research plan : 1990-1991
Research plan. Volume no. 5, 1991-1996
Triennial report 1992/95 : for the period July 1992 to June 1995
All CALM newsletters
Staff annual appraisals
SID Approval-to-publish forms
Returned lists from staff

## DEFINITIONS OF CATEGORIES USED IN SIDPUBS

Abstract (External ) = Abstract or poster abstract presented at a conference, workshop, meeting, etc. external to CALM. Further subdivided by Australian state, or country in which conference, etc. was held.

Abstract (Internal) = Abstract or poster abstract presented at a CALM conference, workshop, meeting, etc.

Book (External) = Book or report published outside of CALM

Book (Internal) = Book published by CALM

Book chapter (External) = Chapter in book or report published outside of CALM

Book chapter (Internal) = Chapter in book published by CALM

Book review (External) = Book review published outside of CALM

Book review (Internal) = Book review published by CALM

Conference paper (External ) = Paper presented at a conference, workshop, meeting, etc. external to CALM. Further subdivided by Australian state, or country in which conference, etc. was held

Conference paper (Internal) = Paper presented at a CALM conference, workshop, meeting, etc.

Electronic newsletter (Internal) = Newsletter accessed through CALMweb

Electronic page (Internal) = CALMweb page

Grant report = Grant report to external funding body

Journal = Whole journal issue edited or produced within CALM

Management plan (Reserve) = Management plan for parks and reserves published by CALM

Management plan (Wildlife) = Management or recovery plan for flora or fauna published by CALM

Miscellaneous (Internal) = CALM video recording, poster, pamphlet

Newsletter = Whole newsletter edited or produced within CALM

Newsletter (External) = Paper published in a newsletter external to CALM

Newsletter (Internal) = Paper in a CALM newsletter

Not yet categorised = In press or submitted titles

Paper (External - Popular) = Articles published outside of CALM in journals designed for public information

Paper (External) = Paper published and reviewed external to CALM

Paper (Internal - Popular) = *Landscope* articles

Paper (Internal) = Paper in a CALM journal

Report (Expedition) = *Landscope Expedition* reports

Report (Recovery - Annual) = Annual reports of Recovery Teams

Report (Unpublished) = CALM unpublished reports

Thesis = Report submitted as a thesis

## NUMBER OF DOCUMENTS PER CATEGORY IN SIDPUBS

| | |
|---|---|
| 5 | Abstract (External - ACT) |
| 2 | Abstract (External - Australia) |
| 1 | Abstract (External - Canada) |
| 1 | Abstract (External - Italy) |
| 7 | Abstract (External - NSW) |
| 5 | Abstract (External - NT) |
| 5 | Abstract (External - New Zealand) |
| 7 | Abstract (External - Qld) |
| 6 | Abstract (External - SA) |
| 2 | Abstract (External - Tas) |
| 2 | Abstract (External - USA) |
| 15 | Abstract (External - Vic) |
| 39 | Abstract (External - WA) |
| 1 | Abstract (External - West Germany) |
| 83 | Abstract (Internal) |
| 192 | Book chapter (External) |
| 26 | Book chapter (Internal) |
| 69 | Book (External) |
| 39 | Book (Internal) |
| 4 | Book review (External) |
| 2 | Book review (Internal) |
| 15 | Conference paper (External - ACT) |
| 2 | Conference paper (External - Australia) |
| 1 | Conference paper (External - Belgium) |
| 1 | Conference paper (External - France) |
| 1 | Conference paper (External - Germany) |
| 1 | Conference paper (External - Japan) |
| 1 | Conference paper (External - Malaysia) |
| 13 | Conference paper (External - NSW) |
| 1 | Conference paper (External - NT) |
| 1 | Conference paper (External - New Caledonia) |
| 2 | Conference paper (External - New Zealand) |
| 1 | Conference paper (External - Philippines) |
| 12 | Conference paper (External - Qld) |
| 15 | Conference paper (External - SA) |
| 1 | Conference paper (External - Tas) |
| 1 | Conference paper (External - UK) |
| 3 | Conference paper (External - USA) |
| 25 | Conference paper (External - Vic) |
| 76 | Conference paper (External - WA) |
| 1 | Conference paper (External - Yugoslavia) |
| 3 | Conference paper (Internal) |
| 1 | Electronic newsletter (Internal) |
| 2 | Electronic page (Internal) |
| 145 | Grant report |
| 28 | Journal |
| 18 | Management plan (Reserve) |
| 33 | Management plan (Wildlife) |
| 4 | Miscellaneous (Internal) |
| 34 | Newsletter |
| 108 | Newsletter (External) |
| 219 | Newsletter (Internal) |
| 170 | Not yet categorised |
| 429 | Paper (External) |
| 31 | Paper (External - Popular) |
| 235 | Paper (Internal) |
| 209 | Paper (Internal - Popular) |
| 15 | Report (Expedition) |
| 38 | Report (Recovery - Annual) |
| 294 | Report (Unpublished) |
| 17 | Thesis |

## CATEGORIES USED IN THIS BIBLIOGRAPHY

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Book (External) - page 305
Book (Internal) - page 308
Grant report - page 310
Journal - page 317
Management plan (Reserve) - page 318
Management plan (Wildlife) - page 319
Paper (External) - page 321
Paper (External - Popular) - page 337
Paper (Internal) - page 338
Paper (Internal - Popular) - page 348
Report (Recovery - Annual) - page 353
Thesis - page 355

The cumulative number of the major items produced since 1985 is graphed in Figures 1-6.

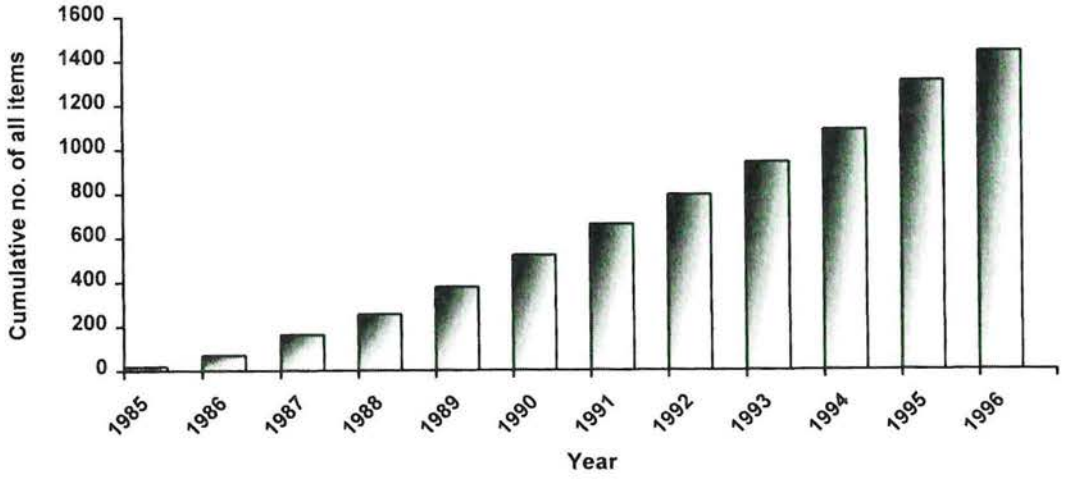


*Figure 1. Cumulative number of all items published.*

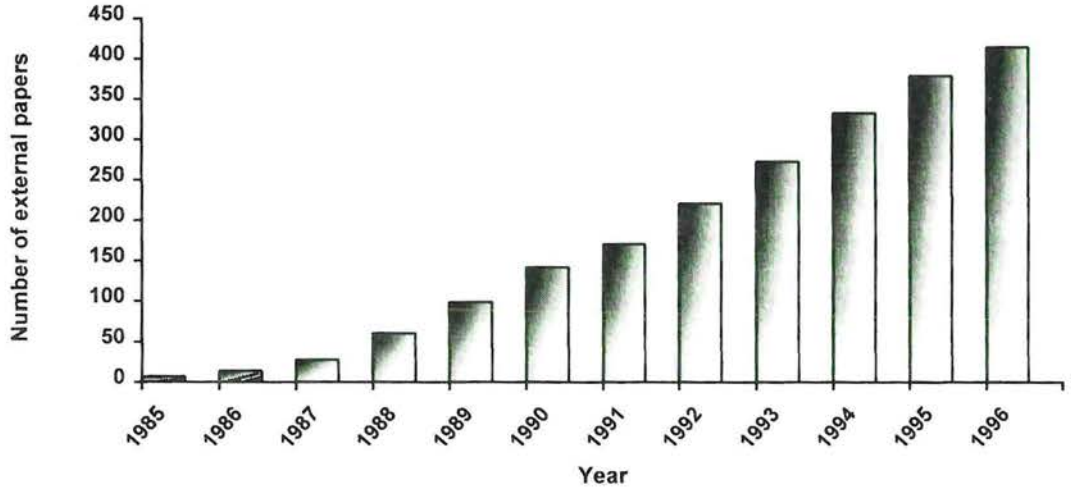


*Figure 2. Cumulative number of external papers.*

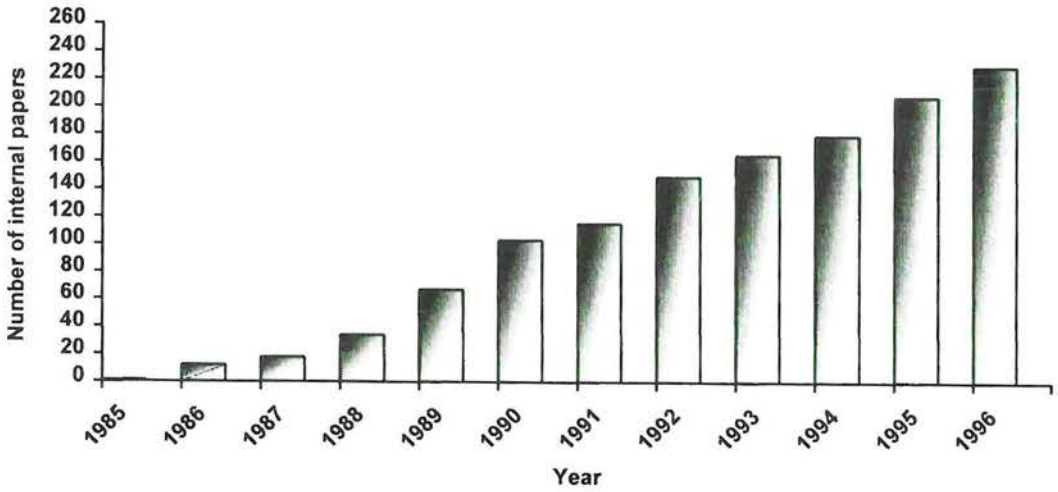


*Figure 3. Cumulative number of internal papers.*

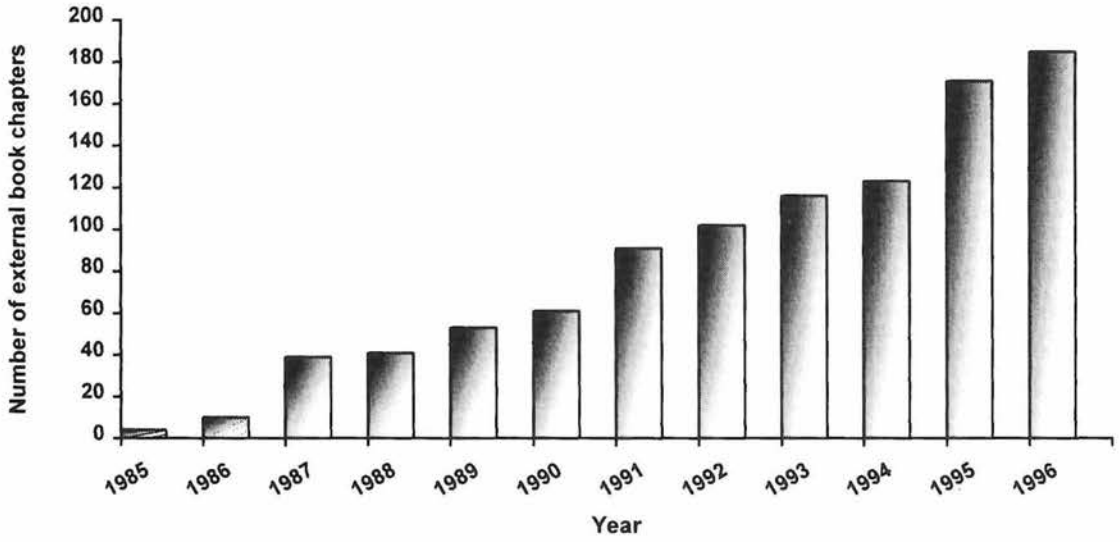


*Figure 4. Cumulative number of external book chapters.*

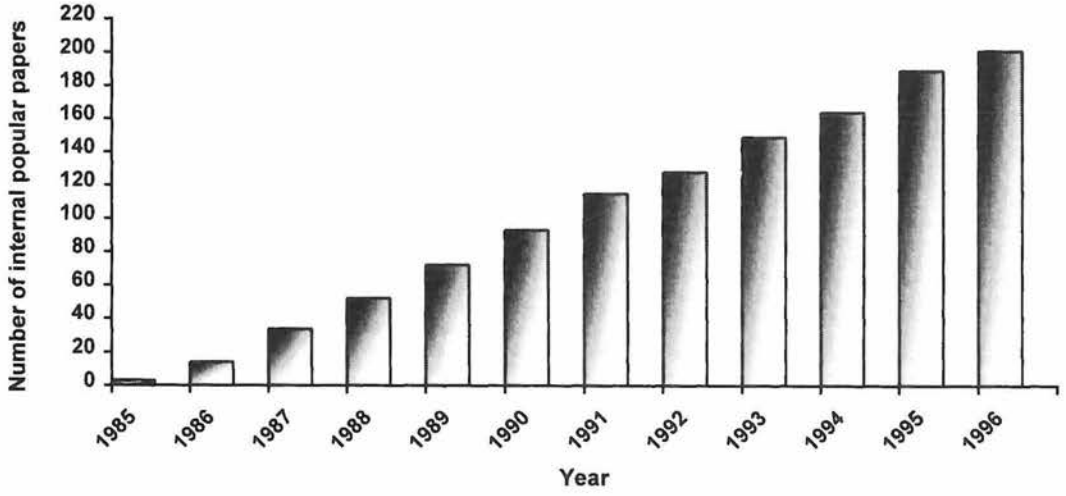


*Figure 5. Cumulative number of internal popular papers.*

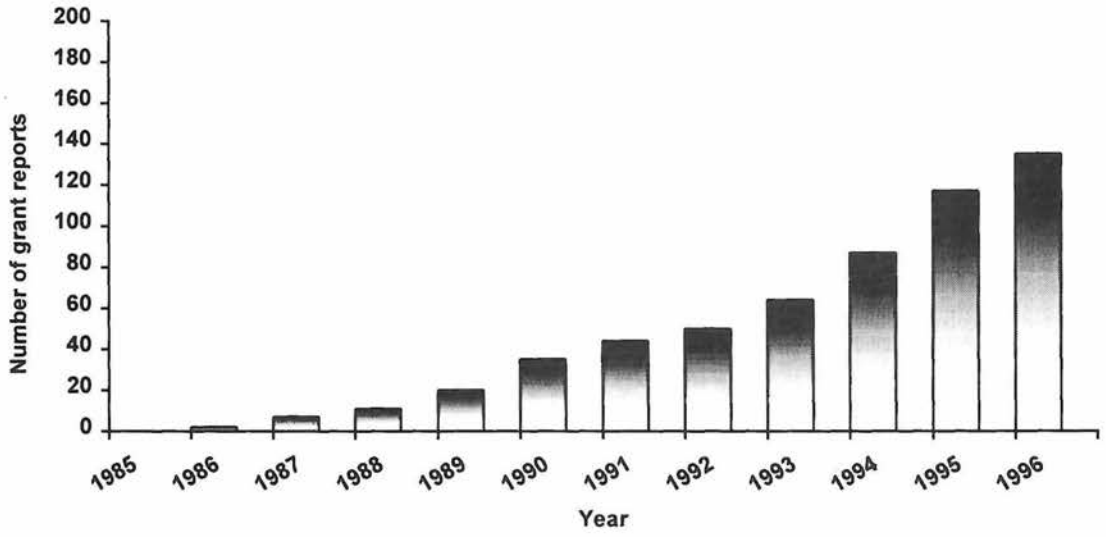


*Figure 6. Cumulative number of grant reports.*

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# A review of prescription burning in rehabilitated bauxite mines in Western Australia

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## SUMMARY

Alcoa of Australia has been rehabilitating after bauxite mining in the jarrah forest for 30 years. In the last 20 years these mined areas have been seeded with understorey legumes to prevent erosion. These legume species grow rapidly and assist in returning the nutrient status through nitrogen-fixation. They are, however, short-lived and senescence has led to large accumulations of fuel in 10- to 20-year-old sites (16-62 t $ha^{-1}$). These fuel loads can be reduced through burning.

This paper summarizes research conducted on prescription burning in these rehabilitated areas. The vegetation structure and fuel loadings of rehabilitated areas are different from those of the native jarrah forest. Fuel loads are higher in rehabilitated areas and have a relatively high proportion (45 per cent) of trash fuel which assists in carrying fire into the crown regardless of fuel moisture conditions. Reaccumulation of fuel following burning in rehabilitated areas is rapid. Vegetation structure appears to be more important than fuel loadings in determining when rehabilitation sites should be burnt. A low proportion of live to dead plant material below 2 m in height would indicate the potential for prescription burning of a rehabilitation site.

Prescription burning of rehabilitated areas has been carried out successfully in both autumn and spring. Spring burns of moderate intensity appear to be the best prescription to maximize native plant establishment and minimize deleterious effects of burning such as the establishment of high densities of non-native eucalypts. Damage to the overstorey in rehabilitated areas was lower after spring than autumn burns.

Seeding of post-burn sites with jarrah and an understorey mix will lead to increased species richness and the potential for establishing jarrah as the overstorey dominant.

Further research is required on the burning of younger rehabilitation sites and the effect of prescription burning on the fauna and soils of these areas. Prescription burning of rehabilitation sites has the potential to reduce fuel loads as well as increasing the establishment of native species in these areas.

## INTRODUCTION

Alcoa of Australia Limited has been rehabilitating mined sites in the jarrah forest since 1966, following the commencement of bauxite mining in 1963. Early rehabilitation sites were planted with pines (e.g. *Pinus pinaster*) or non-native eucalypt species with no understorey seeding. The fuel loads in these areas are generally low and are composed of two layers (litter layer and overstorey). Prescription burns have been carried out in these areas (Appendix 1) but these are not within the scope of this review.

Sites rehabilitated since 1976 have generally been seeded with an understorey mix containing a high proportion of native legume species. As many of these species are short-lived (10 to 15 years) older rehabilitation sites of this style have accumulated substantial fuel loads which are a potential fire hazard. These areas tend to have a fuel structure with three distinct layers: the litter, standing dead and live vegetation, and overstorey. This contrasts with much of the native jarrah (*Eucalyptus marginata*) forest which generally has only two distinct layers of available fuel (litter and overstorey). Sites rehabilitated since 1988 contain exclusively native overstorey species (e.g. *E. marginata* and *E. calophylla*). However, the majority of sites rehabilitated prior to 1988 contain either a mixture of native and non-native overstorey species or contain exclusively non-native species as the overstorey dominants (e.g. *E. resinifera*, *E. maculata* and *E. saligna*). Eastern Australian eucalypts were used owing to the known susceptibility of jarrah to dieback (*Phytophthora cinnamomi*) in the native forest. Subsequent research showed that jarrah stands established

in rehabilitated bauxite mines would not be severely impacted by the dieback fungus (Colquhoun 1992).

This review concentrates on fire management of those sites rehabilitated between 1976 and 1988 that contain a legume understorey and a non-native *Eucalyptus*-dominated overstorey. Fire management of post-1988 rehabilitation is currently not necessary as these sites have not accumulated substantial fuel loads of senesced *Acacia* species, although burning in these areas will need to be investigated in the future. It is likely that many of the principles and procedures that apply to the burning of 1976 to 1988 rehabilitation areas will also apply to post-1988 rehabilitation areas.

The current policy of the Department of Conservation and Land Management (CALM) is to exclude fire from rehabilitation areas and burn the surrounding forest areas which act as fuel-reduced buffer zones. Recent research has involved investigating the possibility of burning rehabilitation sites to reduce fuel loads so that these areas are similar in structure and composition to the surrounding forest. The objective of this review is to provide a summary of the accumulated knowledge on prescription burning in rehabilitated areas. The majority of the material presented in this paper has not been previously published. The information has been collected from 14 recorded burns in rehabilitated areas (Appendix 1). This paper examines fuel characteristics of old rehabilitation and then discusses fire behaviour and important factors that may affect fire behaviour in these areas. The response of the rehabilitated vegetation to burning is then investigated, followed by a discussion of site manipulations which may accompany prescription burns. The response of fauna to burning and the effect of fires on soils in rehabilitated areas are also briefly discussed.

Associated with this review is a practitioners guide to burning rehabilitation that outlines the information that should be collected before, during and after burns in rehabilitation (Appendix 2). This guide was formulated based on the findings reported in this paper to ensure that information collected on burning rehabilitation is standardized and can therefore be directly compared. This will increase the information base about fire response in rehabilitated areas.

All fuel loads described in this review exclude the tree overstorey.

# FUEL CHARACTERISTICS

## Vegetation Structure

Vegetation structure and associated fuel loadings of rehabilitated areas differ from those of the native jarrah forest. While the rehabilitation has three distinct fuel layers (litter, standing vegetation, and overstorey), the native upland forest generally has only two (litter and overstorey). Vegetation structure in the rehabilitated areas and in the native forest was estimated using the point-contact method (Levy and Madden 1933). A pole was divided into 30 cm intervals and the number of contacts of live and dead vegetation up to 3.9 m were recorded in each interval at 28 points in five replicate plots for each burn in rehabilitation and ten replicate plots in the native forest (each plot 20 x 20 m).

While the native forest is dominated by live plant material, 11- to 13-year-old rehabilitation is dominated by dead plant material (Fig. 1a, 1b). The proportion of live to dead plant material is low in the rehabilitation below 1.2 m in height, whereas in the native forest this proportion tends to be high. Dead plant material carries less water than live plant material and therefore tends to be more flammable (Sneeuwjagt and Peet 1985). Another feature of the rehabilitated vegetation structure is the development of a prominent mid-storey layer composed of senescing *Acacia* material. This has important implications in terms of fire management as this dead material assists in carrying fire into the crown under mild burning conditions. The lack of live plant material in the understorey of some of the rehabilitated areas indicates that these systems are in need of a further disturbance, such as a fire, to stimulate regeneration.

The vegetation structure and available fuel loads of rehabilitated areas do not fit any of the standard scrub structural types currently recognized by CALM (Sneeuwjagt and Peet 1985). Instead they represent a unique vegetation structure and therefore require a different fire management strategy. A comprehensive study on the fuel characteristics of 4- to 20-year-old rehabilitation has been carried out by Collins (1996). The results of this study will assist in determining at what age rehabilitated areas can be safely burnt for the first time. Examination of the rehabilitation structure one year after burning (Fig. 1c) showed that burning was successful in decreasing the amount of dead material in these areas as well as stimulating the germination of native species that have the potential to re-establish live vegetation cover.

All burns carried out to date have been in rehabilitated pits that are 8 to 17 years old (Appendix 1). Vegetation structure, the proportion of live to dead plant material and the strategic importance for fire control in rehabilitated areas were the most important factors determining whether a site should be burnt.

## Fuel Loads

Fuel loads in rehabilitated areas (excluding the tree overstorey) have been estimated by collecting all fuel (litter, standing dead <25 mm, and live vegetation <4 mm) present in a 1 x 1 m quadrat. Estimates indicate that in 10- to 15-year-old rehabilitation that has been seeded with an understorey, fuel loads are extremely high (range 16 to 62 t $ha^{-1}$, see Appendix 1). These fuel loads are two to eight times greater than the level recommended for burning under normal prescribed conditions in the jarrah forest (Burrows 1994). Fuel loads in rehabilitated areas either need to be reduced through prescription burning and/or the surrounding forest needs to be burnt regularly to buffer these areas in case of a wildfire.

Fuel loads in rehabilitated areas are heterogenous in their distribution (Table 1). Within a single pit (~10 ha), fuel loads may range from almost zero to over 60 t $ha^{-1}$ in

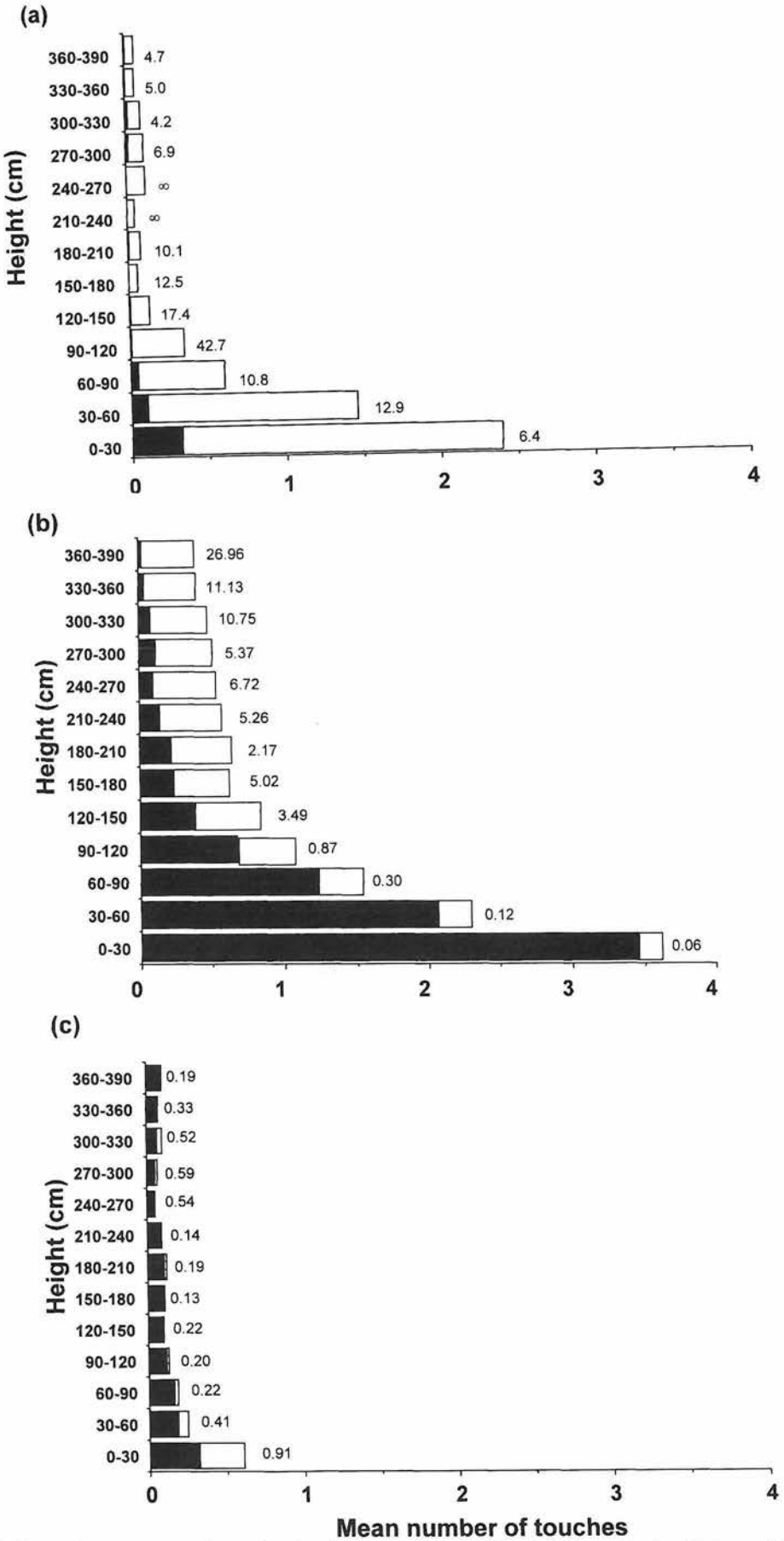


*Figure 1. Vegetation structure estimated using the levy pole method for (a) the native jarrah forest, (b) 11 to 13 year-old unburnt rehabilitation sites and (c) rehabilitation sites one year after a prescribed burn. Solid bars represent dead plant material and open hatched bars represent alive plant material. Numbers on bars are proportions of live to dead plant material.*

TABLE 1
Selected variables for six prescription burns carried out in 1994/95.

| YEAR OF REHABILITATION<br>SEASON | 1981<br>AUTUMN | 1982<br>AUTUMN | 1981<br>SPRING | 1982<br>SPRING | 1983<br>SPRING | 1981<br>SPRING |
|---|---|---|---|---|---|---|
| DATE OF BURN | 18/05/94 | 17/05/94 | 19/09/94 | 10/11/94 | 7/10/94 | 6/11/95 |
| SITE | Jarrahdale | Jarrahdale | Jarrahdale | Jarrahdale | Jarrahdale | Huntly |
| PRE-BURN FUEL LOAD (t ha$^{-1}$) : Range | 23.5-49.3 | 15.4-36.8 | 6.3-46.1 | 18.2-35.4 | 19.6-32.5 | 12.2-39.5 |
| : Mean | 34.7 | 28.5 | 23.4 | 26.1 | 25.1 | 27.35 |
| POST-BURN FUEL LOAD 1 YEAR (t ha$^{-1}$) | 6.4 | 9.5 | 7.9 | 7.5 | 8.0 | NA |
| LITTER DEPTH (cm) | 3.21 | 2.65 | 2.17 | 2.07 | 2.61 | 3.94 |
| SOIL MOISTURE (%): 0-5 cm | NA | NA | 13.3 | 6.2 | 17.3 | 10.4 |
| : 5-10 cm | NA | NA | 10.6 | 5.6 | 12.8 | 11.2 |
| LITTER MOISTURE (%): 0-5 cm | NA | NA | 16.28 | 15.63 | 18.03 | 8.66 |
| : Whole | NA | NA | 19.17 | 15.95 | 70.58 | 22.5 |
| LITTER REMAINING (%) | 12.9 | 9.9 | 46.5 | 24.7 | 53.2 | NA |
| FLAME HEIGHT (m) | 2.0-20.0 | 10.0-20.0 | NA | NA | NA | 0.5-10 |
| FIRE INTENSITY (kW m$^{-1}$)$^{a}$ : Range | 3050-20300 | 270-14700 | 720-2080 | 1044-1566 | 188-1255 | 320-3950 |
| : Mean | 8070 | 5734 | 1312 | 1248 | 376 | 1820 |
| WIND SPEED (km h$^{-1}$) | 0.0-30.0 | 0.0-5.0 | 20.0-38.0 | 0.0-6.0 | 8.0-30.0 | 2.0-10.0 |
| SOIL DRYNESS INDEX | 1962 | 1960 | 442 | 1119 | 506 | |
| TEMPERATURE AT LIGHTING (°C) | 21 | 18 | 16 | 17 | 16 | 24 |
| RELATIVE HUMIDITY AT LIGHTING (%) | 45 | 53 | 35 | 58 | 38 | |
| TIME OF LIGHTING | 4 pm | 4 pm | 2 pm | 8 am | 2 pm | 4 pm |
| RATE OF SPREAD (m h$^{-1}$) | 200-900 | 35-800 | 60-200 | 80-120 | 15-100 | 24-200 |

$^{a}$ Fire intensity is based on fuel load, rate of spread and energy release from the burning of material (Byram 1959).
NA = Not Available.

a very small area. Collins (1996) also found fuel loads in rehabilitated bauxite mines were large and highly variable. In one 15-year-old pit, for example, the fuels ranged from 20 to 120 t ha$^{-1}$. Ground litter fuel is not always continuous in these areas as fuel tends to accumulate in the bottoms of riplines. This results in some areas not being burnt. These unburnt areas are valuable in terms of recruitment of flora and fauna.

In areas where an understorey has been seeded, a large proportion of the available fuel load is present as standing trash. In fact, this layer constitutes on average 45 per cent of the total fuel load (n = 50, range 0 - 90.5 per cent). By contrast, the majority of the native jarrah forest fuel load is leaf and twig material lying on the ground (Burrows1994). The prominent trash layer in rehabilitated sites has the potential to carry a fire into the crown regardless of the moisture conditions present in the litter layer.

Collecting entire fuel loads over areas of 1 m$^2$ in order to establish relationships between litter weight (t ha$^{-1}$) and depth (mm) is extremely time consuming. Such relationships have been established in other forest systems (Sneeuwjagt and Peet 1985). This was first attempted for rehabilitated areas by Smith (1990) in an area that had not been seeded with a legume understorey and contained non-native overstorey species such as *E. globulus* and *E. microcorys* (Fig. 2).

For rehabilitation that has been seeded with a dense legume understorey and has a mixed canopy species composition, a relationship has been established between litter depth and litter weight:

Litter weight (t ha$^{-1}$) = 4.143 + 0.399 (litter depth mm)
($r^2$=0.27, F=8.7, p=0.01)

The litter fuels in these areas consist of eucalypt leaf and twig material as well as *Acacia* leaf, twig and fruit material. Comparison of litter depth to weight relationships in karri, jarrah and wandoo fuel areas (Fig. 2) show that the fuel composition of these rehabilitated areas has led to a different relationship between litter depth and weight. Rehabilitated areas tend to have higher fuel loads at shallow litter depths but fuel loads comparable to karri or jarrah in areas with a deeper litter profile.

Collins (1996) found strong relationships between easily measured fuel characteristics and total fuel weights (Fig. 3). This is important because it allows fuel loads to be measured quickly and easily without the need for intensive sampling, drying and weighing procedures. In rehabilitation that was 13 years old or more the total fuel load was best predicted by the equation:

Total fuel (t ha$^{-1}$) = 1.07 (litter depth) + 8.83
$r^2$ = 0.81

where litter depth is measured in millimetres.
Where the areas were less than 13 years old the best predictor was;

Total fuel (t ha$^{-1}$) = 2.09 (age) + 0.56 (litter depth) - 0.60
$r^2$ = 0.92

where age is years since rehabilitation and litter depth is measured in millimetres.

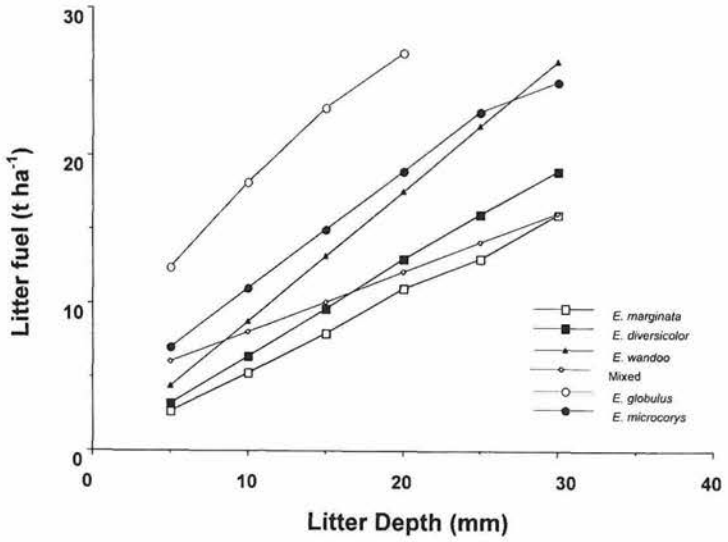


*Figure 2. Litter fuel loads associated with litter fuel depths across a range of overstorey components.*

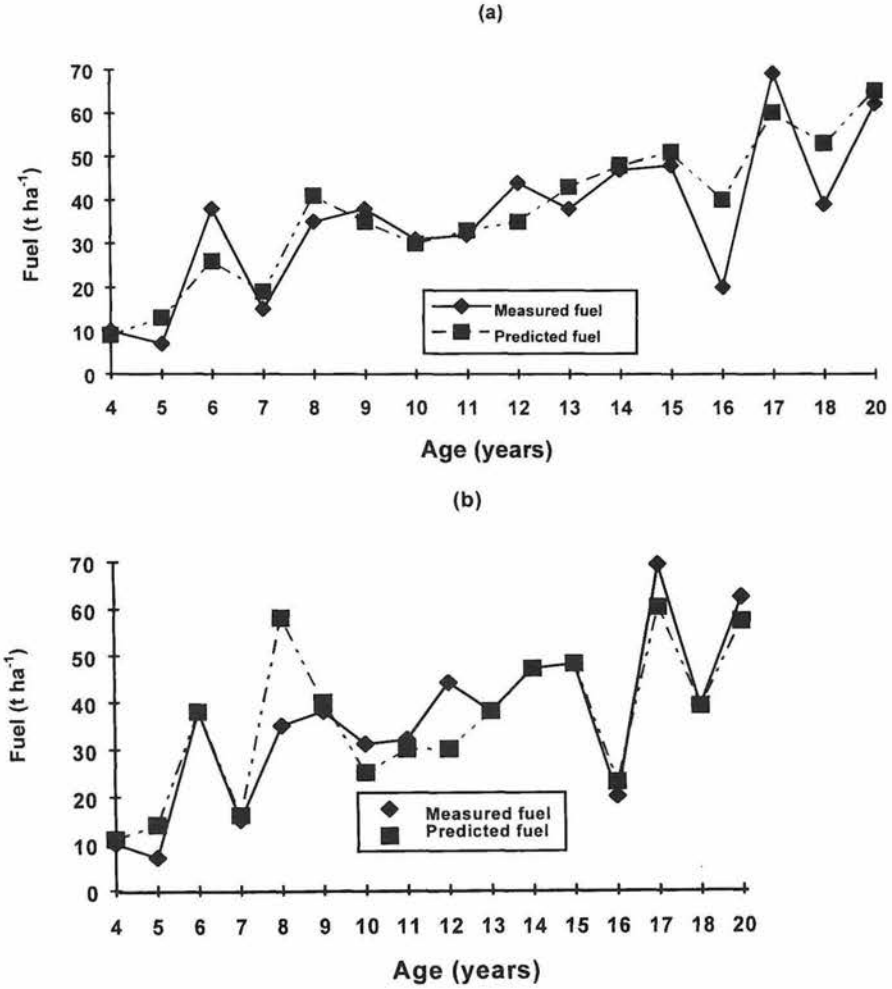


*Figure 3. Predicted and actual total fuel loads. (a) Best model for rehabilitation younger than 13 years. Total fuel (t ha$^{-1}$) = 2.09 age (years) +0.56 litter depth (mm) - 0.60 $r^2$ = 0.92 (b) Best model for rehabilitation 13 years or older. Total fuel (t ha$^{-1}$) = 1.07 litter depth (mm) + 8.83 $r^2$ = 0.81. From Collins (1996).*

Reaccumulation patterns of fuel loads are currently being studied following burning in rehabilitated areas. Fuel levels of between 5 and 10 t $ha^{-1}$ are being obtained one year after prescription burning (Table 1). As these levels are already approaching those recommended as maxima for fire management for the native jarrah forest (8 t $ha^{-1}$) it appears that proportions of live to dead plant material and vegetation structure will be the major determinants of successive fires rather than fuel loads *per se*. However, continuing research into this area will provide more insight as the vegetation develops following burning.

## FIRE BEHAVIOUR AND INFLUENCING FACTORS

### Season

Burning in different seasons can have important effects on fire behaviour and vegetation response. Burning in summer is not practical owing to the extreme fire danger that occurs at this time of the year and imposed legislative constraints. Burning in winter is usually not possible because the fuel is too wet. A comparison of season of burning therefore involves autumn versus spring burning. Autumn burns tend to be of higher intensity owing to the drier nature of the fuel after summer where more fuel is likely to be consumed in the flaming zone. By contrast, spring burns tend to be of lower intensity owing to the high moisture contents of fuels after winter rains.

Five prescription burns encompassing a range of intensities and seasons were carried out in 1994 (Appendix 1, Table 1). The two autumn burns undertaken with dry soil conditions were moderate to very high intensity burns while the burns carried out at different times in spring tended to be low to moderate intensity burns. The Soil Dryness Index (SDI - Burrows 1987) in the spring burns ranged from 442 to 1119 while in the autumn burns the values were approximately 1960. Dry conditions in autumn increase the available fuel load and therefore lead to burns of higher intensity. The lighting technique was similar in four of the five burns with lines of fires being run through the pit at 50 to 100 m spacing with junction zones occurring on a falling hazard. An autumn burn in the 1981 rehabilitation area was established in the center of the pit and the perimeter was then lit. The centre fire drew the perimeter fire towards the middle of the pit leading to extreme fire behaviour when the two lines of fire met.

### Weather

Weather conditions, such as wind speed, ambient temperature, relative humidity and moisture conditions present at the time of burning can drastically affect fire behaviour. Burrows (1994) identified the two most important factors influencing the rate of spread of fires in the jarrah forest as wind speed and fuel moisture content. Recording soil and litter moistures before three spring burns undertaken in rehabilitation in 1994 (Table 1) showed that soil moisture did not have a direct relationship to fire intensity. However, soil moisture influenced fire behaviour in the litter layer with percentage soil moisture being positively correlated with percentage remaining litter ($r^2$=0.57, F=17.3, p=0.001). The different vegetation structure of the rehabilitation with a prominent mid-storey layer affected fire behaviour in a more profound way than the normally important influencing factors of soil and litter moisture. Burning under high soil moisture conditions will not guarantee a low intensity fire in rehabilitated areas.

Ward *et al.* (1991) attributed a difference in fire behaviour between rehabilitation areas burnt at Jarrahdale and Huntly to a difference in wind speed recorded during the fires. The Huntly fire intensity was estimated at between 600 and 1200 kW $m^{-1}$ with a wind speed of 9 to 16 km $h^{-1}$, while fire intensity at the Jarrahdale site ranged from 30 to 283 kW $m^{-1}$ with no wind. This difference in intensity occurred even though the Jarrahdale site had higher fuel loads and lower surface moisture contents (SMC) than the Huntly burn. Smith (1990) indicated that burning in rehabilitated areas with their associated heavy fuel loadings could be successfully undertaken if burning occurred under specific atmospheric conditions. These were calm winds, clear sky and a falling fire hazard (rising humidity and falling temperature). SMC needs to be low enough to sustain fire without being wind driven and fire spots need to be spaced far enough apart so that junction zones of the fires occur late in the day when there is a drop in temperature and rise in humidity.

## EFFECTS OF BURNING ON SOILS

The influence of fires on forest nutrition, in particular the effects on forest soils in Australia, has been the subject of a number of reviews (O'Connell *et al.* 1979; Humphreys and Craig 1981). The intensity, frequency and season of burning, as well as soil and vegetation characteristics, influence the nature and extent of changes in soil chemical properties (Grove *et al.* 1986). Only one major study examining the effect of burning on forest nutrient status has been carried out in rehabilitation areas. Ward *et al.* (1991) examined the effect of two prescribed burns on the nitrogen and phosphorus pools in the soil, litter and understorey at two different sites rehabilitated in the late 1970s. In total, 206 kg $ha^{-1}$ of nitrogen (or 46 per cent of the total before the fire) was lost from the understorey, litter and topsoil (0-5 cm) at the Huntly site following a moderate intensity prescribed burn. At the Jarrahdale site, which contained higher fuel loads and a greater proportion of live plant material, 242 kg $ha^{-1}$ of nitrogen was lost but this represented only 23 per cent of the total nitrogen in the understorey, litter and topsoil at this site. There was no evidence of any loss of phosphorus from either site. The loss of 20 to 50 per cent of the nitrogen from a rehabilitated area could have a significant effect on the growth of trees as nitrogen is the nutrient primarily limiting growth of trees in the jarrah forest (Abbott and Loneragan 1986).

While some nitrogen was lost from the sites, the fire did have some beneficial effects on the cycling and availability of plant nutrients. Available nitrogen, in the form of ammonium ions, increased in the topsoil after the fire and the phosphorus increased in the top 0-2 cm of the soil layer. The concentrations of nitrogen and phosphorus in the litter at both sites were significantly greater after the fire. This should result in a more rapid mineralization of the litter and hence an increased availability of nutrients for uptake by plant roots. In addition, some of the nutrients contained within the standing dead understorey, which are not readily available to be cycled through the system, were redistributed to the soil and litter during the fire, thus becoming more available for cycling and plant uptake (Ward *et al.* 1991). Burning rehabilitation sites stimulated the establishment of nitrogen-fixing legumes (Fig. 4), particularly following autumn fires. These species are capable of re-establishing the pre-fire nitrogen levels. The critical issue therefore appears to be the time interval between burning and the restoration of pre-fire nitrogen levels by legumes. Further research into this aspect of soil nutrition following prescription burning in rehabilitated areas is required.

## VEGETATION RESPONSE

### Trees

Rehabilitation sites seeded with an understorey were also planted with a range of native and non-native eucalypt species in variable proportions. The canopy composition is more variable than in the native jarrah forest with 14 overstorey species recorded in three rehabilitation pits (rehabilitated between 1981 and 1983). Different overstorey species can vary in their tolerance to fire and their seedling recruitment levels following burning. Pre-burn assessment of tree species in five prescription burns carried out in 1994 entailed measurement of bark thickness, diameter at breast height over bark (d.b.h.o.b.) and health of all tree species encountered in five 20 x 20 m plots situated randomly within a pit.

A number of authors have recognized the importance of bark thickness in tree survival following burning (McArthur 1968; Vines 1968; Gill 1980; McCaw *et al.* 1994). A bark thickness of 12.5 mm at breast height is often quoted as the minimum thickness of bark required to survive a moderate intensity burn (Vines 1968). Of 734 trees measured in 11- to 13-year-old rehabilitation, only 13.5 per cent of the trees had a bark thickness of <12.5 mm. The mean d.b.h.o.b. of the tree species in the rehabilitated areas was 16.8 ± 0.3 cm with an average bark thickness of 22.0 ± 0.2 mm and a height of 10.2 ± 0.2 m.

Examination of the effect of five prescription burns of variable season and intensity on 578 trees (14 species) showed that only 3 per cent of the trees were killed across these burns. A further 15 per cent that resprouted basally (below 2 m in height) may be regarded as a partial loss of tree growth. Trees that resprouted from the base or were killed by the burns tended to have thinner bark, smaller diameter and lower height than aerially resprouting trees (Grant *et al.* 1997). Considering that fire intensity in the majority of these burns was high to very high, the overstorey species have shown a remarkable resilience to fire. The extremely low tree mortality recorded can be partly explained by the lack of large fuel components (e.g. fallen logs) in rehabilitation areas that can burn for long periods and lead to tree mortality or fire scar formation. Tree mortality in rehabilitation burns of even high intensity should therefore be relatively low.

Smooth-barked eucalypt species are usually more fire sensitive than rough-barked species owing to differences in the structure and thickness of the bark layer (McArthur 1968). In rehabilitated areas, smooth-barked species showed a 60 per cent greater mortality and number of

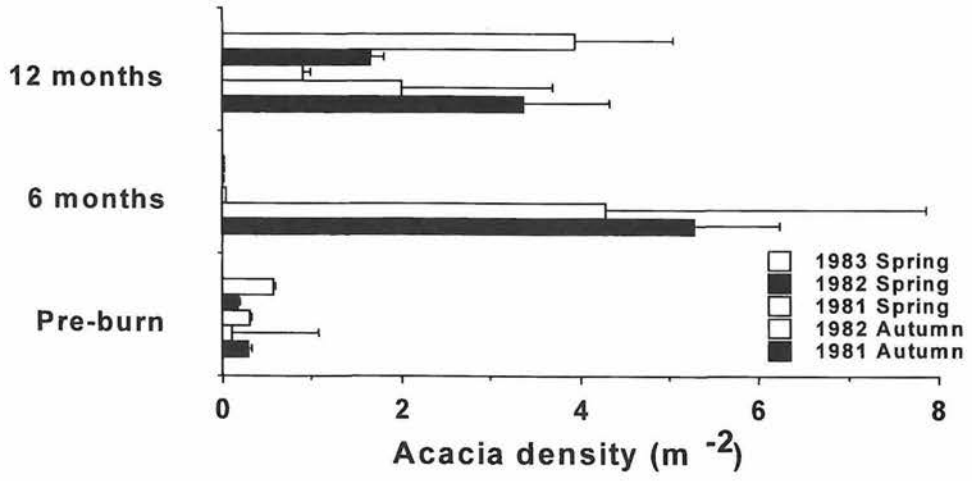


*Figure 4. Acacia density ($m^2$) pre-burn, six months and one year after five prescription burns carried out in 1994 with variable intensities and seasons of burn.*

basal resprouts than rough-barked species (Grant *et al.* 1997). Fire management of rehabilitated areas must involve consideration of bark type of the dominant overstorey: lower fire intensities should be used in areas dominated by smooth-barked species. Trees burnt in the higher intensity autumn burns had 40 per cent higher levels of mortality and exhibited 80 per cent higher levels of basal resprouting than those in spring burn areas. In terms of the effect of fire on the tree species in rehabilitated areas, spring burns appear to be preferable, leading to lower tree mortality and a more rapid and vigorous resprouting response (Grant *et al.* 1997).

## Understorey

An important difference between burns in spring and autumn is the delay between the burn and the winter rains which allow seed germination. Germination is often almost immediate after an autumn burn with the onset of winter rains while seeds in spring burn areas often have to wait until the following winter (~6 months) before they receive adequate water for germination. If plants germinate following spring burns, they may not be sufficiently mature to survive the long summer drought and, therefore, valuable seed resources may be wasted. Burning in autumn tends to favour seeding species (i.e. those species that are killed by fire and rely on seed reserves to invade the post-fire habitat) while burning in spring tends to favour resprouting species (i.e. those species that are not killed by fire and have dormant buds that resprout following burning) as summer is their normal growing season.

Assessment of the understorey response to burning in rehabilitation areas was undertaken following five prescription burns carried out in 1994. These burns encompassed a range of fire intensities and seasons of burning (Table 1). The vegetation response was assessed periodically following the burns. Burning rehabilitation areas caused an increase in plant density one year after the fires (Fig. 5). Pre-burn densities of 2 to 6 plants per square metre increased to 15 to 53 plants per square metre one year after burning.

Seedling establishment was greater following autumn than spring burns. In areas burnt in spring, there is a six-month delay before sufficient water becomes available for germination while germination is almost immediate following autumn burns. Very few plants were recorded in the spring burn areas six months after the fire (Fig. 5) as germination had not commenced. Loss of viability, seed predation and fungal attack of seeds can occur over summer following spring burns. This is the most probable explanation for lower plant establishment following spring compared with autumn burns.

Even though plant densities following spring burns are lower than those following autumn burns they are still three to four times higher than pre-burn densities. Furthermore, a significant proportion of the increased plant establishment following autumn burning is owing to a large increase in the density of eastern Australian eucalypt seedlings (i.e. *E. maculata* and *E. resinifera* - Fig. 6). The high levels of crown scorch and consumption observed in the autumn burns led to a large seed fall from the bradysporous fruits of the eastern Australian eucalypts. Current research is examining reasons for the low level of recruitment of eastern states eucalypt seedlings following spring burns and it appears that predation by ants is the major factor leading to seed loss.

All five burns were successful in stimulating the establishment of at least one *Acacia* per square metre (Fig. 4), which is an establishment criterion for new rehabilitation areas. Legume species are important nitrogen-fixers in the post-fire environment and assist in returning the nutrient status of burnt rehabilitation areas to pre-burn levels. The higher initial densities of *Acacia* spp. following autumn than those following spring burning may be owing to greater penetration of heat during autumn burns leading to greater stimulation of hard-seeded species such as *Acacia*.

One year after burning, weed densities were similar across all burns (Fig. 7) indicating that fire intensity and season had little effect on the flush of weed species often seen in recently-burnt areas. The majority of weed species in rehabilitated areas are wind-dispersed daisies (Asteraceae) including *Conyza* spp., *Senecio* spp., *Sonchus* spp. and *Hypochaeris glabra* (flatweed). Although weed densities were higher in burnt areas than in areas that were not burnt, it is expected that weed densities will decrease with time in burnt areas as the vegetation matures and begins to out-compete annual weed species.

Unlike the native jarrah forest, unburnt rehabilitated areas are dominated by seeding species rather than resprouting species (Fig. 8). This has a large impact on the recovery of the system following a disturbance such as fire. In the native forest which is dominated by resprouting species, very few individuals are killed by fire thus resulting in relatively little change in species composition. In rehabilitation, on the other hand, seeding species are killed by fire and this opens up a gap for reinvasion. Species composition of rehabilitation following a burn may be very different from that before a burn depending on which species invade and successfully establish at a site. For example, burning rehabilitation in autumn at high intensity has led to the proliferation of eastern Australian eucalypt species which are dominating in some areas and out-competing most other species. This is also associated with a shift in fire response strategy in the post-fire environment compared with that of the pre-fire area (Fig. 8). The large increase in resprouters seen in areas burnt in autumn is owing to the proliferation of non-native eucalypt seedlings.

At this stage, it would appear that burning in spring is preferable to burning in autumn in terms of the understorey response as the spring burns did not lead to a proliferation of eastern states eucalypts (Fig. 6) but still showed the positive aspects of burning such as increased plant establishment (Fig. 5). It is often not practical to prescribe a large number of burns in autumn as the available 'window' for burning is often small (i.e. one to two weeks), whereas in spring there are usually two to three months where prescription burning is possible.

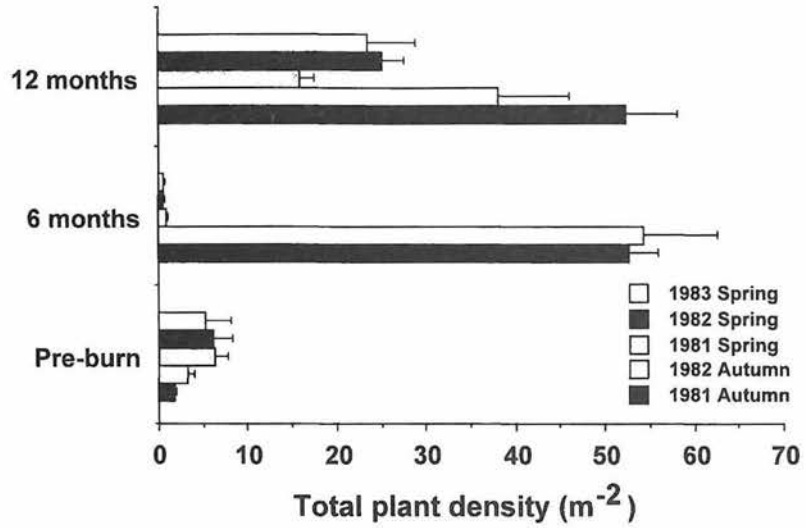


*Figure 5. Total plant density ($m^{-2}$) pre-burn, six months and one year after five prescription burns carried out in 1994 with variable intensities and seasons of burn.*

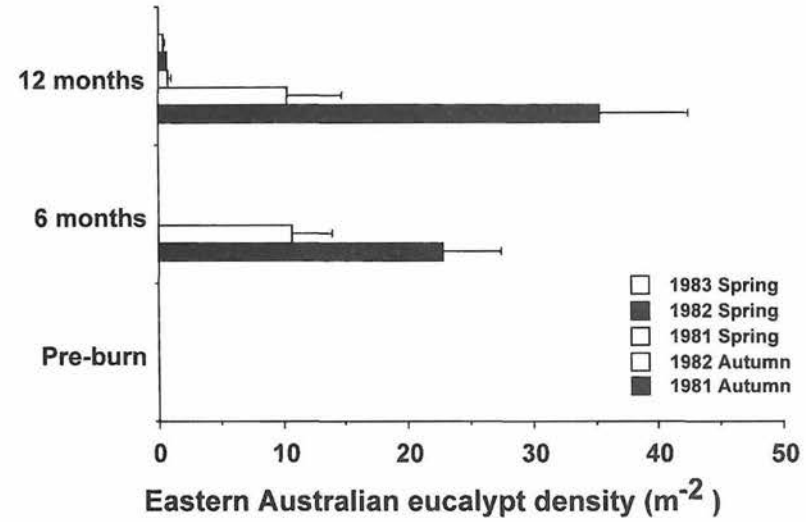


*Figure 6. Eastern states eucalypt density ($m^{-2}$) pre-burn, six months and one year after five prescription burns carried out in 1994 with variable intensities and seasons of burn.*

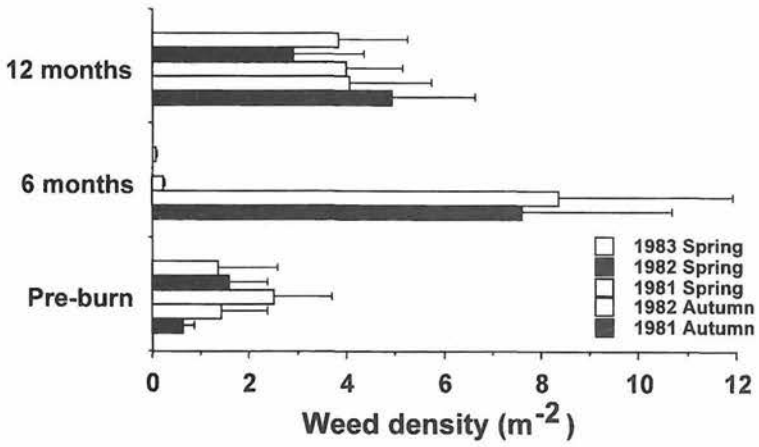


*Figure 7. Weed density ($m^{-2}$) pre-burn, six months and one year after five prescription burns carried out in 1994 with variable intensities and seasons of burn.*

## FAUNA RESPONSE

The response of the fauna to prescription burning in rehabilitated areas has not yet been investigated and is in need of research. During the experimental burns, a number of mammals such as kangaroos, bandicoots and wild pigs were seen escaping. Birds and flying insects can escape through flight while burrowing animals such as lizards, snakes and ants are insulated from the heat of the fire by soil. Of greatest concern are the soil and litter-borne invertebrates and fungi that are so important in nutrient cycling. Although no work has been attempted on these groups in rehabilitation, studies in the native jarrah forest indicate that generally fire has either a small or short-term effect on them. For example, Abbott (1984) found that earthworms, spiders, slaters, termites, earwigs, crickets, beetles, millipedes, flies and ants occurred at significantly greater densities in burnt plots in the jarrah forest while centipedes, silverfish and cockroaches occurred at significantly lower densities in the burnt plots. It was concluded that all but three taxa recovered in density within three years of a moderate intensity fire in the jarrah forest and the relative abundance and/or activity of three other taxa remained depressed on the burnt plot during the same period. By contrast, Springett (1976) concluded that mild fires reduce the density and diversity of soil fauna. In a study on the effect of wildfire on vesicular-arbuscular mycorrhizal fungi Bellgard *et al.* (1994) concluded that although infection was reduced immediately after a burn, infection levels in burnt areas were comparable to pre-burn areas within six months of a wildfire. A comprehensive review of the effect of fire on invertebrates in Australia was recently carried out (Friend 1995) and findings from this study have application to rehabilitated systems.

Burning in rehabilitated sites is always going to occur in relatively small areas (5-15 ha) until these sites can successfully be included in a general fuel reduction program, and therefore the edge effect tends to be relatively large thus allowing mobile animals to escape. A lighting technique that allows an escape passage for animals should be used where possible rather than surrounding them by fire.

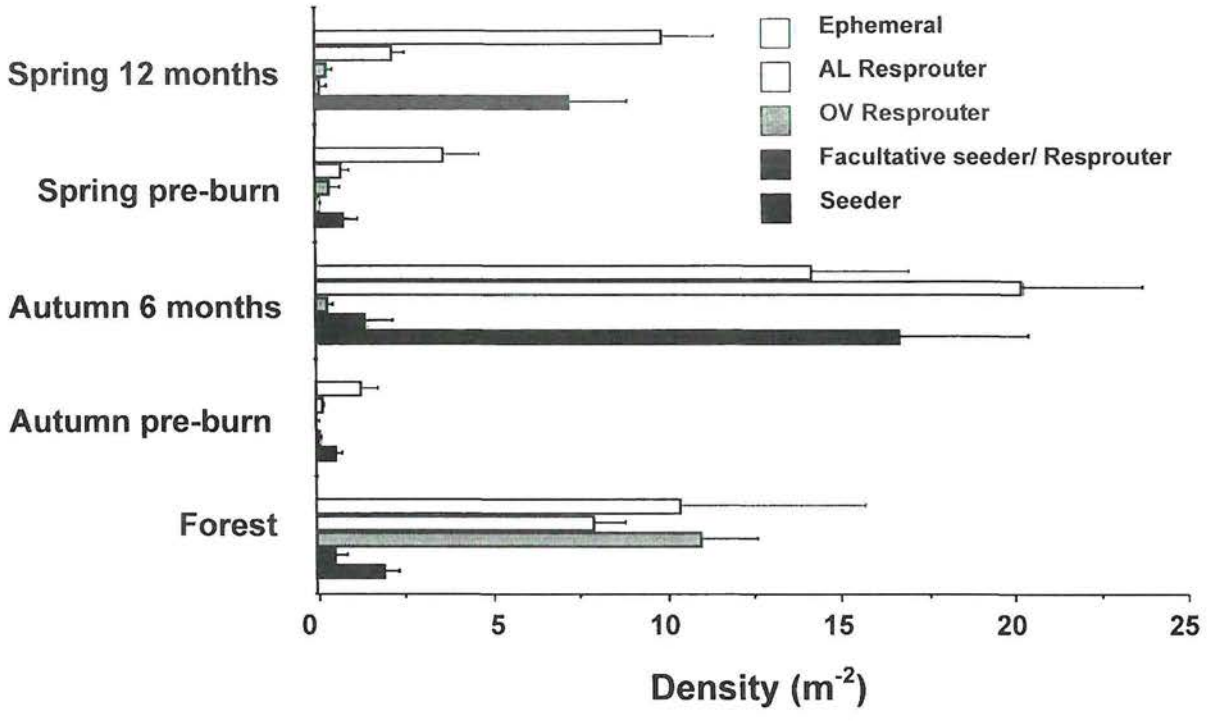


*Figure 8. Densities ($m^{-2}$) of various fire response categories in the native jarrah forest, rehabilitation sites pre-burn and rehabilitation sites one year after being burnt in autumn and spring. Fire response categories are taken from Bell* et al. *1984. OV resprouters are obligate vegetatively-reprouducing resprouters that exhibit very little or no seedling recruitment after fire and AL resprouters are autoregenerating long-lived resprouters that exhibit relatively high levels of seedling recruitment following fire.*

## SITE MANIPULATIONS

It would be desirable to establish jarrah as the overstorey dominant in rehabilitated areas that were originally planted with non-native eucalypt species. Burning in autumn has led to proliferation of eastern Australian eucalypt species (Fig. 6) which makes the task of establishing jarrah as the overstorey dominant more difficult. It is possible to reduce fuel loads and establish jarrah as the overstorey dominant in a single manipulation. A current experiment is investigating the possibility of killing the eastern Australian eucalypt overstorey (through ring-barking or tree notching) leading to seed fall, followed by burning of the area to reduce fuel loads and kill the seed of the eastern Australian eucalypts. Following the burn, these sites will be seeded with jarrah and an understorey mix to increase species richness. Seeding of understorey species has been shown to significantly increase understorey species richness (Fig. 9).

Jarrah establishment rates have been good under an existing canopy although it is unlikely that these seedlings will develop into saplings until competition for water from the existing canopy is removed (Stoneman *et al.* 1994). A number of studies have reported improved seedling establishment following soil scarification (Olsen and Vickery 1989; Koch 1992). In a recent study involving combinations of burning or not burning and soil scarification or not, scarification did not increase jarrah density in burnt or unburnt areas but there was a significant increase in jarrah density following autumn but not spring burning (Fig. 10).

The decreased plant establishment in spring burn areas appears to be related to the seeds remaining dormant in the soil for six months following burning. It appears that burning rehabilitated areas followed by seeding is the most effective treatment to increase understorey richness and establish jarrah as the potential overstorey dominant.

## FURTHER RESEARCH

In the jarrah forest, determining whether a site should be burnt or not is dependent primarily on fuel loads. In all but very young rehabilitation, fuel loads tend to be well above those recommended for the native jarrah forest owing to the high density of legume species at these sites. Further research needs to be carried out to determine the accumulation pattern of fuels in areas rehabilitated after 1988. The response of fauna to burning rehabilitated mine sites and the effect of prescribed burns on soil nutrient levels are areas in need of further research. Current research is concentrating on formulating a one-step manipulation of old rehabilitation sites that will reduce fuel loads and establish jarrah as the overstorey dominant and increase understorey diversity.

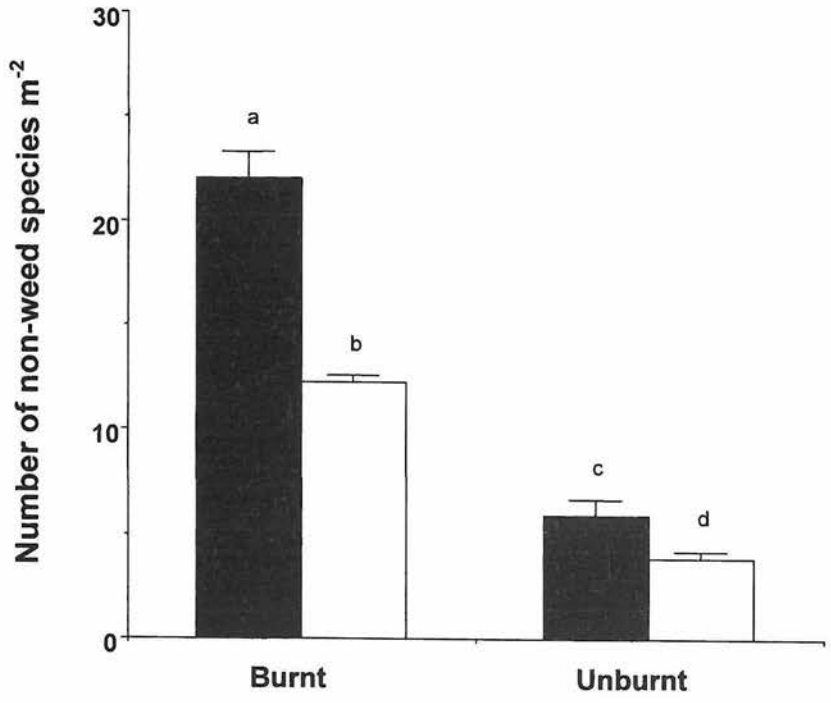


*Figure 9. Number of non-weed species recorded in 2 m x 2 m plots over four treatments (burnt/seeded, burnt/unseeded, unburnt/seeded and unburnt/unseeded) one year after an autumn burn. Solid bars represent seeded treatments and open hatched bars are unseeded treatments. Different letters represent a significant difference ($p<0.05$) using ANOVA. Bars are means ± SE.*

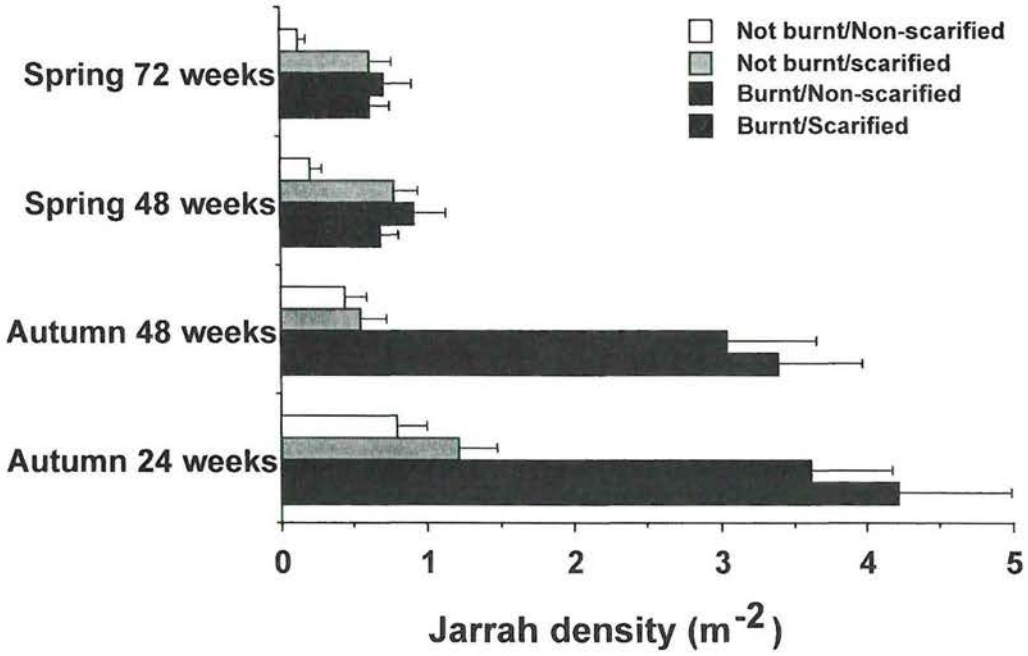


*Figure 10. Jarrah density ($m^{-2}$) 24 and 48 weeks after autumn burning and 48 and 72 weeks after spring burning across four treatments. This represents the best ecological comparison of jarrah density across the two seasons of burning. Bars are means ± SE.*

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APPENDIX 1
Selected features of the 14 recorded burns carried out in rehabilitated areas.

| REHAB. YEAR | DOMINANT OVERSTOREY | YEAR OF BURN | FUEL LOAD (t $ha^{-1}$) | FIRE INTENSITY (kW $m^{-1}$) | AGE AT BURN | MINESITE | SEASON | SIZE (ha) |
|---|---|---|---|---|---|---|---|---|
| 1971 | E. microcorys | 1986 | 13.57 | 50-100 | 15 | Jarrahdale | Spring | 1 |
| 1979 | E. resinifera, E. maculata E. saligna | 1989 | 61.75 | 30-283 | 10 | Jarrahdale | Spring | |
| 1971/1979 | E. agglomerata,E. calophylla, E. wandoo, E. laeliae | 1988 | | | 11,17 | Jarrahdale | Spring | 8 |
| 1977 | E. laeliae | 1987 | 42.95 | 600-1200 | 10 | Huntly | Spring | |
| 1982 | E. wandoo | 1994 | 16 | 1000-1600 | 12 | Jarrahdale | Spring | 9 |
| 1982 | E. maculata, E. resinifera, E. saligna | 1994 | | | 12 | Jarrahdale | Summer | 1 |
| 1981 | E. maculata, E. resinifera, E. wandoo | 1994 | 34.7 | 3050-20300 | 13 | Jarrahdale | Autumn | 10 |
| 1982 | E. maculata, E. resinifera, E. wandoo | 1994 | 28.5 | 270-14700 | 12 | Jarrahdale | Autumn | 10 |
| 1981 | E. maculata, E. resinifera, E. wandoo | 1994 | 23.4 | 720-2080 | 13 | Jarrahdale | Spring | 10 |
| 1982 | E. maculata, E. resinifera, E. wandoo | 1994 | 26.1 | 1044-1566 | 12 | Jarrahdale | Spring | 15 |
| 1983 | E. maculata, E. resinifera, E. wandoo | 1994 | 25.1 | 188-1255 | 11 | Jarrahdale | Spring | 15 |
| 1981 | E. maculata, E. resinifera, E. wandoo | 1995 | 27.35 | 320 -3240 | 13 | Huntly | Spring | 6 |
| 1981 | E. maculata, E. resinifera, E. wandoo | 1996 | 35.73 | 390-2106 | 13 | Huntly | Autumn | 8 |
| 1977 | E. laeliae, E. wandoo | 1985 | | | 8 | Jarrahdale | Autumn | 6 |

APPENDIX 2
Practitioners Guide to Rehabilitation Burns.

## Objectives and Planning

Prior to any burning taking place in rehabilitated areas, it is essential that the risks be assessed and compared with the potential gains. The risks that should be considered include: the potential threat the rehabilitation poses to the strategic fire buffer system, the values at risk both to the rehabilitation directly from the burning and the rehabilitation ecosystem and the forest values adjacent to or near the rehabilitation. If the potential gains do not outweigh the environmental costs then burning should not be undertaken.

During the planning phase, it is essential to determine the objective of the burn. Once the objective is defined, it is possible to analyse the benefits and costs associated with the burn. Other issues in need of consideration include the level of fuel reduction required, the target fuel strata (i.e. litter, standing fuel and/or overstorey), understorey and overstorey management and the impact burning will have on the overstorey seed in the topsoil or in the crown. These issues will determine the composition of the forest remaining after burning and prediction of this outcome prior to burning will assist in longer-term management. These assessments should occur before the development of a prescription because it may identify alternative objectives or strategies. Once it is determined that the burn will proceed, it is necessary to:

(1) develop a prescription using the standard CALM format that relates directly to the burn objectives and ensures all standard operating procedures are met. This prescription must identify the acceptable level of fuel reduction (>75 per cent) and the required proportion of the area that should be burnt (>75 per cent).
(2) incorporate the rehabilitation objectives into the development of a prescription. Burning of rehabilitated areas can lead to a change in vegetation structure from a three-tiered profile (i.e. litter, trash and overstorey) to a two-tiered profile (litter/small scrub and overstorey). Burning rehabilitated systems will also change the nutrient cycle of the system and it is essential that the impact be considered prior to ignition. Season of burning will be an important decision inthis process as this has enormous effects on the post-burn vegetation.

## Pre-burn Assessment

During the fuel sampling phase, the following information should be collected.

(1) In burn areas of less than 10 ha, three fuel sampling transects should be randomly allocated. In burn areas of 10 to 30 ha one transect should be allocated randomly to each 3 ha of burn area. Where the burn area is larger than 30 ha, ten transects should be allocated randomly to the burn area.
(2) At 10 m intervals along the 100 m transect measure litter depth, estimate scrub height, density and percentage dead foliage. This information should be recorded on CALM Fuel Assessment Record sheets.
(3) Using the mean litter depth, calculate the total fuel loads for each transect using the following equations (from Collins 1996).

In rehabilitation that is 13 years old or more

Total fuel (t $ha^{-1}$) = 1.07 litter depth (mm) + 8.83

In rehabilitation that is less than 13 years old

Total fuel (t $ha^{-1}$) = 2.09 age (years) + 0.56 litter depth (mm) - 0.60

Fuel loads can also be calculated using the Forest Fire Behaviour Tables for Western Australia (Sneeuwjagt and Peet 1985) which is commonly called 'the red book'. The relationship between total available fuel loads calculated from litter depth using the red book and the Collins equations is very strong (Fig. 11).

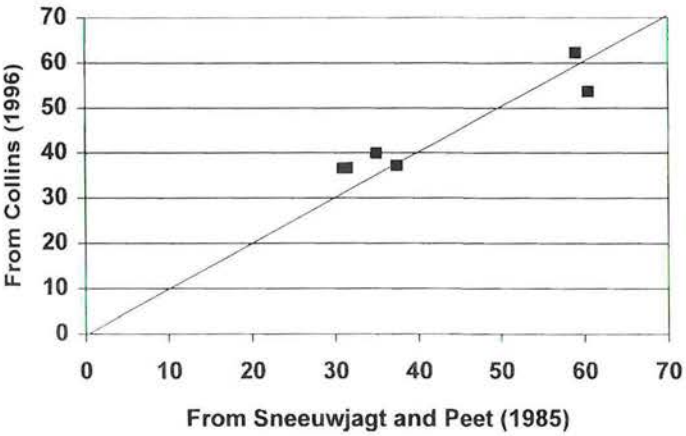


*Figure 11. Relationship between total available fuel (t $ha^{-1}$) calculated using Forest fire behaviour tables for Western Australia (Sneeuwjagt and Peet 1985) and the Collins equations in rehabilitated bauxite mines (Collins 1996).*

When using the red book to calculate fuel loads in rehabilitated areas the following procedure should be used (underlined phrases are those used in the red book):

From the average litter depth per transect, determine the total litter weight from table 7.2.1. Assume the forest type is karri dominant.

From the average scrub height per transect, determine the scrub fuel weight from table 7.4.1. Assume scrub structural type 2 and Total foliage (consumed in moderate wildfires). Dense rehabilitation understorey is classed as Medium and sparse rehabilitation understorey is classed as Sparse in table 7.4.1.

Add together total litter weight and scrub fuel weight from 1 and 2 above to give total fuel weight.

Multiply total litter weight by the available fuel factor to give the available litter weight. In most

cases the available fuel factor is 1.0. In very moist conditions the available fuel factor is 0.7. Available trash is not calculated because this fuel fraction is accounted for in the scrub fuel weight calculation.

Multiply total scrub fuel weight by the scrub flammability factor from table 7.4.2 to give available scrub fuel weight. Dense rehabilitation has a scrub flammability of HIGH while sparse rehabilitation understorey has a scrub flammability of LOW. The average percent dead foliage should also be used in this table to choose the scrub flammability factor.

Available fuel weight = available litter weight + available scrub weight.

(4) Calculate the maximum rates of spread of fire given the available fuel loads that will keep fire intensity below 1500 kW $m^{-1}$.
(5) Record the location of sampling transects on the burning plan.
(6) Measure the height, bark thickness and diameter at breast height of 10 dominant trees along the fuel sampling transects. Trees less than 10 cm dbh and with a bark thickness of <15 mm are likely to suffer bole damage at fire intensities greater than 1500 $kWm^{-1}$. If greater than 20 per cent of the dominant trees measured fall into this category then the burn should not occur. Measuring tree height will assist in determining the flame and scorch heights that will be acceptable to meet the objectives.
(7) Identify roads and tracks that will be safe exit locations.
(8) Locate water resources for fire fighting.
(9) Determine the best season for burning to occur. The majority of burns will occur in spring (unless there are specific objectives for the rehabilitation) although a variable fire regime in rehabilitated areas should be encouraged. The smaller 'window of opportunity' for burning in autumn will restrict broad-scale rehabilitation burns at this time of year.

## During the Prescription Burn

The following should be carried out just prior to and during the burn.

(1) Ensure that all of the standard operating procedures have been met prior to ignition.
(2) Determine a spot and strip width that will achieve the objective of the burn. Owing to the limited information available on burning in rehabilitated areas, it is essential to be conservative. Junction zones of spot fires should meet on a falling hazard when the humidity is rising and ambient air temperature is falling. An absence of cloud will assist in achieving a falling hazard and subsequent reduced fire intensities.
(3) Record the surface moisture content (SMC) and the pre-burn wind speed and direction. SMC should be above 7 per cent and wind speed below 20 km $h^{-1}$ for spring burns. Soil Dryness Index (SDI) should be in the range 400 - 800 for spring burns, although recording fuel moistures in the rehabilitation is more important than the SDI. Burning under these conditions may still lead to 100 per cent crown scorch in some areas but should avoid complete consumption of the canopy.
(4) Record the rate of spread (ROS) of the head and tail fire at the fuel sampling locations.
(5) Record the flame length for the head, flank and tail fire.
(6) Record the temperature, relative humidity and cloud cover and type.

Below is a summary of the ideal pre-burn conditions for burning rehabilitated areas:

| PARAMETERS | SPRING BURN | AUTUMN BURN |
|---|---|---|
| SMC (%) | 7 - 15 | 5 - 10 |
| SDI | 400 - 800 | 1000 - 1500 |
| Wind Speed (km $h^{-1}$) | 0 - 20 | 0 - 10 |
| Lighting Time | 12 - 4 pm | 2 - 6 pm |
| Humidity (%) | 40 - 60 | 30 - 50 |
| Temperature (°C) | 18 - 24 | 20 - 25 |
| ROS | 20 - 120 | 50 - 150 |
| Flame Height (m) | 1 - 4 | 1 - 10 |
| Fire Intensity (kW $m^{-1}$) | 500 - 1500 | 1500 - 2500 |

## Post-burn Assessment

Following the burn:

(1) Remeasure litter depths in the fuel sampling transects and estimate the remaining scrub fuel.
(2) Calculate the quantity of scrub and litter fuel consumed.
(3) Determine fire intensity (I) using the equation:

$$I\ (kW\ m^{-1}) = ROS\ (m\ h^{-1}) \times fuel\ consumed\ (t\ ha^{-1}) \times 0.516$$

Burrows (1994)

(4) Calculate fire intensity based on flame length (L) using the equation:

$$I\ (kW\ m^{-1}) = 293.871(L)^{1.118}$$

Burrows (1994)

and compare to fire intensity calculated using ROS.
(5) Record all of the data and retain with the prescription for the burn.

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# Avifauna of the Irwin Inlet-Broke Inlet-Mt Frankland region of south-west Western Australia, 1912-1913

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## SUMMARY

The ornithologist and oologist S.W. Jackson spent 128 days from October 1912 to February 1913 in the Irwin Inlet-Broke Inlet-Mt Frankland region of south-west Western Australia searching (unsuccessfully) for the nest and eggs of the Noisy Scrub-bird. His unpublished field diaries contain valuable information about 68 bird species observed in a period when settlement was beginning to encroach. His notes on frequency of records of bird species, as well as their nesting and habitats, have been extracted from these diaries and presented by species rather than in chronological sequence. Comparison of the land bird species present in 1912-13 and 1972-87 indicates several genuine (not pseudoturnover) changes: two species (*Pezoporus wallicus, Hirundo ariel)* presumed extinct and 16 species that have colonized, following extensive agricultural development of the region since the 1920s.

Brief notes on other fauna and Aboriginal names of species recorded by Jackson are included.

## INTRODUCTION

In 1912 the prominent grazier and egg collector H.L. White sent the curator of his collection, Sidney William Jackson, to Western Australia to collect the nest and eggs of *Atrichornis clamosus*, the Noisy Scrub-bird (Campbell 1928). This species had last been collected in 1889, but its nest and eggs were still unknown to science. In 1898 Jackson had discovered the nest and eggs of the other species of scrub-bird, *A. rufescens*, and so was an obvious candidate to remedy this deficiency in White's almost complete collection of the eggs of Australian bird species. Jackson was also an experienced bushman. One WA collector, F.B.L. Whitlock, resided at Tudor Siding near Wilson Inlet and from 1908 was employed by White to collect (Whittell 1954). Evidently he had been unable to locate the Noisy Scrub-bird.

Jackson's diaries are of supreme importance in documenting with unusual thoroughness the composition of the avifauna of a near-pristine forested part of Australia. These diaries provide a fundamental reference point with which to compare the avifauna at later times, when settlement resulted in clearing of parts of the forest for agriculture, utilization of natural resources such as timber, and other human-mediated impacts (the arrival of exotic animal species).

Although the diaries were perused by noted ornithologist H.M. Whittell in the early 1950s, he was content to publish excerpts affording 'interesting information' about nine species: *Dromaius novaehollandiae, Sterna bergii, Pezoporus wallicus, Hirundo ariel, Eopsaltria georgiana, Falcunculus frontatus, Psophodes nigrogularis, Pomastomus superciliosus,* and *Strepera versicolor* (Whittell 1952).

The aims of this paper are to collate all of Jackson's records (68 species) and make this information more readily accessible. Background information on the habitats present and examined by Jackson is also given.

## THE DIARIES

Jackson left Sydney on 28 September 1912 by steamer for Albany *via* Melbourne and Adelaide. At Melbourne he visited A.J. Campbell who had collected the Noisy Scrub-bird in 1889 at Torbay (Jackson also visited him on his return, on 8 March 1913). Presumably the habitat and habits of this species were discussed. On 9 October Jackson arrived at Albany, and spent part of the day and all of the next with Whitlock, who assisted him in obtaining provisions and transport to Bow River. Whitlock was to have accompanied Jackson but was unable to do so. On 11 October both men travelled by train to Denmark, where about 250 people lived. October 12 was spent walking west, with stops at Nowhumbup Creek (?near Parry Inlet) and Kent River. The next morning Jackson reached H.T. Saw's farm on the Bow River and proceeded to set up camp in jarrah (*Eucalyptus marginata*) forest beside the river.

Jackson commenced his ornithological observations on 14 October, recording these in six diaries, two of which

are now missing [these covered the period from 18 November to 7 December]. Initially the weather tended to be cool, wet and windy, but by December it was warm with only occasional rain. Jackson departed from Bow River on 19 February.

## HABITATS VISITED

According to Churchward *et al.* (1988) there are 13 broad landform/soil units present in the Irwin Inlet-Broke Inlet-Mt Frankland region. The daily intineraries described (often vaguely) in Jackson's diaries have been mapped in Figure 1; these indicate that Jackson worked extensively in about 7 of these units. In order of decreasing ubiquity the main units are as follows:

1. Marri (*Corymbia calophylla*) - karri (*Eucalyptus diversicolor*) - tingle (*E. guilfoylei/E. jacksoni*) forest. Jackson referred to whipstick wattle scrub, presumably dense thickets of karri wattle (*Acacia pentadenia*) and hazel (*Trymalium floribundum*). Chisholm (1958) included a photograph taken by Jackson.

2. Jarrah - marri low forest, with tea-tree scrub (*Agonis parviceps* and *A. linearifolia*) and sedgeland. Jackson's references to spearwood thickets presumably are to *A. parviceps*. Stunted jarrah grows around the edges of swamps.

3. Jarrah - bullich (*Eucalyptus megacarpa*) woodland.

4. Coastal dunes (heath, peppermint (*Agonis flexuosa*) woodland, banksia woodland, yate (*Eucalyptus cornuta*) woodland.

5. Marri - paperbark (*Melaleuca* sp.) - yarri (*Eucalyptus patens*) - wattie (*Agonis juniperina*) forest.

6. Wattie - paperbark thickets, with tea-tree heath and banksia - sheoak (*Allocasuarina fraseriana*) woodland.

7. Kangaroo grass (*Evandra aristata*) sedgelands.

A vegetation map for the Walpole-Nornalup National Park shows 14 vegetation types (CALM 1992).

## ANNOTATED LIST OF BIRD SPECIES RECORDED

The names and sequence of species follow the Western Australian Museum list (Johnstone unpublished). For the convenience of readers, all distances, heights and other lengths have been metricated and generally rounded off.

### Landbirds

#### *Dromaius novaehollandiae*

Although Emu droppings were frequently met with, birds (1-2) were recorded on only three occasions, in December and January (near coast or on kangaroo grass plains). Jackson remarked about the very dark, almost black plumage, darker than he had seen in New South Wales and Queensland. He speculated that this may have had adaptive value in that it made them hard to detect among the black (burned) trees. Fruits of *Podocarpus drouynianus* were recorded in their droppings. An old nest was discovered within *c.* 250 m of the ocean.

#### *Haliastur sphenurus*

The Whistling Kite was recorded once (31 December).

#### *Accipiter fasciatus*

Brown Goshawks were recorded on 8 days (October, November, January, February), usually singly, near Bow River and Mt Frankland. Jackson noted that this species makes a great noise at dusk as it flies over the tops of the karri trees. One bird was recorded as being chased by two ravens.

#### *Aquila morphnoides*

Little Eagles were recorded on three days, in January and February (2 singles; 3 birds on one day). One bird was shot 5 km west of the entrance to Irwin Inlet.

#### *Aquila audax*

Wedge-tailed Eagles were recorded twice. In October and December (Bow River, Deep River). A nest was seen 28 m above ground in a red tingle tree 10 km west of Bow River.

#### *Falco berigora*

One Brown Falcon was recorded flying over Newdegate Island (18 December).

#### *Phaps elegans*

Brush Bronzewings were recorded on four days, in October, November and February (2 aural records, 1 seen, 1 shot), in *Acacia pentadenia* scrub and jarrah forest. The crop of the shot bird was full of *A. pentadenia* seed.

#### *Calyptorhynchus banksii*

Two Red-tailed Black-cockatoos were recorded on 24 January at their nest, 18 m above ground in a marri tree.

#### *Calyptorhynchus baudinii*

White-tailed Black-cockatoos were recorded as plentiful and noted on 20 days, in all months (sometimes in flocks of *c.* 60 birds) at Bow River, Deep River and Mt Frankland. I have presumed that all records are referable to

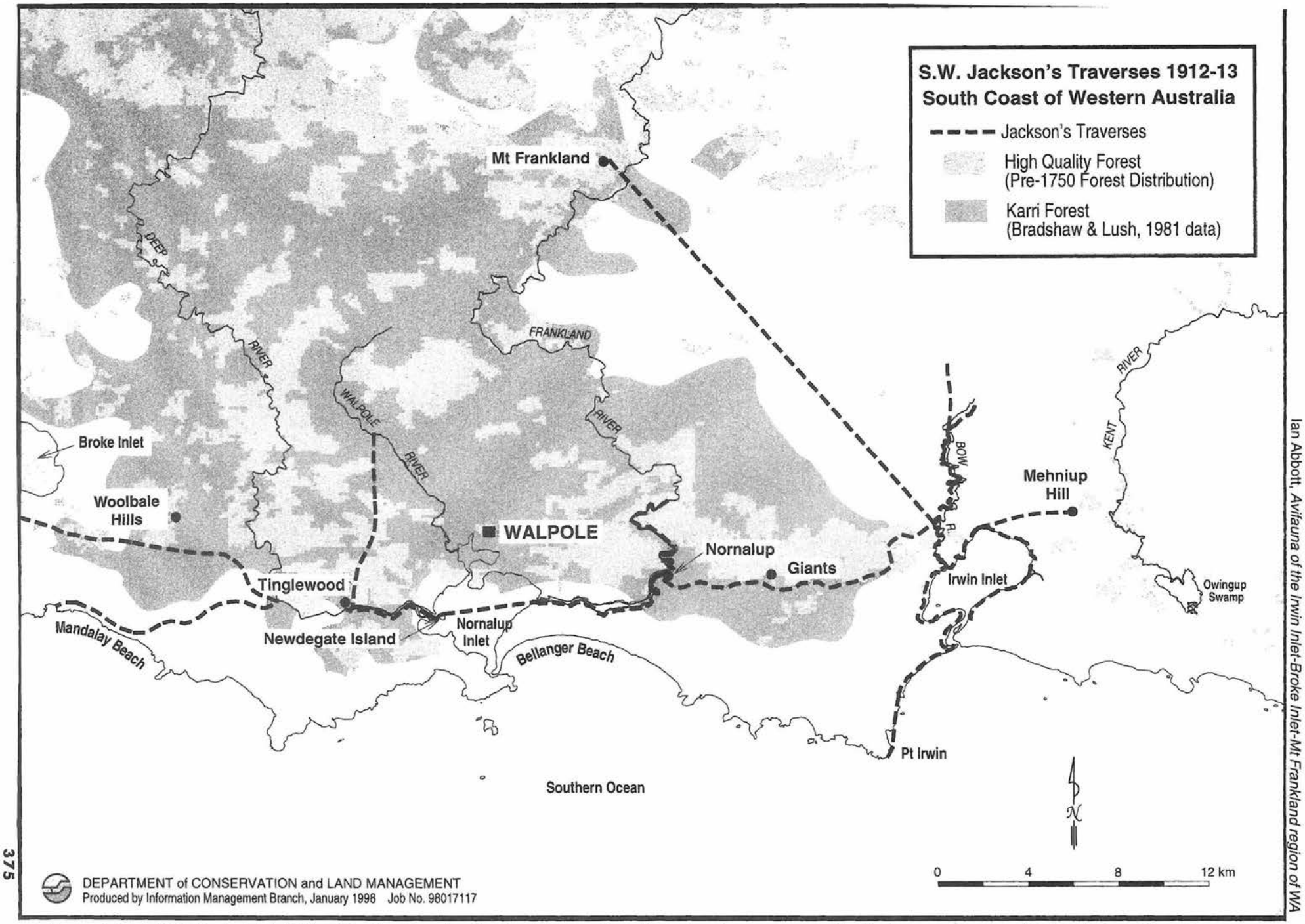


*Figure 1. Irwin Inlet-Broke Inlet-Mt Frankland region, showing localities mentioned in text and areas traversed by Jackson and mentioned in his diaries. The reference to pre-1750 forest distribution in the legend is to the distribution of forest before European settlement, conventionally set at 1750 (Commonwealth of Australia 1997).*

Baudin's Cockatoo. Jackson recorded several food items: bardi extracted from under the loose bark of dead karri and jarrah; *Xanthorrhoea preissii* flowers (?nectar); grubs from saplings of *Acacia pentadenia*; nectar from *Banksia grandis* flowers; and fruits of marri (green seed picked out, fruit left unbroken but detached from tree). Also recorded at Denmark on 2 February.

### *Glossopsitta porphyrocephala*

Purple-crowned Lorikeets were recorded on two days, high up in flowering jarrah trees (29 October) and at Mt Frankland (14 February). This species was noted also at a swamp near Wilson Inlet and at Whitlock's farm (21-22 February).

### *Platycercus zonarius*

Australian Ringnecks were recorded on eight days (October, December, January, February), being noted as plentiful and tame, at Bow River, Deep River and Mt Frankland. Feeding on the ground, at *Xanthorrhoea preissii* flowers, and on *Acacia pentadenia* seed (crop of shot bird) was noted.

### *Platycercus spurius*

Red-capped Parrots were recorded once (3 November), in karri understorey.

### *Platycercus icterotis*

Western Rosellas were recorded on three days: 3 November (1 male, 1 female); 13 January (many feeding on seed of *Allocasuarina decussata*), and 14 February (in karri near top of Mt Frankland).

### *Pezoporus wallicus*

The following is quoted from Whittell's transcription from one of the now-missing diaries: 'Saw Grass parrakeet [Ground Parrot] (like *formosus*) in the long tassel top Kangaroo grass on a plain or swamp (bog). Failed to shoot it.'

### *Cacomantis flabelliformis*

Fan-tailed Cuckoos were recorded on three days: 25 October (plentiful); 12 November (1 juvenile shot in karri forest); and 15 December (Deep River).

### *Chrysococcyx lucidus*

On 16 November the egg of a Bronze Cuckoo was found in a nest of *Acanthiza apicalis*. I have presumed the species to be the Shining Bronze-cuckoo.

### *Ninox novaeseelandiae*

Boobook Owls were recorded on nine occasions in October, November and January, usually calling at night near the Bow River camp. On 8 January, a bird was flushed from a dead and burnt *Allocasuarina decussata* in tingle forest. A bird was heard calling on 14 January in trees near Irwin Inlet.

### *Podargus strigoides*

Tawny Frogmouths were recorded six times from 29 October to 31 January, usually at the camp at Bow River, where one was shot. Four birds were flushed on 12 December from a *Casuarina* log near coastal sand hills west of the camp at Deep River.

### *Eurostopodus argus*

One Spotted Nightjar was flushed off the ground in wattle scrub on 10 November. Jackson wondered how this species could fly through such dense undergrowth.

### *Todiramphus sanctus*

Sacred Kingfishers were noted on three days in October, November and January in both jarrah and karri forest. A nest was seen in a hollow limb of a tall karri tree. This species was also recorded in February at Denmark River and in a swamp near Wilson Inlet.

### *Climacteris rufa*

Rufous Treecreepers were recorded on four days in October, December and February. Jackson regarded them as common and tame, with a call similar to that of *C. picumnus* of NSW. A nest containing two eggs (one fresh, the other heavily incubated) was in a hollow in the top (8 m above ground) of a dead marri tree. The nest was placed 46 cm down the hollow.

### *Malurus splendens*

Splendid Fairy-wrens were recorded four times (November and December) in coastal sand hills. The only forest record was from Mt Frankland.

### *Stipiturus malachurus*

Southern Emu-wrens were noted in heath in coastal sand hills in December (three birds on west bank of Deep River; old nest with dead chick and egg fragments).

### *Pardalotus punctatus*

Spotted Pardalotes were noted twice in February, in jarrah forest south-east of Mt Frankland and at Mt Frankland itself.

### *Pardalotus striatus*

Striated Pardalotes were recorded as plentiful on 27 October and 4 November.

### *Sericornis frontalis*

White-browed Scrubwrens were recorded nesting on 16 October close to the ground in *Gahnia* clumps in wattle scrub. The nest contained two young and one heavily incubated egg.

### *Gerygone fusca*

Western Gerygones were recorded on six days in October, November, December and February. Jackson noted that in December it was not calling as frequently as in October and November. This species occurred more in the larger trees in jarrah forest than in the dense understorey in karri forest.

### *Acanthiza apicalis*

Broad-tailed Thornbills were noted on five days in November, January and February. On 16 November a nest 1.8 m above ground and with one egg was found in wattle scrub. Subsequent records (in January and February) were from jarrah forest. Also recorded at Mt Frankland. Two birds were shot and Jackson recorded the red irides. On 21 February this species was noted in a swamp near Wilson Inlet.

### *Acanthiza inornata*

Western Thornbills were collected on 20 January; their white irides were noted. This species was recorded as 'fairly plentiful', feeding in jarrah saplings and swamp banksia and present in undergrowth on a swamp edge.

### *Melithreptus chloropsis*

Western White-naped Honeyeaters were recorded on five days between October and February. Birds fed on the foliage of *Allocasuarina decussata*, hazel, and kangaroo paw (*Anigozanthos bicolor*). Noted also at Mt Frankland.

### *Phylidonyris novaehollandiae*

New Holland Honeyeaters were recorded on six days from October to January and were noted as common. Feeding at hazel blossom was noted. Nests were discovered close to ground (40 cm, 1.2 m) at the edge of karri forest. One nest had two young birds (30 October). Also noted at Deep River and at a swamp near Wilson Inlet (21 February).

### *Phylidonyris melanops*

Tawny-crowned Honeyeaters were recorded six times in December, January and February, at Deep River, near Irwin Inlet, and near the coast.

### *Acanthorhynchus superciliosus*

Western Spinebills were recorded six times in October, December, January and February. Noted picking at bark on the underside of jarrah limbs like a treecreeper, and also feeding at flowers of *Anigozanthos bicolor*. Recorded in jarrah forest, spearwood swamps, and at Deep River and Mt Frankland.

### *Anthochaera chrysoptera*

Little Wattlebirds were recorded eleven times between October and January. They were noted as more plentiful in January than in November. A nest with one egg was found 2.7 m above ground in *Banksia grandis* on 20 October. Recorded in wattle scrub, yellow tingle forest, and banksia. Birds were seen feeding on nectar of yellow tingle and banksia species.

### *Petroica multicolor*

Scarlet Robins were recorded seven times in October, November, January and February only in jarrah forest. A nest was seen (bird sitting) 15 m above ground in a jarrah tree on 19 October. A nest 15 m above ground in a marri tree contained two young (25 October). By 12 November, young able to fly were seen. Full grown young were still being fed by parents on 20 January. Also recorded at Mt Frankland.

### *Eopsaltria australis*

Yellow Robins were recorded eleven times, in all months. Several nests were located: 14 m above ground in jarrah tree (two young), 16 October; 7 m above ground in *Allocasuarina decussata* tree (two eggs), 23 October; 15 m above ground in jarrah tree (no details); old nest in swamp banksia. Jackson noted that its feeding behaviour, nest, eggs and call were similar to the Yellow Robin in NSW. Noted mainly in jarrah forest; also in wattle scrub. Seen capturing grubs on young jarrah saplings. Recorded at Mt Frankland.

### *Eopsaltria georgiana*

White-breasted Robins were noted 16 times, mainly in October and November. On 21 January noted as 'not so plentiful now'. Confined to wattle scrub in or near karri forest, in contrast to that of the Yellow Robin. Recorded at Mt Frankland. The sharp and shrill note of this species was thought by Jackson to resemble the single alarm note of *Orthonyx temmincki* and *Atrichornis rufescens* of NSW. The actions and call were thought comparable to those of the Yellow Robin in NSW. They were noted as shy. Several nests were recorded: 4 m above ground in wattle scrub, two eggs (10 October); 3.4 m above ground in *Acacia pentadenia* (10 November); one nest 4.3 m up and three others 3.7 m up on fallen karri branches; nest without eggs (16 November). Nest smaller than that of Yellow Robin and not decorated with lichen.

### *Pomatostomus superciliosus*

White-browed Babblers were recorded six times in October and November, always in wattle scrub. All nests found were in *Allocasuarina decussata* trees, 7-9 m above ground level. Three birds were shot; their crops contained ants. Jackson thought that the call was unlike any other babbler species. This species was absent from the Deep River area.

### *Psophodes nigrogularis*

A Western Whipbird was recorded on 23 October: 'Saw ~~bird like~~ Black throated Coachwhip at dense entangled part of whipstick scrub. Note was loud "chop chop"'. This species does not vocalize in this way. Jackson may have misidentified a Golden Whistler.

### *Daphoenositta chrysoptera*

Varied Sittellas were recorded six times, in all months, usually high up in jarrah forest, and therefore hard to shoot. Nonetheless three birds (including one flying young) were secured on 2 January and one other was shot on 24 January. On 26 December, one pair was observed feeding three young near the northern end of Irwin Inlet. Also recorded at a swamp near Wilson Inlet on 21 February. Call and flight were considered similar to those in NSW.

### *Falcunculus frontatus*

Crested Shrike-tits were recorded six times, in October, November, January and February. Mostly observed in tall karri trees, but recorded once in jarrah tree. Jackson considered this species to be rare and difficult to detect (its call was similar to that in NSW but very feeble).

### *Pachycephala pectoralis*

Golden Whistlers were recorded eleven times, mostly confined to dense wattle scrub and not in open jarrah forest. Although noted each month, Jackson stated that they became less plentiful (or just less vocal?) in January. Noted at Mt Frankland.

### *Colluricincla harmonica*

Grey Shrike-thrushes were recorded nine times in October, November, December and February. One bird was seen entering a hollow in a tingle tree, but no nest was there. Recorded also at Deep River and Mt Frankland.

### *Rhipidura fuliginosa*

Grey Fantails were recorded 13 times, in all months. Nest building was first noted on 5 November. Nests were recorded 4.3 or 4.6 m above ground in *Acacia pentadenia* or on fallen limbs caught in standing trees. Feeding of young in the nest was last recorded on 12 December. This species was noted as plentiful, particularly in burned areas and occurring almost anywhere. By 24 January, most had vacated the dense wattle scrub. Recorded as feeding on march flies. Also noted at Mt Frankland and at swamp near Wilson Inlet.

### *Coracina novaehollandiae*

Black-faced Cuckoo-shrikes were recorded four times (October, December and January). They were usually noted as plentiful. At Deep River noted as feeding in tall hazel trees in scrub.

### *Artamus cyanopterus*

Dusky Woodswallows were recorded three times (October, December and January), in jarrah and karri forest.

### *Strepera versicolor*

Grey Currawongs were recorded 16 times, in all months, as plentiful. Nesting was noted as: 21 m above ground in jarrah tree (30 October) and 18 m above ground in a yellow tingle tree (16 January). Fledged young were seen on 4 November (being fed) and 26 December. Seen feeding on the ground and also eating *Bothriembryon* snails picked off the trunk of hazel and karri. Regarded as 'good eating'. Also recorded at Mt Frankland and at swamp near Denmark.

### *Corvus coronoides*

Australian Ravens were noted on eight occasions in all months, in jarrah and karri forest. Particularly noted as rare (2-4), though about 30 were seen on 30 January ('a most unusual sight here'). On 3 February, many were noted as 'now about'. Also recorded at swamp near Wilson Inlet and as destroying much fruit in an orchard.

### *Anthus novaeseelandiae*

Richard's Pipits were recorded three times (November-January) on damp flats near Irwin Inlet, on open ground in coastal sandhills, and on the ground on plains.

### *Stagonopleura oculata*

Red-eared Firetails were recorded once, on 27 October: Jackson saw 'finches' nesting in *Allocasuarina decussata*.

### *Hirundo neoxena*

Welcome Swallows were recorded twice, in January and February ('over the plains' and at Mt Frankland). Also noted at Denmark River (predated by cat).

### *Hirundo ariel*

Fairy Martins were noted once. On 22 December, their nests were seen in a cave of hardened sand on the western bank of Frankland River.

### *Zosterops lateralis*

Grey-breasted White-eyes were recorded ten times, in all months. A nest containing three eggs was found 2.4 m above ground in a paperbark tree on 7 November. Old nests were also found in vines in wattle scrub. Noted at Bow River, Deep River and Mt Frankland. On 31 December observed eating fruits of *Leucopogon verticillatus*. This species was recorded on 31 December as 'now plentiful'.

## Waterbirds

### *Cygnus atratus*

Black Swans were noted on five occasions from November to January: Irwin Inlet ('hundreds'); Deep River ('many') and Frankland River (28 birds, 3.2 km from mouth).

### *Tadorna tadornoides*

Australian Shelducks were recorded on Irwin Inlet on 3 February.

### *Anas superciliosa*

Pacific Black Ducks were recorded six times from November to February: Deep River; Frankland River ('many'); Bow River (7); and Irwin Inlet ('numerous'). This species was also noted on a swamp near Wilson Inlet.

### *Phalacrocorax varius*

Pied Cormorants were recorded on 18 December at Deep River.

### *Phalacrocorax sulcirostris*

Little Black Cormorants were seen on 26 December on rocks on the northern side of Irwin Inlet.

### *Phalacrocorax melanoleucos*

Little Pied Cormorants were noted three times (December, February): Deep River; Frankland River ('many'); and entrance to Irwin Inlet. Also on swamp near Wilson Inlet.

### *Ardea novaehollandiae*

The White-faced Heron was noted on 15 December on Deep River.

### *Ardea sacra*

A Reef Heron was seen on Newdegate Island on 18 December.

### *Nycticorax caledonicus*

Rufous Night Herons were recorded four times at Bow River in January and February. One was seen in a jarrah tree, and was noted to be very tame.

### *Porphyrio porphyrio*

Purple Swamphens were recorded twice in December at Deep River (in reeds on the northern bank inland from its mouth) and at Frankland River (also in reeds along bank).

### *Charadrius rubricollis*

Hooded Plovers were recorded twice in December: single birds on sandbar at mouth of Deep River and on Mandalay beach.

### *Larus pacificus*

The Pacific Gull was seen on Newdegate Island on 18 December.

### *Larus novaehollandiae*

Silver Gulls were recorded three times, in December and February: Gull Rock [a granite rock of diameter *c.* 27 m beside Newdegate Island] (eggs noted 8 and 18 December); Newdegate Island; and the entrance to Irwin Inlet.

### *Sterna bergii*

Crested Terns were recorded three times in December: nesting on Gull Rock; Newdegate Island; and on rocks on the northern side of Irwin Inlet.

### *Sterna nereis*

Fairy Terns were recorded (misidentified as Little Terns '*S. sinensis*') on Newdegate Island on 12 December.

## SPECIES NOT RECORDED

Some of the species listed below are considered likely to have occurred in the region in 1912-13. It is possible, though improbable, that one or two of these species may have been recorded in the diaries that are now missing. Whittell (1952) stated that the six diaries read by him mentioned 'over 60 species'.

### Landbirds

### *Leipoa ocellata* Malleefowl

Jackson's failure to record this species may be taken validly to indicate that it did not occur east of Broke Inlet.

### *Coturnix ypsilophora* Brown Quail

A surprising omission. Ashby and Le Soeuf (1928) provisionally recorded this species in coastal hills near Deep River in October 1927.

### *Circus approximans* Swamp Harrier

A surprising omission. Ashby and Le Soeuf (1928) recorded this species at Deep River in October 1927.

### *Cacatua pastinator* Western Long-billed Corella

Probably indicates that this species did not occur near the coast east of Broke Inlet.

### *Cuculus pallidus* Pallid Cuckoo

Ashby and Le Soeuf (1928) recorded this species at Deep River in October 1927.

### *Atrichornis clamosus* Noisy Scrub-bird

After two days of searching unsuccessfully for this species, Jackson linked their absence with frequent burning of hazel and wattle scrub. Subsequent close examination of the few areas of long-unburned hazel/wattle scrub, and of other habitats, including paperbark, tea-tree, banksia and tall (3.7 m high) sword grass on flats, yielded no indication that Noisy Scrub-birds persisted in the region. On 28 October Jackson received a telegram (in reply to his letter) from A.J. Campbell, advising that the dense undergrowth in karri forest in which Jackson had

been searching is where Campbell had secured his specimen near Torbay in 1889. In January Jackson mentioned feral cats as more of a possible cause of their extinction than bushfires. It is worth noting that Jackson would have been too late to record nesting, as most eggs are laid in June-July (A.H. Burbidge[1], personal communication).

### *Malurus elegans* Red-winged Wren

A surprising omission.

### *Acanthiza chrysorrhoa* Yellow-rumped Thornbill

Recorded in small karri and jarrah suckers on the bank of Denmark River. Pollard (1928) recorded this species on a farm near Deep River.

### *Lichmera indistincta* Brown Honeyeater

Ashby and Le Soeuf (1928) recorded this species at Deep River in October 1927.

### *Myiagra inquieta* Restless Flycatcher

Ashby and Le Soeuf (1928) recorded this species nesting near Deep River in October 1927.

### *Rhipidura leucophrys* Willie Wagtail

Noted only at Denmark (21 February). Ashby and Le Soeuf (1928) recorded this species in a clearing at Tinglewood, Deep River in October 1927.

### *Hirundo nigricans* Tree Martin

A surprising omission. Ashby and Le Soeuf (1928) recorded this species at Deep River in October 1927.

### *Megalurus gramineus* Little Grassbird

Recorded only at swamp near Wilson Inlet (21 February).

## Waterbirds

Jackson's failure to record any of these species may simply indicate the lack of permanent freshwater swamps in the country traversed (Owingup swamp to the east of Irwin Inlet was apparently not examined by him, nor was Crystal Lake south of Deep River).

### *Ixobrychus minutus* Little Bittern

### *Ixobrychus flavicollis* Black Bittern

### *Botaurus poiciloptilus* Australasian Bittern

### *Rallus pectoralis* Lewin's Rail

### *Porzana pusilla* Baillon's Crake

### *Porzana fluminea* Australian Spotted Crake

### *Porzana tabuensis* Spotless Crake

### *Biziura lobata* Musk Duck

### *Phalacrocorax carbo* Great Cormorant

### *Sterna caspia* Caspian Tern

These three last species were recorded in October 1927 near Nornalup Inlet by Ashby and Le Soeuf (1928).

## CHANGES IN THE LANDBIRD AVIFAUNA SINCE 1912-13

Parts of the area surveyed by Jackson were re-examined by ornithologists in 1927, 1972, 1981 and 1985-87 (Table 1). Before these bird lists can be used as a legitimate basis for examining changes in the landbird fauna 14-74 years after Jackson's visit, it is essential to eliminate errors, decide which records represent vagrants, and evaluate whether non listing of species indicates genuine absence or failure to record. If this protocol is not followed, many spurious instances of local extinction or local establishment ('pseudoturnover') will be detected.

Three species appear to have been misidentified and are treated here as having been listed invalidly: *Manorina flavigula*, *Microeca fascinans* (?error for *Eopsaltria georgiana*), and *Psophodes nigrogularis*.

Two species appear to have become locally extinct: *Pezoporus wallicus* and *Hirundo ariel*. *P. wallicus* is susceptible to frequent burning (Burbidge *et al.* 1997) and has not been recorded in the region since 1952 (Baggs 1953), though there is an unsubstantiated record for 1978 (Watkins 1985). The nesting site recorded by Jackson for *H. ariel* needs to be relocated to confirm whether this species still breeds there.

Sixteen species are open country (woodland, pasture) species which were probably not present in the region in 1912-13, as settlement had scarcely encroached: *Elanus caeruleus, Falco cenchroides, F. longipennis, Neophema elegans, Chrysococcyx basalis, Smicrornis brevirostris, Acanthiza chrysorrhoa, Lichmera indistincta, Anthochaera carunculata, Epthianura albifrons, Pachycephala rufiventris, Rhipidura leucophrys, Grallina cyanoleuca, Lalage tricolor, Cracticus torquatus* and *C. tibicen*. One species, *Dacelo novaeguineae*, was introduced to Western Australia but did not reach the Walpole area until after Jackson's visit.

The remaining species not listed by Jackson probably represent vagrants, irregular visitors, rare species, highly localized species, cryptic species, or simply species missed.

It is difficult to interpret the list of waterbird species in Table 1. However, *Chenonetta jubata* and *Vanellus tricolor* are genuine new arrivals favoured by clearing of forest for pasture, and *Phalacrocorax fuscescens* is undoubtedly an error for *P. varius*.

[1] A.H. Burbidge, Wildlife Research Centre, CALM, Woodvale.

TABLE 1
Bird species recorded in the Walpole-Nornalup region at various times since 1912

| SPECIES | 1912-13 (1) | 1927 (2) | 1972 WOOLBALES (3) | 1981 GIANTS (4) | 1986-87 COAST (5) | 1985-87 FOREST (6) |
|---|---|---|---|---|---|---|
| LANDBIRDS | | | | | | |
| *Dromaius novaehollandiae* | • | | • | • | • | |
| *Coturnix ypsilophora* | | • | | | • | • |
| *Pandion haliaetus* | | | | | • | • |
| *Elanus caeruleus* | | | | • | • | |
| *Hamirostra isura* | | | | | | • |
| *Haliastur sphenurus* | • | | • | | | |
| *Accipiter fasciatus* | • | | • | | • | • |
| *A. cirrocephalus* | | | | | | • |
| *Aquila morphnoides* | • | | | | • | • |
| *Aquila audax* | • | • | • | • | • | • |
| *Haliaeetus leucogaster* | | | | | • | |
| *Circus assimilis* | | | • | | • | |
| *C. approximans* | | • | | • | • | • |
| *Falco berigora* | • | • | • | • | • | • |
| *F. cenchroides* | | | • | • | • | • |
| *F. longipennis* | | | • | | | • |
| *F. peregrinus* | | | • | | • | • |
| *Phaps chalcoptera* | | | • | | • | • |
| *P. elegans* | • | | • | • | • | • |
| *Calyptorhynchus banksii* | • | | • | | | • |
| *C. baudinii* | • | • | • | • | • | • |
| *Glossopsitta porphyrocephala* | • | • | • | • | • | • |
| *Platycercus zonarius* | • | • | • | • | • | • |
| *P. spurius* | • | | • | | • | • |
| *P. icterotis* | • | • | • | • | • | • |
| *Neophema elegans* | | | • | | • | |
| *N. petrophila* | | | • | | • | |
| *Pezoporus wallicus* | • | | | | | |
| *Cuculus pallidus* | | • | • | • | | • |
| *Cacomantis flabelliformis* | • | • | • | • | • | • |
| *Chrysococcyx basalis* | | | • | | • | • |
| *C. lucidus* | • | | | • | • | • |
| *Ninox novaeseelandiae* | • | • | • | | | |
| *Tyto novaehollandiae* | | | | | | • |
| *T. alba* | | | | | | • |
| *Podargus strigoides* | • | | • | | | • |
| *Eurostopodus argus* | • | | | | | • |
| *Aegotheles cristatus* | | | | | | • |
| *Dacelo novaeguineae* | | | • | • | • | • |

TABLE 1 (continued)

| SPECIES | 1912-13 (1) | 1927 (2) | 1972 WOOLBALES (3) | 1981 GIANTS (4) | 1986-87 COAST (5) | 1985-87 FOREST (6) |
|---|---|---|---|---|---|---|
| *Todiramphus sanctus* | • | | | • | | • |
| *Climacteris rufa* | • | • | • | • | | • |
| *Malurus splendens* | • | • | • | • | • | • |
| *M. elegans* | | | | | • | • |
| *Stipiturus malachurus* | • | | • | • | • | • |
| *Pardalotus punctatus* | • | • | • | | • | • |
| *P. striatus* | • | • | • | • | • | • |
| *Sericornis frontalis* | • | • | • | • | • | • |
| *Smicrornis brevirostris* | | | | | | • |
| *Gerygone fusca* | • | • | • | • | • | • |
| *Acanthiza apicalis* | • | • | • | • | • | • |
| *A. inornata* | • | | • | • | • | • |
| *A. chrysorrhoa* | | • | • | | | • |
| *Lichmera indistincta* | | • | • | | • | • |
| *Melithreptus chloropsis* | • | • | • | • | • | • |
| *Phylidonyris novaehollandiae* | • | • | • | • | • | • |
| *P. nigra* | | | • | | • | • |
| *P. melanops* | • | • | • | | • | • |
| *Acanthorhynchus superciliosus* | • | • | • | • | • | • |
| *Manorina flavigula* | | | • | | | |
| *Anthochaera chrysoptera* | • | • | • | | • | • |
| *A. carunculata* | | | • | • | • | • |
| *Epthianura albifrons* | | | | | | • |
| *Microeca fascinans* | | • | | | | • |
| *Petroica multicolor* | • | • | • | • | • | • |
| *Eopsaltria australis* | • | • | • | | | • |
| *E. georgiana* | • | | • | • | • | • |
| *Pomatostomus superciliosus* | • | | • | • | • | • |
| *Psophodes nigrogularis* | ? | | | | | |
| *Daphoenositta chrysoptera* | • | | • | • | • | • |
| *Falcunculus frontatus* | • | | • | | | • |
| *Pachycephala pectoralis* | • | • | • | • | • | • |
| *P. rufiventris* | | | | | | • |
| *Colluricincla harmonica* | • | • | • | • | • | • |
| *Myiagra inquieta* | | • | • | | | • |
| *Rhipidura fuliginosa* | • | • | • | • | • | • |
| *R. leucophrys* | | • | • | | | • |
| *Grallina cyanoleuca* | | | • | • | | • |
| *Coracina novaehollandiae* | • | | • | • | • | • |
| *Lalage tricolor* | | | | | | • |
| *Artamus cyanopterus* | • | • | • | • | • | • |
| *Cracticus torquatus* | | | • | | • | |

TABLE 1 (continued)

| SPECIES | 1912-13 (1) | 1927 (2) | 1972 WOOLBALES (3) | 1981 GIANTS (4) | 1986-87 COAST (5) | 1985-87 FOREST (6) |
|---|---|---|---|---|---|---|
| *C. tibicen* | | | • | • | • | • |
| *Strepera versicolor* | • | | • | • | • | • |
| *Corvus coronoides* | • | | • | • | • | • |
| *Anthus novaeseelandiae* | • | | • | • | • | • |
| *Stagonopleura oculata* | • | | • | • | • | • |
| *Hirundo neoxena* | • | • | | | • | • |
| *H. nigricans* | | • | • | • | • | • |
| *H. ariel* | • | | | | | |
| *Zosterops lateralis* | • | • | • | • | • | • |
| WATERBIRDS | | | | | | |
| *Biziura lobata* | | • | | | | |
| *Cygnus atratus* | • | • | | | | |
| *Tadorna tadornoides* | • | | | | | |
| *Chenonetta jubata* | | | | • | | |
| *Anas superciliosa* | • | • | • | • | • | |
| *Anhinga melanogaster* | | | • | • | | |
| *Phalacrocorax carbo* | | • | | • | | |
| *P. varius* | • | | | | | |
| *P. sulcirostris* | • | | | | | |
| *P. fuscescens* | | • | | | | |
| *P. melanoleucos* | • | • | | • | | |
| *Pelecanus conspicillatus* | | • | | • | | |
| *Ardea pacifica* | | | | • | | |
| *A. novaehollandiae* | • | | • | • | | |
| *A. alba* | | | • | | | |
| *A. sacra* | • | | | | | |
| *Nycticorax caledonicus* | • | | | | | |
| *Porphyrio porphyrio* | • | • | | | | |
| *Vanellus tricolor* | | | • | | | |
| *Charadrius ruficapillus* | | | • | | | |
| *C. rubricollis* | • | | | | | |
| *Larus pacificus* | • | • | | | | |
| *L. novaehollandiae* | • | • | • | | • | |
| *Sterna caspia* | | • | | | | |
| *S. bergii* | • | • | | | | |
| *S. nereis* | • | | | | | |

(1) October 1912 – February 1913, coastal and forest. This paper, Whittell (1952).
(2) October 1927, coastal and forest. Ashby and Le Soeuf (1928), Pollard (1928).
(3) Autumn 1972, coastal and forest. Christensen *et al.* (1985).
(4) Summer 1981, forest. Christensen *et al.* (1985).
(5) October 1986, January 1987, April 1987, July 1987, coastal. Wardell-Johnson (unpublished).
(6) December 1985, February 1986, April/May 1986, August 1986, October/November 1986, February 1987, March/April 1987, December 1987, forest. Wardell-Johnson (unpublished).

## FIRE

Jackson was quick to observe the past ravages of fire, evidenced by the trunks of large jarrah and tingle trees burnt up to a height of 20-27 m. He first mentioned bushfires on 20 December, when near Deep River he 'passed between two big bush fires & huge volumes of smoke were issuing from them & travelling to the east'. His next mention (near Bow River) was on 8 January and from mid January there are frequent references to raging fires. He noted that every tree on Mt Frankland showed 'signs of where fire has been on it, and the greater proportion of them have their trunks jet black for [18 or 21 m] up, and this was more noticeable lower down the mountain and for about [300 m] up from the river base'.

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APPENDIX

## Other fauna recorded

Jackson provided incidental notes on other fauna encountered. Where necessary, I have quoted from his diaries. ? indicates uncertainty.

### *Mammals*

Grey-bellied Dunnart (*Sminthopsis griseoventer*)('small marsupial smaller than a rat and with small teeth. Tail like rat... Nose long & pointed, ears rather large & lovely brown fur'). Two specimens (one with pouched young) preserved in spirit were purchased in 1934 by the Australian Museum (S. Ingleby[2], personal communication).

Western Ringtail Possum (*Pseudocheirus occidentalis*)('saw 2 nests of scrub opossum built up in top of [whipstick] wattle sapling in [whipstick wattle] scrub, and another in some suckers on the side of a Tingle Tingle').

Common Brushtail Possum (*Trichosurus vulpecula*)('opossum', 'fairly common' ). Bellanger (1980), who lived at Nornalup after 1910, published a photograph of an albino of this species.

?Tammar Wallaby (*Macropus eugenii*)('scrub wallaby...stands less than 2 ft [0.6 m] high. Colour of fur brown & reddish on back of neck'). Bellanger (1980) mentions 'wallabies' ringbarking fruit trees and states that they 'generally disappeared' during the 1930s.

Western Grey Kangaroo (*Macropus fuliginosus*). Seven recorded near coast. Jackson (1913) noted that this species was 'fairly plentiful on the sandhills and small grass plains'. Bellanger (1980) mentioned that this species seems to favour the open coastal plains and hills.

Quokka (*Setonix brachyurus*)('caught a wallaby in trap. The usual very small animal about 2 ft [0.6 m] high'; 'wallabies sleep under [sword grass]...The wallabies are exceedingly small here [Deep River] & weigh up to 14 lbs [6 kg] or more, & about 2 ft 6 [0.75 m] long from nose to to tip of tail, the latter being about 9 inches [20 cm] long and covered with short bristley hairs'). Many 'wallabies' were observed in bracken on Newdegate Island. Peden (1992), who lived in the Walpole area from 1921, mentions this species.

Water-rat (*Hydromys chrysogaster*). One caught in a lobster trap in Bow River, 10 January. Photograph published in Jackson (1913).

?Black Rat (*Rattus rattus*). Rats seen on the barque Mandalay, which was stranded between Long Point and Cliffy Head in May 1911.

Dingo (*Canis lupus*). Frequently heard; their scats contained bones and fur of 'scrub wallaby'. Two were trapped at Bow River, one of which had head, legs, belly, sides and tail brown and back nearly black. Jackson in 1931 presented a skull to the Australian Museum (S. Ingleby, personal communication).

Cat (*Felis catus*). Tracks first recorded on 13 December, near Deep River. Two cats were on board the Mandalay when she wrecked (see above).

Cattle (*Bos taurus*). On 28 December Jackson met Mr Moriarty who had earlier brought over 300 head from inland for grazing on the coastal country on the west side of Irwin Inlet. He was accompanied by four Aborigines and had taken ten days to bring the cattle down. 'These men set fire to a lot of country about here'.

### *Reptiles*

Tiger Snake (*Notechis scutatus*) ( 'The species chiefly met with was a black one measuring up to [1.5 m] long'; 'brown snake with black coloured belly...blackish on back & shiney, copper...for 2 rows of scale all along side just above belly scales. Belly scales yellowish with black across joints of each segment'; ' black snakes plentiful', Bow River).

?Dugite (*Pseudonaja affinis*) ('brown snake with pink belly [43 cm] long'; 'brown or copper head snake').

*Tiliqua rugosa* ('scaly back lizard' on sandy ground near coast).

### *Invertebrates*

Tree snails (*Bothriembryon jacksoni, B. fuscus* and *B. revectus*)(green; striped (zebra) species in karri forest; Deep and Bow Rivers; see Iredale 1939).

Marron (*Cherax tenuimanus*). Almost black; to 25 cm in length, in Bow River.

Koonac (*Cherax preissi*) in black bog, Bow River.

Gilgie (*Cherax quinquecarinatus*) in very small freshwater creeks in the bush away from rivers; about 5-7 cm in length.

Tick-tock (*Cicadetta quadricincta*), 10 December. Small black cicada making a thin peculiar tapping call all day. Notes resemble a jeweller's small hammer tapping some solid object quickly.

March flies (*Scaptia gemina, S. georgii, S. bicolorata* and *Mesomyia norrisi*) feeding on yellow tingle nectar and human blood.

Golden-haired Skipper (*Hesperilla chrysotricha*) 20 December, near coast.

[2] Dr S. Ingleby, Collection Manager, Mammal Section, Australian Museum, College St, Sydney

Gum Moth Caterpillar (*Opodiphthera helena*)
31 December, feeding on foliage of jarrah suckers.

Whistling Moth (*Hecatesia thyridion*) 30 October. Termed 'singing moth' and noted as settling chiefly on *Xanthorrhoea* leaves.

Black Sawfly (*Perga*) larvae, 24 and 31 December, feeding on foliage of jarrah saplings.

Bull Ant (*Myrmecia ?vindex*) 13 December.

Sticknest Ant (*Iridomyrmex ?purpureus*). Nests noted.

Feral Bee (*Apis mellifera*), swarm near Bow River.

## Plants

Jackson collected and dried 8545 plant specimens. These were donated by H.L. White to the New South Wales Herbarium.

## Aboriginal Names

These names were provided to Jackson at Deep River by A.G. Muir of Mordalup on 21 December . They do not, however, necessarily pertain to the Walpole region.

### *Plants*

Marry (*Corymbia calophylla*)
Karri (*Eucalyptus diversicolor*)
Cherrela (*E. marginata*)
Bullegit 'Blue gum' (*E. megacarpa*)
Condorun 'Emu berry or plum' (*Podocarpus drouynianus*)
Barluck (*Xanthorrhoea preissii*)
Bonga 'Swamp banksia' (*Banksia littoralis*)
Pidnidge 'Big river banksia' (*B. seminuda*)
Mungitch or Mungite (*B. grandis*)
Pint or Pent 'Yellow waratah flower banksia with prickly leaf' (*B. ilicifolia*)
Byon (*Macrozamia riedlei*)
Gnettuck 'whipstick wattle or hazel'. Netic is the accepted name for *Bossiaea aquifolium* and *B. webbii*; whipstick wattle is probably *Acacia pentadenia*; and hazel is *Trymalium spathulatum*.
Queel 'Sheoak' (*Allocasuarina fraseriana*)
Cudditch 'Kangaroo Paw" (*Anigozanthos flavidus*)
Budgegegth 'Swamp Swordgrass' (*Anarthria scabra*)
Kiber 'Square nail rush' (*Lepidosperma tetraquetrum*)
Monduc 'bracken fern' (*Pteridium aquilinum*)

### *Animals*

Quocker 'Small scrub wallaby' (*Setonix brachyurus*)
Quaint 'Bandicoot' (*Isoodon obesulus*)
Yerkine 'Dingo' (*Canis lupus*)
Uren 'Pineapple scale lizard' (*Tiliqua rugosa*)
Wetch 'Emu' (*Dromaius novaehollandiae*)
Yonger 'Kangaroo' (*Macropus fuliginosus*)

## The Man

Judged by the material in his diaries, Jackson was dedicated and assiduous in searching for the Noisy Scrub-bird, but fortunately was not focused solely on that species. Nearly every day (including Saturdays and Sundays) was spent in the bush and it was not unusual for him to spend 7-12 hours traversing 16-30 km. Frequently he records the nuisance and inconvenience caused by large numbers of blood-sucking march flies. At his Bow River camp he was also discomforted by sandflies, mosquitoes, fleas, snakes and prowling dingoes. He subsisted on tinned meat with little fresh food, though he does record eating 'opossum', 'scrub wallaby' and marron.

Throughout his time in Western Australia, he remained cheerful, although he did note on 16 December 'another disappointing day'. His only reference to illness was towards the end of his sojourn, when on 27 January, 6, 7 and 16 February he mentions dizziness and a 'touch of the sun'. This was probably an indication of overwork, as Jackson frequently did not retire until after midnight because he was busy developing photographic plates, pressing plant specimens and packing up his specimens. His two day dash to Mt Frankland in February across waterless country 'all in the interests of science' could have cost him his life. Later, on 5 March, Jackson noted 'get medicine in Port Adelaide for the pains in my insides'.

Jackson seems to have bonded in spirit with this part of Australia. On 11 February he recorded 'The calmness and silence here often at night (as tonight) I have never noticed anywhere else in my life. It is beyond description'.

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## LIST OF REFEREES

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